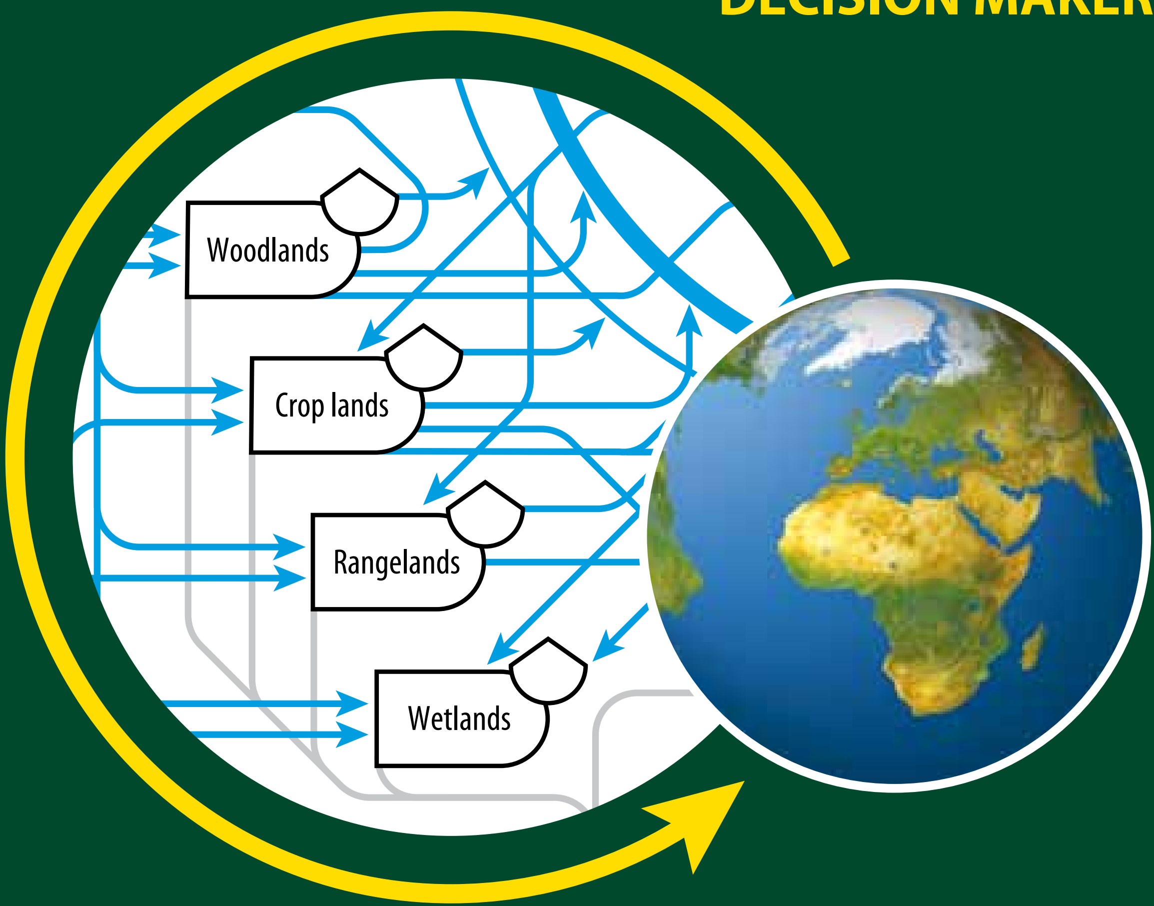
ENVIRONMENTAL ACCOUNTING

of National Economic Systems

An Analysis of West African Dryland Countries within a Global Context

SUMMARY FOR DECISION MAKERS



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Contents

Abbreviations and acronyms

EER	Emergy Exchange Ratio
EIR	Emergy Investment Ratio
ELR	Environmental Loading Ratio
EMR	Emergy Money Ratio
ESI	Emergy Sustainability Index
EYR	Emergy Yield Ratio
GDP	gross domestic product
HDI	United Nations Development Programme's Human Development Index
NEAD	National Environmental Accounting Database
PPP	Purchasing Power Parity
TSWI	Total System Well-being Index
UEV	Unit Emergy Value

$ refers to US dollar in this report

Main messages

The threat to sustainable development posed by natural resource degradation and loss of ecosystem services has been recognized for decades, but the fundamental principles of sustainable land and natural resource management are yet to be translated into globally effective policies and tools. Over-emphasis on financial capital optimization, often at the expense of natural and social capital, remains the norm.

Natural resources such as forests and topsoils may accrue over hundreds of years and are effectively non-renewable: they constitute a significant source of national wealth or capital, similar to the stocks of financial capital. However, there are strong incentives to over-exploit land resources because they are effectively free – the costs of their extraction (e.g., soil erosion) are borne by society, now or in the future, and not by individual land users. Levels of exploitation have reached a point where it is now critical to include natural capital and ecosystem services in national accounting.

A number of economic methods for valuation of ecological services have been proposed, and have matured considerably in the last decades. These methods seek to integrate the value of nature's work into decision-making by direct and indirect inference of people's willingness to pay for those services. In this study we take an alternative, biophysical approach to quantifying values of ecological services. Environmental accounting is a tool for holistic evaluation of systems of people and nature, based on our physical understanding of energy and material flow through systems. Accounting for basic physical flows and transformations of energy and materials used in economic processes permits direct linkage with macroeconomic value of flows, both where there is a market (that is, where money is a measure of value) and for flows for which no market exists (that is, where we have previously assumed that services are free).

This study provided detailed environmental accounting of 134 national economies, with a special focus on five dryland countries of the West Africa Sahel. Environmental accounting was used for four primary tasks in this work: 1) understanding the comparative resource basis of nations, 2) determining the value of global losses of natural capital, 3) quantifying links between a nation's resource basis and indicators of human welfare, and 4) examining implications of biophysical valuation on international trade and debt.

