EMERGY ACCOUNTING OF THE RESOURCE BASIS OF NATIONS, HUMAN WELL-BEING AND INTERNATIONAL DEBT.

By

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This document is dedicated to my grandparents, for all of their love and support.

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LIST OF ACCRONYMS

EBEER	Emergy Based Equitable Exchange Rate (ECR_A/ECR_B)
ECR	Emergy Currency Ratio (Emergy Use/$GDP_{local\ currency\ units}$)
EDR	Emergy Dollar Ratio (Emergy Use/$GDP_{U.S.dollars}$)
EF	Ecological Footprint
EIF	Emergy Inequity Factor (OER/EBEER)
ETWI	Emergy Total Wellbeing Index (Percent Renewable * HDI)
EWI	Ecosystem Well-being Index
HDI	Human Development Index
HWI	Human Well-being Index
NEAD	National Environmental Accounting Database
OER	Official Exchange Rate
UN	United Nations
WI	Well-being Index
YESI	Yale Environmental Sustainability Index

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Despite the abundance of sustainable development research and literature, there is a need to substantiate and quantify the links between poverty and the environment. Environmental accounting was used to quantify the resource basis of 134 nations (ca. 2000) in emergy units using the National Environmental Accounting Database (NEAD) and provide a uniform set of indicators of resource use, partitioning, trade and environmental condition. The overall objective of this work was to demonstrate the relationships between human and environmental well-being and evaluate the equity of international loans and debt repayments.

In Part 1, these indices, such as emergy percent renewable and non-renewable emergy use per capita, were compared to social, political, economic and environmental indicators of welfare. The emergy indices were also compared to popular composite welfare and sustainability indices including the Yale Environmental Sustainability Index (ESI) and the United Nations Development Program's Human Development Index

(HDI). An inverse relationship was found between human well-being and environmental well-being. In particular, a strong negative association was observed between the percent of total emergy from renewable sources and HDI, and a strong positive association was observed between non-renewable emergy use per capita and HDI. This suggests that countries with a high proportion of their resource use coming from non-renewable sources have greater human welfare. A new indicator, termed the Emergy Total Well-being Index (ETWI), is proposed that integrates human welfare and resource sustainability; countries with high ETWI include Iceland, Argentina and Suriname.

In Part 2, relationships between debt, currency exchange ratios and emergy money ratios were explored. An Emergy Based Equitable Exchange Rate (EBEER) was developed and used to calculate the emergy adjusted international debt of five West African focal nations. An emergy inequity factor (EIF) was also developed which measures the difference between the EBEER and currency exchange rate, and therefore the emergy benefit to one nation when trading with another. All five focal nations were found to have repaid their debt in terms of embodied environmental work, and the emergy benefit to the U.S. when trading with these nations continues to increase over time.

This study provides a unique view of national resource use, quantifies relationships between human and environmental well-being, introduces a new benchmarking tool of total sustainability, and scientifically justifies African debt relief.

CHAPTER 1
INTRODUCTION

Social equality, economic stability, environmental conservation and global carrying capacity, each of which is a part of the broader concept of sustainable development (Munasinghe and McNeely 1995), have become familiar issues in contemporary society. The duration of non-renewable resource supplies is in question (Deffeyes 2001) and the developing countries of Africa, such as Niger and Mali, are going further and further into economic debt (Cheru 2002, Boafo-Arthur 2003) while their populations face chronic hunger and environmental crises (UN Millennium Project 2005, 2005a). With the release of the United Nations Millennium Development Goals (UN Millennium Project 2005, 2005b), and from the growing recent literature on sustainable development (e.g., Asefa 2005), poverty disparity (e.g., Greenhalgh 2005), natural resource depletion (e.g., Aleklett and Campbell 2003) and the effects of pollutants on humans (e.g., Evans and Smith 2005) and the environment (e.g., Givati and Rosenfeld 2005), it becomes evident that there is a need to quantify the relationship between the human well-being, ecological well-being and economic conditions of nations.

Statement of the Problem

Researchers monitor various indicators of ecological, economic and social condition in order to compare well-being and progress towards sustainability between nations. Examples of these include international debt, Gross Domestic Product (GDP) and carbon dioxide emission rates, as well as popular aggregated indices such as Yale's Environmental Sustainability Index (YESI) and the United Nations Development

Programme's Human Development Index (HDI). However, there is no single index which serves as a universally accepted measure of sustainability (Kaufmann and Cleveland 1995, Hanley 2000). Indicators such as GDP are criticized for being one dimensional and therefore inadequate predictors of total well-being (Steer and Lutz 1993), while aggregated indices such as the YESI are criticized for subjective methodology and for combining too many disparate variables (Morse and Frasier 2005, Ecologist 2001), thereby masking more relationships than they reveal. Likewise, there is an abundance of literature on the economic (Ndikumana and Boyce 2003) and ethical (Motehabi 2003) aspects of African international debt, but nothing which quantifies the impact of this debt on human well-being. Despite advances in sustainability and well-being research, there is a great need to quantify the links between international debt, environmental sustainability, human well-being, and non-economic resource flows.

Plan of Study

This thesis addresses the above issues using a technique of Environmental Accounting. To better understand the various indices of well-being and their relationship to quantitative measures of resource use and environmental contributions to well-being, several indices of well-being were evaluated for 134 nations of the world. Since environmental contributions to economies or individuals are not adequately captured in monetary terms (Odum 1996), environmental services at the national level were evaluated using emergy. From these evaluations, indices of sustainability and environmental contributions were calculated for each country (Sweeney et al. 2006, in press). Emergy indices for each country were compared with indices of well-being. Then, as case studies, five nations of the Sahel region of Africa were evaluated in detail including their balance of trade and their national debt. Relationships between debt, currency exchange ratios and emergy money ratios were explored.

Literature Review

Environmental Accounting

Environmental Accounting (Odum 1996), called emergy synthesis (ES), provides a means for assessing the environmental resource base and economic flows for coupled human-environment systems using common biophysical units called solar emjoules. By quantifying a nation's resource basis in biophysical units, ES can evaluate national economies, human use of the environment, and provides a quantitative measure of sustainability. Emergy is defined as "all the available energy that was used in the work of making a product and expressed in units of one type of energy" (Odum, 1996). It is a measure of real wealth, taking into account the work of nature and humans in production (Odum 1996). In the emergy accounting methodology (details of which can be found in Odum, 1996), system stocks and flows are measured in a common unit (solar emjoules) based on the total direct and indirect energy required to produce a product or service (Odum 1996). By expressing both economic and environmental components in common units, emergy permits meaningful comparison of the resource requirements for national economic processes, and consequently a means to monitor and compare sustainability.

This technique has been used to evaluate national economies (Ulgiati et al. 1994) international trade (Brown and Ulgiati 2001, Brown 2003), various economic sectors (forestry (Tilley and Swank 2003), agriculture (Lefroy and Rydberg 2003, Panzieri et al. 2003), energy (Bastianoni et al. 2005, Brown and Ulgiati 2002)) and environmental services (water, sunlight (Campbell 2004)); in all cases, the technique offers a useful complement to economic evaluation of costs and benefits by examining the environmental work embodied in goods and services. Recent developments in environmental accounting data synthesis across nations (Sweeney et al. 2006, in press) permit application to the questions of linkages between human well-being, economic equity and environmental condition examined in this study.

Well-being and Sustainability Indicators

Because sustainability is an interdisciplinary concept, measuring it requires a combination of economic and ecological analyses (Kaufmann and Cleveland 1995). While sustainable development has many definitions, the concept can be summarized as an economic growth path with a non-declining level of human well-being (often interpreted as non-declining consumption) and environmental well-being (Hanley 2000). It encompasses the concerns of the community, economy and environment (Morse 2004). Following the Agenda 21 commitment to "expand existing systems of national accounts in order to integrate environmental and social dimensions in the accounting framework" (as cited in Steer and Lutz 1993) there has been a movement away from focusing solely on economic aspects of development (Steer and Lutz 1993). While GDP has traditionally been used as a macroeconomic indicator of growth, it does not necessarily reflect environmentally friendly growth (Munasinghe and McNeely 1995) or actual human well-being (Steer and Lutz 1993). In fact, there is no one conceptual framework which captures well-being (van Kamp et al. 2003), and as Hanley (2000) shows in his discussion of the Green Net National Product (NNP), a good measure of well-being is not necessarily a good measure of sustainability.

"Indicators are measurements selected to represent a larger phenomenon of interest" (Cole et al. 1998). Specifically, sustainability indicators allow researchers and policymakers to monitor human impacts on the environment and to relate human use to a reproducible indicator (Munasinghe and McNeely 1995). These indicators are necessary to monitor whether development is truly sustainable (Hanley 2000) by simplifying complexity (Morse 2004). However, they may also oversimplify reality (Morse 2004, Morse and Frasier 2005). For example, poverty is a concept that is not simple to define, for it can encompass more that just inadequate income (Ahlburg 1996, Morse 2004). Likewise, while aggregation of data to produce indicators is necessary, critics say that aggregations can be arbitrary and misleading (Steer and Lutz 1993).

There have been numerous efforts by various international organizations to quantify human and/or ecological well-being. The most notable include the ecological footprint (Loh and Wackernagel 2004), the Yale Environmental Sustainability Index (Esty et. al. 2005), the Human Development Index (Murphy and Ross-Larson 2004) and the Well-being Index (Prescott-Allen 2001).

The ecological footprint (EF) is an index of natural resource consumption reported in the number of global hectares (def. = a hectare with the global average biological productivity) necessary to support one person; it is computed on a nation-by-nation basis offering a convenient comparator for environmental accounting metrics at the same scale. The EF includes the area of built up land, the area necessary to renewably provide the amount of water withdrawn, and the area required to provide food, timber and energy in addition to the area to absorb wastes. For example, the EF for a country includes the biocapacity (in hectares) needed to sequester the carbon produced by that country from the burning of fossil fuels. The EF does not include waste flows for which there is no limit considered sustainable (e.g., heavy metals, plutonium, CFCs, dioxins) or for which there are currently no reliable data on waste impacts (e.g., acid rain). A higher

EF corresponds to elevated consumption of resources per person (Loh and Wackernagel 2004). Figure 1-1 depicts global measurements of the EF.

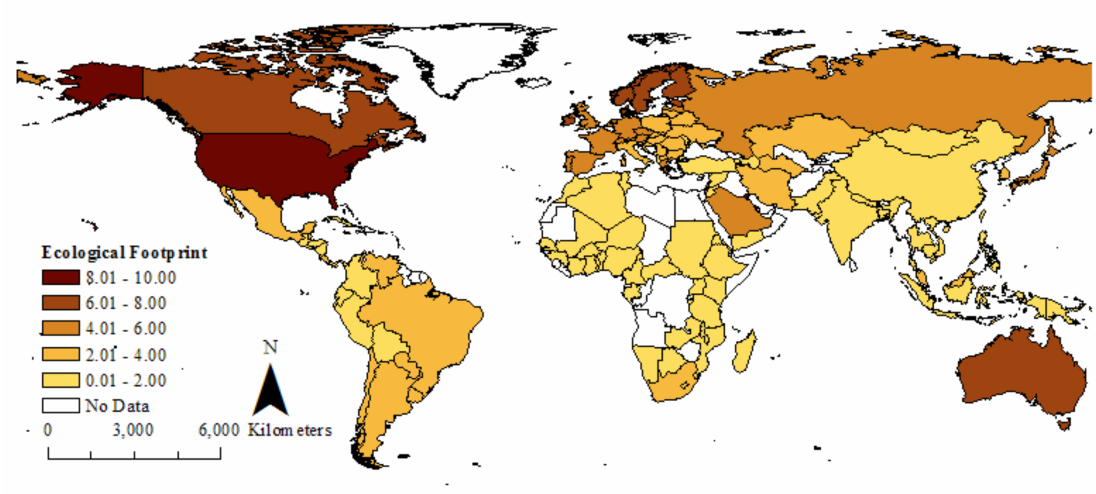

Figure 1-1: Map of ecological footprint in hectares per person. Data from Loh and Wackernagel, 2004.

Rees (1996), one of the creators of the EF, explores the rational for an indicator such as the EF by revisiting the definition of carrying capacity. His discussion recognizes the role of the second law of thermodynamics in self organizing ecosystems and the human economy, and that trade and technology can only increase efficiency of resource use, not increase carrying capacity. Rees (2002) also used the ecological footprint methodology as well as ecological economic theory as a basis for his conceptual framework for development, which recognizes that there are biophysical limits to expansion and that maximizing income does not necessarily maximize well-being.

The EF is perhaps the most referenced sustainability indicator in current literature. Ko et al. (1998) calculated the EF for four of the five countries in their study on national sustainability trends. Van Vuuren and Smeets (2000) computed time series EF values for Benin, Bhutan, Costa Rica and the Netherlands using local land production data instead of the global average. They found that using local land production instead of the global average makes it more difficult to make comparisons between nations, but is more relevant to national policy. They also found that looking at the disaggregated components of the EF is more applicable to guiding policy than the total EF (van Vuuren and Smeets 2000). Ferng (2002) reviews some of the remaining criticisms of the updated EF. Among them, while the EF is useful for raising public and political awareness of societies' environmental impacts, the EF is a static index making it difficult to apply to policy, and specifically energy policy. Although the updated EF methodology includes estimates of the embodied energy of imported non-energy products in the national energy budget, Ferng suggests that the EF ignores the linkages between the final consumption of goods and services, final energy consumption, and the primary energies required directly and indirectly. Ferng includes these linkages in a proposed framework and calculations for the energy footprint (Ferng 2002). York et al. (2005) concluded that the EF is a valid indicator of ecological impact due to its strong correlations with CO2 emissions, use of ozone-depleting substances and nuclear energy production, both with and without the fossil fuel and nuclear components of the EF included in the analysis. Using data for the 1999 EF (which has a slightly different methodology from the 2001 EF used in this study) they also found an overall trend of impact intensity (measured by EF/total GDP) decreasing as affluence (measured by GDP per capita) increases, but that there is high variability in impact intensity among the low income nations, with many of them being among the most efficient nations in the study (York et al. 2005).

The EF does not contain any information on economic or social development (van Vuuren and Smeets 2000). However, Jorgenson (2003), using a structural equation modeling approach and maximum likelihood estimation, found that world system position (a combination of relative military power, economic power and global dependence) has a positive effect on per capita EF, domestic inequality has a negative effect on per capita EF, urbanization has a positive effect on per capita EF and literacy rates have a positive effect on per capita EF.

The Yale Environmental Sustainability Index (YESI) is a measure of a country's environmental health, resource use and institutional mechanisms to change society's environmental and resource use trajectory. The index is based on five components (state of environmental systems, stress on those systems, human vulnerability to environmental change, social and institutional capacity to cope with stresses, and contribution to global stewardship) derived from 21 indicators considered fundamental to sustainability (e.g., water quality, reducing air pollution, basic human sustenance, science and technology). Seventy-six variables are transformed to comparable scales, then aggregated and used to score countries in these 21 indicator categories. The 21 indicators are weighted equally, regardless of how many variables they are based on, and then averaged to determine a country's YESI. The YESI score is meant to quantify a country's ability to avoid environmental deterioration. The higher a country's YESI score, the more likely it is to maintain environmental health and resources in the future (Esty et. al. 2005). Figure 1-2 depicts global measurements of the YESI.

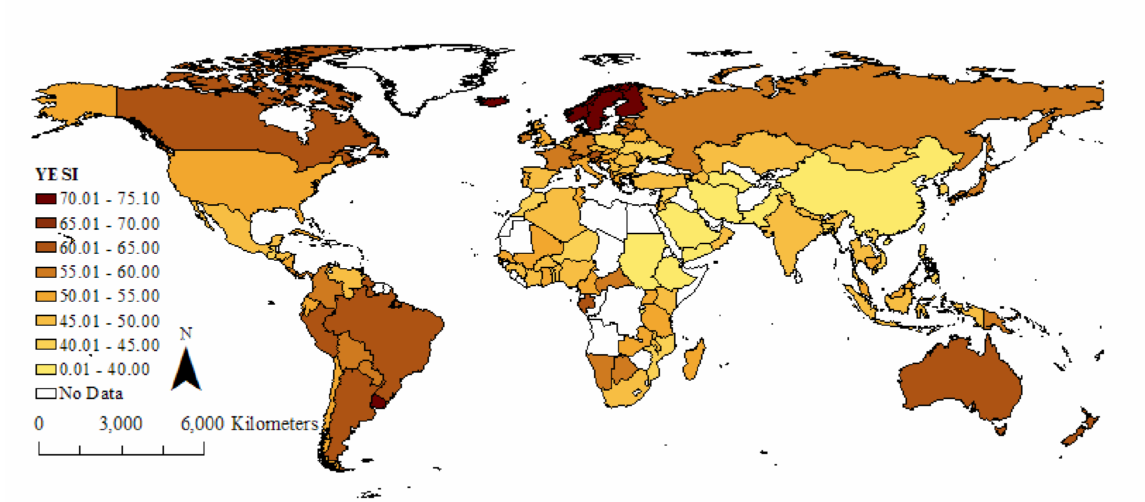

Figure 1-2: Map of the Yale Environmental Sustainability Index. Data from Esty et. al., 2005.

The main criticisms of the YESI arise from the aggregation and weighting of indicators (The Ecologist 2001, Morse 2004, Morse et al. 2005). One of the five YESI categories, "Social and Institutional Capacity", supplies 7 of the 22 equally weighted indicators and duplicates information already supplied in other sections of the YESI (The Ecologist 2001). The Ecologist (2001) also points out that having the "capacity" to solve environmental problems is not the same as solving them. By changing the methods used to aggregate the indicators and removing indicators which had methodology problems, the Ecologist recreated the YESI with vastly different results

To test the Ecologist's criticisms and reworking of the YESI, Morse et al. (2005) used principle component analysis to study the relationships between the components of the YESI. Additional criticisms they discuss include that 24 of the 68 variables used to compute the YESI rely on varying degrees of imputed data. For example, 65 % of the data which comprises the "Air Quality" indicator is imputed instead of observed values (Morse 2004, Morse et al. 2005). They found that while there is a strong positive relationship between GDP and YESI for low income countries, this relationship may plateau and decline with higher income levels, which means that the inference made by the creators of the YESI that sustainability does not constrain economic growth (Esty and Levy 2000, cited by Morse et al. 2005) is misleading. They also found that depending on the variables included and the way they are aggregated, many different versions of the YESI are possible, some positively and some negatively correlated with GDP per capita (Morse et al. 2005).

The Human Development Index (HDI) is a measure of a country's average achievement in human development based upon a long and healthy life (life expectancy at birth), knowledge (adult literacy rate and gross school enrollment ratio) and standard of living (Gross Domestic Product per capita). Each indicator's range is transformed to a scale from zero to one, with zero being the minimum value and one being the maximum value for each indicator for a specific year. Countries are given a score in each of the three categories. These scores are then averaged to determine the HDI. The higher a country's HDI, the higher its level of human development (Murphy and Ross-Larson 2004). Figure 1-3 depicts global measurements of the HDI.

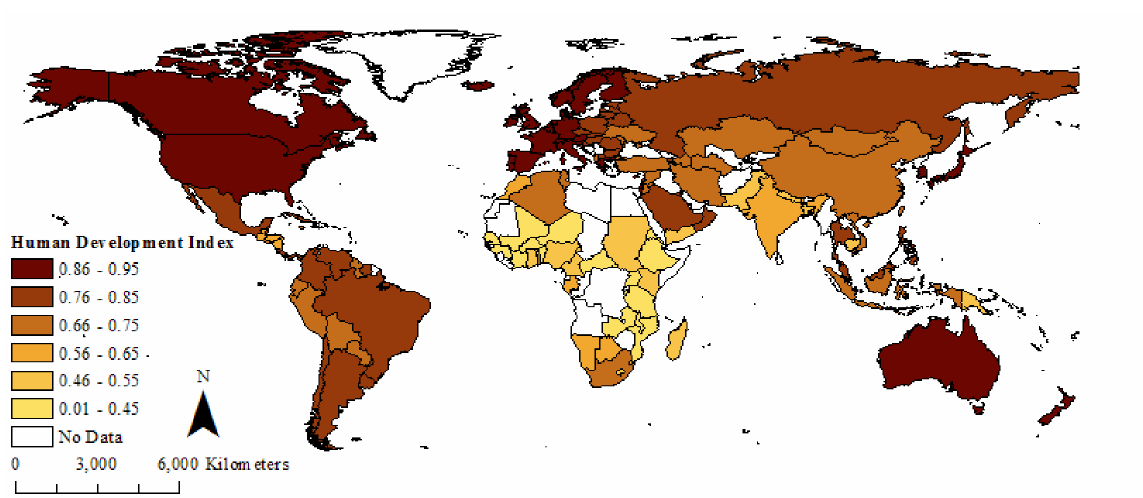

Figure 1-3: Human Development Index. Data from Murphy and Ross-Larson, 2004.

The three components of the HDI were selected because they are common development indicators and can be combined using simple and transparent methods (Morse 2004). Some have suggested that the HDI should include a “happiness” component in order to reflect true human well-being (Morse 2004) and Van Den Berg (2002) suggests that the HDI, like GDP, fails to measure lifetime well-being of individuals. It has also been suggested that the HDI should be modified to include whether or not a country is environmentally sustainable (Morse 2004). While many modifications and alternatives to the HDI have been suggested (see Ivanova et al. 1998, Noorbakhsh 1998, Anad and Sen 2000, Ogwang and Abdou 2002, Lind 2003, Morse 2003), the UN maintains that the HDI is meant to provide a summary measure, not a comprehensive measure, of human development by measuring average achievement, not disparities and deprivation (Fukuda-Parr 2001).

The Physical Quality of Life Index (PQLI), which is an unweighted average of infant mortality rate, adult literacy rate and life expectancy at birth has also been used to rank countries based on human well-being (Mazumdar 1999), though not as extensively as the HDI.

The Prescott-Allen Well-being Index (WI) is a combined measure of environmental and human welfare. It is based on the concept that ecosystem well-being and human well-being should be measured separately, then equally weighted and considered together. Countries are given performance scores from zero to 100 for both aspects of well-being. These performance scores are separately called the Human Well-being Index (HWI) and Ecosystem Well-being Index (EWI). The HWI is a composite of indicators in the five categories of health and population, wealth, knowledge and culture, community and equity. The EWI is composed of indicators in the five categories of land, water, air, species and genes and resource use. HWI and EWI are then averaged to determine a country's WI. A high WI corresponds to a high total well-being (Prescott-Allen 2001). No studies were found in the current literature which make use of the WI.

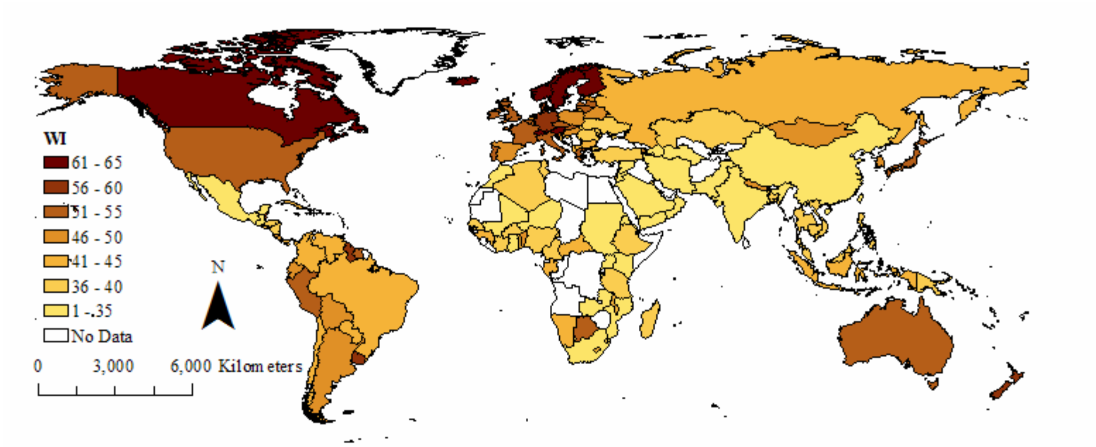

Figure 1-4: Map of the Well-being Index. Data from Prescott-Allen, 2001.

Aggregated indices which were not evaluated though they have become popular in the current literature are the Index of Sustainable Economic Welfare (ISEW, Daly and Cobb 1989) and the Genuine Progress Indicator (GPI, Loh and Wackernagel 2004) which have currently only been calculated for a few countries (Lawn 2003, for a review of ISEW studies and critiques see Neumayer 1999) or regionally (Costanza et al. 2004). Other aggregate indices include the achievement index and the improvement index which have been calculated for countries of the European Union to compare quality of life (Yoruk and Zaim 2003). Sutton (2003) created an environmental sustainability index for each nation by dividing the total value of a nation's ecosystem services (measured by a landcover dataset matched to ecosystem service values) by the amount of light energy emitted by that nation (measured from nighttime satellite imagery). This index was then compared to the YESI and EF and found to be related to the EF deficit (or the hectares of impact which surpass the country's total hectares). Ronchi et al. (2002) created an aggregate sustainability index specific to Italy by combining indicators they felt reflected national and local peculiarities, which they say is important in any sustainability index and lacking in the popular aggregated indices (such as HDI and ISEW)..

At the regional level, Troyer (2002) used systems theory, where political units can import or export their sustainability, to create a GIS which ranked human welfare (based on census data such as longevity and education) and ecological welfare (based on the EPAs aquatic monitoring data) at the watershed level to identify regions with above average human and ecological conditions (which he therefore classified as sustainable developments) in Ohio. In a similar study, Gustavson et al. (1999) created a watershed level model using regional level human and ecological well-being indicators.

Aggregated indices have also been created to evaluate specific engineering processes, such as the sustainable process index (SPI) which Narodoslawsky and Krotscheck (2004) have used to compare different energy generating technologies.

Various indicators of pollution levels and socio-economic conditions have also been used to compare economic development and environmental sustainability between nations. Kaufmann and Cleveland (1995) suggest that an overall sustainability measure has no meaning and instead researchers should model the use of particular forms of life support and the environment's ability to provide it. Supporting the Kuznets curve hypothesis, or the inverted U shape relationship between income and environmental degradation (see Dinda 2004 and Dinda 2005 for a review of the Kuznets curve literature), there have been studies relating economic growth to energy use (Cleveland et al. 1984) and environmental degradation as measured by various pollutants (Grossman and Krueger 1999). However, Arrow et al. (1995) argue that Kuznet curves have only been shown to apply to a few pollutants and do not consider system-wide consequences of the pollutants. Ko et al. (1998) and Tharakan et al. (2001) found that in the respective countries studied, agricultural efficiency had decreased with industrial development, and even when energy and carbon efficiency increased, total amount of resource use also increased drastically, leading them to conclude that environmental impact also increased (Tharakan et al. 2001) and that there are limitations to the prospects of sustainable development (Ko et al. 1998). Kratena (2004) created a global energy input-output system to account for carbon emissions and develop an ecological value added (EVA) sustainability indicator. Finally, the IPAT theory (where environmental impact is the product of population, affluence and technology) and variations of the IPAT equation have been used to show the relationship between economic development and CO2 emission (York et al. 2003).

Despite the links found between economic development, resource use and the environment, few of the studies reviewed explicitly studied the relationship between these factors and human well-being. Also, political issues such as corruption have long been identified as an important element in sustainable development (Morse 2004), but political and governmental indicators are not directly included in the popular aggregate indices. For these reasons, I chose to analyze the indices and indicators listed and defined in Appendix A in order to further relate human well-being, the environment and socio-economic conditions.

African External Debt

Malnutrition, HIV, access to water, poor sanitation, disease, environmental degradation and general poverty (Buve 2002, Pasteur and Mann 1999 cited in Poku 2002, UN Millennium Project 2005, 2005b) are all aspects of the development crisis that is underway in Sub-Saharan Africa. Of the 38 Heavily Indebted Poor Countries (HIPC) currently identified by the World Bank and the International Monetary Fund, 32 are in Sub-Saharan Africa (The World Bank 2006). While there is no one cause, many believe that an inequitable international economy (and more specifically, inequitable international trading) is the root of Africa's development problems (Boafo-Arthur 2003). With globalization, Africa struggles to compete at a global level as foreign direct investments steadily decline and are inequitably distributed, state capabilities are diminishing, unemployment remains high, and countries are in a cycle of taking out more loans to pay the interest on existing loans (Boafo-Arthur 2003). One of the most common ways to address Africa's developmental problems has been external economic aid, leading to the debt which has continued to increase despite IMF and World Bank structural adjustment programs (Boafo-Arthur 2003). Table 1-1 shows the long term debt outstanding of Sub-Saharan African countries as of the end of the year 2000.

These external debts, their repayments and accumulating interest have caused an ethical dilemma (Motlhabi 2003). In order to make debt payments, countries must make tradeoffs (Cheru 2002, Boafo-Arthur 2003, Mahdavi 2004). For example, with the exception of South Africa, all Sub-Saharan African countries spend more money on debt payments than on health (Boafo-Arthur 2003). Arimah (2003) found that cities within African HIPCs have inadequate provisions of basic infrastructure (water, electricity, sanitation and telecommunications). However, Boyce and Ndikumana (2001) found that when capital flight (large, private outflows of funds, Ndikumana and Boyce 2003) was

Table 1-1: Reported long term debt outstanding for Sub-Saharan African nations

Nation	**Long Term Debt Outstanding (LDOD)**	**Nation**	**Long Term Debt Outstanding (LDOD)**
Nigeria	30,234,900,000	Somalia	1,825,100,000
South Africa	15,308,000,000	Niger	1,527,300,000
Sudan	10,927,100,000	Benin	1,441,900,000
Cote d'Ivoire	10,545,700,000	Togo	1,230,400,000
Angola	8,084,800,000	Burkina Faso	1,229,600,000
Congo, Dem. Rep.	7,880,200,000	Rwanda	1,148,500,000
Cameroon	7,757,700,000	Liberia	1,040,100,000
Mozambique	6,216,700,000	Burundi	1,036,000,000
Tanzania	5,760,000,000	Chad	1,031,200,000
Ethiopia	5,326,900,000	Sierra Leone	1,005,800,000
Ghana	5,251,400,000	Mauritius	952,900,000
Kenya	5,220,500,000	Central African Rep.	795,700,000
Zambia	4,508,200,000	Guinea-Bissau	715,500,000
Madagascar	4,285,800,000	Lesotho	656,700,000
Congo, Rep.	3,757,500,000	Gambia	437,900,000
Gabon	3,453,500,000	Botswana	437,800,000
Senegal	3,205,200,000	Cape Verde	314,600,000
Uganda	3,051,300,000	Seychelles	310,900,000
Zimbabwe	2,978,900,000	Sao Tome and Principe	300,400,000
Guinea	2,940,400,000	Eritrea	298,000,000
Mali	2,671,000,000	Swaziland	286,700,000
Malawi	2,544,600,000	Comoros	207,900,000
Mauritania	2,028,500,000	Equatorial Guinea	198,900,000

Data from GDF 2005, reported in year 2000 U.S. dollars.

accounted for, all of the 25 Sub-Saharan African countries studied were net creditors, meaning that private external assets were greater than external debt. This capital flight was found to be exacerbated by debt, with every dollar borrowed, approximately 80 cents left the country as capital flight (Ndikumana and Boyce 2003). These external assets are held by a minority (Boyce and Ndikumana 2001), whereas if external debt forces the government to decide between making repayments and investing in human capital, the results will be felt by the impoverished majority.

The problem of African debt and repayments may be confounded by the exchange rate. Exchange rate fluctuations are important because they influence prices, wages, interest rates, production levels and employment opportunities, therefore affecting the welfare of citizens (Isard 1995). Monetary exchange rates date back to the Middle Ages, when secondary markets developed at international trading fairs for buying and selling bills of exchange, paper instruments representing gold or silver held in the banks of major trading cities. These rates would fluctuate in response to developments in the balance of trade (Isard 1995). Prior to 1871, a system of flexible exchange rates prevailed as the relative price of gold and silver varied (Alogoskoufis 1994). This was followed by the 1871-1941 gold standard, a system of fixed exchange rates (Alogoskoufis 1994). During the World Wars, a variety of exchange rate arrangements developed, followed by the Bretton Woods system of fixed but adjustable rates from 1950 to the early 1970s, (Alogoskoufis 1994) and the current system of floating exchange rates, managed floating rates, fixed rates and combination systems (Alogoskoufis 1994, Isard 1995, Frankel 1993).

With the advent of telephones and computer networking, current foreign exchange is a global, 24 hour a day process. When countries fix their exchange rate, they must intervene in the market by buying or selling their currency when necessary to keep the exchange rate stationary. With floating exchange rate systems, authorities do not intervene in the market (Isard 1995). However, floating exchange rates vary inexplicably and the variation can not be explained by changes in money supplies (Frankel 1993).

There are a variety of exchange rate arrangements which range between complete fixed and freely floating. The degree of exchange rate variability often reflects the nature of policies in place to stabilize the exchange rate, as keeping exchange rates stable can sometimes involve very high costs to the country (Isard 1995)

Four of the five West African countries studied in detail in this thesis share the same currency, the Communaute Financiere Africaine franc (CFA). These countries, Burkina Faso, Mali, Niger and Senegal, are members of the West African Economic and Monetary Union (WAEMU) of the CFA franc Zone (International Monetary Fund 2004). Member countries of the CFA franc zone are those which were occupied by France at the end of World War I (Fielding and Shields 2005). The CFA franc zone is classified by the International Monetary Fund (IMF) as an exchange arrangement with no separate legal tender (IMF 2004), which means that there is a single central bank (Fielding and Shields 2005) and individual countries do not control their domestic monetary policy (IMF 2004). The CFA franc zone has a historical agreement with the French treasury guaranteeing a fixed rate of exchange between the CFA and euro (and previously the French franc), but there are rules limiting African government borrowing to prevent abuse of this agreement (Fielding and Shields 2005). As is expected of monetary unions (Rose and Engel 2002) the CFA franc zone has increased trade and decreased market shocks for member countries (Fielding and Shields 2005).

Mauritania was a member of the CFA franc zone until 1973, at which time it exited to pursue its identity as an Arab state (Fielding and Shields 2005). Mauritania’s currency, the ouguiya (MRO), is classified as managed floating, which means the monetary authority attempts to influence the exchange rate without having a specific path or target (IMF 2004).

In theory, exchange rates should reflect the relative purchasing power, or purchasing power parity (PPP), of currencies (Cassel 1918, cited by Isard 1995) where the nominal exchange rate[1] equals the ratio of national price levels (Isard 1995). This PPP hypothesis of how exchange rates adjust reflects two-way causation, with exchange rates adjusting to changes in national price level ratios and vise versa (Isard 1995). Evidence supports criticisms of the PPP hypothesis confirming that the proposed relationship between nominal exchange rates and national price levels may be valid in the long term, but is not valid in the short or medium term (Isard 1995).

Alba and Park (2004) found mixed empirical support for PPP in the lira to euro exchange rate while researching the costs and benefits of Turkey joining the European Union. Examining the real exchange rate in Croatia, Payne et al. (2005) found no evidence for the purchasing power parity theory of exchange rate determination. They conclude that their findings support the doubt that the purchasing power parity theory holds for transition economies (Payne et al 2005). Likewise, Lopez et al. (2005) found that the purchasing power parity theory held for only 9 of the 16 industrialized countries studied. Overall, whether or not the PPP theory holds for exchange rates in the long run is still controversial (Lopez et al. 2005).

[1]The nominal exchange rate is the actual exchange rate, or the number of domestic currency units which can purchase a foreign currency unit. The real exchange rate is the nominal exchange rate adjusted by ratios of national price levels and tells us the ratio of goods that can be purchased in two different countries for a given amount of money (Isard 1995).

Research Objectives

This thesis is divided into two main parts. The first compares the indices calculated from emergy analyses of 134 nations to a variety of commonly used sustainability and well-being indicators to answer the following questions:

1. How are the emergy indices related to each other and can they be used to rank the so called sustainability of nations? Hypothesis 1: Emergy indices will allow grouping of nations into classes that conform with normative classifications based on development status and resource use intensity.

2. How are the commonly used well-being and sustainability indicators related to each other, why do they disagree, and are their criticisms valid? Hypothesis 2: Measures of human well-being is negatively correlated with measures of environmental well-being. Hypothesis 3: Examination of index components will clarify apparent discrepancies.

3. How do emergy indices and the above mentioned well-being and sustainability indices relate, and what can an evaluation of the resource basis of a nation tell us about the welfare of the people and the environment? Hypothesis 4: Human welfare indices are positively correlated with the use of non-renewable emergy.. Hypothesis 5: Environmental welfare indices are negatively correlated with the use of non-renewable emergy.

4. Which countries create high welfare (as measured by the above mentioned well-being and sustainability indices) with sustainable practices (as measured by the emergy indices)? *Hypothesis 6: Comparison of indices allows for the identification of nations with high overall well-being. Hypothesis 7: A national ranking of overall well-being can be created by combining measures of human welfare and emergy sustainability.*

The second part of this thesis evaluates trade equity between nations, particularly Africa and the global economy, and uses emergy to evaluate the equity of international loans and debt repayments. This second part of this thesis was guided by the following questions:

5. Is the emergy money ratio (EMR, which is traditionally calculated using a nominal exchange rate) an appropriate comparator of trade and debt repayment equity? *Hypothesis 8: Due to the influence of the exchange rate, the traditional use of the EMR should be modified for international exchange calculations.*

6. What is the level of African international debt when disbursements and repayments are enumerated in units of embodied environmental work (emergy) instead of money? *Hypothesis 9: African nations have repaid their debt if measured in environmental work, or real wealth.*

The results of this study will enhance sustainability assessment by providing data on relationships between the resource basis of an economy and patterns of national welfare as well as the resource consequences of international loans.

CHAPTER 2
METHODS

This section contains a description of the study area, followed by the methods for a comparison of well-being indices and analysis of international debt, with specific emphasis on five West African focal countries; Burkina Faso, Mali, Mauritania, Niger and Senegal. Part 1 utilizes the results of national emergy analyses of 134 nations from the National Environmental Accounting Database (Sweeney et al. 2006, in press) to compare indices of well-being and develop a new emergy index. Part 2 employs the emergy accounting methodology to analyze the international debt of the five focal countries from 1970 to 2000.

Study Area

For the majority of Part 1, the study area includes 134 nations for which national emergy analyses were available for the year 2000 from the National Environmental Accounting Database (NEAD) compiled by Sweeney et al. (2006, in press). While many well-being and trade measures used in this thesis may vary by region, all analyses were done at the national scale because of data availability. Throughout the thesis and particularly in Part 2, special emphasis is placed on Burkina Faso, Mali, Mauritania, Niger and Senegal. These five West African nations are located in the Sahel region and were chosen because they are part of a broader study on dryland management.

The Sahel region of Africa is located on the southern border of the Sahara Desert. It extends through the countries of Burkina Faso, Chad, Ethiopia, Mali, Mauritania, Niger, Senegal, Somali and Sudan. While a variety of soils can be found throughout the

Sahel, almost all have low chemical fertility (Koechlin 1997). There is a large gradient of average rainfall and vegetation between the northern and southern Sahel, with ecosystems including semi-desert, steppe and savanna (Keochlin 1997). The availability of water is considered the primary limiting factor in this region (Koechlin 1997). The Sahel has been increasing in aridity for the past 5000 years, and since the mid 1960's, the region has been known world-wide as an area of drought, desertification and famine (Agnew 1995).

Part 1: Comparative Analysis of Wellbeing and Sustainability Indicators Using Emergy Accounting

For the first part of this thesis, emergy indices previously calculated for 134 nations were reduced to their latent variables using principle component analysis. The nations were grouped by their emergy signatures using cluster analysis. Pearson correlations were used to compare indicators of human and environmental wellbeing to each other and to the emergy indices.

Emergy

The emergy flows identified in Figure 2-1 and Table 2-1 were calculated for 134 nations for the year 2000 and aggregated into various emergy indices (defined in Table 2-2) within the NEAD by Sweeney et al. (2006, in press). Each of these NEAD analyses were compiled from the same data sources using the methods described in Odum, 1996. A sample of the emergy indices for all of the nations in the NEAD can be found in Appendix B. Due to the large number of emergy indices, pearson correlations were calculated for the normalized emergy indices to eliminate redundancy. If two indices were correlated with an R of 0.8 or above (significant at .01 level, 2-tailed), the one less commonly used in interpretation of an emergy synthesis or less insightful for national.

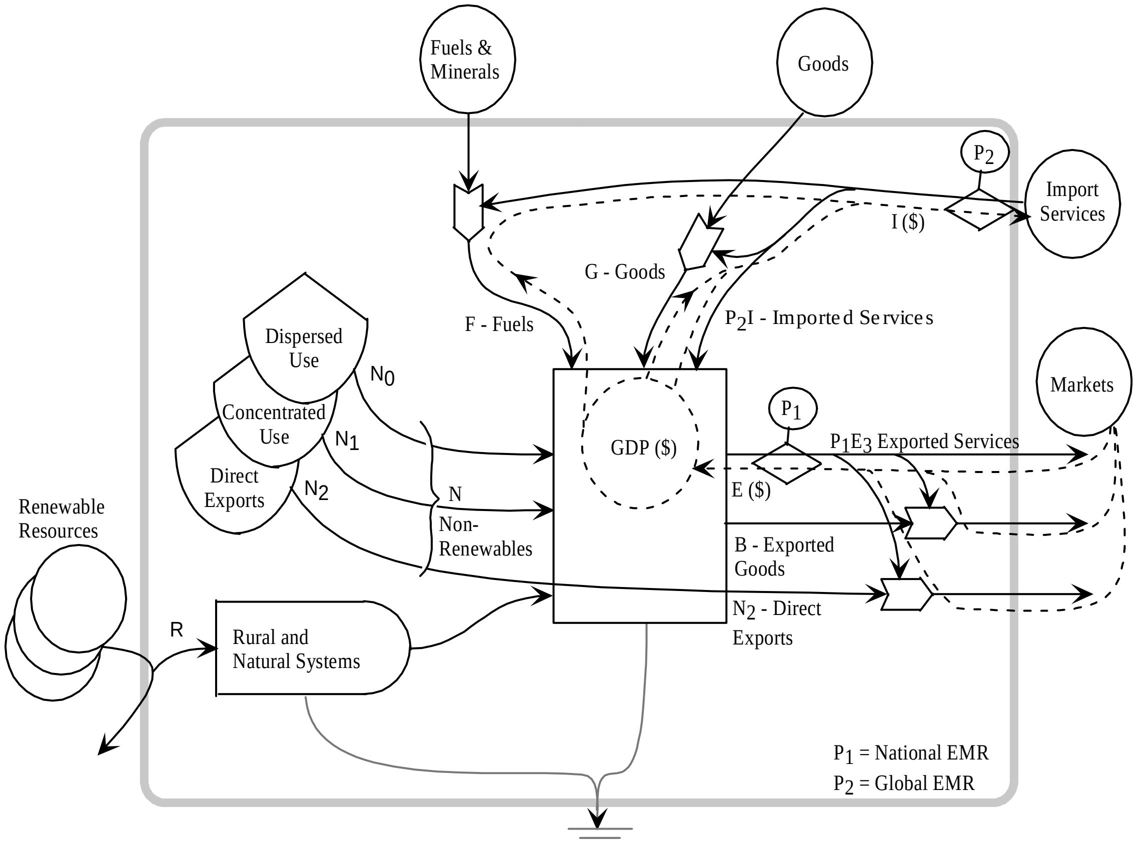

Figure 2-1: Systems diagram of a nation showing aggregated emergy flows. Adapted from Odum, 1996. Definitions of symbols found in Appendix B.

Table 2-1: Definitions of emergy flows and storages

Emergy Flow Symbol	Emergy Flow Name
R	Renewable sources used (e.g., rain, tide, sunlight)
N	Non-renewable sources
N_0	Dispersed non-renewable rural source
N_1	Concentrated non-renewable use
N_2	Non-renewables exported without use
F	Imported fuels and minerals
G	Imported goods
I	Dollars paid for imports
P_2I	Emergy value of goods and services imported
E	Dollars paid for exports
B	Exported products transformed within the nation
P_1E_3	Exported services
X	Gross Domestic Product
P_2	World emergy money ratio (used for imports)
P_1	Nation emergy money ratio (used for exports)

Table 2-2: Definitions of emergy indices

Emergy Indices	Symbol and/or Equation	Units	Source
Renewable emergy flow	R	sej/yr	Odum, 1996
Flow from indigenous nonrenew reserves	N	sej/yr	Odum, 1996
Flow of imported emergy	F(i) + G(i) + P2I	sej/yr	Odum, 1996
Total emergy inflows	R + N + F(i) + G(i) + P2I	sej/yr	Odum, 1996
Total emergy used, U	N0+N1+R+F(i)+G(i)+P2I - F(e)	sej/yr	Odum, 1996
Total exported emergy	F(e) + G(e) + P1E	sej/yr	Odum, 1996
Fraction emergy use from indigenous source	(NO+N1+R) / U	ratio	Odum, 1996
Imports minus exports	[F(i) + G(i) + P2I] - [F(e) + G(e) + P1E]	sej/yr	Odum, 1996
Export to Imports	[F(e) + G(e) + P1E] / [F(i) + G(i) + P2I]	ratio	Odum, 1996
N2/total exports	N2/[F(e) + G(e) + P1E]	ratio	Sweeney et al. 2006, in press
Fraction used, locally renewable (or percent renewable)	R/U	ratio	Odum, 1996
Fraction of use purchased	[F(i) + G(i) + P2I] / U	ratio	Odum, 1996
Fraction imported service	P2I / U	ratio	Odum, 1996
Fraction of use that is free	(R+N0)/U	ratio	Odum, 1996
Ratio of concentrated to rural	[F(i)+G(i)+P2I+N1-F(e)] / (R+N0)	ratio	Odum, 1996
Use per unit area, Empower Density	U / area (ha)	sej/m2/yr	Odum, 1996
Use per person	U / population	sej/capita	Odum, 1996
Renewable use per person	R/population	sej/capita	Odum, 1996
Non-renewable use per person	NR/population	sej/capita	Sweeney et al. 2006, in press
Renewable carrying capacity at present living standard	Country Population =(R/U) (population)	# of people	Odum, 1996
Emergy Money Ratio	P1=U/GNP	sej/$	Odum, 1996
Ratio of electricity to use	electricity/U	ratio	Odum, 1996
Fuel use per person	fuel/population	sej/capita	Odum, 1996
Investment Ratio	[F(i) + G(i) + P2I] / (R+N0+N1)	ratio	Odum, 1996
Environmental Loading Ratio	[(F(i)+G(i)+P2I)+N0+N1-F(e)] / R	ratio	Brown and Ulgiati, 1997
Emergy Yield Ratio	U / [N0+N1+F(i)+G(i)+P2I(i)-F(e)]	ratio	Odum, 1996
Emergy Sustainability Index	EYR / ELR	ratio	Brown and Ulgiati, 1997
Soil loss/area	soil loss/area (ha)	ratio	Cohen et al. 2006, in press
Soil loss/use	soil loss/U	ratio	Cohen et al. 2006, in press
NR water/use	NR water/U	ratio	Cohen et al. 2006, in press
NR fish/use	NR fish/Ue	ratio	Cohen et al. 2006, in press
NR forest/use	NR forest/U	ratio	Cohen et al. 2006, in press
Slow renewables/use	[soil loss+NRwater +NRfish +NRforest]/U	ratio	Cohen et al. 2006, in press
ABR	Agriculture and livestock production/soil loss	ratio	Cohen, 2003

comparisons was dropped from the analysis. Exceptions were made for emergy indices which although highly correlated with other indices, have individual importance in interpreting results of an emergy analysis.

In order to compare nations using a practical number of measures, dimension-reducing techniques were required. Specifically, because many of the national level indicators are correlated, a smaller number of composite latent variables could be extracted using a principal components analysis (PCA). This was done using emergy indices for 120 nations out of the 134 nations in the NEAD. Fourteen nations in the database were not included in the PCA because one or more of the emergy indices could not be calculated due to missing data. Before the PCA was performed, indicators which were identical or very similar to others by definition were eliminated. For example, because Percent of Use Free and Fraction of Use Purchased are by definition complimentary, Fraction of Use Purchased was removed from the PCA.

Finally, in order to deduce groups of nations according to their natural resource basis, a cluster analysis was performed on the nations based on the emergy principle components. This allowed for comparison between natural resource based clusters (defined using emergy) and clusters of nations defined by normative categories such as "developing" and "developed". The clusters used were determined by selecting a manageable number of clusters which had comparable similarity values from a dendrogram.

Wellbeing and Sustainability Indicators

Composite indices of human, economic and environmental sustainability, as well as many social, economic, governmental and environmental indicators which are either common in the literature or are currently receiving much global media attention (Flanders and Ross-Larson 2002, Cheru 2002, Poku 2002, York et al. 2003) were compared to each other and emergy indices in order to test hypotheses one through five. The comparison of wellbeing and sustainability indicators was carried out on 7 overall groups of indicators (see Table 2-3) which were selected as follows.

Group 1: Aggregate indices, so termed because they are each composed of several metrics, were chosen because they have become popular in the literature for describing and comparing nations. These include the EF, YESI, HDI, WI, EWI and HWI which were introduced in Chapter 1. Some indices, such as the Genuine Progress Indicator (GPI) and the Gross National Happiness (GNH) could not be analyzed because they have not been computed for many countries.

Groups 2-5: To select a manageable set of social, economic, governmental and environmental indicators to evaluate from a population of over 1200 indicators with global data coverage, a process of eliminating obscure or redundant indicators was conducted. First, approximately 50 indicators were selected based on their frequency of citation in the literature and the degree of global media attention they are receiving (Flanders and Ross-Larson 2002, Cheru 2002, Poku 2002, York et al. 2003). Then, this first group of 50 indicators was correlated (Pearson) against the entire population of 1200 indicators. Any of the indicators from the population which were not correlated with the original 50 with an R of 0.8 (significant at .01 level, 2-tailed) or above were also selected.

Groups 6 and 7: Metrics within the YESI and HDI were selected for evaluation in order to clarify apparent discrepancies between sustainability indices and explore the criticisms of these indices (see literature review in Chapter 1).

A complete list of indices, their definitions and sources can be found in Appendix A. All data were from the year 2000 when available. This final list was then organized into the thematic groups and sub-groups found in Table 2-3 to simplify interpretation of the analysis. To prepare them for analysis, all indices and indicators were evaluated for normality and transformed where appropriate.

Table 2-3: Indicator groups

Group Number	**Group**	**Sub-groups**	**Number of Indicators**
1	Aggregate indices		6
2	Social well-being indicators	Quality of life and health, education, labor, demographics	20
3	Government and political indicators	Economic freedom, civil freedom, quality of governance, political risk to finance and investment	24
4	Economic indicators	Income, use of money, military, tourism, technology, debt, aid	18
5	Environmental indicators	Land use, fertilizer use, deforestation, water quality, air quality, energy	13
6	YESI component indices		26
7	HDI component indices		3

In order to elucidate overlap and inconsistencies between the various indices and to provide insight regarding which countries are providing for the well-being of their population and environment, Pearson correlations between all indicators and emergy indices were conducted.

A regression analysis was performed to identify those countries whose human well-being, as measured by the HDI, was higher or lower than would be predicted based on their non-renewable emergy use per capita. A new index was proposed that combined the HDI and emergy percent renewable. Based on the premis that environmental sustainability can be defined as minimizing the percent of resource use which comes from non-renewable resources, and human sustainability can be defined as maximizing human well-being as measured by the HDI then a new indicator of total well-being can be derived. The formula for this new indicator, the Emergy Total Well-being Index (ETWI) is

$$ETWI = HDI * \%R$$

where

HDI = the Human Development Index
%R = the percent of a nation's total emergy use which comes from renewable sources.

To determine its capabilities as a well-being indicator, the ETWI was then compared to the aggregate indices using Pearson correlations.

Part 2: Analysis of West African Debt Using Environmental Accounting

For the second part of this thesis, trade equity between nations was evaluated and an Emergy Based Equitable Exchange Rate was developed and used to analyze the international debt of the West African focal countries.

The Emergy Money Ratio

As discussed in Chapter 1, the emergy money ratio (EMR) is a nation's total emergy use divided by the GDP. Traditionally, the EMR has been calculated using the GDP as reported in U.S. dollars which facilitated comparison between nations. This portion of the study examines whether an estimate of a nation's EMR based on the world EMR is accurate over time, and whether the influence of the exchange rate affects the EMR over time. To avoid confusion, for the remainder of this thesis, the EMR will be called either the emergy dollar ratio (EDR) which is the total use divided by the GDP as reported in U.S. dollars, or the emergy currency ratio (ECR) which is the total use divided by the GDP as reported in local currency units.

To evaluate the suitability of using EDR estimations in place of measured values for international comparisons over time, estimated EDRs were compared to time series EDRs and time series ECRs for the five focal countries.

The estimated EDRs were calculated as follows. From the 2000 global total emergy use value calculated from NEAD by Sweeney et al. (2006, in press) and previously calculated global total emergy use values for various years (Brown and Ulgiati 1999) adjusted to the 2000 global emergy use baseline, a global total emergy use value was estimated for each year from 1970 to 2000 using a linear interpolation (Brown and Ulgiati 1999, Ferreyra and Brown 2003). This same rate of change of total use was applied to the 2000 total emergy use values of each focal country, calculated by Sweeney et al. (2006, in press), to estimate a total emergy use for each of these countries for each year from 1970 to 2000. This estimated total emergy use was divided by the annual reported GDP in current U.S. dollars to arrive at a year specific estimated EDR for each country.

The time series EDRs and time series ECRs were calculated from emergy evaluations of the focal countries which were done at five year intervals when possible, depending on data availability. Time series emergy evaluations were calculated by Cohen et al. (2006, in press), using the methods described in Odum (1996) for the focal countries for the following years (Table 2-4):

Table 2-4: Years of available time series emergy data for the five focal countries

Target year	**Burkina Faso**	**Mali**	**Mauritania**	**Niger**	**Senegal**
1970	1970	1970	1970	1970	1970
1975	1975	1975	1972	1975	1975
1980		1979		1979	1979
1985	1983	1987			1986
1990		1990			1990
1995	1995	1996	1995	1995	1995
2000	2000	2000		2000	2000

Time series evaluations from Sweeney et al. 2006, in press.

Year specific time series EDRs and time series ECRs were calculated for the focal countries using a linear interpolation of the total emergy use values from the emergy evaluations referred to in Table 2-4, divided by the annual reported GDP in current U.S. dollars or current local currency units (LCU), respectively.

Emergy Based Equitable Exchange Rate

In order to avoid converting a nation's GDP to U.S. dollars using a market based exchange rate, an Emergy Based Equitable Exchange Ratio (EBEER) was developed. The formula for the EBEER is

$$EBEER = \frac{ECR_A}{ECR_B}$$

OR

$$EBEER = \frac{Use_A / GDP_A}{Use_B / GDP_B}$$

where

ECR_A = ECR of country A in country A's LCU
ECR_B = ECR of country B in country B's LCU
Use_A = total emergy use of country A in sej
Use_B = total emergy use of country B in sej
GDP_A = GDP of country A in country A's LCU
GDP_B = GDP of country B in country B's LCU

To determine what an equitable exchange rate would be for each of the focal countries when trading with the United States, a focal country LCU/U.S. dollar EBEER was calculated for each focal country annually from 1970 to 2000. This was done using the time series ECRs (described above, interpolated using the evaluations referred to in Table 2-4) for the focal countries, and a linear interpolation of the 2000 U.S. total use value (calculated from the NEAD) depreciated at the same rate of change as the world total emergy use values calculated in Brown and Ulgiati, 1999. A one time LCU/U.S. dollar EBEER was also calculated for each of the countries in the NEAD for the year 2000. These EBEERs were then compared to the reported official exchange rate (OER, see definition in Appendix A) and the purchasing power parity (PPP) ratio using Pearson correlations. Finally, by dividing the OER (focal country LCU to U.S. dollar) by the EBEER (focal country LCU to U.S. dollar), an emergy inequity factor (EIF) was calculated for each year from 1970 to 2000 which shows the degree to which the United States is benefiting from exchanges with the focal countries.