ENVIRONMENTAL ACCOUNTING

- The central premise of environmental accounting is that sunlight, the basic energy source for all global processes, is a useful common currency for all global processes; solar energy is embodied in all goods, whether environmental or economic. All processes rely on energy and are subject to energy laws. Flows in environmental accounting are reported as the quantity of solar energy that went into making them; we call this quantity solar emergy. Emergy is thus taken as a measure of "real" public wealth that complements market-based or use-value measures.
- An advantage of expressing different types of environmental and economic work in the same units is that the impact of alternative policy or intervention options can be evaluated in terms of trade-offs between economy and environment, and between the environmental flows themselves. This aids in the identification of policies and practices that sustain natural resources for long-term societal benefits.
- The environmental accounting steps used in this study were:
  1. Energy systems diagrams were drawn that depict all the major types of natural resources and environmental and economic flows at the national level.
  2. Data on each of the system components and annual flows in the diagram were acquired in standard units. A national environmental accounting database was compiled for 134 nations for the year 2000.
  3. Energy and material flows were converted into emergy units using standard conversion factors.
  4. Emergy stocks and flows were aggregated to provide various indices of environmental sustainability and also expressed in monetary terms.

GLOBAL RESOURCE USE

- Globally there is a need for substantial policy revision to address profoundly unsustainable human development. Humans are nearly 70% reliant on non-renewable resource flows derived from historical accumulations of energy (soils, fuels, minerals) that are now being rapidly depleted. The globe currently relies on emergy flows that are three times greater than the annual renewable supply. Efforts to live within the planet's means should be amongst the grand policy challenges of this century.
- Many developed nations derive less than 1% of their emergy use from renewable flows, operating instead primarily on imported emergy from outside the national system. The staggering degree to which this is unsustainable should be clear, and policy actions to reduce this dependence to the maximum extent possible are urgently needed. Some countries typically regarded as highly sustainable in fact have poor resource sustainability, largely because they rely heavily on non-renewable energy resources.
- Natural capital depletion (i.e., consumption in excess of replacement) was observed to represent an annual global cost of over $1.5 trillion in 2000. Soil erosion has the largest but hidden cost to society, at about $640 billion annually, twice that of each of the next most important losses, from deforestation, over-fishing and over-use of water resources.

RESOURCE USE IN SAHELIAN COUNTRIES

- The five focal West African country economies are strongly reliant on natural capital flows while simultaneously depleting their natural capital, rendering them extremely vulnerable to potential shocks. For instance, Mali, Mauritania and Niger obtain around 75% of their total emergy use from free environmental flows, while many western European nations derive less than 1% of their emergy use from these flows. The five West African nations rely on natural capital depletion for between 5–27% of their total emergy use.
- The major source of natural capital depletion is soil erosion, equivalent to $1.2 billion (in 2000 currency) across the five Sahelian focal nations, and equivalent to nearly 10% of the combined GDP of those nations. These fluxes are comparable in magnitude to the economic value of all national exports from the five nations.
- General trends in various emergy metrics for the five Sahelian nations between 1965–2000 indicate increasing total resource use and increasing reliance on non-renewable sources of emergy for the generation of economic product. The emergy use per capita has been systematically declining, both overall and in comparison with the global average.
- Increased emergy use, including greater use of fossil fuels and electricity generation, will be an essential component of the development of the Sahelian focal nations. Environmental pollution due to industrial development is currently of lower priority for the focal countries than natural resource management, but preventative measures are strongly recommended to ensure environmental loads stay low as these countries develop.
- Large and immediate investments in sustainable natural resource management are vital to the economic and environmental security of these countries. The main priority for investment is in improved soil management in all five focal countries, while in Senegal sustainable fisheries management is also of high priority.

TRADE AND INTERNATIONAL DEBT

- We analysed the balance of trade on a non-monetary, environmental work basis and examined structural sources of inequity embedded in the financial system, both between national trading partners and among commodities. Because prices generally are fundamentally distorted with respect to the environmental work required for the production of goods and services, their exchange has significant resource consequences, structurally disadvantaging one country over another. Among the most disadvantaged nations in this regard are those in sub-Saharan Africa; whereas the United States, Switzerland and Japan are among the main benefactors from this structural trade inequity. For example, when Niger trades with the global economy the resources necessary to generate revenue are 10-fold higher than the resources it receives in return.
- In addition, less developed countries tend to be resource exporters, while highly developed nations tend to be resource importers; this serves to widen the gap in resource endowment over time. A policy implication is that trade agreements should be made more consistent with the real wealth that traded commodities represent, and compensation to resource exporting countries made to more accurately reflect the value of exported goods.

- When we apply the concept of trade equity to international loans, we see that West African countries (and indeed most of the developing world) export large quantities of local environmental capital, either in the form of mined resources, agricultural commodities or other raw goods, in order to generate international currency to make their debt payments. For example, each unit of currency borrowed represents purchasing power in the global market; but to service that debt a country like Niger appropriates approximately 12 times the environmental resource for repayment. Loan interest serves only to exacerbate the problem.
- This inequity becomes clear when debt repayments are compared in emergy units. In emergy terms, the five targeted West Africa nations have repaid their loans, and have indeed become emergy creditors. This is most pronounced for Mauritania and Senegal, who officially owe $4.8 and $8.9 billion, respectively, but have overpaid by $77 and $18 billion respectively if the flows are examined in emergy units. Hence developed country economies are in effect extracting resources from poorer developing countries by receiving debt repayments at inequitable Emergy Money Ratios. Thus central to achieving goals of sustainability and equity is support for on-going policies that result in immediate and total debt relief for these five nations. The general framework for assessing inequity is expected to imply the same conclusion for all of sub-Saharan Africa.