Analysis of West African Debt

An EBEER was also calculated for each of the focal nations versus the world for each year from 1970 to 2000 and used to adapt the method described in Brown (2003) for evaluating international exchange. Using the time series and database resources described in Sweeney et al. (2006, in press) and Cohen et al. (2006, in press), the emergy value of the existing long term external debt and debt disbursements from 1970 to 2000 of each West African focal nation was compared to the emergy of the debt service to determine how much, if any, “real wealth” (as defined by Odum, 1996) is owed by these nations. National level long term debt outstanding (LDOD), debt disbursements, debt service and average interest (The World Bank Group, GDF Online 2005) and Gross Domestic Product (The World Bank Group, WDI Online 2005) data from 1970 to 2000 was obtained from the World Bank in current U.S. dollars for each West African country for which time series emergy evaluations were completed (See Appendix A for definitions of debt indicators). A year specific emergy debt, or "EMdebt", value was calculated for each country using the following formula:

$$EMdebt_n = (DO_{n-1} * I_n) + D_n - (DS_n * OER_n * EBEER_n)$$

where

$EMdebt_n$ = cumulative EBEER EMdebt at the end of year n
DO_{n-1} = total long term debt outstanding in U.S. dollars at the end of year n-1[2]
I_n = reported average interest rate for year n
D_n = reported total long term disbursements in U.S. dollars at the end of year n
DS_n = report total long term debt service in U.S. dollars at the end of year n
OER_n = reported official exchange rate (focal country LCU/U.S. dollars) for year n
$EBEER_n$ = focal country to world for year n

Each country's annual EMdebt outstanding was then summed from 1970 to 2000 and compared to their reported U.S. dollar long term debt outstanding for the year 2000 to determine the difference between a country's monetary debt and when a country's debt would be paid off if loans and repayments were adjusted for the real wealth which they represent.

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[2] For 1970, the reported debt outstanding was used. For all other years, debt outstanding was calculated based on the previous year's debt outstanding in order to exclude interest and debt forgiven which may or may not be included in the World Bank's reported debt outstanding.

CHAPTER 3
RESULTS

The results are separated into two parts. Part 1 presents results of comparison among existing indices of human welfare, environmental condition, and resource use intensity as measured using emergy. Part 2 examines international debt payments, and places international loans and debt service into an environmental context using emergy.

Part 1: Comparative Analysis of Wellbeing and Sustainability Indicators Using Emergy Accounting

This section presents results of dimensionality reduction of emergy indices (including the principal components and cluster analyses), followed by correlations among aggregate indices, between the aggregate indices and emergy indices/principle components, and between other wellbeing indicators and emergy indices/principle components.

Emergy Indicators

Emergy analysis using the National Environmental Accounting Database (NEAD, Sweeney et al. 2006, in press) resulted in summary indices for 134 nations. Table 3-1 shows some of these emergy indices for a sample of 34 nations and demonstrates the scope of the emergy indices dataset.

Principle component analysis

The standard emergy analysis results in over 30 separate indices. Data compression of the emergy indices of 120 nations using PCA yielded 5 principal components, selected because they accounted for 76.1% of the variability in the dataset.

The correlations between the raw data are summarized in Appendix C (Table C-1). The loadings between the PCs and emergy indices can be found in Table 3-2. Those loadings on each PC which are color coded in Table 3-2 were used to determine the principle component names found in Table 3-3.

Table 3-1: Sample results from a national emergy synthesis database

	U	**U/Capita**	**R/U**	**EMR**	**Exports/ Imports**	**IR**
Belgium	2.10E+24	2.00E+17	0.00	9.20E+12	2.00	5.36
Jordan	1.80E+23	3.50E+16	0.01	2.10E+13	0.91	0.50
Hungary	3.70E+23	3.70E+16	0.02	7.90E+12	1.59	4.83
Japan	7.11E+24	5.60E+16	0.03	1.49E+12	0.44	2.25
Poland	1.30E+24	3.50E+16	0.03	8.10E+12	1.32	0.72
Denmark	4.80E+23	9.00E+16	0.04	3.00E+12	1.20	5.70
Sweden	8.40E+23	9.50E+16	0.05	3.50E+12	1.39	3.05
South Africa	2.10E+24	4.70E+16	0.08	1.60E+13	4.84	0.16
Saudi Arabia	9.06E+23	4.09E+16	0.09	4.80E+12	8.63	0.39
United States	1.90E+25	6.60E+16	0.12	1.90E+12	0.41	1.43
Pakistan	6.60E+23	4.60E+15	0.17	1.00E+13	0.90	0.42
El Salvador	9.70E+22	1.60E+16	0.22	7.40E+12	0.46	0.81
Malaysia	1.70E+24	7.50E+16	0.24	1.90E+13	4.66	0.80
China	1.28E+25	9.96E+15	0.26	1.18E+13	2.06	0.33
India	5.26E+24	5.17E+15	0.29	1.12E+13	1.24	0.17
Ghana	2.00E+23	1.00E+16	0.31	4.00E+13	1.96	0.36
Peru	1.50E+24	5.70E+16	0.34	2.80E+13	5.18	0.06
Russia	7.40E+24	5.09E+16	0.35	2.85E+13	7.78	0.10
Mauritania	1.27E+23	4.81E+16	0.42	1.41E+14	16.33	0.07
United Kingdom	5.45E+24	9.25E+16	0.44	3.79E+12	0.98	0.95
Australia	4.80E+24	2.50E+17	0.49	1.20E+13	4.94	0.14
Brazil	6.97E+24	4.06E+16	0.51	1.16E+13	3.24	0.12
Canada	6.00E+24	2.00E+17	0.51	8.50E+12	2.68	0.48
Malawi	3.70E+22	3.20E+15	0.55	2.10E+13	1.66	0.19
Senegal	8.47E+22	9.01E+15	0.56	1.94E+13	1.08	0.35
Nicaragua	9.80E+22	1.90E+16	0.59	2.50E+13	1.05	0.25
Colombia	9.80E+23	2.30E+16	0.62	1.20E+13	3.21	0.14
Burkina Faso	4.30E+22	3.60E+15	0.71	2.00E+13	0.75	0.24
Gambia	1.10E+22	8.50E+15	0.76	2.70E+13	0.49	0.27
Niger	5.14E+22	4.79E+15	0.84	2.86E+13	2.58	0.12
Mali	8.37E+22	7.03E+15	0.84	3.43E+13	1.11	0.13

See table 2-2 for definitions of indicators. Nations are sorted by percent renewable.
Data from Sweeney et al. 2006, in press

Table 3-2: Loadings of emergy indices on principle components. Those highlighted were used in determination of PC names.

Emergy index	PC1	PC2	PC3	PC4	PC5
LN N0	0.237	0.738	-0.390	0.209	0.143
N1	0.445	0.409	-0.279	-0.070	-0.132
N2(M)	0.200	0.411	0.087	0.045	0.084
N2(F)	0.294	0.383	0.215	0.348	0.219
N2	0.332	0.517	0.210	0.288	0.212
LN F(I)	0.921	0.147	-0.237	-0.152	-0.051
LN G(I)	0.927	0.220	-0.201	-0.121	0.018
LN I	0.950	0.182	-0.185	-0.118	0.002
LN P2I	0.950	0.182	-0.185	-0.118	0.002
LN F(E)	0.824	0.402	0.175	0.178	0.057
LN G(E)	0.843	0.284	-0.133	-0.281	-0.098
LN E	0.923	0.298	-0.084	-0.055	0.003
LN P1E	0.771	0.528	0.024	-0.169	-0.074
LN X	0.908	0.285	-0.220	-0.025	-0.043
LN P1	-0.715	0.325	0.253	-0.204	-0.156
LN R	0.153	0.908	-0.231	-0.199	-0.108
LN N	0.697	0.603	-0.017	0.187	0.033
LN Total Inflow	0.767	0.595	-0.084	-0.083	-0.129
LN Use	0.760	0.573	-0.136	-0.157	-0.151
Fraction Indigenous	-0.632	0.643	0.073	0.148	-0.077
Imports-Exports	-0.059	-0.363	-0.181	-0.067	-0.204
LN Exports/Imports	-0.125	0.646	0.503	0.126	-0.081
F(i)/G(i)	-0.100	-0.192	0.052	-0.073	-0.333
LN F(e)/G(e)	0.332	0.299	0.403	0.567	0.190
N2/Exports	0.014	0.400	0.376	0.654	0.129
R/Use	-0.797	0.431	-0.049	-0.231	-0.090
LN Fraction Imported Services	0.690	-0.524	-0.153	0.009	0.236
Percent Free	-0.828	0.409	-0.116	-0.143	-0.034
LN Concentrated/Rural	0.828	-0.456	0.119	0.086	0.051
LN Use/Area	0.708	-0.247	0.051	-0.388	-0.055
LN Use/Capita	0.513	0.204	0.593	-0.453	-0.033
LN R/Capita	-0.270	0.619	0.344	-0.424	0.014
LN NonRenewable/Capita	0.563	0.404	0.514	0.100	0.170
LN Renewable Carrying Capacity	-0.170	0.728	-0.579	0.090	-0.081
LN Use/GDP	-0.715	0.325	0.253	-0.204	-0.156
Electricity Consumption/Use	-0.022	0.029	-0.48	0.542	-0.471
Natual Log Fuel Use/Capita	0.827	-0.076	0.351	-0.082	0.051
LN Investment Ratio	0.644	-0.648	-0.125	-0.083	0.137
LN Environmental Loading Ratio	0.798	-0.486	0.087	0.154	0.061
LN Environmental Yield Ratio	-0.745	0.358	0.030	-0.283	-0.250
LN Emergy Sustainability Index	-0.804	0.463	-0.057	-0.194	-0.115
LN Soil Loss/Area	-0.002	0.046	-0.428	-0.435	0.583
LN Soil Loss/Use	-0.584	0.241	-0.388	-0.033	0.517
NonRenewable Water/Use	0.043	0.015	-0.256	0.644	-0.480
NonRenewable Fish/Use	-0.005	0.133	0.129	-0.047	0.137
NonRenewable Forestry/Use	-0.437	0.004	-0.200	0.110	0.384
LN Slow Renewables/Use	-0.555	0.249	-0.315	0.422	0.337
LN ABR	0.601	-0.368	0.056	0.146	-0.498

Table 3-3: Emergy principle components

Principle Component (PC)	Name	Cumulative Variability Explained
PC 1	Magnitude of the Economy	39%
PC 2	Magnitude of Natural Resource Base	57%
PC 3	Per Capita Emergy Intensity	64%
PC 4	Raw Resource Export	71%
PC 5	Non-Renewable (Natural Capital) Intensity	76%

Cluster analysis

Table 3-4 shows the results of the cluster analysis of the 120 countries analyzed. Groups of countries are similar based on their resource basis measured by the emergy principle components. Figure 3-1 is a dendrogram of these results. The clustering appears to be along a gradient from least “developed” to most “developed”. Figure 3-2, scatter plots of emergy PC1 versus emergy PC2 (a), emergy PC2 versus emergy PC3 (b) and emergy PC5 versus emergy PC1 (c) with countries grouped by cluster, shows that these clusters form distinct groups on all of the emergy PC axes.

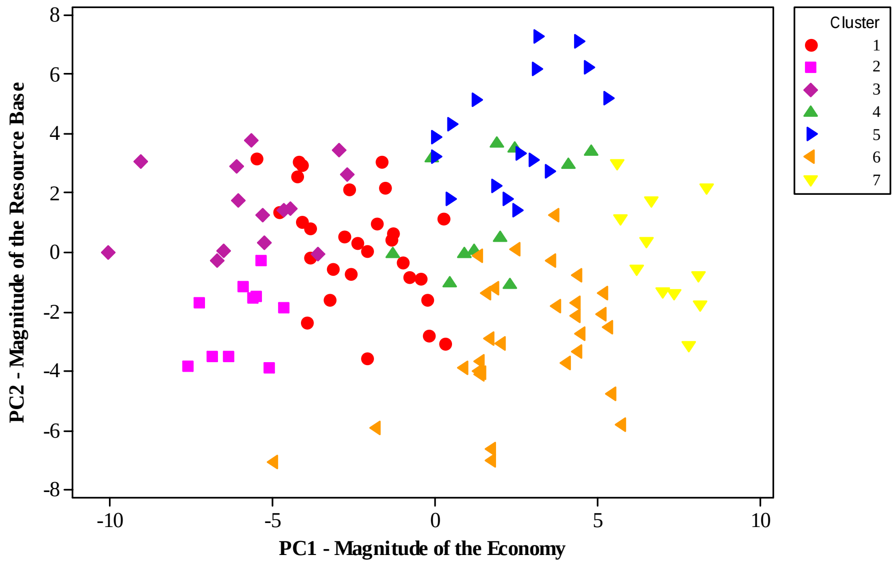
Table 3-5 lists the United Nations defined Least Developed Countries (LDC). Among the LDC are the five West African focal countries. Of the 26 nations on the LDC list which were included in the PCA and cluster analysis, 6 nations are in emergy cluster 1, 10 nations are in emergy cluster 2, 9 nations are in emergy cluster 3, and 1 nation is in emergy cluster 6. As the dendrogram in Figure 3-1 shows, clusters 1, 2 and 3, which contain the majority of the LDC nations, are distinctly different on a resource basis (measured in emergy) from the other 4 clusters of nations. Cluster 1 appears to contain the more developed of the “developing” countries, and notably, Senegal and Mauritania are the only focal dryland nations in that group.

Table 3-4: Clusters of nations.

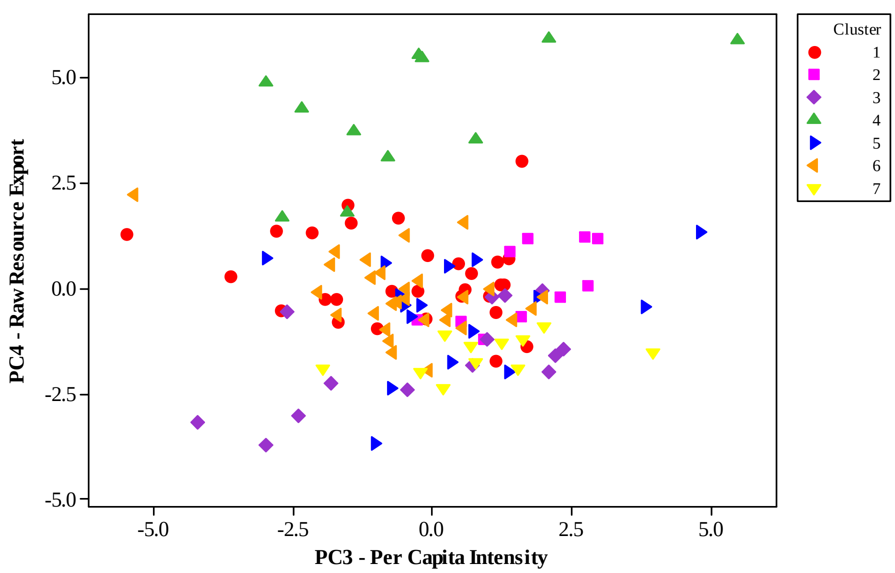
Cluster Number	Nation	ISO Code	Cluster Number	Nation	ISO Code	Cluster Number	Nation	ISO Code
Cluster 1	Albania	ALB	Cluster 3	Cambodia	KHM	Cluster 6	Austria	AUT
	Cuba	CUB		Ethiopia	ETH		Czech Rep.	CZE
	El Salvador	SLV		Nepal	NPL		Portugal	PRT
	Costa Rica	CRI		Paraguay	PRY		Denmark	DNK
	Guatemala	GTM		Tanzania	TZA		Sweden	SWE
	Serbia Montenegro	SCG		Mali	MLI		Greece	GRC
	Belize	BLZ		Niger	NER		Hungary	HUN
	Togo	TGO		Madagascar	MDG		Switzerland	CHE
	Cote dIvoire	CIV		Mozambique	MOZ		Israel	ISR
	Senegal	SEN		Central African Rep.	CAF		Kuwait	KWT
	Honduras	HND		Guinea Bissau	GNB		Bulgaria	BGR
	Nicaragua	NIC		Iceland	ISL		Tunisia	TUN
	Panama	PAN		Papua New Guinea	PNG		Morocco	MAR
	Bolivia	BOL		Suriname	SUR		Romania	ROU
	Ecuador	ECU	Cluster 4	Algeria	DZA		Finland	FIN
	Cameroon	CMR		Libya	LBY		Poland	POL
	Zambia	ZMB		Nigeria	NGA		Philippines	PHL
	Sudan	SDN		Syria	SYR		Turkey	TUR
	Congo	COG		Yemen	YEM		Thailand	THA
	Guinea	GIN		Iran	IRN		Belarus	BLR
	Mongolia	MNG		Venezuela	VEN		Croatia	HRV
	Mauritania	MRT		Norway	NOR		Estonia	EST
	Gabon	GAB		Saudi Arabia	SAU		Lithuania	LTU
	Botswana	BWA		Egypt	EGY		Jamaica	JAM
	Ghana	GHA		Pakistan	PAK		Jordan	JOR
	Kenya	KEN	Cluster 5	Argentina	ARG		Cyprus	CYP
	Namibia	NAM		India	IND		Lebanon	LBN
	Uruguay	URY		Colombia	COL		Djibouti	DJI
	Zimbabwe	ZWE		Peru	PER		Swaziland	SWZ
Cluster 2	Benin	BEN		Chile	CHL	Cluster 7	Belgium	BEL
	Malawi	MWI		South Africa	ZAF		Germany	DEU
	Burkina Faso	BFA		Ukraine	UKR		Japan	JPN
	Uganda	UGA		Malaysia	MYS		Italy	ITA
	Eritrea	ERI		Ireland	IRL		Netherlands	NLD
	Sierra Leone	SLE		New Zealand	NZL		France	FRA
	Gambia	GMB		Australia	AUS		Spain	ESP
	Lesotho	LSO		Brazil	BRA		Korea, Rep. of	KOR
	Burundi	BDI		Russian Federation	RUS		Mexico	MEX
	Rwanda	RWA		Canada	CAN		United Kingdom	GBR
				China	CHN		United States	USA
				Indonesia	IDN			

Clusters are in order of their appearance in Figure 3-1.

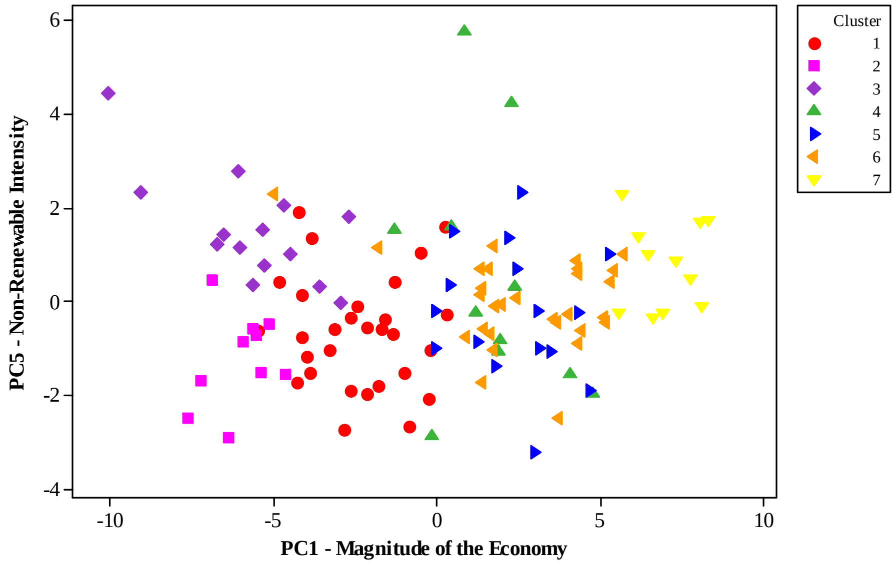
Figure 3-1: Dendrogram of cluster analysis of observations based on the emergy principle component axes. ISO three digit codes are displayed


Cluster
1
2
3
4
5
6
7
PC2 - Magnitude of the Resource Base
PC1 - Magnitude of the Economy
8
6
4
2
0
-2
-4
-6
-8
-10
-5
0
5
10

(a)


Cluster
1
2
3
4
5
6
7
PC4 - Raw Resource Export
PC3 - Per Capita Intensity
5.0
2.5
0.0
-2.5
-5.0
-5.0
-2.5
0.0
2.5
5.0

(b)



(c)

Figure 3-2: Scatter plot of emergy PC1 versus emergy PC2(a), emergy PC3 versus emergy PC4 (b) and emergy PC5 versus emergy PC1 (c) with cluster groupings.

Table 3-5: LDC emergy clusters

Nation[3]	Emergy Cluster	Nation	Emergy Cluster
Benin	2	Malawi	2
Burkina Faso	2	Mali	3
Burundi	2	Mauritania	1
Cambodia	3	Mozambique	3
Central African Republic	3	Nepal	3
Djibouti	6	Niger	3
Eritrea	2	Rwanda	2
Ethiopia	3	Senegal	1
Gambia	2	Sierra Leone	2
Guinea	1	Sudan	1
Guinea-Bissau	3	Togo	1
Lesotho	2	Uganda	2
Madagascar	3	Zambia	1

LDC classification data from UN Conference on Trade and Development, 2002.

[3]The following nations are classified as LDC but were not among the 120 countries included in the emergy PCA and cluster analysis: Afghanistan, Angola, Bangladesh, Bhutan, Cape Verde, Chad, Comoros, Democratic Republic of the Congo, Equatorial Guinea, Haiti, Kiribati, Lao, Liberia, Maldives, Myanmar, Samoa, Sao Tome and Principe, Solomon Islands, Somalia, Timore – Leste, Tuvalu, United Republic of Tanzania, Vanuatu and Yemen.

Table 3-6 lists the current member countries of the Organization for Economic Co-Operation and Development (OECD), all of which were ratified members by the end of December of 2000. The OECD defines itself as nations committed to democratic government and a market economy (OECD, 2006). OECD nations are among the wealthiest countries financially (OECD, 2006). They are often referred to in contrast to developing countries (Flanders and Ross-Larson 2002), and nominally they are considered the most developed countries. Of the 25 OECD nations which were included in the emergy PCA and cluster analysis, one nation, Norway, was in emergy cluster 4. The nations in cluster 4 are all desert economies except Norway and Venezuela and all of the cluster 4 nations are major fuel exporters. Of the other 24 OECD nations, 4 were in emergy cluster 5 (which includes most of the major resource exporters in the world), 9 were in emergy cluster 6 and 11 were in emergy cluster 7. All of the emergy cluster 7 nations are OECD members. The distance between clusters 6 and 7 and the rest of the emergy clusters suggest that the cluster 6 and 7 nations are largely the developed world.

Table 3-6: OECD emergy clusters

Nation[4]	**Emergy Cluster**	**Nation**	**Emergy Cluster**
Australia	5	Korea, Rep. of	7
Austria	6	Mexico	7
Belgium	7	Netherlands	7
Canada	5	New Zealand	5
Czech Republic	6	Norway	4
Finland	6	Poland	6
France	7	Portugal	6
Germany	7	Spain	7
Greece	6	Switzerland	6
Hungary	6	Turkey	6
Ireland	5	United Kingdom	7
Italy	7	United States	7
Japan	7		

OECD data from Organization for Economic Co-Operation and Development, 2006.

[4] The following countries are members of OECD but were not among the 120 countries included in the emergy PCA and cluster analysis: Denmark, Iceland, Luxembourg, Slovak Republic and Sweden.

Comparative Analysis of Aggregate Indices[5]

Table 3-7 is a correlation matrix showing the relationships between the aggregate indices of environmental and/or human wellbeing. Notably, the Yale Environmental Sustainability Index (YESI) is significantly positively correlated with the Ecological Footprint. The YESI is also strongly correlated with measures of human wellbeing, such as the Human Development Index (HDI) and Human Wellbeing Index (HWI), as well as the Wellbeing Index (WI), which is an average of the Ecosystem Wellbeing Index (EWI) and HWI. Conversely, relationships between the other indicators suggest that as measures of environmental wellbeing increase, measures of human wellbeing decrease. For example, the HDI and HWI are both positively correlated with the EF and negatively correlated with the EWI.

Table 3-7: Correlation matrix of aggregate indices

	LN EF	**YESI**	**HDI**	**WI**	**HWI**	**EWI**
LN Total Ecological Footprint (EF)	1					
Yale Environmental Sustainability Index (YESI)	0.408(**)	1				
Human Development Index (HDI)	0.855(**)	0.417(**)	1			
Wellbeing Index (WI)	0.630(**)	0.723(**)	0.644(**)	1		
Human Wellbeing Index (HWI)	0.880(**)	0.519(**)	0.931(**)	0.795(**)	1	
Ecosystem Wellbeing Index (EWI)	-0.600(**)	0.140	-0.645(**)	0.067	-0.552(**)	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

5 Definitions and data sources of all indices can be found in Appendix A.

Table 3-8 shows the strongest correlations between the aggregate indices and the emergy indices. The complete correlation matrix can be found in Appendix C, Table C-2. The correlations in Table 3-8 demonstrate the following relationships:

1. As resource based measures of sustainability increase (percent renewable and the emergy sustainability index), environmental wellbeing as indicated by the EF and EWI increases and human wellbeing as indicated by the HDI and HWI decreases.

2. As resource use intensity increases (emergy use/area, emergy use/capita, non-renewable emergy use/capita and the emergy investment ratio), environmental wellbeing, as indicated by the EF and EWI, decreases and human wellbeing, as indicated by the HDI and HWI, increases.

Table 3-8: Correlation matrix of aggregate indices and key emergy indices

	LN EF	**YESI**	**HDI**	**WI**	**HWI**	**EWI**
R/Use	-0.567(**)	0.089	-0.612(**)	-0.163	-0.530(**)	0.648(**)
LN Use/Area	0.560(**)	0.081	0.689(**)	0.426(**)	0.712(**)	-0.586(**)
LN Use/Capita	0.768(**)	0.539(**)	0.748(**)	0.676(**)	0.768(**)	-0.333(**)
LN NonRenewable /Capita	0.554(**)	0.220(*)	0.593(**)	0.331(**)	0.511(**)	-0.387(**)
LN Investment Ratio	0.555(**)	0.124	0.577(**)	0.360(**)	0.585(**)	-0.467(**)
LN Emergy Sustainability Index	-0.589(**)	0.082	-0.628(**)	-0.200(*)	-0.559(**)	0.644(**)

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

However, the above relationships between emergy indices and environmental wellbeing were not found to be true for the YESI. Of all the aggregate indices tested, the YESI had the lowest correlations with emergy indices. This suggests that the YESI may not be exclusively measuring environmental sustainability, as its name suggests.

Table 3-9 is a correlation matrix showing the relationship between the aggregate indices and the emergy principle components.

Table 3-9: Correlation matrix between aggregate indices and emergy principle components

	LN EF	YESI	HDI	WI	HWI	EWI
PC1 – Magnitude of the Economy	0.776(**)	0.118	0.832(**)	0.381(**)	0.784(**)	-0.798(**)
PC2 – Magnitude of Natural Resource Base	-0.080	0.099	-0.074	-0.105	-0.111	0.044
PC3 – Per Capita Emergy Intensity	0.331(**)	0.243(*)	0.257(**)	0.319(**)	0.242(*)	0.027
PC4 – Raw Resource Export	-0.262(**)	-0.419(**)	-0.292(**)	-0.474(**)	-0.407(**)	0.041
PC5 – Non-Renewable (Natural Capital) Intensity	0.054	0.228(*)	0.068	0.115	0.022	0.119

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

In general, the correlations in Table 3-9 suggest the following relationships:

1. As magnitude of the economy (PC1) increases, environmental wellbeing as indicated by the EF and EWI decreases, human wellbeing as indicated by the HDI and HWI increases, and overall wellbeing as indicated by the WI increases.

2. As per capita emergy intensity (PC3) increases, environmental wellbeing as indicated by the EF decreases, human wellbeing as indicated by the HDI and HWI increases, and overall wellbeing as indicated by the WI increases.

3. As raw resource export (PC4) decreases, environmental wellbeing as indicated by the EF decreases, human wellbeing as indicated by the HDI and HWI increases, and total wellbeing as indicated by the WI increases.

Again, the above relationships between emergy principle components and environmental wellbeing were not found to be true for the YESI. To explore these discrepancies with the YESI as well as some of the criticisms of the YESI and the HDI discussed in Chapter 1, the results of an analysis of the components of the YESI and HDI are presented later in this chapter.

Comparative Analysis of Miscellaneous Well-being Indicators and Emergy Indices[6]

Social well-being indicators

The Human Poverty Index-1 (HPI-1) and the Gini Index are semi-aggregated social well-being indices, and therefore analyzed separately from the raw indicators presented below. The HPI-1 is calculated for developing countries along with the HDI, and is a measure of a country's deprivations in the three HDI categories. The Gini Index is a measure of inequality, with high values equaling high inequality. Table 3-10 below shows the strongest correlations between emergy indices and these two indices. A complete correlation matrix can be found in Appendix C, Table C-3. Table 3-10 shows that as percent renewable increases, and as total use per capita, non-renewable use per capita, fuel use per capita and magnitude of the economy decrease, poverty and inequality increase.

Table 3-10: Correlation matrix of poverty and inequlity measures

	HPI-1	**Gini Index**
HPI-1 Value (%)	1	
Gini Index	-0.182	1
LN GDP	-0.462(**)	-0.343(**)
R/Use	0.555(**)	0.445(**)
LN Use/Capita	-0.618(**)	-0.273(**)
LN Non-Renewable/Capita	-0.612(**)	-0.233(*)
LN Fuel Use/Capita	-0.785(**)	-0.476(**)
PC1 - Magnitude of the Economy	-0.670(**)	-0.503(**)

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

[6] Definitions of all indices can be found in Appendix A.

Table 3-11 shows the strongest correlations between other miscellaneous social wellbeing indicators and the emergy indices. A complete correlation matrix can be found in Appendix C, Table C-4. Interpretation of the correlations reveals the following relationships between a nation's resource basis and indicators of social welfare:

1. Quality of Life and Health:
   As percent renewable increases and as total emergy use per capita, emergy from fuel per capita, or magnitude of the economy (PC1) decrease, life expectancy decreases while percent of the population not using improved water sources, percent of underweight children and percent of the population living with HIV/AIDS all increase.

2. Education:
   As percent renewable increases and as total emergy use per capita, non-renewable emergy use per capita, emergy from fuel use per capita, or magnitude of the economy (PC1) decrease, the adult literacy rate, gross school enrollment ratio and the ratio of girls to boys in primary and secondary education all decrease.

3. Labor:
   As emergy use per capita, emergy from fuel use per capita, or per capita emergy intensity (PC3) decrease, percentage of the employed population working in agriculture increases and percentage of the employed population working in the service sector decreases. As the environmental loading ratio increases, the percentage of the employed population working in the industry sector increases.

4. Demographics:
   As emergy use per capita, emergy use per area, emergy from fuel use per capita or magnitude of the economy decrease and as percent renewable increases, the proportion of the population living in rural areas and the age dependency ratio both increase and the international migration stock (or percent of population which was born in another country) decreases. As GDP, emergy use per capita, emergy use per area, fuel use per capita or magnitude of economy increase, the number of people per capita who leave their country as refugees decreases.

Table 3-11: Correlation matrix of miscellaneous social indicators and emergy indices.

	LN GDP	R/Use	LN Use/Area	LN Use/Capita	LN Non-Renewable /Capita	LN Fuel Use/Capita	LN Env. Loading Ratio	PC1 - Magnitude of Economy	PC3 - Per Capita Emergy Intensity
Quality of Life and Health									
Life Expectancy at birth	0.621(**)	-0.582(**)	0.671(**)	0.605(**)	0.509(**)	0.837(**)	0.598(**)	0.775(**)	-0.151
Pop. not using improved water sources	-0.413(**)	0.461(**)	-0.431(**)	-0.345(**)	-0.285(*)	-0.627(**)	-0.461(**)	-0.618(**)	-0.079
Underweight children under age five	-0.265(*)	0.518(**)	-0.338(**)	-0.615(**)	-0.540(**)	-0.691(**)	-0.521(**)	-0.523(**)	-0.444(**)
LN Population living with HIV/AIDS	-0.503(**)	0.402(**)	-0.442(**)	-0.363(**)	-0.336(**)	-0.597(**)	-0.426(**)	-0.588(**)	0.018
Education									
Adult literacy rate	0.351(**)	-0.554(**)	0.501(**)	0.618(**)	0.510(**)	0.734(**)	0.550(**)	0.635(**)	0.267(*)
Gross enrollment ratio	0.579(**)	-0.524(**)	0.577(**)	0.693(**)	0.547(**)	0.783(**)	0.517(**)	0.741(**)	0.272(**)
Ratio of girls to boys education	0.261(**)	-0.319(**)	0.430(**)	0.605(**)	0.443(**)	0.616(**)	0.332(**)	0.447(**)	0.393(**)
Employment									
Employment in agriculture	-0.415(**)	0.131	-0.355(**)	-0.700(**)	-0.413(**)	-0.676(**)	-0.221	-0.389(**)	-0.411(**)
Employment in industry	0.300(*)	-0.453(**)	0.466(**)	0.364(**)	0.220	0.549(**)	0.504(**)	0.480(**)	0.106
Employment in services	0.355(**)	0.010	0.251(*)	0.647(**)	0.374(**)	0.545(**)	0.060	0.252	0.390(**)
Demographics									
Rural population	-0.573(**)	0.484(**)	-0.544(**)	-0.722(**)	-0.620(**)	-0.821(**)	-0.516(**)	-0.701(**)	-0.439(**)
Age dependency ratio	-0.575(**)	0.594(**)	-0.663(**)	-0.594(**)	-0.460(**)	-0.828(**)	-0.597(**)	-0.791(**)	-0.171
LN International migration stock	0.102	-0.283(**)	0.203(*)	0.360(**)	0.206(*)	0.414(**)	0.316(**)	0.259(**)	0.377(**)
LN Refugees by country of origin/capita	-0.475(**)	0.059	-0.281(**)	-0.435(**)	-0.281(**)	-0.249(**)	-0.101	-0.407(**)	-0.046

Governmental and political indicators

Table 3-12 shows the strongest correlations between governmental and political indicators and the emergy indices. A complete correlation matrix can be found in Appendix C, Table C-5. Interpretation of these correlations reveals the following relationships between a nation's resource basis and government related welfare indices:

1. Economic freedom (Fraser Institute and Heritage foundation):
   As percent renewable and raw resource export (PC4) increase, the Fraser Institute (FI) size of the government indicator (which represents the government's support of economic freedom) also increases. However, as percent renewable and raw resource export (PC4) increase, the FI legal system and property rights (legal structure's support of economic freedom and protection of property rights) indicator and the freedom to trade internationally indicator both decrease. As total emergy use per capita, fuel per capita, or magnitude of the economy (PC1) increase and raw resource export (PC4) decreases, the FI's degree to which countries' policies and institutions support economic freedom summary indicator increases and the Heritage Foundation economic freedom summary index decreases (meaning greater economic freedom).

2. Civil freedom (Freedom House):
   As total emergy use per capita, fuel per capita, or magnitude of the economy (PC1) increase, the Freedom House status and political rights and civil liberties indicators increase.

3. Quality of Governance (Governance Matters):
   As percent renewable increases, all of the Governance Matters (GM) quality of governance indicators decrease. As total emergy use per capita, fuel per capita, magnitude of the economy (PC1) increases and raw resource export (PC4) decreases, all of the GM quality of governance indicators increase.

4. Political risk to finance and investment (Political Risk Yearbook):
   As percent renewable increases, all of the Political Risk Yearbook (PRY)'s political risk indicators increase. As total emergy use per capita, fuel per capita, magnitude of the economy (PC1) increases and raw resource export (PC4) decreases, all of the PRY's political risk indicators decrease.

Table 3-12: Correlation matrix of governmental and political indicators and emergy indices.

	R/Use	Natural Log Use/Capita	Natual Log Fuel Use/Capita	PC1 - Magnitude of the Economy	PC4 – Raw Resource Export
Economic freedom					
FI Size of Government	0.331(**)	-0.182	-0.256(*)	-0.250(*)	-0.123
FI Legal System and Property Rights	-0.364(**)	0.664(**)	0.637(**)	0.606(**)	-0.373(**)
FI Sound Money	-0.087	0.421(**)	0.288(**)	0.291(**)	-0.397(**)
FI Trade Internationally	-0.354(**)	0.614(**)	0.594(**)	0.614(**)	-0.533(**)
FI Regulation	-0.173	0.606(**)	0.471(**)	0.421(**)	-0.511(**)
FI Summary Index	-0.190	0.630(**)	0.513(**)	0.498(**)	-0.559(**)
Heritage Foundation Summary Score	0.279(**)	-0.622(**)	-0.491(**)	-0.516(**)	0.419(**)
Civil freedom					
Freedom House Political Rights	0.150	-0.576(**)	-0.405(**)	-0.388(**)	0.503(**)
Freedom House Civil Liberties	0.146	-0.625(**)	-0.423(**)	-0.370(**)	0.522(**)
Freedom House Status	0.170	-0.566(**)	-0.402(**)	-0.379(**)	0.499(**)
Quality of Governance					
GM Voice and Accountability	-0.238(**)	0.681(**)	0.525(**)	0.496(**)	-0.517(**)
GM Political Stability	-0.329(**)	0.601(**)	0.566(**)	0.480(**)	-0.421(**)
GM Government Effectiveness	-0.326(**)	0.664(**)	0.598(**)	0.637(**)	-0.397(**)
GM Regulatory Quality	-0.229(*)	0.533(**)	0.384(**)	0.468(**)	-0.360(**)
GM Rule of Law	-0.373(**)	0.688(**)	0.642(**)	0.646(**)	-0.340(**)

Table 3-12: Continued.

	R/Use	Natural Log Use/Capita	Natual Log Fuel Use/Capita	PC1 - Magnitude of the Economy	PC4 – Raw Resource Export
GM Control of Corruption	-0.343(**)	0.668(**)	0.608(**)	0.602(**)	-0.341(**)
Political risk to finance and investment					
PRY Turmoil 18 month	0.392(**)	-0.529(**)	-0.539(**)	-0.461(**)	0.365(**)
PRY Financial Transfer 18 month	0.387(**)	-0.565(**)	-0.594(**)	-0.570(**)	0.370(**)
PRY Direct Investment 18 month	0.224(*)	-0.529(**)	-0.408(**)	-0.368(**)	0.448(**)
PRY Export Market Risk 18 month	0.406(**)	-0.599(**)	-0.590(**)	-0.567(**)	0.406(**)
PRY Turmoil 5 year	0.435(**)	-0.430(**)	-0.544(**)	-0.471(**)	0.314(**)
PRY Financial Transfer Risk 5 year	0.461(**)	-0.574(**)	-0.660(**)	-0.648(**)	0.347(**)
PRY Direct Investment Risk 5 year	0.296(**)	-0.597(**)	-0.506(**)	-0.490(**)	0.474(**)
PRY Export Market Risk 5 year	0.384(**)	-0.600(**)	-0.619(**)	-0.604(**)	0.345(**)

Economic indicators

Table 3-13 shows the strongest correlations between economic indicators and the emergy indices. A complete correlation matrix can be found in Appendix C, Table C-6. Interpretation of the correlations reveals the following relationships between a nation's resource basis and indicators of economic welfare:

1. Income:
   As total emergy use per capita, non-renewable emergy use per capita, magnitude of the economy (PC1) or per capita emergy intensity (PC3) increases and raw resource export (PC4) or percent renewable decrease, GDP per capita increases.

2. Use of money:
   As percent renewable increases, expenditure on health and education and household consumption expenditure decrease. As total emergy use per capita, non-renewable emergy use per capita, magnitude of the economy (PC1), or per capita emergy intensity (PC3) and raw resource export (PC4) decrease, expenditure on health and household consumption expenditure increase. As total emergy use per capita, non-renewable emergy use per capita or magnitude of the economy (PC1) increase, expenditure on education increases.

3. Military:
   As the resource base of the nation (PC2) increases, arms imports increases. As raw resource export (PC4) increases, military expenditure increases

4. Tourism:
   As total emergy use per capita, non-renewable emergy use per capita, or magnitude of the economy (PC1) and as percent renewable or raw resource export (PC4) decrease, international tourism arrivals increase.

5. Technology:
   As total emergy use per capita, non-renewable emergy use per capita or magnitude of the economy (PC1) increase, cost of a telephone call decreases. As percent renewable increases, the cost of a telephone call also increases. As total emergy use per capita, non-renewable emergy use per capita, magnitude of the economy (PC1), or per capita emergy intensity (PC3) increase and as percent renewable or raw resource export (PC4) decrease, the number of internet users increases.

6. Debt:
   As percent renewable increases and emergy use per area, emergy of fuel use per capita, IR or magnitude of the economy decrease (PC1), debt stocks per capita decreases and total debt as a percentage of GNI increases. As emergy use per capita, non-renewable emergy use per capita, per capita emergy intensity (PC3) or non-renewable intensity (PC5) increase, total debt stocks per capita increases.

Table 3-13: Correlation matrix of economic indicators and emergy indices.

	Imports-Exports	R/Use	LN Use/Area	LN Use/Capita	LN Non-Renewable/ Capita	LN Fuel/Capita	LN Investment Ratio
Income							
LN GDP per capita	0.034	-0.526(**)	0.686(**)	0.805(**)	0.593(**)	0.859(**)	0.572(**)
Use of money							
LN Health expenditure per capita	0.076	-0.514(**)	0.672(**)	0.778(**)	0.537(**)	0.827(**)	0.588(**)
Expenditure per student, primary	0.157	-0.319(**)	0.217	0.236(*)	0.073	0.396(**)	0.452(**)
LN Household consump. expenditure per cap	0.093	-0.471(**)	0.689(**)	0.816(**)	0.550(**)	0.837(**)	0.554(**)
Military							
LN Military expenditure	-0.011	-0.084	-0.129	-0.095	0.072	0.068	-0.059
LN Arms imports	-0.131	-0.054	0.131	0.164	0.305(*)	0.229	-0.093
Tourism							
LN International tourism, number of arrivals	-0.090	-0.493(**)	0.554(**)	0.444(**)	0.409(**)	0.588(**)	0.408(**)
Technology							
LN Internet users (per 1,000 people)	-0.015	-0.526(**)	0.695(**)	0.800(**)	0.554(**)	0.841(**)	0.579(**)
Telephone average cost of call to US	0.057	0.445(**)	-0.559(**)	-0.405(**)	-0.402(**)	-0.568(**)	-0.501(**)
Debt							
Total debt (EDT)/GNI	0.152	0.411(**)	-0.322(**)	-0.097	-0.176	-0.398(**)	-0.371(**)
LN Total debt stocks/capita	-0.037	-0.412(**)	0.447(**)	0.708(**)	0.537(**)	0.676(**)	0.350(**)
Aid							
LN Aid per capita	0.445(**)	0.120	-0.084	0.056	-0.207(*)	-0.177	0.100

Table 3-13: Continued.

	PC1 - Magnitude of the Economy	PC2 - Magnitude of Natural Resource	PC3 - Per capita emergy intensity	PC4 – Raw Resource Export	PC5 - Non-Renewable Intensity
Income					
LN GDP per capita	0.816(**)	-0.08	0.332(**)	-0.264(**)	0.035
Use of money					
LN Health expenditure per capita	0.789(**)	-0.122	0.315(**)	-0.294(**)	0.033
Expenditure per student, primary	0.407(**)	-0.265(*)	0.034	-0.044	-0.084
LN Household consump. expenditure per cap	0.783(**)	-0.049	0.327(**)	-0.350(**)	-0.020
Military					
LN Military expenditure	-0.014	-0.111	0.067	0.307(**)	-0.127
LN Arms imports	0.468(**)	0.384(**)	-0.180	0.057	-0.115
Tourism					
LN International tourism, number of arrivals	0.851(**)	0.131	-0.088	-0.238(*)	-0.054
Technology					
LN Internet users (per 1,000 people)	0.775(**)	-0.101	0.305(**)	-0.372(**)	0.081
Telephone average cost of call to US	-0.557(**)	0.150	-0.098	0.117	-0.202
Debt					
Total debt (EDT)/GNI	-0.511(**)	0.084	0.091	0.029	-0.101
LN Total debt stocks/capita	0.497(**)	-0.135	0.404(**)	-0.126	0.278(*)
Aid					
LN Aid per capita	-0.422(**)	-0.427(**)	0.136	-0.293(**)	0.002

7. Aid
   As the emergy of imports - exports increases and non-renewable emergy per capita decreases, aid per capita increases. As magnitude of the economy (PC1), magnitude of the resource base (PC2) or raw resource export (PC3) decrease, aid per capita increases.

Environmental and land use indicators

Table 3-14 shows the strongest correlations between environmental and land use indicators and the emergy indices. A complete correlation matrix can be found in Appendix C, Table C-7. Interpretation of the correlations reveals the following relationships between a nation's resource basis and environmental welfare tendencies:

1. Land Use:
   As emergy use per area increases, hectares per person of arable land and percent of land in permanent pasture both decrease. As magnitude of the economy (PC1) or emergy use per area increase and natural capital intensity (PC5) decreases, percent of cropland that is irrigated increases. As magnitude of the economy (PC1) increases and percent renewable, emergy use per capita, non-renewable emergy use per capita, magnitude of the resource base of the nation (PC2) or per capita emergy intensity (PC3) decrease, percent of land which is arable increases.

2. Fertilizer Use:
   As percent renewable increases and emergy use per area, emergy use per capita, non-renewable emergy use per capita, or magnitude of the economy (PC1) decrease and as raw resource export (PC4) increases, fertilizer consumption decreases.

3. Deforestation:
   As emergy use per capita increases and raw resource export (PC4) decreases, percent of land area which is forested increases.

4. Water Quality:
   As percent renewable increases and the emergy investment ratio, emergy use per area or magnitude of the economy (PC1) decrease, organic water pollutants emitted per worker increases.

5. Air Quality:
   As percent renewable decreases and emergy use per area, emergy use per capita, non-renewable emergy use per capita or magnitude of the economy (PC1) increase, CO_2 emissions per capita increase.

6. Energy:
   As percent renewable decreases and emergy use per capita, non-renewable emergy use per capita, magnitude of the economy (PC1) or per capita emergy intensity

(PC3) increase, combustible renewables and waste as a percent of total energy decreases. As percent renewable decreases and as emergy use per capita, non-renewable emergy use per capita, magnitude of the economy (PC1), or per capita emergy intensity (PC3) increase and as raw resource export (PC4) decreases, electric power consumption per capita increases. As percent renewable decreases and as emergy use per capita or magnitude of the economy (PC1) increase, percent of electricity produced from coal increases. As emergy use per capita increases and as raw resource export (PC4) decreases, percent of electricity production from oil sources decreases.

YESI and HDI Components

Yale Environmental Sustainability Index

Table 3-15, a correlation matrix of the components of the YESI, shows that the Reducing Environmental Stresses (RES) Component is negatively correlated with EF and positively correlated with the EWI (as would be expected of an environmental wellbeing indicator), whereas the Reducing Human Vulnerability (RHV) and Social and Institutional Capacity (SIC) Components are strongly positively correlated HDI, HWI, GDP and the GDP Index (GDP Index is the United Nations Development Programme’s adjusted GDP per capita. See explanation of HDI in Appendix A). These two components are also negatively correlated with EWI and positively correlated with EF. This suggests that these two components, which make up 1/3 of the YESI, may be better indicators of human wellbeing than environmental wellbeing.

Table 3-14: Correlation matrix of environment and land use indicators and emergy indices.

	R/Use	LN Use/Area	LN Use/ Capita	LN Non-Renewable/ Capita	LN Investment Ratio
Land use					
LN Land use, arable land (hectares per person)	0.070	-0.419(**)	-0.029	-0.011	-0.122
Permanent pasture (% of land area)	0.176	-0.323(**)	-0.091	-0.019	-0.258(**)
LN Irrigated land (% of cropland)	-0.199(*)	0.285(**)	0.159	0.223(*)	0.017
LN Arable land (% of land area)	-0.377(**)	0.354(**)	-0.388(**)	-0.371(**)	0.413(**)
Fertilizer use					
LN Fertilizer consumption	-0.398(**)	0.701(**)	0.433(**)	0.287(**)	0.495(**)
Deforestation					
Forest area (% of land area)	0.145	0.111	0.303(**)	0.128	-0.056
Water Quality					
Organic water pollutant (BOD) emissions/worker	0.527(**)	-0.459(**)	-0.210	-0.163	-0.495(**)
Air Quality					
LN CO2 emissions (metric tons per capita)	-0.669(**)	0.596(**)	0.731(**)	0.697(**)	0.523(**)
Energy					
LN Combustible renewables and waste (% of total energy)	0.456(**)	-0.310(**)	-0.380(**)	-0.393(**)	-0.235(*)
LN Electric power consumption (kwh per capita)	-0.545(**)	0.566(**)	0.814(**)	0.576(**)	0.511(**)
LN Electricity production from coal sources (% of total)	-0.402(**)	0.355(**)	0.019	0.002	0.284(*)
LN Electricity production from oil sources (% of total)	-0.104	-0.106	-0.335(**)	-0.071	-0.046

Table 3-14: Continued.

	PC1 - Magnitude of the Economy	PC2 - Magnitude of Natural Resource Base	PC3 - Per capita emergy intensity	PC4 – Raw Resource Export	PC5 - Non-Renewable Intensity
Land use					
LN Land use, arable land (hectares per person)	-0.090	0.188(*)	-0.085	-0.019	0.112
Permanent pasture (% of land area)	-0.228(*)	0.124	0.048	-0.068	0.028
LN Irrigated land (% of cropland)	0.356(**)	0.060	0	-0.086	-0.402(**)
LN Arable land (% of land area)	0.296(**)	-0.364(**)	-0.542(**)	-0.039	-0.004
Fertilizer use					
LN Fertilizer consumption	0.669(**)	-0.116	-0.052	0.248(**)	0.023
Deforestation					
Forest area (% of land area)	-0.007	0.187	0.093	0.343(**)	0.119
Water Quality					
Organic water pollutant emissions (BOD)/worker	-0.740(**)	0.114	0.155	-0.084	0.128
Air Quality					
LN CO2 emissions (metric tons per capita)	0.845(**)	-0.042	0.364(**)	0.129	0.061
Energy					
LN Combustible renewables and waste (% of total energy)	-0.500(**)	0.132	-0.364(**)	0.089	0.078
LN Electric power consumption (kwh per capita)	0.763(**)	-0.145	0.369(**)	0.307(**)	0.091
LN Electricity production from coal sources (% of total)	0.440(**)	-0.243	-0.086	0.239	0.018
LN Electricity production from oil sources (% of total)	-0.074	-0.236(*)	-0.047	-0.360(**)	-0.071

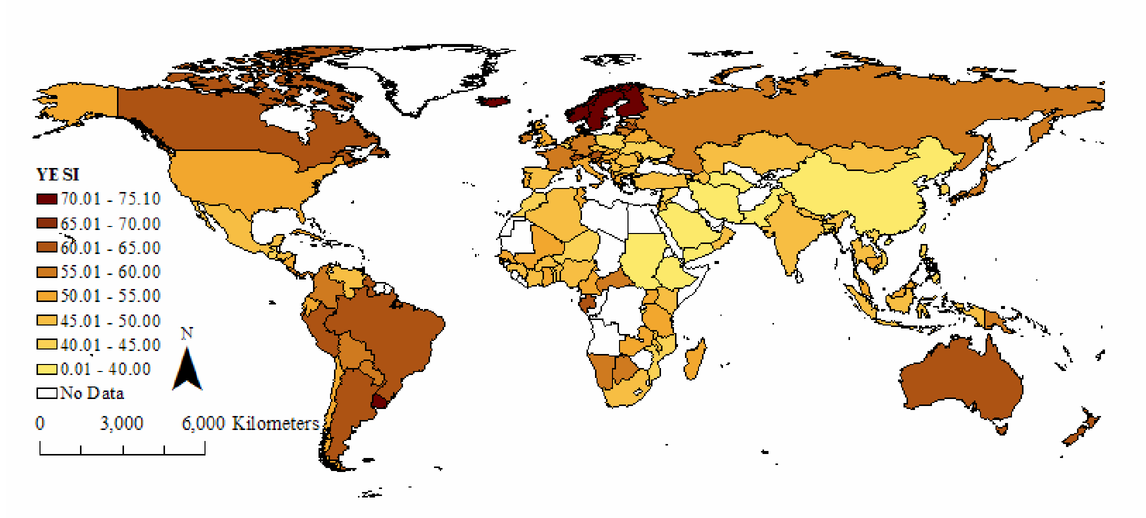
As illustrated by Figure 3-3, the YESI also shows no relationship to the percent of emergy from renewable resources (also called percent renewable), a resource based measure of environmental sustainability. Table 3-16 shows the strongest correlations between the emergy indices and YESI components. A complete correlation matrix can be found in Appendix C, Table C-8. As Table 3-16 shows, ten of the 21 YESI indicators are uncorrelated or significantly negatively correlated with percent renewable (R/U). The difference between the YESI and percent renewable is particularly interesting in the Sub-Saharan African nations in Figure 3-3 below. While the YESI defines these nations as unsustainable, by emergy measures they have relatively low non-renewable emergy use per capita and a large percent of their total emergy use comes from renewable sources.

Likewise, as is shown in Table 3-16, eight of the 21 indicators which make up the YESI have a strong and significant positive correlation to magnitude of the economy (PC1). Interestingly, the YESI and the environmental governance indicator are significantly negatively correlated with raw resource export (PC4). These relationships and the nature of the indicators showing surprising correlations (such as reducing population pressure, human sustenance and science and technology) suggest that the YESI may be partially measuring economic development as well as environmental conditions. Also, the YESI is significantly positively correlated to total emergy use per capita ($R = 0.54$, see Figure 3-4) and fuel use per capita ($R = .23$). This again is the opposite of what one would expect of an environmental sustainability indicator.

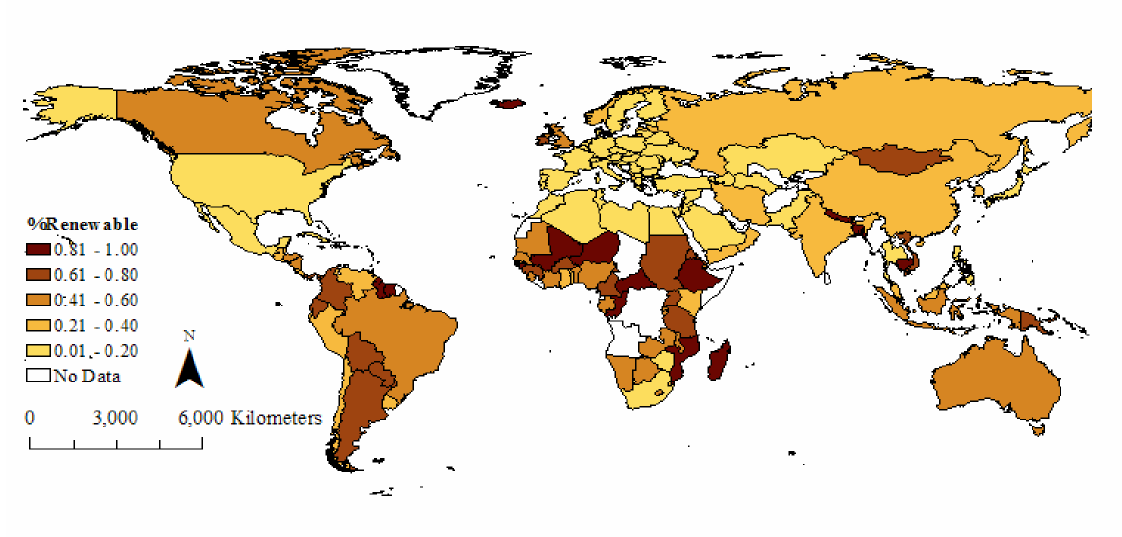
Table 3-15: Correlation matrix of aggregate indices including YESI components.

	YESI	ES Component	RES Component	RHV Component	SIC Component	GS Component
Yale Environmental Sustainability Index (YESI)	1					
ESI - Environmental Systems (ES) Component	0.691(**)	1				
ESI - Reducing Environmental Stresses (RES) Component	0.156	0.353(**)	1			
ESI - Reducing Human Vulnerability (RHV) Component	0.482(**)	0.076	-0.312(**)	1		
ESI - Social and Institutional Capacity (SIC) Component	0.652(**)	0.134	-0.510(**)	0.622(**)	1	
ESI - Global Stewardship (GS) Component	0.282(**)	-0.045	-0.021	-0.356(**)	0.160	1
Natural Log Total Ecological Footprint	0.408(**)	0.164	-0.448(**)	0.811(**)	0.657(**)	-0.397(**)
HDI	0.417(**)	0.101	-0.412(**)	0.839(**)	0.684(**)	-0.371(**)
Wellbeing Index	0.723(**)	0.387(**)	-0.222(*)	0.617(**)	0.738(**)	0.044
Human Wellbeing Index	0.519(**)	0.103	-0.477(**)	0.836(**)	0.821(**)	-0.208(*)
Ecosystem Wellbeing Index	0.140	0.367(**)	0.484(**)	-0.535(**)	-0.341(**)	0.408(**)
Natural Log GDP	0.132	-0.213(*)	-0.532(**)	0.545(**)	0.605(**)	-0.182(*)
GDP Index	0.445(**)	0.120	-0.496(**)	0.850(**)	0.747(**)	-0.323(**)

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).