POVERTY, RESOURCES AND HUMAN WELL BEING

- We propose that countries should gauge their development progress based not only on measures such as the human development index and economic performance but also in terms of the degree to which their total resource use is derived from renewable as opposed to non-renewable energy sources, and on environmental loads.
- We therefore developed a Total System Well-being Index that adjusts the widely used Human Development Index (which combines measures of life expectancy, literacy, educational attainment and GDP per capita) for the degree of reliance on locally renewable resources.
- The Sahelian nations are generally in the lower half of TSWI globally. Values have been declining over the period of record. This suggests that despite comparatively high levels of renewable resource use (all five nations fall in the upper 20% of nations globally), recent increases in the Human Development Index have been outpaced by the increasing dependence on non-renewable emergy. Moreover, the rate of decline appears to have increased over the last decade. On the other hand, some nations are able to provide a relatively high level of human well-being using a relatively low level of non-renewable resources or total resources per person. Further comparative analysis could provide valuable insights into sustainable policies.
- In summary, by tracking the environmental work necessary to generate ecological services, environmental accounting provides a common framework for analysis for evaluation of systems of people and nature, leading to valuable quantitative insights into sustainable resource use, trade and debt inequities, and human well-being.

APPLICATION OF ENVIRONMENTAL ACCOUNTING

- National environmental accounting tracking systems should be implemented, drawing on the massive improvements in whole-earth surveillance technologies that can help parameterize and refine the simple models used in this study. This kind of integrated thinking – economy, society, environment – when implemented on a project-by-project and policy-by-policy basis, and evaluated at the national scale via high quality standardized data, could be used effectively to judge development strategies and learn efficiently from successes and failures.

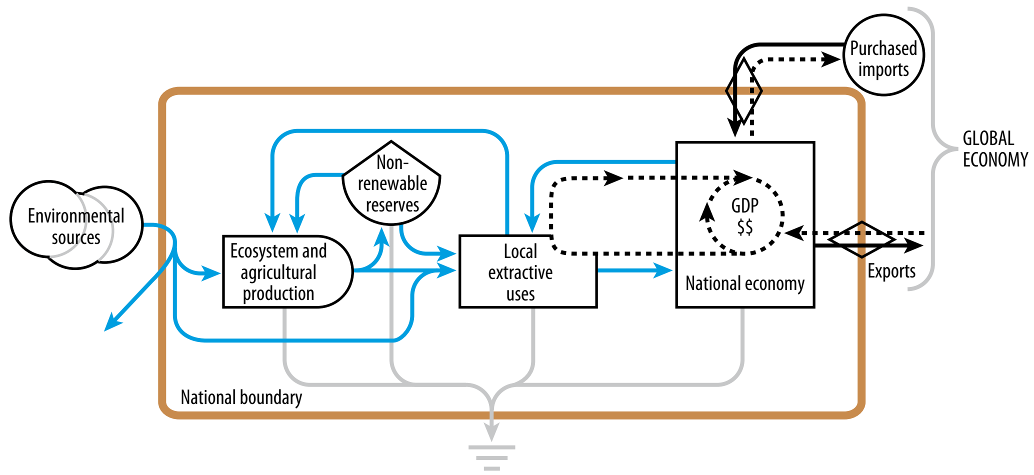
Natural resource depletion and development decision making

Over the last several decades, increasing human population, economic development and emergence of global markets have driven unprecedented land use and global change, resulting in immense pressure on natural resources; these pressures are projected to intensify further over the next several decades. Sahelian rural populations are especially dependent on land resources for their subsistence, including food, fibre, livestock fodder, and medicine, which also constitute their main source of income. Human well-being in drylands is therefore particularly vulnerable to desertification, which undermines the resource base that provides these services. However, this reliance goes far beyond the provisioning services that land provides, and includes services such as maintenance of biodiversity; regulation of hydrological and nutrient cycles, disease, and climate; and cultural services such as aesthetic value and ecotourism. Maintenance of stable agro-ecosystems in the Sahel is a key strategy for sustainability, and a prerequisite for maintaining adaptive capacity in the face of climate and global change.

Although the threat to sustainable development posed by natural resource degradation and loss of ecosystem services has been recognized for decades, the fundamental principles of sustainable

FIGURE 1

Systems schematic of the interface of environmental and economic systems showing flows of energy and materials (solid lines) and money (dashed lines).



land and natural resource management are yet to be translated into globally effective policies and tools. Over-emphasis on financial capital optimization, often at the expense of natural and social capital, remains the norm. It is essential for sustainable policy that the costs of environmental work be incorporated into decision making.

Currently, in economic systems money exchanged for resources is paid only for the human services embodied in obtaining those resources and the work of nature, or ecosystem services, are considered as free. However, as stocks and flows of environmental systems are now declining, it is paramount that their true value be incorporated into decision (Figure 1) making if further development is to be sustainable. Natural resources such as forests and topsoils may accrue over hundreds of years and are only slowly renewable: they constitute a significant source of national wealth or capital, similar to the stocks of financial capital. Land resource stocks are effectively non-renewable, and their depletion represents loss of national wealth: it is usually extremely expensive to pay for replacements. However, there are strong incentives to over-exploit land resources because they are effectively free – the costs of their extraction (e.g., soil erosion) are borne by society, now or in the future, and not by individual land users.

One of the primary challenges facing policy makers attempting to incorporate social or natural capital into their decision process is that these forms of wealth are neither traded nor priced. For natural capital in particular: what is the value of topsoil, virgin rain forest, river flows and clean water, coastal fisheries, or geologic work that concentrated and made useful metals and minerals? As evidence accrues that all these services are being lost, the grand challenge of including natural capital and ecosystem services in national accounting grows.