(a)



(b)

Figure 3-3: Maps of sustainability indices (a) Map of the Yale Environmental Sustainability Index. Data from Esty et al. 2005 (b) Map of emergy percent renewable

Table 3-16: Correlations of YESI components

	R/Use	PC1 - Magnitude of Economy	PC4 – Raw Resource Export
Environmental Sustainability Index (ESI)	0.089	0.118	-0.419(**)
ESI - Environmental Systems (ES) Component	0.386(**)	-0.260(**)	-0.189
ES - Air Quality Indicator	-0.454(**)	0.394(**)	-0.147
ES - Biodiversity Indicator	0.285(**)	-0.430(**)	0.162
ES - Land Indicator	0.529(**)	-0.483(**)	0.194(*)
ES - Water Quality Indicator	0.110	0.129	-0.429(**)
ES - Water Quantity Indicator	0.479(**)	-0.267(**)	-0.270(**)
ESI - Reducing Environmental Stresses (RES) Component	0.351(**)	-0.566(**)	0.159
RES - Reducing Air Pollution Indicator	0.578(**)	-0.783(**)	0.255(**)
RES - Reducing Ecosystem Stress Indicator	0.043	-0.089	0.113
RES - Reducing Population Pressure Indicator	-0.599(**)	0.740(**)	-0.342(**)
RES - Reducing Waste and Consumption Pressures Indicator	0.195(*)	-0.363(**)	0.257(**)
RES - Reducing Water Stress Indicator	0.610(**)	-0.731(**)	0.092
RES - Natural Resource Management Indicator	0.260(**)	-0.462(**)	0.241(*)
ESI - Reducing Human Vulnerability (RHV) Component	-0.626(**)	0.752(**)	-0.219(*)
RHV - Environmental Health Indicator	-0.501(**)	0.770(**)	-0.377(**)
RHV - Basic Human Sustinence Indicator	-0.637(**)	0.796(**)	-0.123
RHV - Reducing Env-Related Nat. Disaster Vulnerability Ind.	-0.289(**)	0.156	0.039
ESI - Social and Institutional Capacity (SIC) Component	-0.270(**)	0.615(**)	-0.496(**)
SIC - Environmental Governance Indicator	-0.317(**)	0.582(**)	-0.513(**)
SIC - Eco-Efficiency Indicator	0.532(**)	-0.490(**)	-0.171
SIC - Private Sector Responsiveness Indicator	-0.381(**)	0.677(**)	-0.304(**)
SIC - Science and Technology Indicator	-0.524(**)	0.790(**)	-0.381(**)
ESI - Global Stewardship (GS) Component	0.405(**)	-0.386(**)	-0.209(*)
GS - Participation in International Collaborative Efforts Indicator	-0.072	0.400(**)	-0.336(**)
GS - Greenhouse Gas Emissions Indicator	0.629(**)	-0.629(**)	-0.132
GS - Reducing Transboundary Environmental Pressures Indicator	0 .233(*)	-0.414(**)	-0.043

Highlighted correlations are those discussed in the text. See Table C-2 for complete correlation matrix.

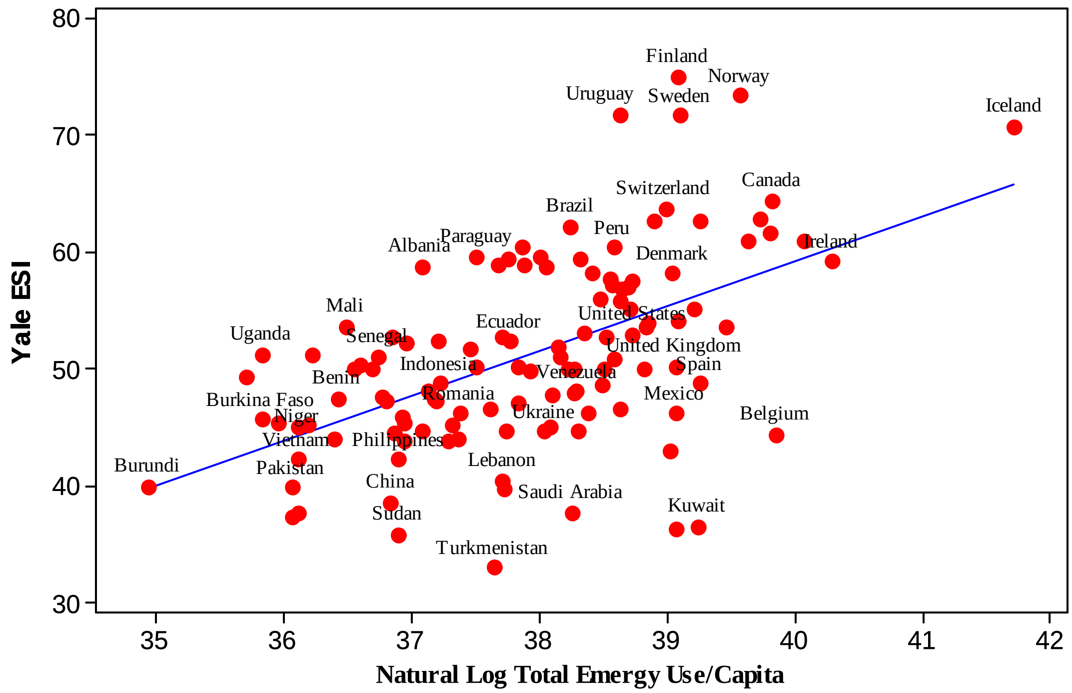
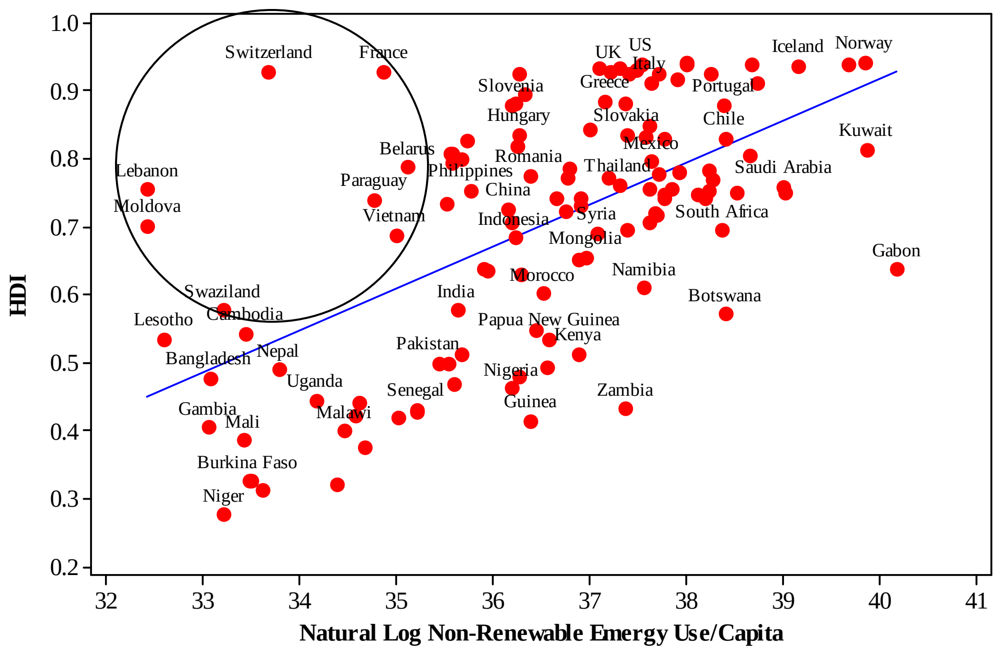


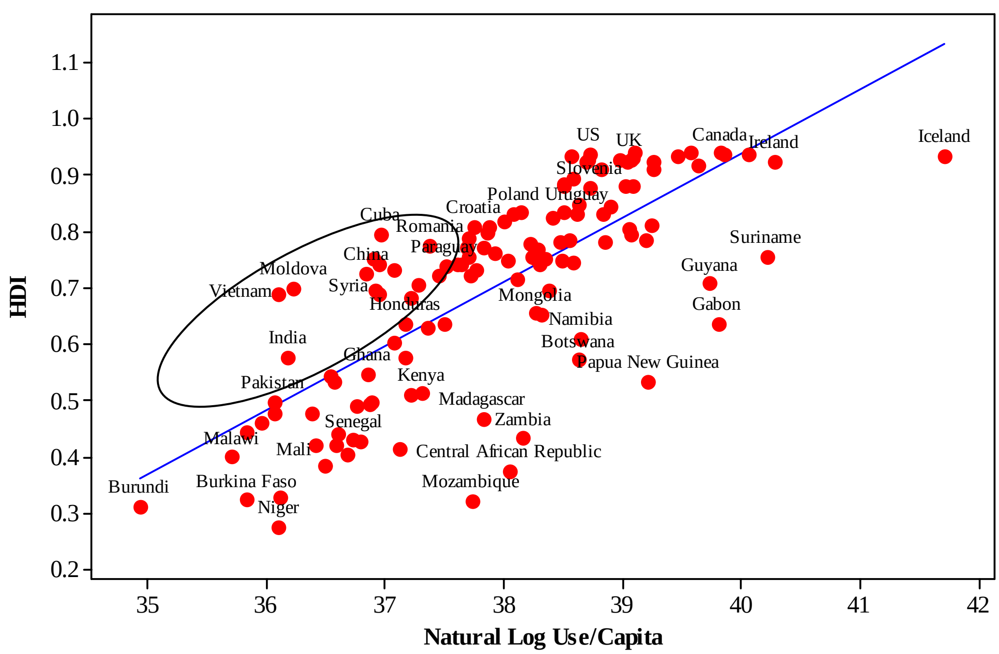
Figure 3-4: Scatter plot of the Yale Environmental Sustainability Index versus natural log of total emergy use per capita. R value of 0.54 is significant at 0.01 (2-tailed) level using Pearson correlation.

Human Development Index

Results show that the Human Development Index (HDI) is significantly positively correlated with non-renewable emergy use per capita (R = 0.59, Figure 3-5 a) and total emergy use per capita (R = .75, Figure 3-5 b), as well as PC1 – Magnitude of the Economy. The countries which are circled in Figure 3-5 have high HDI and relatively low non-renewable emergy use per capita or total use per capita. In other words, their ability to generate human welfare is greater than might be expected based on their resource use patterns.



(a)



(b)

Figure 3-5: HDI scatter plots **(a) Scatter plot of HDI versus the natural log of non-renewable emergy use per capita. (b) Scatter plot of HDI versus the natural log of total emergy use per capita. R values are significant at 0.01 (2-tailed) level using Pearson correlation.**

Figure 3-6 is a graph of the residuals from the regression analysis predicting HDI from non-renewable emergy use per capita. Countries with high positive residuals, including France, Lebanon, Moldova, Paraguay and Switzerland, have better human welfare (as measured by the HDI) than would be predicted based on their non-renewable resource use per capita. Countries with high negative residuals, including Burkina Faso, Mozambique, Niger, Senegal and Uganda, have lower human welfare than would be predicted based on their non-renewable resource use per capita. This may suggest an efficiency of resource use index that can be used as a measure of a human dimension of sustainability.

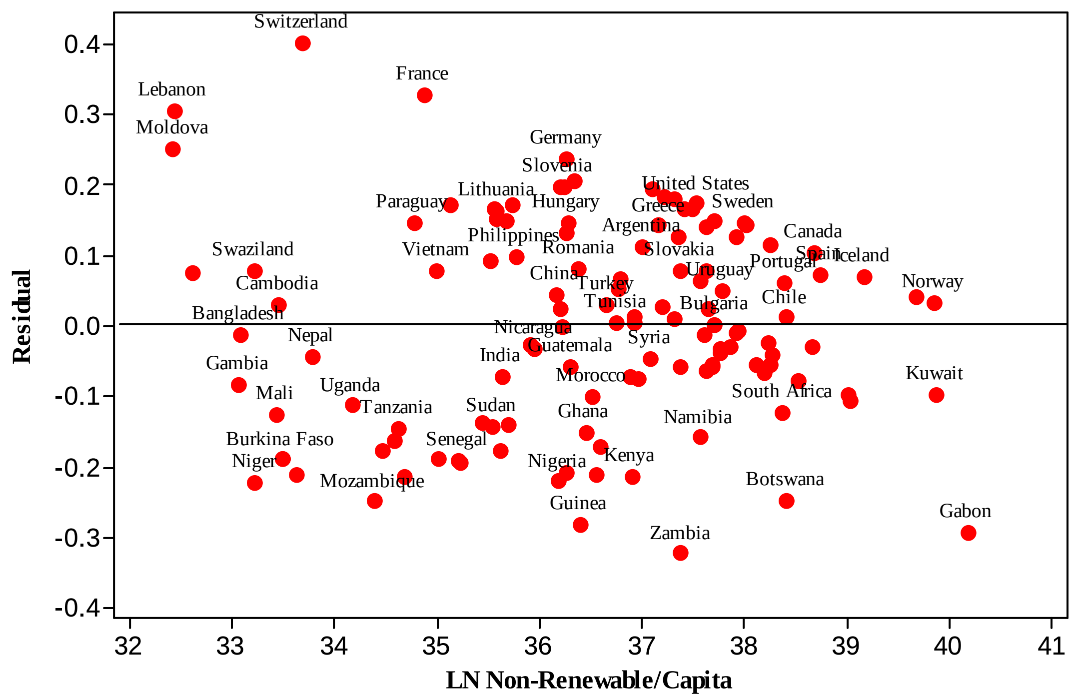


Figure 3-6: Graph of regression residuals of prediction of HDI from LN non-renewable emergy use per capita versus LN non-renewable emergy use per capita.

HDI has been criticized as a human wellbeing indicator because it is partially composed of GDP per capita (Steer and Lutz 1993). However, the above relationships were also observed between the individual components of the HDI (Table 3-17). This suggests that despite inclusion of GDP per capita, HDI adequately captures human wellbeing as measured by its other two components (life expectancy and education).

Table 3-17: Correlation matrix of components of the HDI and emergy indices

	HDI	Life Expectancy Index	Education Index	GDP Index	LN Use/ Capita	LN Non-Renewable/ Capita	PC1 - Magnitude of the Economy
HDI	1						
Life Expectancy Index	0.927(**)	1					
Education Index	0.926(**)	0.774(**)	1				
GDP Index	0.935(**)	0.813(**)	0.802(**)	1			
LN Use/Capita	0.748(**)	0.605(**)	0.695(**)	0.789(**)	1		
LN Non-Renewable/Capita	0.593(**)	0.510(**)	0.554(**)	0.594(**)	0.711(**)	1	
PC1 – Magnitude of the Economy	0.832(**)	0.774(**)	0.729(**)	0.837(**)	0.513(**)	0.563(**)	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Therefore, the Emergy Total Wellbeing Index (ETWI), the product of HDI and emergy percent renewable, may capture total wellbeing. Figure 3-7 is a map of the new ETWI. Both HDI and the percent of emergy use from renewable resources are on 0-1 scales, so their product has a maximum of 1 and a minimum of 0. Countries with a high ETWI have both high HDI (human welfare) and high percent of emergy use from renewable resources (environmental sustainability). Figure 3-8 is a bar graph showing each nation's ETWI score and HDI score. National rankings and ETWI values can be found in Table 3-18.

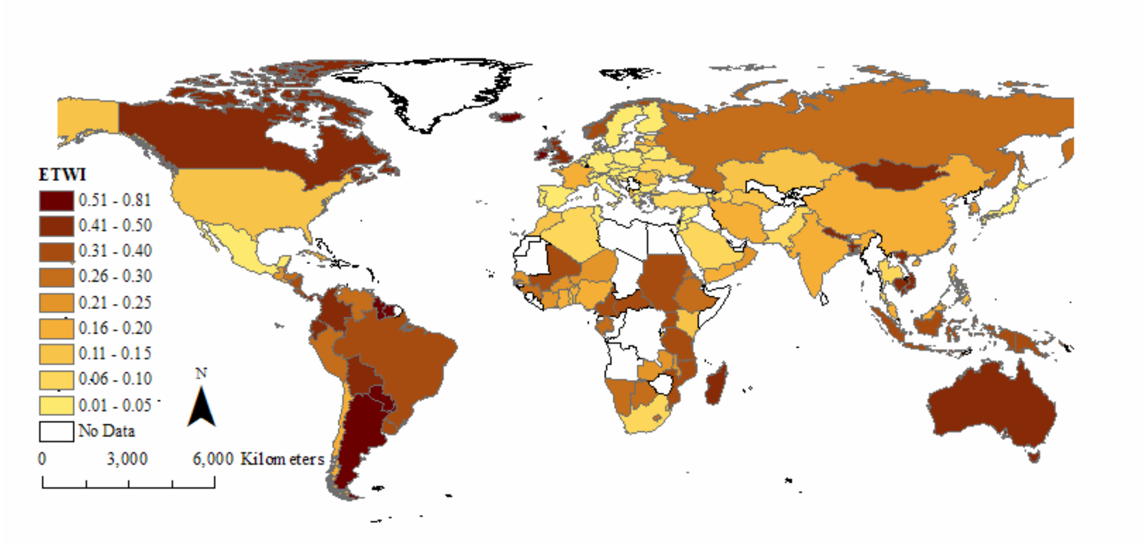


Figure 3-7: Map of the Emergy Total Wellbeing Index (HDI * percent of emergy use from renewable resources).

Table 3-19 shows the correlations between the ETWI and the aggregate indices. Interestingly, the ETWI is not correlated with the WI, which should also be a measure of total wellbeing. Also, while the ETWI is positively correlated with measures of environmental well-being, it is negatively correlated with measures of human well-being such as the HDI and HWI.

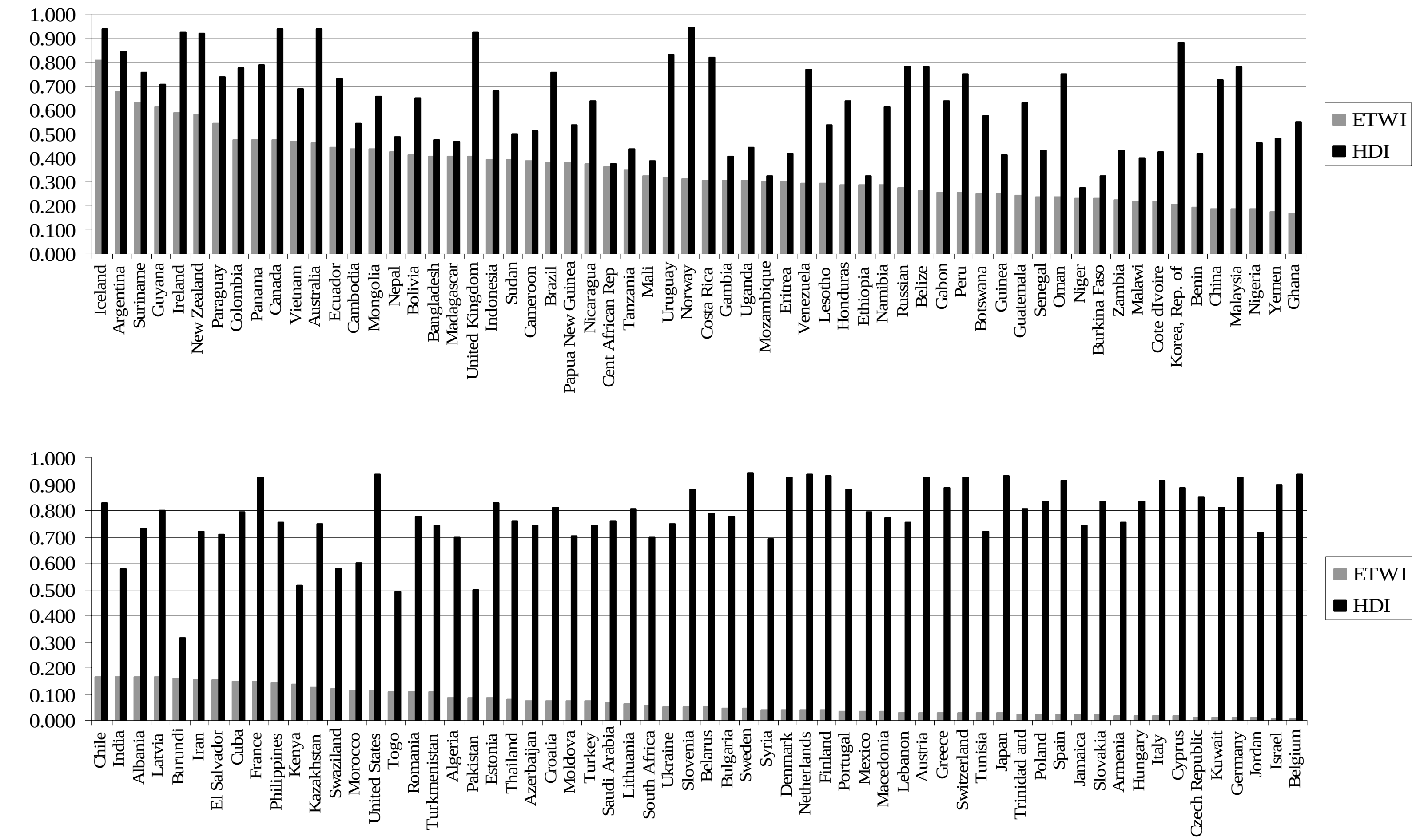


Figure 3-8: Bar graph of national ETWI and HDI scores in order of ETWI score.

Table 3-18: National rankings and values for new wellbeing index

Rank	Nation	HDI * Percent Renewable	Rank	Nation	HDI * Percent Renewable	Rank	Nation	HDI * Percent Renewable
1	Iceland	0.805	43	Belize	0.265	85	Azerbaijan	0.076
2	Argentina	0.673	44	Gabon	0.257	86	Croatia	0.076
3	Suriname	0.633	45	Peru	0.256	87	Moldova	0.075
4	Guyana	0.615	46	Botswana	0.253	88	Turkey	0.073
5	Ireland	0.585	47	Guinea	0.250	89	Saudi Arabia	0.067
6	New Zealand	0.584	48	Guatemala	0.243	90	Lithuania	0.062
7	Paraguay	0.541	49	Senegal	0.240	91	South Africa	0.055
8	Colombia	0.478	50	Oman	0.235	92	Ukraine	0.054
9	Panama	0.478	51	Niger	0.233	93	Slovenia	0.050
10	Canada	0.477	52	Burkina Faso	0.232	94	Belarus	0.050
11	Vietnam	0.469	53	Zambia	0.226	95	Bulgaria	0.047
12	Australia	0.461	54	Malawi	0.221	96	Sweden	0.047
13	Ecuador	0.444	55	Cote dIvoire	0.217	97	Syria	0.042
14	Cambodia	0.439	56	Korea, Rep. of	0.208	98	Denmark	0.041
15	Mongolia	0.436	57	Benin	0.195	99	Netherlands	0.039
16	Nepal	0.428	58	China	0.191	100	Finland	0.038
17	Bolivia	0.412	59	Malaysia	0.190	101	Portugal	0.037
18	Bangladesh	0.407	60	Nigeria	0.189	102	Mexico	0.035
19	Madagascar	0.407	61	Yemen	0.175	103	Macedonia	0.035
20	United Kingdom	0.406	62	Ghana	0.170	104	Lebanon	0.031
21	Indonesia	0.396	63	Chile	0.168	105	Austria	0.029
22	Sudan	0.391	64	India	0.165	106	Greece	0.029
23	Cameroon	0.388	65	Albania	0.165	107	Switzerland	0.028
24	Brazil	0.383	66	Latvia	0.164	108	Tunisia	0.028
25	Papua New Guinea	0.382	67	Burundi	0.160	109	Japan	0.026
26	Nicaragua	0.375	68	Iran	0.157	110	Trinidad and Tobago	0.025
27	Central African Rep.	0.362	69	El Salvador	0.155	111	Poland	0.022
28	Tanzania	0.352	70	Cuba	0.151	112	Spain	0.022
29	Mali	0.325	71	France	0.150	113	Jamaica	0.022
30	Uruguay	0.320	72	Philippines	0.142	114	Slovakia	0.021
31	Norway	0.309	73	Kenya	0.135	115	Armenia	0.019
32	Costa Rica	0.308	74	Kazakhstan	0.123	116	Hungary	0.017
33	Gambia	0.308	75	Swaziland	0.122	117	Italy	0.015
34	Uganda	0.304	76	Morocco	0.116	118	Cyprus	0.015
35	Mozambique	0.302	77	United States	0.114	119	Czech Republic	0.011
36	Eritrea	0.298	78	Togo	0.110	120	Kuwait	0.010
37	Venezuela	0.294	79	Romania	0.107	121	Germany	0.009
38	Lesotho	0.292	80	Turkmenistan	0.107	122	Jordan	0.009
39	Honduras	0.290	81	Algeria	0.085	123	Israel	0.003
40	Ethiopia	0.286	82	Pakistan	0.085	124	Belgium	0.003
41	Namibia	0.285	83	Estonia	0.083			
42	Russian Federation	0.274	84	Thailand	0.080			

Table 3-19: Correlations between ETWI and aggregate indices

	ETWI
EF	-0.305(**)
ESI	0.304(**)
HDI	-0.217(*)
WI	0.086
HWI	-0.203(*)
EWI	0.451(**)

** Correlation is significant at the 0.01 level (2-tailed).* Correlation is significant at the 0.05 level (2-tailed).

Part 2: Analysis of the Emergy Money Ratio and International Debt[7]

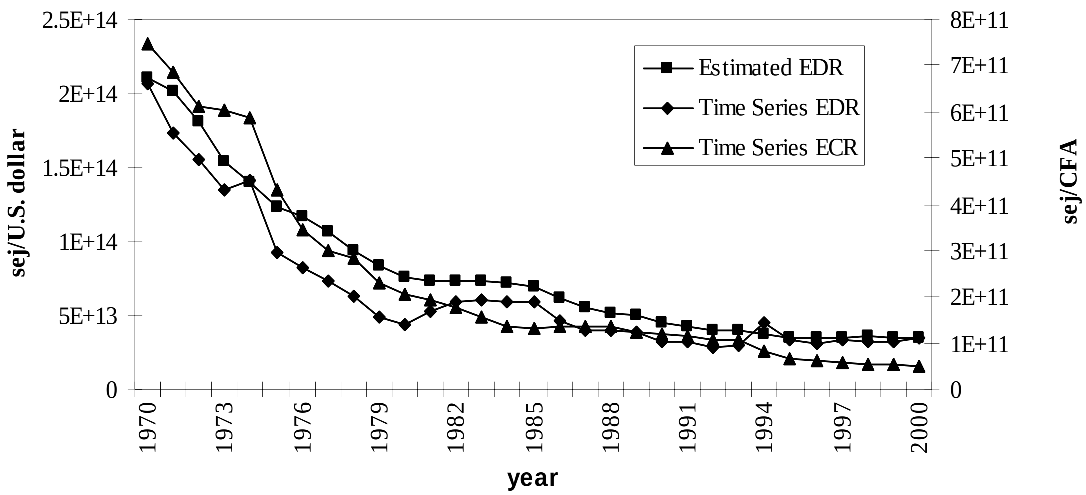
The following are the results of the emergy money ratio analysis followed by the EBEER and EMdebt analysis of West Africa.

The Emergy Money Ratios

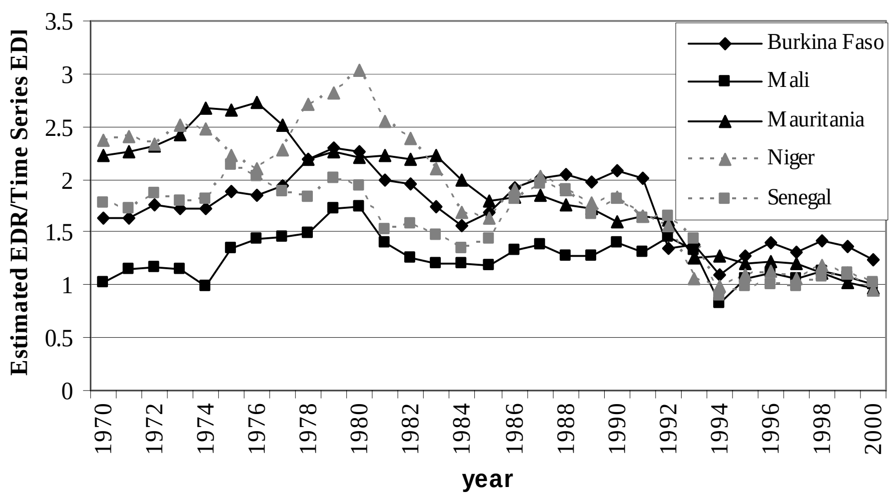
Figure 3-9a shows the slopes of the estimated emergy dollar ratio (EDR), time series EDR, and the time series emergy currency ratio (ECR) for Mali (graphs of the other four West African focal countries yielded similar results). Figure 3-9b shows the ratio of the estimated EDR to the time series EDR for the five focal countries. These figures show that while the time series EDR and the time series ECR change at a similar rate as the estimated EDR (Figure 3-9a), the ratio of the estimated EDR to the time series EDR is variable over time (Figure 3-9b); it also suggests that the estimated EDR systematically overestimates the actual EDR. This observation leads to the conclusion that the estimated EDR is not adequate for time series calculations, such as cumulative international debt. Also, it is possible that the difference between the slopes of the time

[7] All correlations in this section are significant at the 0.01 level (2-tailed).

series EDR and the time series ECR (Figure 3-9b) may be attributed to exchange rate fluctuations. This supports the need for the new EBEER calculation.