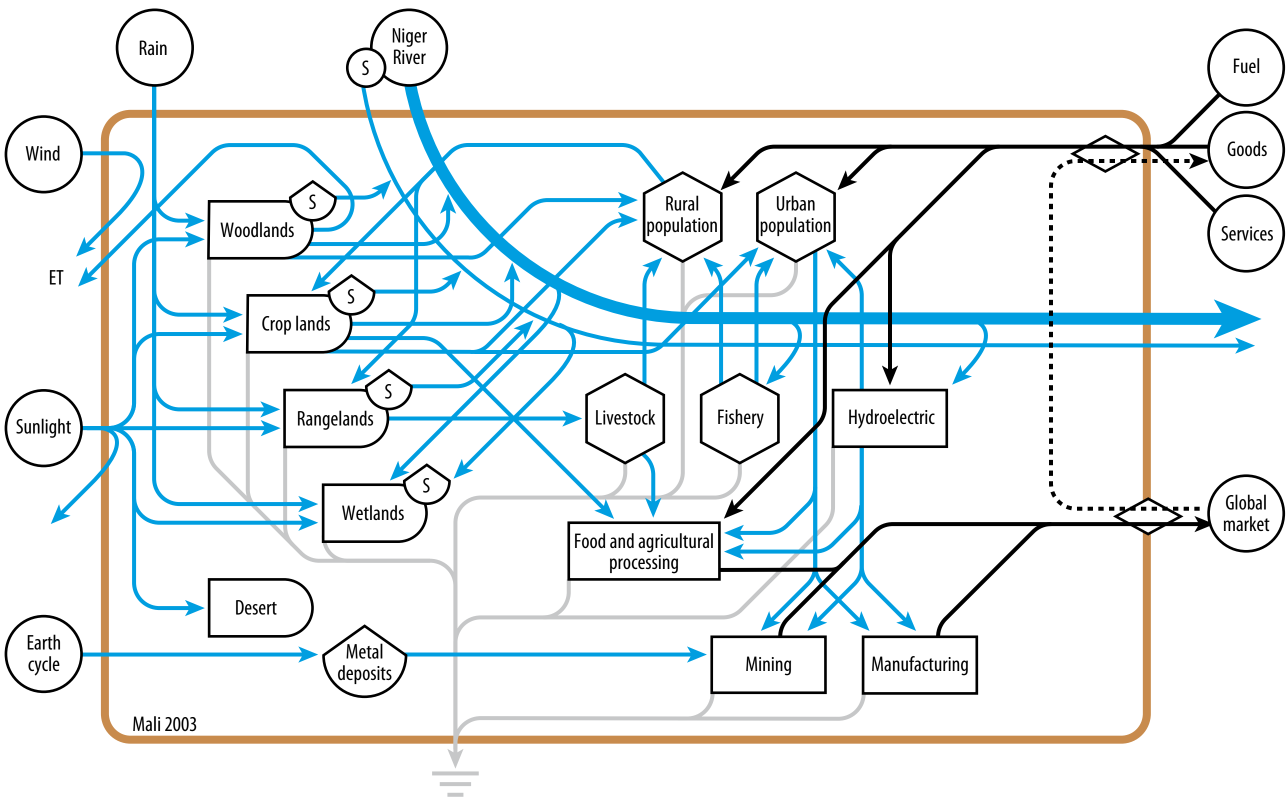
Environmental accounting

Environmental valuation is a relatively new field and rapidly developing. A number of economic methods for valuation of ecological services have been proposed, and have matured considerably in the last decades. These methods seek to integrate the value of nature's work into decision making by direct and indirect inference of people's willingness to pay for those services. Problems arise where services are diffuse or not obvious, or where multiple values overlap. Moreover, measures of people's perceived value of nature's work aren't based on the biophysical system that is being valued, leading to significant conceptual dissonance.

In this study we take an alternative, biophysical approach to quantifying values of ecological services. Specifically, we track the environmental work necessary to generate the services, reasoning that the more work embodied in ecosystem services, the greater the cost of losing that service. As such, environmental accounting is a tool for holistic evaluation of systems of people and nature; since environmental work is in both environmental and human systems, a common framework for analysis is made possible. The foundation of the method is our physical understanding of energy and material flow through systems. Accounting for basic physical flows

FIGURE 2

Detailed systems diagram of the nation of Mali (c. 2003) showing the primary sources of energy and materials, internal stocks, transformation sectors, exports and imports. The Niger River figures prominently in many aspects of national condition.



and transformations of energy and materials used in economic processes permits direct linkage with macroeconomic value of flows, both where there is a market (that is, where money is a measure of value) and for flows for which no market exists (that is, where we have previously assumed that services are free).

The central premise of environmental accounting is that sunlight, the basic energy source for all global processes, is a useful common currency for all global processes; solar energy is embodied in all goods whether environmental or economic. All processes rely on energy and are subject to energy laws. Flows

TABLE 1

Data compiled for each of the system components and annual flows in the systems diagrams in standard units (Joules, grams) and converted into solar emergy values using standard conversion factors (Unit Emergy Values – UEV).

						Year: 2000 Counby: Niger
	Line item	flow	units	UEV	UEV units	emergy, sej
RENEWABLE FLOWS:						
1	Sunlight	2.7E+21	J	1.0E+00	sei/J	2.7E+21
2	Deep heat	2.0E+18	J	5.8E+04	sei/J	1.2E+23
3	Tide	0.0E+00	J	7.4E+04	sei/J	0.0E+00
4	Wind	5.3E+18	J	2.5E+03	sei/J	1.3E+22
5	Total water	1.4E+18	J	varies	sei/J	4.3E+22
6	Waves	0.0E+00	J	5.1E+04	sei/J	0.0E+00
INTERNAL TRANSFORMATIONS (ECONOMIC):						
7	Agriculture production	4.5E+16	J	varies	sei/J	8.5E+21
8	Livestock production	2.0E+15	J	varies	sei/J	6.6E+21
9	Fisheries production	4.2E+13	J	8.40E+06	sei/J	3.5E+20
10	Fuelwood production	5.0E+16	J	varies	sei/J	1.8E+21
11	Industrial roundwood production	2.6E+15	J	varies	sei/J	2.4E+20
12	Water extraction	1.1E+16	J	2.4E+05	sei/J	2.6E+21
13	Hydroelectricity	0.0E+00	J	2.8E+05	sei/J	0.0E+00
14	Total electocity	1.1E+15	J	2.9E+05	sei/J	3.1E+20
INDIGENOUS NONRENEWABLE EXTRACTION:						
15	Forestry	4.5E+15	J	varies	sei/J	1.7E+20
16	Fisheries	0.0E+00	J	8.4E+06	sei/J	0.0E+00
17	Water	0.0E+00	J	2.8E+05	sei/J	0.0E+00
18	Topsoil losses, organic matter	2.6E+17	J	varies	sei/J	1.3E+21
19	Coal	4.3E+15	J	6.6E+04	sei/J	2.8E+20
20	Natural Gas	0.0E+00	J	6.8E+04	sei/J	0.0E+00
21	Oil	0.0E+00	J	9.4E+04	sei/J	0.0E+00
22	Minerals	6.4E+10	g	varies	sei/g	5.9E+20
23	Metals	2.9E+09	g	varies	sei/g	5.0E+20
IMPORTS:						
24	Fuels	4.1E+15	J	varies	sei/J	1.4E+21
25	Metals	2.2E+10	g	varies	sei/g	5.0E+20

in environmental accounting are reported as the quantity of solar energy required to make them; we call this quantity solar emergy.

Environmental accounting using emergy involves four basic steps:

1. For any system of interest (in this work we focus on national systems) energy systems diagrams are drawn that depict all the major types of natural resources (e.g., forests, wetlands, croplands), and economic activities (e.g., agricultural processing, manufacturing, mining). The diagrams depict flows that connect system components, both within the system and across the system boundary (Figure 2). These include both environmental flows (e.g., rivers, solar energy, precipitation, forest harvesting) and economic flows (e.g., purchases of fuel, goods and services, and sale of natural resource products and manufactured goods).
2. Acquire data on each of the system components and annual flows in the diagram in standard units (Joules, grams) (Table 1).
3. Convert energy and material flows into emergy using conversion factors called Unit Emergy Values (UEV) to quantify the solar emergy, the basic accounting unit. This accommodates the fundamental recognition that different types of energy are not of equivalent quality, and indeed require different amounts of solar energy for their creation (Table 1).

FIGURE 3

Generic national diagram with flows of renewable resources (R), non-renewable sources from within the country (N), imports of fuels (F), goods (G) and services (I), exports of goods (B) and services (E), and GDP (X). Flows on each line are for Mali (c. 2000).