(a)



(b)

Figure 3-9: EDR comparison graphs of (a) the estimated EDR, the time series EDR and the time series ECR for Mali from 1970 to 2000 and (b) the ratio of the estimated EDR to the time series EDR for the five West African focal countries from 1970 to 2000.

Emergy Based Equitable Exchange Rate

Table 3-20 shows the results of the EBEER calculations for the five focal countries in U.S. dollars/nation LCU.

Table 3-20: U.S./focal country EBEER values from 1970 to 2000

Year	Burkina Faso	Mali	Mauritania	Niger	Senegal
1970	44.29	15.85	1.69	44.36	49.30
1971	43.95	16.47	1.70	44.96	47.73
1972	43.04	16.61	1.59	39.59	46.91
1973	37.41	14.39	1.47	37.87	39.99
1974	40.38	13.38	1.65	40.08	43.46
1975	39.40	16.13	1.56	32.16	45.46
1976	42.96	19.25	1.68	33.92	48.38
1977	46.18	20.07	1.56	37.81	45.95
1978	48.24	18.83	1.38	41.21	41.09
1979	47.57	20.55	1.42	40.39	42.58
1980	46.44	20.60	1.38	43.08	40.70
1981	52.78	21.47	1.46	46.63	41.48
1982	62.85	23.24	1.55	52.92	51.84
1983	64.76	25.86	1.67	54.12	55.94
1984	66.77	29.68	1.74	49.81	58.82
1985	73.75	29.77	1.89	49.30	64.03
1986	65.04	25.76	1.85	44.26	62.38
1987	58.95	23.31	1.85	40.92	58.33
1988	59.34	21.42	1.80	38.29	56.19
1989	61.17	22.90	1.94	38.16	52.89
1990	55.29	21.32	1.75	33.72	49.17
1991	55.08	20.90	1.85	31.34	45.81
1992	52.06	21.61	1.92	28.01	43.44
1993	52.39	21.29	2.06	28.14	40.51
1994	59.62	25.87	2.14	36.96	49.48
1995	61.61	29.78	2.12	36.98	49.37
1996	69.44	31.89	2.29	39.04	50.89
1997	74.55	34.74	2.50	41.39	56.88
1998	81.39	37.33	2.85	47.27	63.70
1999	82.31	37.41	2.91	46.09	67.73
2000	85.53	39.89	3.17	46.05	72.58

The ratio of the OER to EBEER (termed the emergy inequity factor, EIF) in any given year describes the advantage to the US when trading with one of the focal nations. Figure 3-10 shows that the EIF has increased over time for each of the focal nations, and is currently greater than 10:1 for all focal nations.

As discussed in Chapter 1, in theory the market should set the exchange rate near purchasing power parity (PPP). For the year 2000, the reported PPP ratio is better correlated with the Emergy Based Equitable Exchange Rate (EBEER, R=0.96, n=129) than with the reported official exchange rate (OER, R=0.89, n = 130). However, both comparisons include as a factor the arbitrary units of currency. To control for those currency units, Figure 3-11 is a graph of the OER divided by PPP versus the OER divided by the EBEER, or in other words, a monetary inequity factor versus the EIF. It illustrates that the EBEER and PPP are significantly correlated even when the currency units are removed (R = 0.40, n = 128). It also shows that all countries fall above a one to one line, meaning their EIF is greater than their monetary inequity factor. Nations which fall near the coordinates (1,1) have an OER which is approximately equal to their PPP ratio and EBEER. These nations include Austria, Denmark, France, Germany, Sweden, Switzerland, Syria, the United Kingdom and the United States.

Over time, PPP is also better correlated with the EBEER than with the OER for the focal countries Burkina Faso (R = 0.90 and 0.80 respectively) and Niger (R = 0.89 and 0.68 respectively). PPP is equally correlated with the EBEER and with the OER for the focal countries Mali (R = 0.93) and Mauritania (R = 0.93). PPP is better correlated with the OER than with the EBEER for the focal country Senegal (R = 0.86 and 0.67 respectively). This implies that PPP may be difficult to accurately measure for transitional and developing economies.

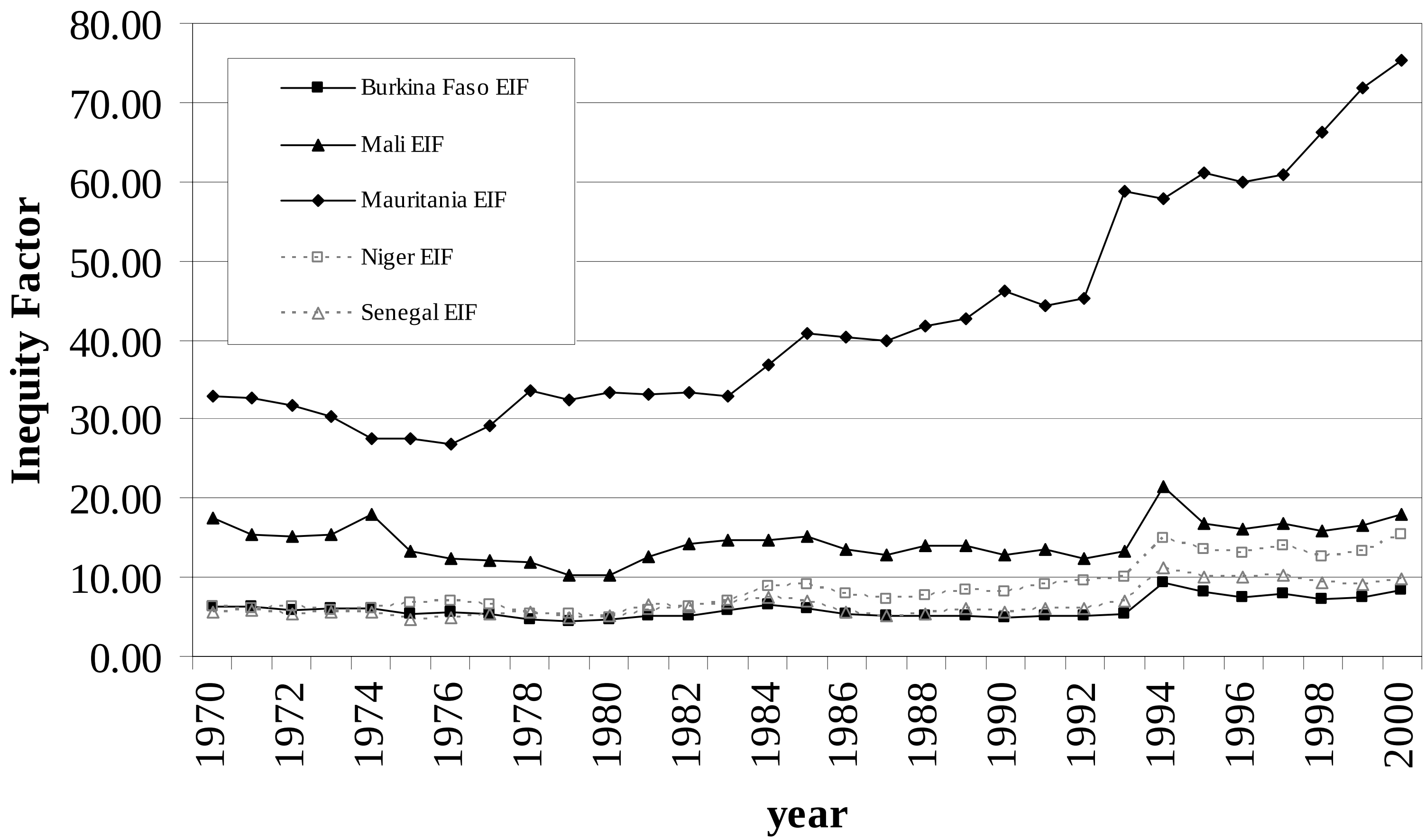


Figure 3-10: Graph of emergy inequity factors from 1970 to 2000.

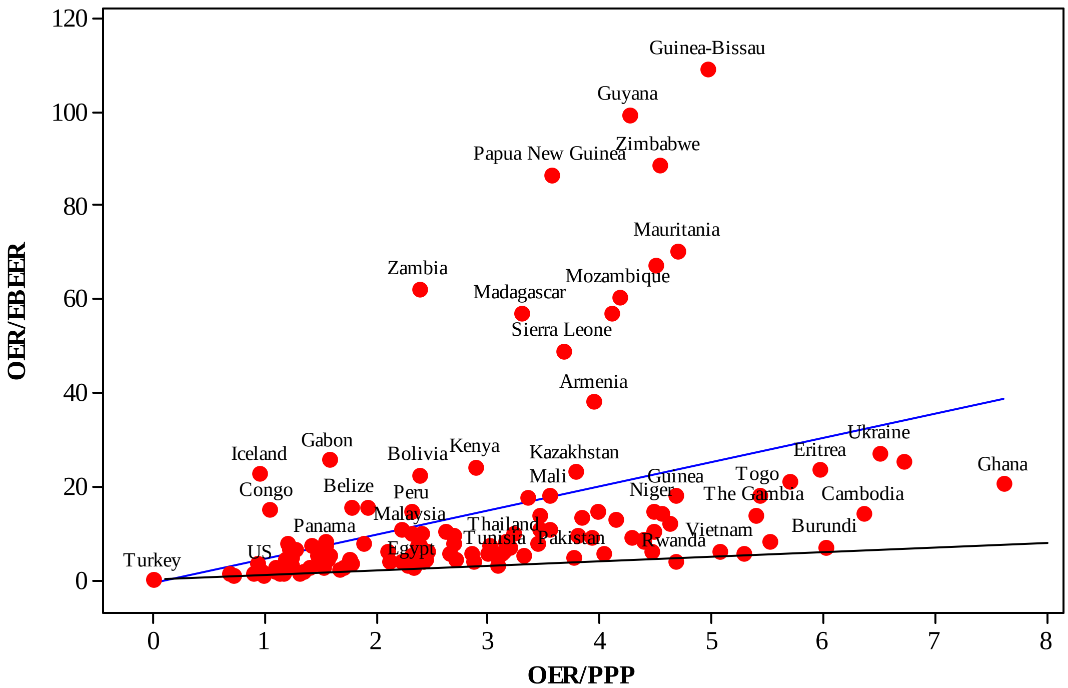


Figure 3-11: Scatter plot of OER/EBEER versus OER/PPP, including a regression line (blue) and a 1 to 1 line (black). Data for PPP ratio and OER from the World Bank, WDI Online 2005.

Figure 3-12 is a graph of the ratios of the EBEER to PPP and OER to PPP for the West African focal countries. In all cases, the ratios in Figure 3-12 suggest that the OER overestimates the PPP ratio and the EBEER underestimates the PPP ratio. In other words, PPP underestimates the inequality between nations as measured by the EBEER. Also, the slope of the EBEER:PPP values appears to be less variable than the slope of the OER:PPP values for all five countries.

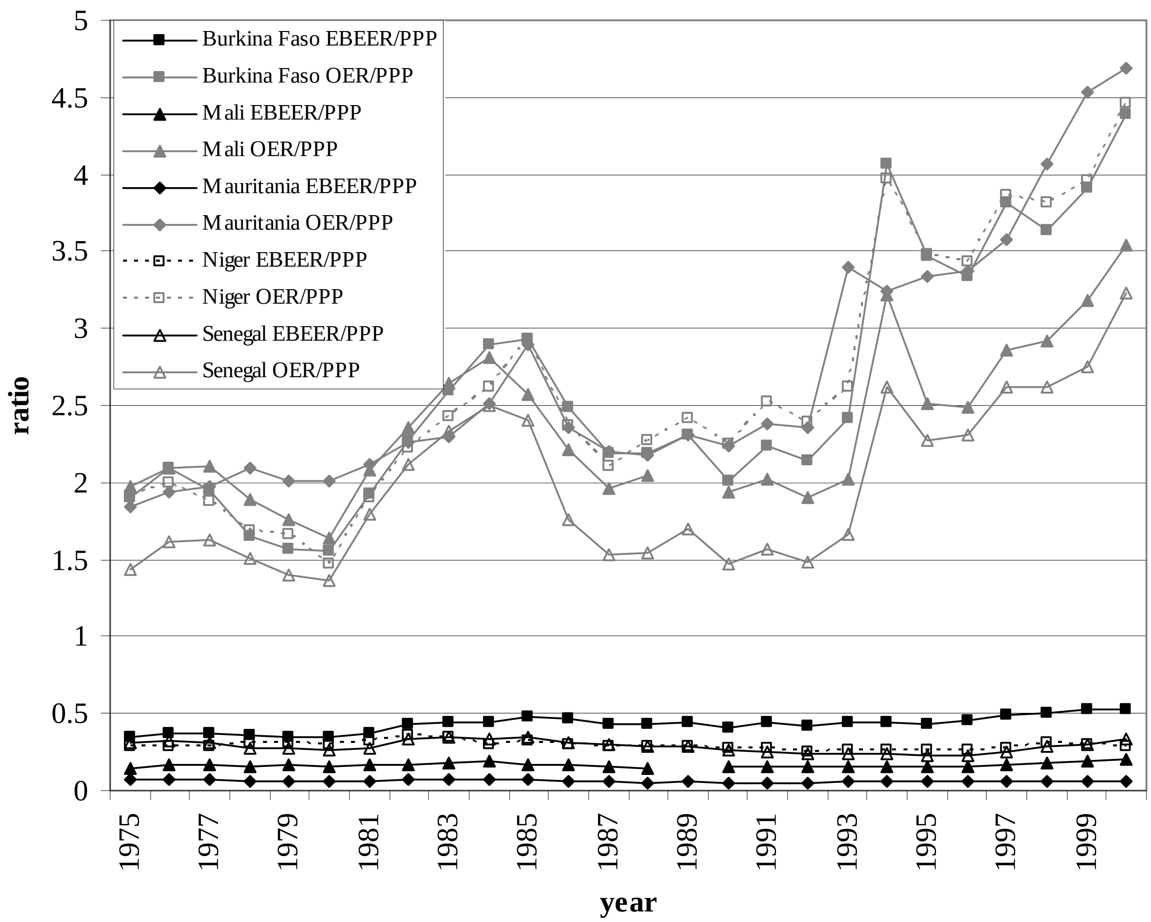


Figure 3-12: Graph of the ratios of EBEER to PPP and OER to PPP from 1975 to 2000 for the five focal countries. Data for OER and PPP from the World Bank, WDI Online 2005.

EMdebt

Due to the above results on the difference between an estimated EDR and measured EDR over time and the influence of the exchange rate on the EDR, EMdebt was only calculated for nations with available time series data using the EBEER method. The calculated annual EMdebt values can be found in Appendix D, Table D-1. Table 3-21 shows these EMdebt results for the five West African focal nations. The values are in U.S. dollars. In summary, Table 3-21 shows that while the five focal countries have a large negative official debt balance, they are net creditors in terms of debt calculations based on embodied environmental work.

Table 3-21: Official debt versus EMdebt.

Nation	**2000 Official debt outstanding balance**	**2000 EBEER EMdebt balance**	**Year of repayment for EBEER based EMdebt**
Burkina Faso	-3.31E+09	1.11E+09	1994
Mali	-6.16E+09	8.22E+09	1986
Mauritania	-4.77E+09	7.65E+10	1971
Niger	-4.10E+09	9.46E+09	1979
Senegal	-8.86E+09	1.83E+10	1975

Figure 3-13 shows that while each of the five focal countries' official long term external debt (LDOD) continuously increased from 1970 to 2000, their EMdebt decreased sharply and has been repaid.

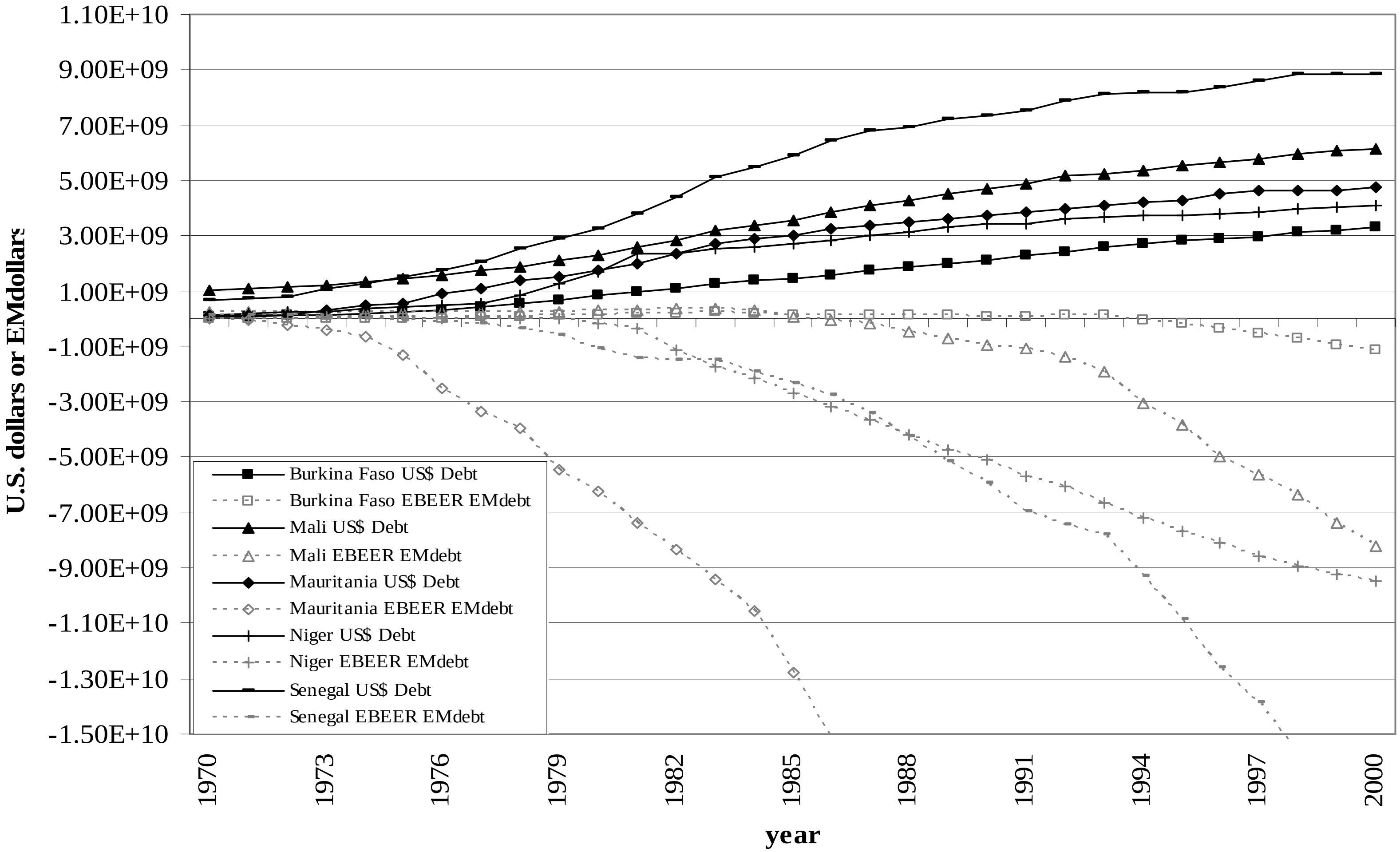


Figure 3-13: Graphs of US dollar debt and EMdebt. Official US dollar long term external debt (LDOD, data from the World Bank, GDF Online 2005) versus EBEER EMdebt (results in U.S. dollars) for the five West African focal nations

CHAPTER 4
DISCUSSION

This chapter contains discussion of this study's findings on emergy, well-being and debt, followed by general conclusions of this thesis.

Emergy: Evaluating the Resource Basis of Nations

Hypothesis 1: Emergy indices will allow grouping of nations into classes that conform with normative classifications based on development status and resource use intensity.

The cluster analysis both quantitatively verified normative country groupings and pointed out interesting relationships that might otherwise be overlooked. The largest gap in similarity is between clusters 1 through 3 and clusters 4 through 6. Clusters 1 through 3 contain most of the 26 poorest nations in the world and are dominated by nations in Sub-Saharan Africa. Notably, two of the focal nations are in cluster 1, one is in cluster 2, and two are in cluster 3. Therefore, despite their regional grouping for the drylands management project, from an emergy perspective they have fundamental differences which could have significant policy implications.

Figure 3-2 depicts that LDCs and developing countries (clusters 1-3) typically have low magnitude of the economy (PC1) and moderate magnitude of their resource base (PC2). Among these LDCs and developing countries, the cluster 3 nations (which include Mali, Niger) have the lowest raw resource export (PC4) and the highest non-renewable intensity (PC5). The cluster 2 nations (which include Burkina Faso) have the highest per capita intensity of the developing nations, and interestingly Burundi, Uganda, Rwanda and Burkina Faso are ranked 5th through 8th in highest per capita emergy intensity of all nations studied.

There is also a large difference in similarity values between clusters 4/5 and clusters 6/7. Clusters 4 and 5 contain a mix of transitional nations and developed nations, all of which have a moderate magnitude of their economy and a high magnitude of their resource base. While the cluster 5 nations have moderate raw resource export, the cluster 4 nations (which include Nigeria, Norway and Saudi Arabia) have the highest raw resource export of all of the nations studied. This is logical as these nations are the major global fuel exporters. Clusters 6 and 7 contain most of the developed nations, with cluster 7 consisting of only the most developed nations. All of the cluster 7 nations have higher magnitude of the economy than the cluster 6 nations, and the cluster 6 nations have a slightly higher raw resource export than the cluster 7 nations. These results suggest that the most developed nations are those that support their large economies by exploiting the raw resources of other nations, or that as nations develop, they become increasingly reliant on other countries raw resources.

The principle components (PCs) chosen to represent the emergy indices accounted for 76.1% of the variability in the dataset. The remaining 23.9% which is not accounted for may explain why certain countries are grouped inexplicably in the cluster analysis. Most notably, Djibouti, one of the 26 least developed countries (LDC), appears in cluster 6 which is dominated by highly developed nations. Examination of Djibouti's individual emergy indices shows that it has low exports and a high emergy investment ratio (IR) relative to other LDC's and developing countries. Swaziland and Tunisia, normatively considered developing countries, are also in cluster 6. Relative to other developing countries, they have very low percent renewable and high IRs. Iceland, considered a highly developed country, appears in cluster 3 which is otherwise composed of only LDCs and developing countries. This may be due to Iceland's exceptionally high percent renewable, which resembles that of a developing country. This suggests that the five PCs used in the analysis do not account for some measure of affluence relative to resource use which is captured in the individual emergy indices.

Magnitude of the resource base (PC2), which accounts for approximately 20% of the variance in the emergy data set, is not significantly correlated with any of the aggregate well-being indices. However, this is not unexpected as it is not on a per capita basis, and because high availability of resources does not necessarily mean they are used sustainably or efficiently. Additionally, these resources may not be directly exploited by the population. This highlights the uniqueness of the information an emergy evaluation can provide.

Well-being: Linking Poverty and the Environment

Hypothesis 2: Measures of human well-being are negatively correlated with measures of environmental well-being.

The correlations between the aggregate indices in Table 3-7 and Table 3-8 suggest that human well-being and environmental well-being have an inverse relationship. From a resource use perspective (Table 3-9), nations which maximize the magnitude of their economy and their per capita emergy intensity have higher human well-being and lower environmental well-being. Those nations with high raw resource export, which the cluster analysis suggests are the transitional nations, appear to have low human well-being and environmental well-being.

Hypothesis 3: Examination of index components will clarify apparent discrepancies.

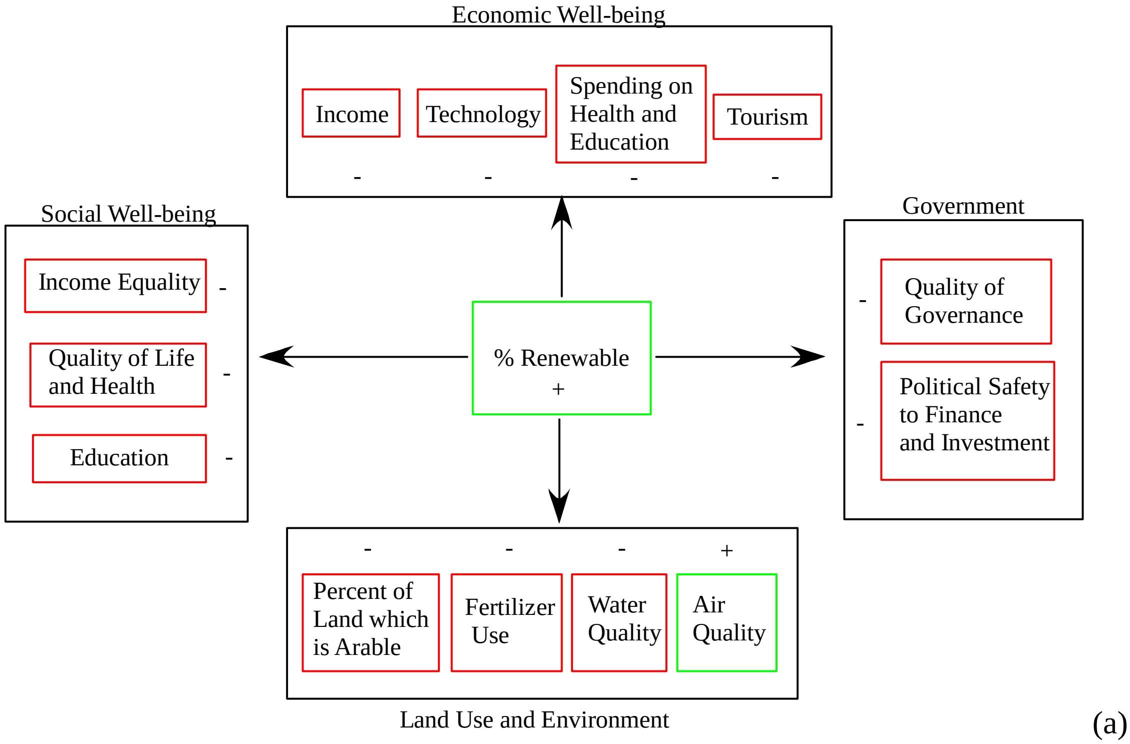
Correlations between the emergy indices and aggregate indices components identified resource use linked foundations for the discrepancies between a nation's various index rankings. Noteworthy discrepancies in well-being indices include that the Yale Environmental Sustainability Index (YESI), which should depict how sustainable a nation is, is significantly positively correlated with the Ecological Footprint (EF), which should depict how unsustainable a nation is. The YESI is also positively correlated with measures of human well-being. The results of the correlations between the YESI components and the emergy indices (Table 3-15 and Table 3-16) indicate that, as the literature suggests (The Ecologist 2001, Morse 2004, Morse et al. 2005), the nature of the data which composes the YESI gives an unmerited sustainability credit to developed countries. As Morse and Fraser (2005) explain, the YESI makes "dirty nations look clean".

Contrary to criticism (Ivanova et al. 1998, Noorbakhsh 1998, Anand and Sen 2000, Ogwang and Abdou 2002, Lind 2003, Morse 2003), correlations between the HDI components and emergy indices (Table 3-17) suggest that the choice of components does not significantly weaken the HDI's integrity as a social well-being indicator.

Hypothesis 4: Human welfare indices are positively correlated with the use of non-renewable emergy.. Hypothesis 5: Environmental welfare indices are negatively correlated with the use of non-renewable emergy.