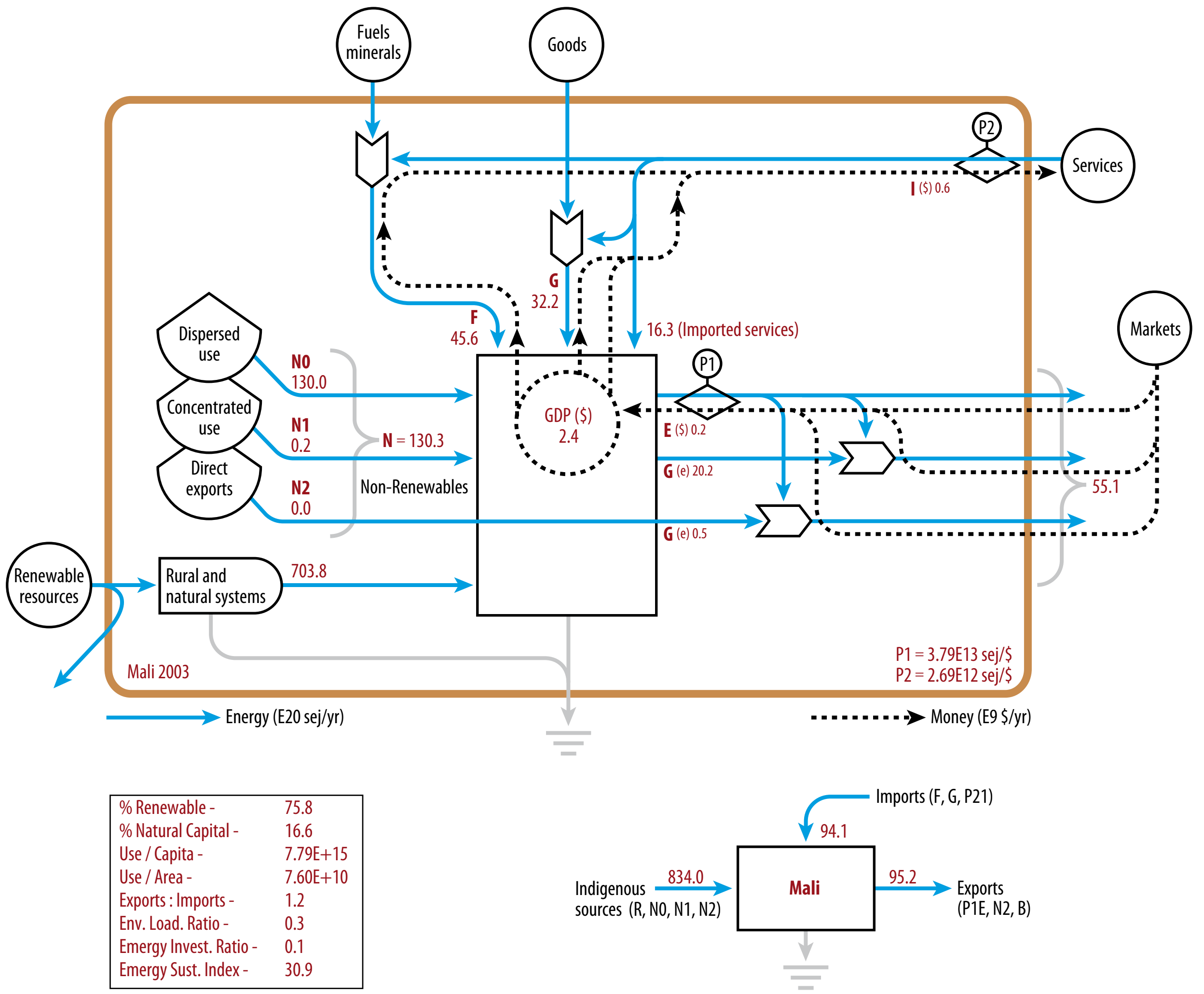


TABLE 2

Summary flows and indices for national environmental accounting. Summary flows are linked directly to Figure 3.

Code	Summary flows	Description
R	Renewable sources	Largest renewable flow to avoid double-counting
N	Nonrenewable resources from within	Sum of indigenous nonrenewable extraction items
N0	Dispersed nonrenewable	Sum of forestry, fishery, soil and water extraction
N1	Concentrated nonrenewable used	Sum of fuel, metal and mineral production minus N2
N2	Portion of N1 exported without use	Sum of raw fuel, metal, mineral export
F_i	Imported fuels and minerals	Sum of fuels, metals, minerals imported
G_i	Imported goods	Sum of remaining imported materials & electricity
I	Dollars paid for imports	Service in Imports, $ value
P2I	Emergy of services in imports	Service in Imports($) * World emergy to dollar ratio(sej/$)
F_e	Exported fuels and minerals	Sum of fuels, metals, minerals exported
G_e	Exported goods	Sum of remaining exported materials & electricity
E	Dollars received for exports	Service in Exports, $ value
P1E	Emergy value of goods and service exports	Sum of all items in Export section
X	Gross domestic product	Use UN statistical data
P2	World emergy/$ ratio, used in imports	Total Global Emergy Use / Gross World Product
P1	Country emergy/$ ratio	National Emergy Use / Gross Domestic Product
Code	Indices	Computation
IMP	Imported emergy	F+G+P2I
U	Total emergy used, U	N0+N1+R+F+G+P2I
EXP	Total exported emergy	P1E+N2
%Indig.	Fraction emergy use from indigenous source	(NO+N1+R) / U
EXP:IMP	Export to Imports	(N2+P1E) / (F+G+P2I)
%R	Fraction used, locally renewable	R/U
%Free	Fraction of use that is free	(R+N0)/U
Conc:Disp	Ratio of concentrated to dispersed	(F+G+P2I+N1) / (R+N0)
U/A	Emergy Use per area	U / area
R/A	Renewable emergy use per area	U / area
U/#	Use per person	U / population
CC	Renewable carrying capacity	(R/U) * population
%Elec	Ratio of electricity to use	(el)/U
Fuel/Cap	Fuel use per person	fuel/population
EIR	Investment ratio, imports/indigenous use	(F+G+P2I) / (R+N0+N1)
ELR	Environmental loading ratio, (NR use)/R	[(F+G+P2I)+N0+N1] / R
EYR	Yield ratio, total use / imports	U / (F+G+P2I)
ESI	ESI, Emergy Sustainability Index	EYR / ELR
%Soil	Soil loss/use	Soil loss / U

4. Synthesize the disparate flows of emergy into and among the system components (Figure 3) and compute various indices of environmental sustainability (Table 2). This synthesis, where all flows are in common units, permits unique insight into the resource basis of the system and patterns of human-environment interactions. Emergy flows can ultimately be expressed in monetary terms via a simple imputation process to aid in expression of resource values.

An advantage of expressing different types of environmental and economic work in the same units is that the impact of alternative policy or intervention options can be evaluated in terms of trade-offs between economy and environment, and between the environmental flows themselves. A fundamental philosophical feature of the approach is that it is based on "donor value", derived from summing the resources investments made in each step required to make a product, rather than "perceived value", which is the utility of a product as perceived by what people think it is worth. Emergy, which is defined as the amount of energy that went into creating something, is thus taken as a measure of "real" public wealth that complements market-based or use-value measures. By explicit accounting of resource values, emergy analysis aids in the identification of policies and practices that sustain natural resources for long-term benefits. As such, environmental accounting can be viewed as an ecosystems approach that is complementary to economic valuation.