A summary of the relationships between well-being and emergy measures of environmental sustainability (percent renewable) or economic development (magnitude of the economy) can be found in Figure 4-1. The relationships depicted in Figure 4-1 reinforce the above findings regarding the aggregate indices. As environmental sustainability (as measured by percent renewable) increases, social well-being, economic well-being, and governmental well-being decrease. Arable land and water quality also decrease, while the only indicator which shows improvement is air quality. Fertilizer use decreases as percent renewable increases, however it is unclear whether this is an economic result since most nations with high percent renewable are developing nations, or an indicator of better land quality

As economic development increases (as measured by magnitude of the economy), social well-being, economic well-being and governmental well-being increase. Irrigation, fertilizer use, and water quality also increase. The only well-being indicator which decreases with economic development is air quality. This finding conflicts with the Kuznets curve theory which suggests that air quality at first decreases, but then increases with development (Dinda 2004). However, the only air quality indicator included in this study was carbon dioxide emissions per capita.



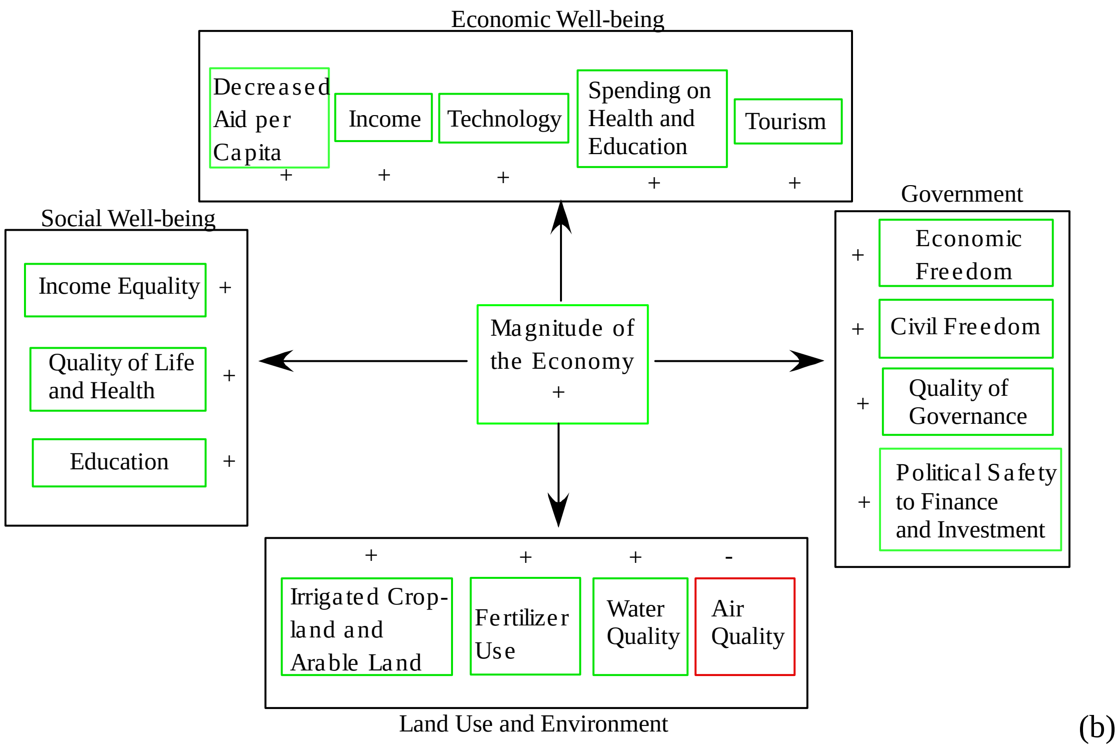


Figure 4-1: Summary diagrams of the relationships between well-being and percent renewable (a) and magnitude of the economy (b).

One interesting result of the well-being correlations which is not displayed in Figure 4-1 is that of debt and aid. Although debt per capita decreases as percent renewable decreases or magnitude of the economy increases (which would be expected), debt as a percentage of gross national income increases. This suggests that debt can have a positive impact on development and a nation's economy. There is also a significant negative correlation between aid per capita and raw resource export, perhaps again reflecting influence of the transitional economies discussed above.

Hypothesis 6: Comparison of indices allows for the identification of nations with high overall well-being. Hypothesis 7: A national ranking of overall well-being can be created by combining measures of human welfare and emergy sustainability.

If one accepts the premise that the HDI accurately reflects human well-being, the comparisons in Figure 3-5 and the proposed Emergy Total Well-being Index (ETWI) provide a measure of the efficiency of resource use. Nations who have a high ETWI score (which include Iceland, Argentina, Suriname, Guyana and Ireland) are generating human welfare on a more renewable resource basis.

Interestingly, the ETWI is not correlated with the Well-being Index (WI), although both combine human well-being and environmental well-being, and therefore should be measures of total well-being. This is especially surprising since the individual components of the WI appear to be adequate measures of human and environmental well-being, respectively (see Table 3-7). The Human Well-being Index (WI) is significantly positively correlated with the HDI and the Ecosystem Well-being Index (EWI) is significantly negatively correlated with the Ecological Footprint (EF). One reason for this discrepancy is that the WI is an average of human and environmental well-being, whereas the ETWI is a product of the two, making it more sensitive to extreme values. This may make the ETWI more useful than the WI for identifying nations with high total well-being, as nations must score high in both components to receive a high total score, whereas an average may mask a deficiency in one category.

Debt: Analysis of the Equity in International Exchange

Hypothesis 8: Due to the influence of the exchange rate, the traditional use of the EMR should be modified for international exchange calculations.

Although in theory the economic official exchange rate (OER) should set itself at purchasing power parity (PPP, Cassel 1918, cited by Isard 1995), this is not always the case. The difference between the OER and PPP is expressed as a monetary inequity factor in Figure 3-10 which is the lower bound of actual inequity. The Emergy Inequity Factor (EIF, or the ratio of the OER to EBEER) is systematically higher than the monetary inequity factor, with all nations falling on or above the one to one line. Only those nations which fall near the coordinates (1,1) on Figure 3-10 have an OER which sets near both PPP and EBEER, and is therefore just. All of these nations are developed countries, including France, Sweden, the United Kingdom and the United States. Most of the nations with the highest EIFs are nations of Sub-Saharan Africa, and interestingly, have moderate monetary inequity factors.

The EIF has increased over time for each of the focal nations (Figure 3-9), and is currently greater than 10:1. This has important implications for international trade and loans for these nations, as they are losing increasingly more embodied work as they trade with the United States.

While the EBEER appears to underestimate PPP by approximately ½ in favor of developing nations, it is very stable over time relative to the OER. The OER overestimates PPP in favor of developed nations by between approximately 1.5/1 and 5/1. Additionally, this overestimation is extremely variable and continues to increase over time.

As the ratio of the estimated EDR to the time series EDR was found to be variable over time (Figure 3-8b), it was concluded that time series data is necessary for debt calculations. Additionally, due to the influence of the monetary exchange rate (Figure 3-8a) and the inequity of the OER for developing nations (Figure 3-10 and Figure 3-11), it was concluded that these calculations should be done in local currency units (LCU) using the EBEER.

Hypothesis 9: African nations have repaid their debt if measured in environmental work, or real wealth.

Results of the EMdebt calculations show that the five focal nations have drastically over-serviced their debt in terms of embodied environmental work. In most cases, by the year 2000 these nations have repaid their debt two fold.

Strengths of the EBEER calculation are that the EMdebt results are in U.S. dollars, making it easy to interpret, and a market exchange rate is not directly used. However, debt service is reported by the World Bank in U.S. dollars. It was calculated back to LCU using the reported OER. Because the reported OER is a yearly average, there is the potential for error in this calculation if the exchange rate which the World Bank used to report debt service in U.S. dollars is different from the reported OER used here. With this possible exception, the EBEER creates an exchange rate which is independent of the economic market and reflects the ratio of currency buying power between to countries as measured by emergy.

Conclusions

By providing data on relationships between the resource basis of an economy and patterns of national welfare as well as the resource basis of international loans, this study is a contribution to sustainability assessment.

While the global database is an invaluable tool for international comparison, regional level analyses may be more informative, particularly in developing countries, and should be included in a management and policy guiding study, such as the dryland management project. A question that arises from this study is whether national average indices really apply at local levels. For example, would regional level ECRs more accurately represent the reality of trade for populations?

Findings of this study include that as human well-being increases, environmental well-being decreases, which poses challenges for sustainable development. Despite the pessimism of this observation, the ETWI appears to be an improvement to the available well-being indicators and a significant contribution to the quest for an objective and inclusive sustainability measure. The ETWI is a useful tool for benchmarking a nation’s current total well-being status, allowing for a future analysis of national improvements well-being. An interesting insight made possible by the uniqueness of the emergy methodology is that of the relationship between raw resource export and human well-being, including economic development. Results suggest that there may be a Kutznet curve relationship between a country’s raw resource exports and its development status.

It has been suggested that international debt requires nations to make tradeoffs between debt servicing and investments in human capital (Cheru 2002, Boafo-Arthur 2003, Mahdavi 2004). With this in mind, the results regarding EMdebt point to an ethical tragedy. As the focal nation EMdebt results show, money spent servicing loans by Sub-Saharan African nations which may have been paid off in emergy as early as the 1970s, could possibly have been spent on such things as healthcare and basic infrastructure.

In conclusion, this study has made a substantial contribution to sustainable development research by providing a unique view of resource use and new measure of total sustainability, as well as providing a scientifically based justification for immediate African debt relief.

APPENDIX A
DEFINITIONS AND SOURCES OF INDICES

Definitions of Aggregate Indices and Other Summary Indices

Ecological Footprint The Ecological Footprint (EF) is a national index of natural resource consumption reported in the number of global hectares (a hectare with the average biological productivity for a hectare on Earth) it would take to support one person from that nation. The Total EF includes the amount of built up land, the amount of water withdrawn, and the area required to provide and absorb the waste from food, timber and energy consumption. For example, the EF for a country includes the biocapacity needed to sequester the carbon produced by that country from the burning of fossil fuels. The EF does not include waste flows for which there is no limit considered sustainable (e.g. heavy metals, plutonium, CFCs, dioxins) or for which there is currently no reliable data on the wastes impact (e.g. acid rain). A higher EF corresponds to a higher consumption of resources per person (Loh and Wackernagel 2004). This index and its component indicators were calculated using data from the year 2001.

Ecosystem Wellbeing Index See description of the Wellbeing Index.

Fraser Institute Economic Freedom of the World Indices The Fraser Institute evaluates the degree to which countries' policies and institutions support economic freedom in five areas (size of government, legal structure and protection of property rights, access to sound money, international exchange, and regulation) based on 38 components and sub-components. Countries with higher scores have more economic freedom (Gwartney and Lawson 2004). These indices were calculated using data from the years 1999 and 2000.

Freedom House Indices Political rights and civil liberties are measured on a one-to-seven scale, with one representing the highest degree of freedom and seven the lowest. For freedom status, countries whose combined average ratings for political rights and for civil liberties fell between 1.0 and 2.5 were designated "free" (reclassified as 1), between 3.0 and 5.5 “partly free” (reclassified as 2) and between 5.5 and 7.0 “not free" (reclassified as 3) (Freedom House, Inc. 2005). These indices were calculated using data from the year 2000.

Gini Index The Gini Index measures the equality in the distribution of income within a country. The cumulative percentage of total income received is plotted against the cumulative number of recipients, starting with the poorest as a Lorenz curve. The Gini Index is the area between this curve and the diagonal (which would be perfect equality), expressed as a percentage of the maximum area under the diagonal. A percentage value of 0 would be complete equality, a percentage value of 100 would be complete inequality (Flanders and Ross-Larson 2002). This index was calculated using data from the most recent year available.

Governance Matters Indices The six Governance Matters indices (voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption) are based on the survey responses of citizens, non-governmental organizations, commercial risk-rating agencies and think-tanks regarding perceptions of the quality of governance. They are measured in units ranging from about

-2.5 to 2.5, with higher scores corresponding to better governance (Kaufmann, Kraay and Mastruzzi 2003). These indices were calculated using data from the year 2000.

Heritage Foundation Index of Economic Freedom The Index of Economic Freedom is a measure of 10 factors of economic freedom (trade policy, fiscal burden of government, government intervention in the economy, monetary policy, capital flows and foreign investment, banking and finance, wages and prices, property rights, regulation, and informal market activity). The factors are derived from 50 independent variables. Low scores correspond to high economic freedom (Miles, Feulner and O'Grady 2005). This index was calculated using data from the years 1999 and 2000.

Human Development Index The Human Development Index (HDI) is a measure of a country’s average achievement in human development based upon a long and healthy life (life expectancy at birth), knowledge (adult literacy rate and gross enrolment ratio) and standard of living (Gross Domestic Product per capita). Each indicator’s range is transformed to a scale from zero to one, with zero being the minimum value and one being the maximum value for each indicator for a specific year. Countries are given a score in each of the three categories (Life Expectancy Index, Education Index and GDP Index). These scores are then averaged to determine the HDI. The higher a country’s HDI, the higher its level of human development. Countries are also ranked and classified by their HDI as countries of "high" (reclassified as 3), "medium" (reclassified as 2) or "low" (reclassified as 1) human development (Flanders and Ross-Larson 2002). This index and its component indicators were calculated using data from the year 2000.

Human Poverty Index-1 The Human Poverty Index -1 (HPI-1) is a measure of a country's deprivations in the three HDI categories. It is a combination of the probability at birth of not surviving to age 40, the adult illiteracy rate, and an unweighted average of the population without sustainable access to an improved water source and children under weight for age (Flanders and Ross-Larson 2002). This index was calculated using data from the year 2000.

Human Wellbeing Index See description of the Wellbeing Index.

Political Risk Yearbook Indices The Political Risk Yearbook (PYR) forcasts risks to international business based on political, economic and social research. Turmoil refers to 18 month and five year forcasts of a country's level of turmoil (classified as low, moderate, high or very high, reclassified as 1, 2, 3 and 4 respectively). Turmoil includes protests, general strikes, crime, civil violence and war. The PYR also publishes 18 month and five year forcasts of risk to financial transfer, direct investment and the export market (classified using a letter grading scale from A+ to F, reclassified numerically from 1 to 13). Forcasts are taken from individual country reports completed during 2000 (Coplin and O'Leary 2001). These indices were calculated using data from the years 1999 and 2000.

Wellbeing Index The Wellbeing Index (WI) is similar to the ESI. It is based on the concept that ecosystem wellbeing and human wellbeing should be measured separately, then equally weighted and considered together. Countries are given performance scores from zero to 100 for both aspects of wellbeing. These performance scores are separately called the Human Wellbeing Index (HWI) and Ecosystem Wellbeing Index (EWI). The HWI is a composite of indicators in the five categories of health and population, wealth, knowledge and culture, community and equity. The EWI is composed of indicators in the five categories of land, water, air, species and genes and resource use. HWI and EWI are then averaged to determine a country's WI. A high WI corresponds to a high total wellbeing (Prescott-Allen 2001). These indices were calculated using data from the most recent year available.

Yale Environmental Sustainability Index The Yale Environmental Sustainability Index (YESI) is a measure of a country's environmental health and history, resource use and institutional mechanisms to change society's environmental and resource use trajectory. The index is based on five components (state of environmental systems, stress on those systems, human vulnerability to environmental change, social and institutional capacity to cope with stresses, and contribution to global stewardship) derived from 21 indicators considered fundamental to sustainability (e.g. water quality, reducing air pollution, basic human sustenance, science and technology). Seventy-six variables are transformed to comparable scales, then aggregated and used to score countries in these 21 indicator categories. The 21 indicators are weighted equally and then averaged to determine a country's ESI. The ESI score is meant to quantify a country's ability to avoid environmental deterioration. The higher a country's ESI score, the more likely it is to maintain environmental health and resources in the future (Esty et al. 2005). This index and its component indicators were calculated using data from the most recent year available

Definitions of Miscellaneous Wellbeing Indicators[8]

Adult literacy rate (% age 15 yrs and above) The percentage of people aged 15 and above who can, with understanding, both read and write a short, simple statement on their everyday life (Flanders and Ross-Larson 2002).

Age dependency ratio (dependents to working-age population) Age dependency ratio is the ratio of dependents--people younger than 15 and older than 64--to the working-age population--those ages 15-64. For example, 0.7 means there are 7 dependents for every 10 working-age people (The World Bank Group, WDI Online 2005).

Agriculture, value added (% of GDP) Agriculture corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3 (The World Bank Group, WDI Online 2005).

Aid per capita (current US$) Aid per capita includes both official development assistance (ODA) and official aid, and is calculated by dividing total aid by the midyear population estimate (The World Bank Group, WDI Online 2005).

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[8]The following definitions are taken directly from their respective sources and computed using data from the year 2000 unless otherwise noted

Arms exports (constant 1990 US$) Arms transfers cover the supply of military weapons through sales, aid, gifts, and those made through manufacturing licenses. Data cover major conventional weapons such as aircraft, armored vehicles, artillery, radar systems, missiles, and ships designed for military use. Excluded are transfers of other military equipment such as small arms and light weapons, trucks, small artillery, ammunition, support equipment, technology transfers, and other services (The World Bank Group, WDI Online 2005).

Arms imports (constant 1990 US$) Arms transfers cover the supply of military weapons through sales, aid, gifts, and those made through manufacturing licenses. Data cover major conventional weapons such as aircraft, armored vehicles, artillery, radar systems, missiles, and ships designed for military use. Excluded are transfers of other military equipment such as small arms and light weapons, trucks, small artillery, ammunition, support equipment, technology transfers, and other services (The World Bank Group, WDI Online 2005).

Average interest (%) Interest represents the average interest rate on all new public and publicly guaranteed loans contracted during the year. To obtain the average, the interest rates for all public and publicly guaranteed loans have been weighted by the amounts of the loans. Public debt is an external obligation of a public debtor, including the national government, a political subdivision (or an agency of either), and autonomous public bodies. Publicly guaranteed debt is an external obligation of a private debtor that is guaranteed for repayment by a public entity (The World Bank Group, GDF Online 2005).

CO2 emissions (metric tons per capita) Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include contributions to the carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring (The World Bank Group, WDI Online 2005).

Combined primary, secondary and tertiary gross enrollment ratio (%) The gross enrollment ratio is the number of students enrolled in a level of education, regardless of age, as a percentage of the population of official school age for that level (Flanders and Ross-Larson 2002). Data for this indicator is from the year 1999.

Combustible renewables and waste (% of total energy) Combustible renewables and waste comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste, measured as a percentage of total energy use (The World Bank Group, WDI Online 2005).

Current account balance (% of GDP) Current account balance is the sum of net exports of goods, services, net income, and net current transfers (The World Bank Group, WDI Online 2005).

Debt outstanding (LDOD), total long-term (US$) Long-term debt outstanding and disbursed (LDOD) is the total outstanding long-term debt at year end. Long-term external debt is defined as debt that has an original or extended maturity of more than one year and that is owed to nonresidents and repayable in foreign currency, goods, or services. Long-term debt has three components: Public debt, which is an external obligation of a public debtor, including the national government, a political subdivision (or an agency of either), and autonomous public bodies; Publicly guaranteed debt, which is an external obligation of a private debtor that is guaranteed for repayment by a public entity; Private nonguaranteed external debt, which is an external obligation of a private debtor that is not guaranteed for repayment by a public entity. Public and publicly guaranteed long-term debt are aggregated (The World Bank Group, GDF Online 2005).

Debt service (LTDS), total long-term (US$) Long-term debt service payments (LTDS) are the sum of principal repayments and interest payments in the year specified. Long-term external debt is defined as debt that has an original or extended maturity of more than one year and that is owed to nonresidents and repayable in foreign currency, goods, or services (The World Bank Group, GDF Online 2005).

Disbursements, total long-term (DIS, US$) Disbursements on long-term debt are drawings on loan commitments during the year specified. Long-term external debt is defined as debt that has an original or extended maturity of more than one year and that is owed to nonresidents and repayable in foreign currency, goods, or services (The World Bank Group, GDF Online 2005).

Electric power consumption (kwh per capita) Electric power consumption measures the production of power plants and combined heat and power plants, less distribution losses, and own use by heat and power plants (The World Bank Group, WDI Online 2005).

Electricity production from coal sources (% of total) Sources of electricity refer to the inputs used to generate electricity. This indicator refers to the percentage generated from coal (The World Bank Group, WDI Online 2005).

Electricity production from oil sources (% of total) Sources of electricity refer to the inputs used to generate electricity. Oil refers to crude oil and petroleum products (The World Bank Group, WDI Online 2005).

Employment in agriculture (% of total employment) Employment in agriculture is the proportion of total employment recorded as working in the agricultural sector. Employees are people who work for a public or private employer and receive remuneration in wages, salary, commission, tips, piece rates, or pay in kind. Agriculture includes hunting, forestry, and fishing, corresponding to major division 1 (ISIC revision 2) or tabulation categories A and B (ISIC revision 3) (The World Bank Group, WDI Online 2005).

Employment in industry (% of total employment) Employment in industry is the proportion of total employment recorded as working in the industrial sector. Employees are people who work for a public or private employer and receive remuneration in wages, salary, commission, tips, piece rates, or pay in kind. Industry includes mining and quarrying (including oil production), manufacturing, electricity, gas and water, and construction, corresponding to major divisions 2-5 (ISIC revision 2) or tabulation categories C-F (ISIC revision 3) (The World Bank Group, WDI Online 2005).

Employment in services (% of total employment) Employment in services is the proportion of total employment recorded as working in the services sector. Employees are people who work for a public or private employer and receive remuneration in wages, salary, commission, tips, piece rates, or pay in kind. Services include wholesale and retail trade and restaurants and hotels; transport, storage, and communications; financing, insurance, real estate, and business services; and community, social, and personal services, corresponding to divisions 6-9 (ISIC revision 2) or tabulation categories G-P (ISIC revision 3) (The World Bank Group, WDI Online 2005).

Expenditure per student, primary (% of GDP per capita) Public expenditure per student (primary) is the public current spending on education divided by the total number of students by level, as a percentage of GDP per capita (The World Bank Group, WDI Online 2005).

Fertilizer consumption (100 grams per hectare of arable land) Fertilizer consumption (100 grams per hectare of arable land) measures the quantity of plant nutrients used per unit of arable land. Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). The time reference for fertilizer consumption is the crop year (July through June). Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded (The World Bank Group, WDI Online 2005).

Food production index (1999-2001 = 100) Food production index covers food crops that are considered edible and that contain nutrients. Coffee and tea are excluded because, although edible, they have no nutritive value (The World Bank Group, WDI Online 2005).

Forest area (% of land area) Forest area is land under natural or planted stands of trees, whether productive or not (The World Bank Group, WDI Online 2005).

GDP per capita (constant 2000 US$) GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant U.S. dollars (The World Bank Group, WDI Online 2005).

GDP per capita (PPP US$) GDP is the total output of goods and services for final use produced by an economy, by both residents and non-residents, regardless of the allocation to domestic and foreign claims. It does not include deductions for depreciation of physical capital or depletion and degradation of natural resources. PPP (purchasing power parity) is a rate of exchange that accounts for price differences across countries, allowing international comparisons of real output and incomes. At the PPP US$ rate (as used in this Report), PPP US$1 has the same purchasing power in the domestic economy as $1 has in the United States (Flanders and Ross-Larson 2002).

GDP per capita rank minus HDI rank See description of HDI in Appendix A (Flanders and Ross-Larson 2002).

GNI per capita, Atlas method (current US$) GNI per capita (formerly GNP per capita) is the gross national income, converted to U.S. dollars using the World Bank Atlas method, divided by the midyear population. GNI is the sum of value added by all resident producers plus any product taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad. GNI, calculated in national currency, is usually converted to U.S. dollars at official exchange rates for comparisons across economies, although an alternative rate is used when the official exchange rate is judged to diverge by an exceptionally large margin from the rate actually applied in international transactions. To smooth fluctuations in prices and exchange rates, a special Atlas method of conversion is used by the World Bank. This applies a conversion factor that averages the exchange rate for a given year and the two preceding years, adjusted for differences in rates of inflation between the country, and through 2000, the G-5 countries (France, Germany, Japan, the United Kingdom, and the United States) (The World Bank Group, WDI Online 2005).

Health expenditure per capita (current US$) Total health expenditure is the sum of public and private health expenditures as a ratio of total population. It covers the provision of health services (preventive and curative), family planning activities, nutrition activities, and emergency aid designated for health but does not include provision of water and sanitation. Data are in current U.S. dollars (The World Bank Group, WDI Online 2005).

Hospital beds (per 1,000 people) Hospital beds include inpatient beds available in public, private, general, and specialized hospitals and rehabilitation centers. In most cases beds for both acute and chronic care are included (The World Bank Group, WDI Online 2005).

Household final consumption expenditure per capita (constant 2000 US$) Household final consumption expenditure per capita (private consumption per capita) is calculated using private consumption in constant 2000 prices and World Bank population estimates. Household final consumption expenditure is the market value of all goods and services, including durable products (such as cars, washing machines, and home computers), purchased by households. It excludes purchases of dwellings but includes imputed rent for owner-occupied dwellings. It also includes payments and fees to governments to obtain permits and licenses. Here, household consumption expenditure includes the expenditures of nonprofit institutions serving households, even when reported separately by the country. Data are in constant 2000 U.S. dollars (The World Bank Group, WDI Online 2005).

International migration stock (% of population) Migration stock is the number of people born in a country other than that in which they live. It also includes refugees (The World Bank Group, WDI Online 2005).

Internet users (per 1,000 people) Internet users are people with access to the worldwide network (The World Bank Group, WDI Online 2005).

Land use, arable land (% of land area) Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded (The World Bank Group, WDI Online 2005).

Land use, arable land (hectares per person) Arable land (hectares per person) includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded (The World Bank Group, WDI Online 2005).

Land use, irrigated land (% of cropland) Irrigated land refers to areas purposely provided with water, including land irrigated by controlled flooding. Cropland refers to arable land and land used for permanent crops (The World Bank Group, WDI Online 2005).

Life expectancy at birth (years) The number of years a newborn infant would live if prevailing patterns of age specific mortality rates at the time of birth were to stay the same throughout the child’s life (Flanders and Ross-Larson 2002).

Military expenditure (% of GDP) Military expenditures are based on the NATO definition, which includes all current and capital expenditures on the armed forces, including peacekeeping forces; defense ministries and other government agencies engaged in defense projects; paramilitary forces, if these are judged to be trained and equipped for military operations; and military space activities. Such expenditures include military and civil personnel, including retirement pensions of military personnel and social services for personnel; operation and maintenance; procurement; military research and development; and military aid (in the military expenditures of the donor country). Excluded are civil defense and current expenditures for previous military activities, such as for veterans' benefits, demobilization, conversion, and destruction of weapons. This definition cannot be applied for all countries, however, since that would require much more detailed information than is available about what is included in military budgets and off-budget military expenditure items (The World Bank Group, WDI Online 2005).

Official exchange rate (LCU per US$, period average): Official exchange rate refers to the exchange rate determined by national authorities or to the rate determined in the legally sanctioned exchange market. It is calculated as an annual average based on monthly averages (local currency units relative to the U.S. dollar, The World Bank Group, WDI Online 2005).

Organic water pollutant (BOD) emissions (kg per day per worker) Emissions per worker are total emissions of organic water pollutants divided by the number of industrial workers. Organic water pollutants are measured by biochemical oxygen demand, which refers to the amount of oxygen that bacteria in water will consume in breaking down waste. This is a standard water-treatment test for the presence of organic pollutants (The World Bank Group, WDI Online 2005).

Out-of-pocket health expenditure (% of private expenditure on health) Out of pocket expenditure is any direct outlay by households, including gratuities and in-kind payments, to health practitioners and suppliers of pharmaceuticals, therapeutic appliances, and other goods and services whose primary intent is to contribute to the restoration or enhancement of the health status of individuals or population groups. It is a part of private health expenditure (The World Bank Group, WDI Online 2005).

Percent of population living with HIV/AIDS in 2001 The estimated number of people living with HIV/AIDS at the end of the year specified (United Nations Program on HIV/AIDS 2004). Data for this indicator is from the year 2001.

Permanent pasture (% of land area) Permanent pasture is land used for five or more years for forage crops, either cultivated or growing wild. Total land area is a country's total area, excluding area under inland water bodies. In most cases the definition of inland water bodies includes major rivers and lakes (The World Bank Group, WDI Online 2005).

Population ages 0-14 (% of total) Population ages 0 to 14 is the percentage of the total population that is in the age group 0 to 14 (The World Bank Group, WDI Online 2005).