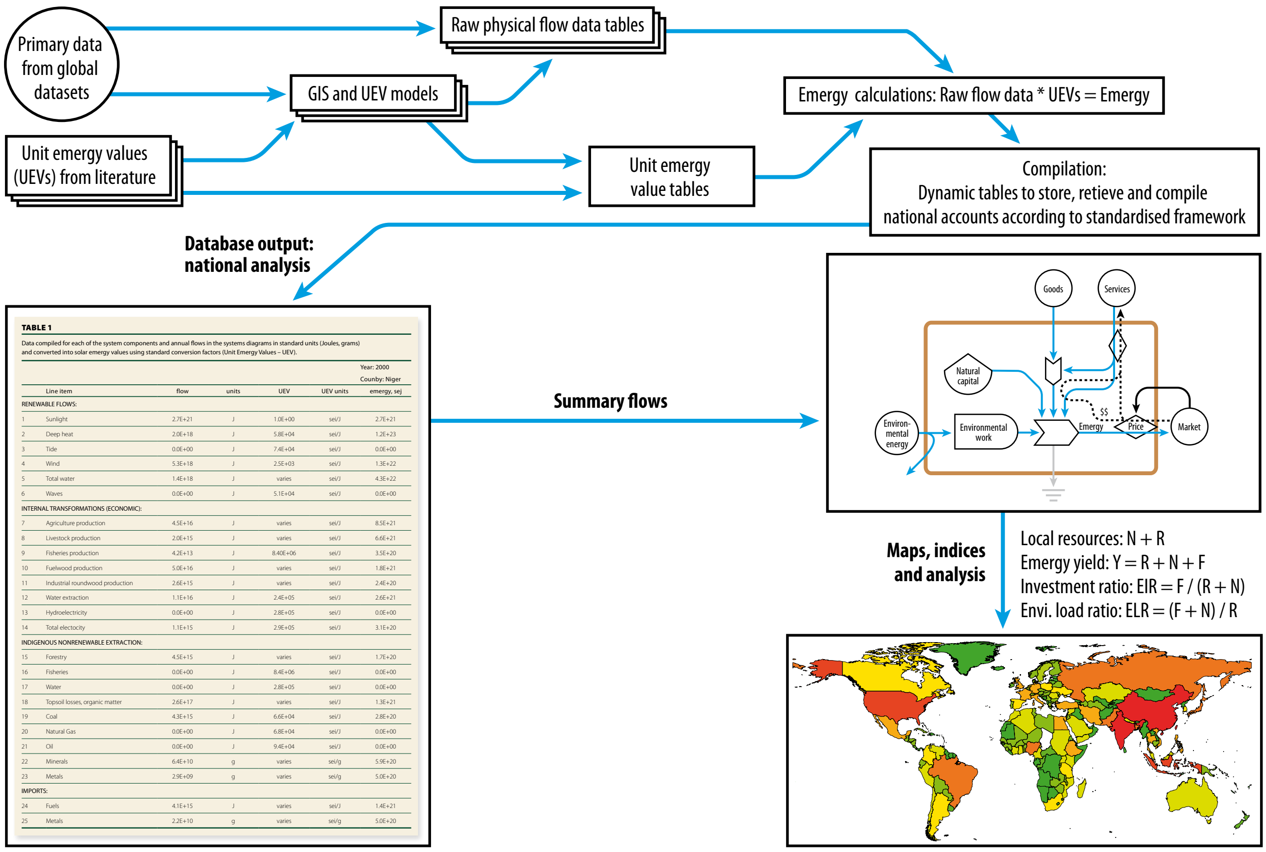
This study provided detailed environmental accounting of 134 national economies, with a special focus on the dryland countries of West Africa. Environmental accounting is used for four primary tasks in this work: 1) understanding the comparative resource basis of nations, 2) determining the value of global losses of natural capital, 3) quantifying links between a nation's resource basis and indicators of human welfare, and 4) examining implications of biophysical valuation on international trade and debt.

National environmental accounting database

For the first time, global energy, material, and money flows, aggregated by national political boundaries, were compiled within a database producing standardized, automated emergy syntheses for 134 nations for the year 2000 (Figure 4). The National Environmental Accounting Database (NEAD) compiles data from a variety of national level databases with global coverage, such as the Food and Agriculture Organization (agricultural sector production, natural resource use) and the United Nations Statistics Division (trade data). Primary raw unit data are linked to energy content values and emergy conversion factors from the literature. Emergy calculations are organized according to existing national templates; summary flows and indices are output. In this study the database is used to examine various attributes of human-environment interactions at the national and global scales.

FIGURE 4

Schematic of the global emergy database.



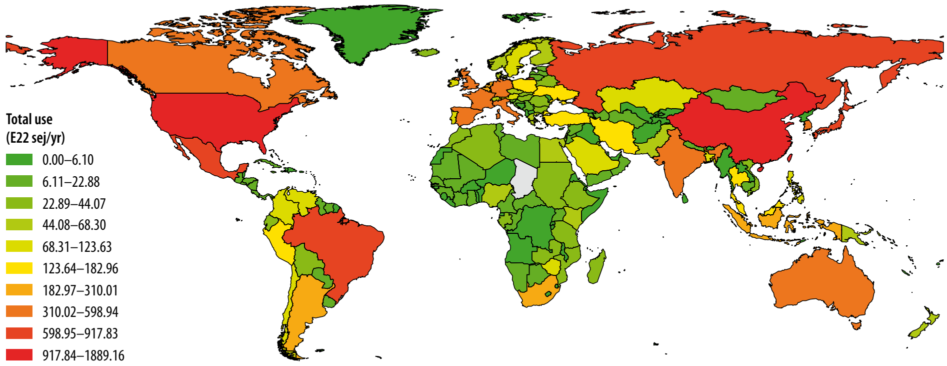
Renewable and non-renewable resource use

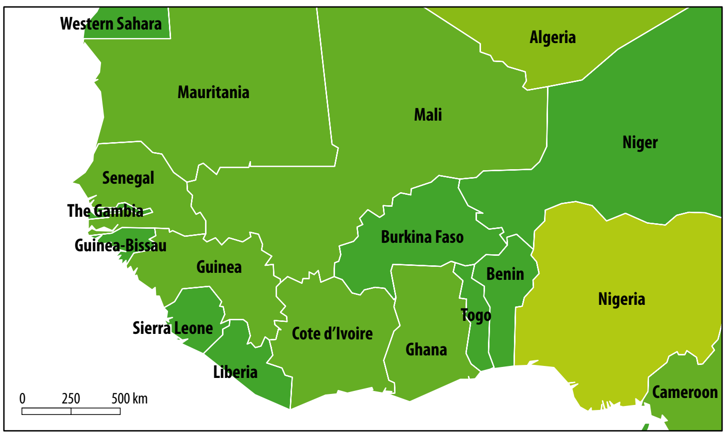
Among the key insights of environmental accounting is an understanding of the resource basis of human systems, and an estimation of the degree to which contemporary resource use exceeds renewable supply. Globally, in terms of total emergy use, we estimate that humans are nearly 70% reliant on non-renewable resource flows derived from historical accumulations of energy (soils, fuels, minerals) that are now being rapidly depleted. This serves as a quantitative reminder of the unsustainable nature of our development.