Population ages 15-64 (% of total) Population ages 15 to 64 is the percentage of the total population that is in the age group 15 to 64 (The World Bank Group, WDI Online 2005).

Population ages 65 and above (% of total) Population ages 65 and above is the percentage of the total population that is 65 or older (The World Bank Group, WDI Online 2005).

Population below income poverty line (%) $1/day (1993 PPP US$) 1983-2000 The percentage of the population living below $1 a day—at 1985 international prices (equivalent to $1.08 at 1993 international prices), adjusted for purchasing power parity (Flanders and Ross-Larson 2002). Data for this indicator is from the years 1983 to 2000.

Population below income poverty line (%) $2/day (1993 PPP US$) 1983-2000 The percentage of the population living below $2 a day—at 1985 international prices (equivalent to $2.16 at 1993 international prices), adjusted for purchasing power parity (Flanders and Ross-Larson 2002). Data for this indicator is from the years 1983 to 2000.

Population not using improved water sources (%) The proportion of the population not using any of the following types of water supply for drinking: piped water, a public tap, a borehole with a pump, a protected well, a protected spring or rainwater (Flanders and Ross-Larson 2002).

PPP conversion factor to official exchange rate ratio Purchasing power parity conversion factor is the number of units of a country's currency required to buy the same amount of goods and services in the domestic market as a U.S. dollar would buy in the United States. Official exchange rate refers to the exchange rate determined by national authorities or to the rate determined in the legally sanctioned exchange market. It is calculated as an annual average based on monthly averages (local currency units relative to the U.S. dollar) (The World Bank Group, WDI Online 2005).

Purchasing power parity conversion factor (LCU per international $) Purchasing power parity conversion factor is the number of units of a country's currency required to buy the same amounts of goods and services in the domestic market as U.S. dollar would buy in the United States (The World Bank Group, WDI Online 2005).

Ratio of girls to boys in primary and secondary education (%) Ratio of girls to boys in primary and secondary education is the percentage of girls to boys enrolled at primary and secondary levels in public and private schools (The World Bank Group, WDI Online 2005).

Refugee population by country or territory of asylum per capita Refugees are people who are recognized as refugees under the 1951 Convention Relating to the Status of Refugees or its 1967 Protocol, the 1969 Organization of African Unity Convention Governing the Specific Aspects of Refugee Problems in Africa, people recognized as refugees in accordance with the UNHCR statute, people granted a refugee-like humanitarian status, and people provided with temporary protection. Asylum seekers are people who have applied for asylum or refugee status and who have not yet received a decision or who are otherwise registered as asylum seekers. Country of asylum is the country where an asylum claim was filed (The World Bank Group, WDI Online 2005). Refugees were divided by population to acquire refugees per capita.

Refugee population by country or territory of origin per capita Refugees are people who are recognized as refugees under the 1951 Convention Relating to the Status of Refugees or its 1967 Protocol, the 1969 Organization of African Unity Convention Governing the Specific Aspects of Refugee Problems in Africa, people recognized as refugees in accordance with the UNHCR statute, people granted a refugee-like humanitarian status, and people provided with temporary protection. Asylum seekers are people who have applied for asylum or refugee status and who have not yet received a decision or who are otherwise registered as asylum seekers. Country of origin generally refers to the nationality or country of citizenship of a claimant (The World Bank Group, WDI Online 2005). Refugees were divided by population to acquire refugees per capita.

Rural population (% of total population) Rural population is calculated as the difference between the total population and the urban population (The World Bank Group, WDI Online 2005).

Tax revenue (% of GDP) Tax revenue refers to compulsory transfers to the central government for public purposes. Certain compulsory transfers such as fines, penalties, and most social security contributions are excluded. Refunds and corrections of erroneously collected tax revenue are treated as negative revenue (The World Bank Group, WDI Online 2005).

Telephone average cost of call to US (US$ per three minutes) Cost of international call to U.S. is the cost of a three-minute, peak rate, fixed line call from the country to the United States (The World Bank Group, WDI Online 2005).

Total debt (EDT)/GNI (%) Total external debt to gross national product (The World Bank Group, GDF Online 2005).

Total debt stocks per capita (EDT/capita) Total debt stocks (EDT) consists of public and publicly guaranteed long-term debt, private nonguaranteed long-term debt (whether reported or estimated by the staff of the World Bank), the use of IMF credit, and estimated short-term debt (The World Bank Group, GDF Online 2005). EDT was divided by population to acquire EDT/capita.

Underweight children under age five (%) 1995-2000 Includes moderate and severe underweight, which is defined as below two standard deviations from the median weight for age of the reference population (Flanders and Ross-Larson 2002). Data for this indicator is from 1995-2000.

Unemployment, total (% of total labor force) Unemployment refers to the share of the labor force that is without work but available for and seeking employment. Definitions of labor force and unemployment differ by country (The World Bank Group, WDI Online 2005).

APPENDIX B

INDICES DATA AND DEFINITIONS OF EMERGY SYMBOLS AND FLOWS

Table B-1 contains indices of the 134 nations found in the National Environmental Accounting Database (Sweeney et al. 2006)

Table B-1: Indices from Sweeney et al. 2006

Nation	Use	Exports/ Imports	R/U	Use/Area	Use/ Capita	NonRenew/ Capita	IR	ELR	EYR
Albania	3.92E+22	0.41	0.22	1.43E+12	1.26E+16	2.64E+15	1.32	3.46	1.29
Algeria	3.27E+23	6.06	0.12	1.37E+11	1.08E+16	1.71E+16	0.46	7.19	1.14
Argentina	2.90E+24	3.16	0.80	1.06E+12	7.83E+16	1.17E+16	0.08	0.25	4.94
Armenia	1.41E+23	2.68	0.03	4.95E+12	4.52E+16	4.04E+16	0.09	38.47	1.03
Australia	4.81E+24	4.94	0.49	6.31E+11	2.51E+17	1.69E+17	0.14	1.04	1.97
Austria	9.12E+23	1.20	0.03	1.11E+13	1.13E+17	4.10E+16	1.58	30.94	1.03
Azerbaijan	9.06E+22	4.50	0.10	1.05E+12	1.11E+16	1.07E+16	0.22	8.71	1.11
Bangladesh	8.78E+23	1.58	0.85	6.56E+12	6.36E+15	2.30E+14	0.13	0.17	6.76
Belarus	2.39E+23	1.37	0.06	1.15E+12	2.38E+16	1.80E+15	6.41	14.91	1.07
Belgium	2.09E+24	2.00	0.00	6.91E+13	2.04E+17	3.20E+16	5.36	322.97	1.00
Belize	2.52E+22	1.26	0.34	1.10E+12	1.05E+17	3.98E+16	0.39	1.95	1.51
Benin	4.09E+22	0.58	0.46	3.69E+11	6.57E+15	1.61E+15	0.41	1.15	1.87
Bolivia	3.63E+23	2.06	0.63	3.35E+11	4.37E+16	1.04E+16	0.18	0.59	2.71
Botswana	1.03E+23	4.35	0.44	1.75E+11	5.95E+16	4.73E+16	0.36	1.26	1.79
Brazil	6.97E+24	3.24	0.51	8.25E+11	4.06E+16	2.16E+16	0.12	0.98	2.02
Bulgaria	3.21E+23	2.59	0.06	2.90E+12	3.96E+16	2.38E+16	0.54	15.44	1.06
Burkina Faso	4.34E+22	0.75	0.71	1.58E+11	3.64E+15	3.45E+14	0.24	0.40	3.50
Burundi	9.32E+21	0.37	0.51	3.63E+11	1.49E+15	3.99E+14	0.29	0.96	2.04
Cambodia	9.75E+22	5.68	0.81	5.52E+11	7.41E+15	3.34E+14	0.17	0.24	5.22
Cameroon	2.19E+23	3.56	0.76	4.67E+11	1.45E+16	3.14E+15	0.09	0.32	4.13

Table B-1: Continued.

Nation	Use	Exports/ Imports	R/U	Use/Area	Use/ Capita	NonRenew/ Capita	IR	ELR	EYR
Canada	6.04E+24	2.68	0.51	6.64E+11	1.96E+17	6.27E+16	0.48	0.97	2.03
Central African Republic	1.24E+23	15.27	0.97	1.99E+11	3.34E+16	1.15E+15	0.01	0.04	28.63
Chile	1.11E+24	3.32	0.20	1.48E+12	7.30E+16	4.74E+16	0.23	3.94	1.25
China	1.28E+25	2.06	0.26	1.37E+12	9.96E+15	5.03E+15	0.33	2.81	1.36
Colombia	9.76E+23	3.21	0.62	9.40E+11	2.32E+16	9.22E+15	0.14	0.62	2.63
Congo	9.35E+22	22.00	0.90	2.74E+11	2.71E+16	1.81E+16	0.05	0.11	9.93
Costa Rica	1.26E+23	1.38	0.38	2.49E+12	3.21E+16	5.55E+15	0.82	1.66	1.60
Cote d’Ivory	1.51E+23	1.91	0.51	4.75E+11	9.54E+15	1.96E+15	0.43	0.97	2.03
Croatia	1.10E+23	0.87	0.09	1.95E+12	2.47E+16	2.74E+15	3.98	9.62	1.10
Cuba	1.26E+23	0.31	0.19	1.14E+12	1.12E+16	2.81E+15	1.29	4.26	1.23
Cyprus	4.10E+22	0.33	0.02	4.44E+12	5.24E+16	5.44E+15	11.26	58.94	1.02
Czech Republic	6.15E+23	1.80	0.01	7.96E+12	5.99E+16	2.18E+16	1.87	77.18	1.01
Denmark	4.81E+23	1.20	0.04	1.13E+13	9.03E+16	2.37E+16	5.70	21.83	1.05
Djibouti	7.93E+21	0.11	0.43	3.45E+11	1.19E+16	1.43E+14	1.26	1.33	1.75
Ecuador	3.13E+23	4.44	0.61	1.13E+12	2.52E+16	1.07E+16	0.15	0.65	2.54
Egypt	4.94E+23	0.87	0.08	4.96E+11	7.28E+15	4.93E+15	0.52	12.16	1.08
El Salvador	9.67E+22	0.46	0.22	4.66E+12	1.56E+16	5.20E+15	0.81	3.56	1.28
Eritrea	2.87E+22	0.19	0.71	2.37E+11	7.74E+15	1.04E+15	0.19	0.41	3.43
Estonia	6.59E+22	1.84	0.10	1.52E+12	4.82E+16	3.29E+15	5.29	8.94	1.11
Ethiopia	3.18E+23	1.76	0.87	2.84E+11	4.84E+15	3.50E+14	0.06	0.14	7.92
Finland	4.90E+23	1.28	0.04	1.61E+12	9.46E+16	1.90E+16	3.16	23.54	1.04
France	3.82E+24	0.78	0.16	7.00E+12	6.44E+16	1.39E+15	4.62	5.18	1.19
Gabon	2.44E+23	46.74	0.40	9.47E+11	1.94E+17	2.80E+17	0.03	1.48	1.68
Germany	5.25E+24	0.89	0.01	1.50E+13	6.38E+16	5.62E+15	10.28	99.61	1.01
Ghana	1.97E+23	1.96	0.31	8.55E+11	1.01E+16	6.71E+15	0.36	2.23	1.45
Greece	5.76E+23	0.48	0.03	4.40E+12	5.28E+16	1.37E+16	2.55	29.55	1.03
Guatemala	1.92E+23	0.89	0.39	1.77E+12	1.68E+16	5.81E+15	0.42	1.59	1.63
Guinea	1.07E+23	4.43	0.61	4.37E+11	1.32E+16	6.33E+15	0.08	0.65	2.53
Guinea-Bissau	4.54E+22	5.06	0.97	1.62E+12	3.32E+16	2.69E+14	0.02	0.03	35.11
Guyana	1.37E+23	11.84	0.87	6.94E+11	1.80E+17	2.17E+16	0.07	0.15	7.62

Table B-1: Continued.

Nation	Use	Exports/ Imports	R/U	Use/Area	Use/ Capita	NonRenew/ Capita	IR	ELR	EYR
Honduras	9.02E+22	1.07	0.45	8.06E+11	1.40E+16	3.93E+15	0.36	1.20	1.83
Hungary	3.68E+23	1.59	0.02	3.98E+12	3.67E+16	5.64E+15	4.83	49.26	1.02
Iceland	3.67E+23	5.67	0.86	3.66E+12	1.30E+18	1.02E+17	0.07	0.16	7.13
India	5.26E+24	1.24	0.29	1.77E+12	5.17E+15	2.96E+15	0.17	2.49	1.40
Indonesia	3.08E+24	4.94	0.58	1.68E+12	1.45E+16	5.40E+15	0.19	0.73	2.38
Iran	1.60E+24	5.26	0.22	9.80E+11	2.41E+16	2.32E+16	0.15	3.59	1.28
Ireland	1.19E+24	3.42	0.63	1.73E+13	3.12E+17	1.76E+16	0.46	0.58	2.72
Israel	3.43E+23	0.69	0.00	1.69E+13	5.68E+16	5.99E+15	12.35	295.25	1.00
Italy	4.14E+24	0.80	0.02	1.41E+13	7.19E+16	2.19E+16	2.12	60.26	1.02
Jamaica	1.11E+23	1.10	0.03	1.03E+13	4.32E+16	2.52E+16	0.73	33.49	1.03
Japan	7.11E+24	0.44	0.03	1.90E+13	5.60E+16	1.59E+16	2.25	34.75	1.03
Jordan	1.78E+23	0.91	0.01	1.94E+12	3.54E+16	2.32E+16	0.50	78.45	1.01
Kazakhstan	8.16E+23	10.19	0.16	3.05E+11	5.21E+16	5.39E+16	0.13	5.08	1.20
Kenya	4.89E+23	2.25	0.26	8.59E+11	1.60E+16	1.05E+16	0.09	2.80	1.36
Kuwait	2.49E+23	9.81	0.01	1.39E+13	1.11E+17	2.06E+17	0.32	82.15	1.01
Latvia	6.60E+22	1.04	0.20	1.04E+12	2.78E+16	3.10E+15	2.22	3.88	1.26
Lebanon	8.28E+22	0.15	0.04	8.09E+12	2.38E+16	1.21E+14	20.92	23.67	1.04
Lesotho	1.36E+22	1.78	0.55	4.49E+11	7.64E+15	1.44E+14	0.77	0.83	2.21
Libya	1.46E+23	8.44	0.16	8.27E+10	2.78E+16	6.11E+16	0.36	5.35	1.19
Lithuania	9.87E+22	1.10	0.08	1.51E+12	2.82E+16	2.84E+15	5.08	11.96	1.08
Macedonia	5.47E+22	2.57	0.04	2.20E+12	2.70E+16	1.43E+16	0.79	21.31	1.05
Madagascar	4.27E+23	11.15	0.87	7.35E+11	2.68E+16	2.90E+15	0.03	0.15	7.59
Malawi	3.66E+22	1.66	0.55	3.90E+11	3.22E+15	9.28E+14	0.19	0.81	2.23
Malaysia	1.72E+24	4.66	0.24	5.23E+12	7.47E+16	2.96E+16	0.80	3.11	1.32
Mali	8.37E+22	1.11	0.84	6.86E+10	7.03E+15	3.27E+14	0.13	0.19	6.29
Mauritania	1.27E+23	16.33	0.42	1.24E+11	4.81E+16	2.51E+16	0.07	1.40	1.72
Mexico	9.15E+24	0.82	0.04	4.76E+12	9.24E+16	2.22E+16	3.14	21.43	1.05
Moldova	2.31E+22	0.79	0.11	6.92E+11	5.40E+15	1.20E+14	6.77	8.40	1.12
Mongolia	1.04E+23	9.37	0.67	6.65E+10	4.16E+16	1.12E+16	0.09	0.50	2.99
Morocco	3.68E+23	1.63	0.19	8.25E+11	1.27E+16	7.21E+15	0.78	4.21	1.24

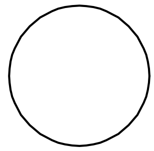
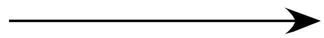
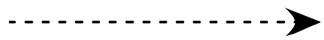
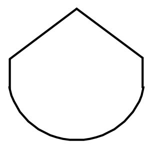
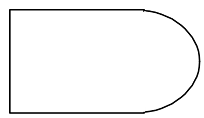
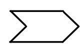
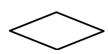
Table B-1: Continued.

Nation	Use	Exports/ Imports	R/U	Use/Area	Use/ Capita	NonRenew/ Capita	IR	ELR	EYR
Mozambique	4.35E+23	7.08	0.94	5.55E+11	2.44E+16	8.55E+14	0.03	0.07	16.32
Namibia	1.16E+23	2.56	0.47	1.40E+11	6.10E+16	2.05E+16	0.30	1.14	1.87
Nepal	2.17E+23	2.90	0.87	1.59E+12	9.23E+15	4.69E+14	0.08	0.15	7.86
Netherlands	2.17E+24	1.35	0.04	6.42E+13	1.37E+17	1.30E+16	11.19	22.72	1.04
New Zealand	6.18E+23	2.44	0.64	2.31E+12	1.63E+17	2.91E+16	0.26	0.57	2.75
Nicaragua	9.78E+22	1.05	0.59	8.13E+11	1.93E+16	4.06E+15	0.25	0.70	2.44
Niger	5.14E+22	2.58	0.84	4.06E+10	4.79E+15	2.67E+14	0.12	0.19	6.26
Nigeria	4.74E+23	5.75	0.41	5.20E+11	4.13E+15	5.20E+15	0.39	1.45	1.69
Norway	6.83E+23	3.90	0.33	2.22E+12	1.53E+17	2.01E+17	1.00	2.04	1.49
Oman	1.09E+23	6.87	0.31	5.14E+11	4.19E+16	8.89E+16	0.61	2.19	1.46
Pakistan	6.57E+23	0.90	0.17	8.43E+11	4.60E+15	2.46E+15	0.42	4.87	1.21
Panama	1.63E+23	0.62	0.61	2.14E+12	5.51E+16	9.52E+15	0.28	0.65	2.55
Papua New Guinea	5.71E+23	3.37	0.71	1.26E+12	1.07E+17	7.74E+15	0.31	0.40	3.51
Paraguay	1.07E+23	3.69	0.73	2.68E+11	1.95E+16	1.25E+15	0.26	0.37	3.71
Peru	1.48E+24	5.18	0.34	1.16E+12	5.71E+16	3.55E+16	0.06	1.92	1.52
Philippines	8.01E+23	2.11	0.19	2.69E+12	1.06E+16	3.42E+15	1.05	4.31	1.23
Poland	1.34E+24	1.32	0.03	4.39E+12	3.45E+16	2.07E+16	0.72	37.05	1.03
Portugal	9.42E+23	0.98	0.04	1.02E+13	9.41E+16	4.70E+16	0.85	23.02	1.04
Romania	3.85E+23	1.52	0.14	1.67E+12	1.71E+16	6.30E+15	0.99	6.22	1.16
Russia	7.40E+24	7.78	0.35	4.36E+11	5.09E+16	2.95E+16	0.10	1.85	1.54
Rwanda	1.42E+22	0.21	0.49	5.70E+11	1.84E+15	4.95E+14	0.31	1.03	1.97
Saudi Arabia	9.06E+23	8.63	0.09	4.62E+11	4.09E+16	8.70E+16	0.39	10.28	1.10
Senegal	8.47E+22	1.08	0.56	4.41E+11	9.01E+15	1.94E+15	0.35	0.79	2.26
Serbia & Montenegro	1.49E+23	1.12	0.15	1.46E+12	1.42E+16	7.19E+15	0.54	5.85	1.17
Sierra Leone	6.00E+22	0.22	0.58	8.37E+11	1.36E+16	1.05E+15	0.53	0.74	2.36
Slovakia	2.87E+23	1.90	0.03	5.88E+12	5.32E+16	1.71E+16	2.24	37.89	1.03
Slovenia	1.31E+23	1.19	0.06	6.52E+12	6.60E+16	5.21E+15	6.46	16.69	1.06
South Africa	2.06E+24	4.84	0.08	1.69E+12	4.67E+16	4.62E+16	0.16	11.54	1.09
South Korea	4.15E+24	1.32	0.24	4.23E+13	8.86E+16	1.67E+16	1.36	3.24	1.31
Spain	4.55E+24	1.08	0.02	9.11E+12	1.12E+17	6.66E+16	0.64	41.21	1.02

Table B-1: Continued.

Nation	Use	Exports/ Imports	R/U	Use/Area	Use/ Capita	NonRenew/ Capita	IR	ELR	EYR
Sudan	3.30E+23	3.80	0.78	1.39E+11	1.05E+16	2.70E+15	0.05	0.28	4.62
Suriname	1.24E+23	9.80	0.84	7.68E+11	2.92E+17	2.74E+16	0.08	0.19	6.15
Swaziland	1.44E+22	2.11	0.21	8.37E+11	1.38E+16	2.65E+14	3.36	3.73	1.27
Sweden	8.44E+23	1.39	0.05	2.05E+12	9.53E+16	3.16E+16	3.05	19.23	1.05
Switzerland	6.10E+23	0.75	0.03	1.53E+13	8.51E+16	4.24E+14	28.19	31.63	1.03
Syria	1.84E+23	4.06	0.06	9.97E+11	1.11E+16	1.26E+16	0.18	15.39	1.06
Tanzania	2.75E+23	1.69	0.80	3.10E+11	7.88E+15	1.07E+15	0.08	0.25	4.98
Thailand	1.81E+24	2.87	0.10	3.53E+12	2.97E+16	1.59E+16	0.63	8.58	1.12
The Gambia	1.12E+22	0.49	0.76	1.12E+12	8.54E+15	2.27E+14	0.27	0.31	4.19
Togo	4.67E+22	1.88	0.22	8.59E+11	1.02E+16	7.52E+15	0.27	3.49	1.29
Trinidad & Tobago	1.19E+23	3.15	0.03	2.32E+13	9.21E+16	6.16E+16	0.92	30.96	1.03
Tunisia	1.76E+23	1.27	0.04	1.13E+12	1.85E+16	9.08E+15	1.47	25.22	1.04
Turkey	1.48E+24	0.67	0.10	1.92E+12	2.16E+16	8.26E+15	1.11	9.13	1.11
Turkmenistan	1.03E+23	10.35	0.14	2.11E+11	2.22E+16	3.85E+16	0.20	5.94	1.17
Uganda	8.51E+22	0.79	0.69	4.26E+11	3.62E+15	6.87E+14	0.14	0.46	3.18
Ukraine	1.63E+24	4.27	0.07	2.70E+12	3.28E+16	2.52E+16	0.32	12.87	1.08
United Kingdom	5.45E+24	0.98	0.44	2.26E+13	9.25E+16	1.44E+16	0.95	1.29	1.78
United States	1.88E+25	0.41	0.12	2.05E+12	6.60E+16	1.99E+16	1.43	7.25	1.14
Uruguay	1.98E+23	1.40	0.39	1.14E+12	5.94E+16	2.54E+16	0.23	1.59	1.63
Venezuela	1.03E+24	9.03	0.38	1.17E+12	4.25E+16	4.15E+16	0.14	1.62	1.62
Vietnam	3.75E+23	2.34	0.68	1.15E+12	4.81E+15	1.58E+15	0.22	0.47	3.14
Yemen	8.32E+22	5.27	0.37	1.58E+11	4.62E+15	5.62E+15	0.38	1.73	1.58
Zambia	3.89E+23	10.96	0.52	5.25E+11	3.73E+16	1.70E+16	0.03	0.91	2.09
Zimbabwe	1.23E+24	8.66	0.05	3.19E+12	9.76E+16	8.93E+16	0.04	19.33	1.05

Symbols used in Figure 2-1 (Adapted from Odum, 1996):

1. System Frame
2. Source 
3. Pathway Line (material) 
4. Pathway Line (currency) 
5. Storage Tank 
6. Producer 
7. Interaction 
8. Transaction 

APPENDIX C
CORRELATION MATRICES

Table C-1 shows the correlation matrix between all emergy indices. Indices which are highlighted yellow were removed from individual index analyses. The R values of the correlations highlighted in red in Table C-1 were above the 0.80 cutoff, however the indices were kept in the analyses due to their individual importance in interpreting national level emergy synthesis results.

Object 1: Table C-1 Emergy indices complete correlation matrix Excel

Object 2: Table C-1 Emergy indices complete correlation matrix CSV

The following tables contain the complete versions of the correlation matrices presented in Chapter 3.

Object 3: Table C-2 Aggregate indices complete correlation matrix Excel

Object 4: Table C-2 Aggregate indices complete correlation matrix CSV

Object 5: Table C-3 HPI-1 and Gini Index complete correlation matrix Excel

Object 6: Table C-3 HPI-1 and Gini Index complete correlation matrix CSV

Object 7: Table C-4 Social indicators complete correlation matrix Excel

Object 8: Table C-4 Social indicators complete correlation matrix CSV

Object 9: Table C-5 Government and political indicators complete correlation matrix Excel

Object 10: Table C-5 Government and political indicators complete correlation matrix CSV

Object 11: Table C-6 Economic indicators complete correlation matrix Excel

Object 12: Table C-6 Economic indicators complete correlation matrix CSV

APPENDIX D
ANNUAL EMDEBT VALUES

Table D-1: EBEER based Emdebt for the five West African focal countries from 1970 to 2000.

Year	Burkina Faso	Mali	Mauritania	Niger	Senegal
1970	2.08E+07	2.38E+08	2.63E+07	3.17E+07	1.45E+08
1971	1.64E+07	2.37E+08	-3.21E+07	3.38E+07	1.30E+08
1972	1.54E+07	2.48E+08	-2.37E+08	3.96E+07	1.02E+08
1973	1.55E+07	2.21E+08	-4.37E+08	4.32E+07	7.11E+07
1974	1.80E+07	2.24E+08	-6.28E+08	5.87E+07	1.72E+07
1975	2.12E+07	2.30E+08	-1.29E+09	5.36E+07	-2.85E+07
1976	3.21E+07	2.36E+08	-2.50E+09	3.96E+07	-8.07E+07
1977	5.90E+07	2.44E+08	-3.34E+09	3.16E+07	-1.58E+08
1978	7.83E+07	2.44E+08	-3.94E+09	2.02E+07	-3.23E+08
1979	1.21E+08	2.65E+08	-5.46E+09	-1.82E+07	-5.82E+08
1980	1.39E+08	3.01E+08	-6.21E+09	-1.47E+08	-1.08E+09
1981	1.66E+08	3.38E+08	-7.40E+09	-3.46E+08	-1.42E+09
1982	1.89E+08	3.55E+08	-8.31E+09	-1.16E+09	-1.48E+09
1983	2.24E+08	3.85E+08	-9.39E+09	-1.71E+09	-1.51E+09
1984	2.04E+08	3.22E+08	-1.06E+10	-2.17E+09	-1.89E+09
1985	1.61E+08	7.91E+07	-1.28E+10	-2.72E+09	-2.31E+09
1986	1.46E+08	-1.85E+07	-1.51E+10	-3.17E+09	-2.72E+09
1987	1.56E+08	-1.74E+08	-1.79E+10	-3.66E+09	-3.39E+09
1988	1.31E+08	-4.83E+08	-2.14E+10	-4.22E+09	-4.24E+09
1989	1.14E+08	-6.96E+08	-2.43E+10	-4.75E+09	-5.13E+09
1990	9.66E+07	-9.29E+08	-2.88E+10	-5.11E+09	-5.90E+09
1991	9.60E+07	-1.08E+09	-3.17E+10	-5.68E+09	-6.98E+09
1992	1.34E+08	-1.36E+09	-3.44E+10	-6.04E+09	-7.43E+09
1993	1.34E+08	-1.94E+09	-3.99E+10	-6.63E+09	-7.79E+09
1994	-3.33E+07	-3.03E+09	-4.45E+10	-7.20E+09	-9.28E+09
1995	-1.96E+08	-3.83E+09	-4.95E+10	-7.65E+09	-1.09E+10
1996	-3.40E+08	-4.96E+09	-5.55E+10	-8.09E+09	-1.26E+10
1997	-5.42E+08	-5.65E+09	-6.10E+10	-8.56E+09	-1.39E+10
1998	-7.22E+08	-6.36E+09	-6.66E+10	-8.96E+09	-1.56E+10
1999	-9.29E+08	-7.39E+09	-7.19E+10	-9.22E+09	-1.69E+10
2000	-1.11E+09	-8.22E+09	-7.65E+10	-9.46E+09	-1.83E+10

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