Total emergy use globally is estimated to be 48 x 10^{24} sej per year (sej is solar emergy joules); 15 x 10^{24} is derived from renewable flows, the remainder from non-renewable stocks. However, emergy use per nation is far from evenly distributed; Sahelian nations, specifically Niger, Mali, Mauritania, Senegal and Burkina Faso, use much less emergy than most nations, ranking from 107 to 117 of the 134 nations analyzed (Figure 5). Highest ranking in terms of total emergy use is the United States of America, with approximately 12.6% of total global use. Expressing total emergy use per unit area of each country places Niger, Mauritania and Mali among the four lowest ranking emergy users in the world. Small, highly industrialized nations, such as Japan, South Korea, and Western European nations, operate with intense spatial concentration of emergy flows, 100 or more times higher than the Sahelian nations.

FIGURE 5

Global total emergy use (U). Values and global ranks (out of 134 nations) contain five focal Sahelian countries and 9 other nations of varying size, location, and development status.

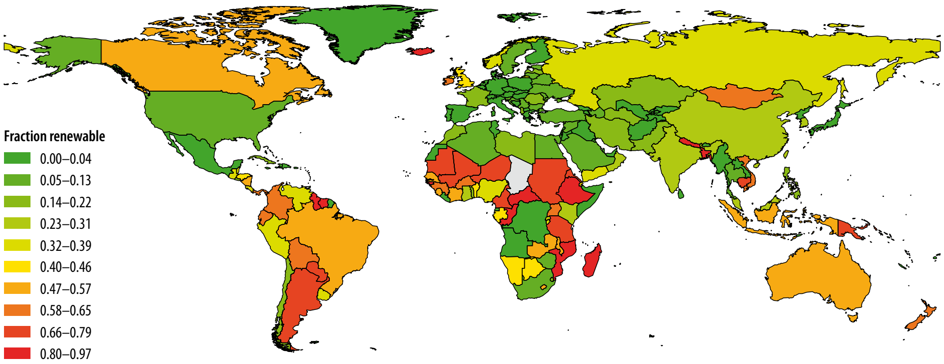


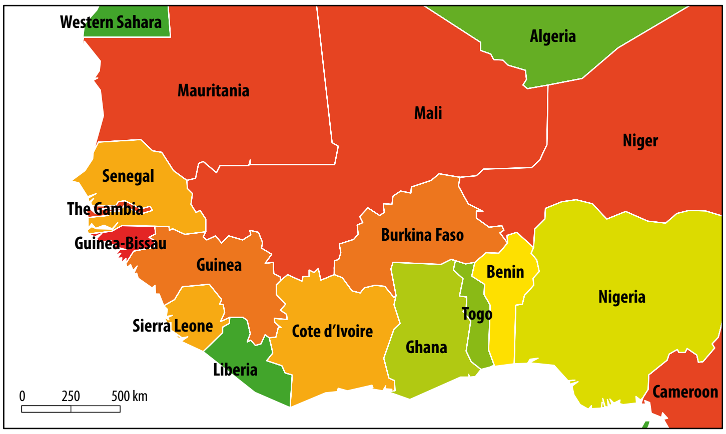


Country	Total use E22 sej/yr	Global rank
United States	1889.2	1
China	1285.6	2
Brazil	917.8	6
France	742.3	15
Indonesia	710.8	16
Saudi Arabia	707.7	35
Sweden	598.9	37
Kenya	545.1	47
Nicaragua	533.4	101
Mali	**525.3**	**107**
Senegal	**482.8**	**110**
Mauritania	**455.3**	**113**
Niger	**415.2**	**118**
Burkina Faso	**414**	**119**

FIGURE 6

Global map of indigenous renewable fraction of use (%R), with West Africa inset. The table of values and global ranks (out of 134 nations) contains the five focal Sahelian countries and nine other comparison nations of varying size, location, and level of development.

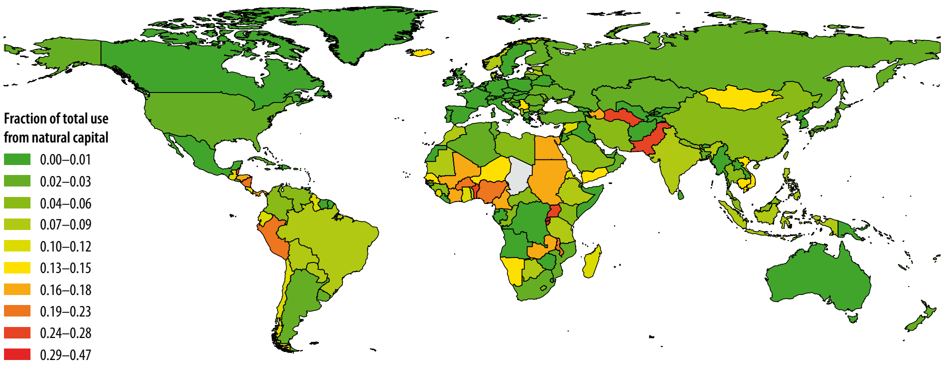


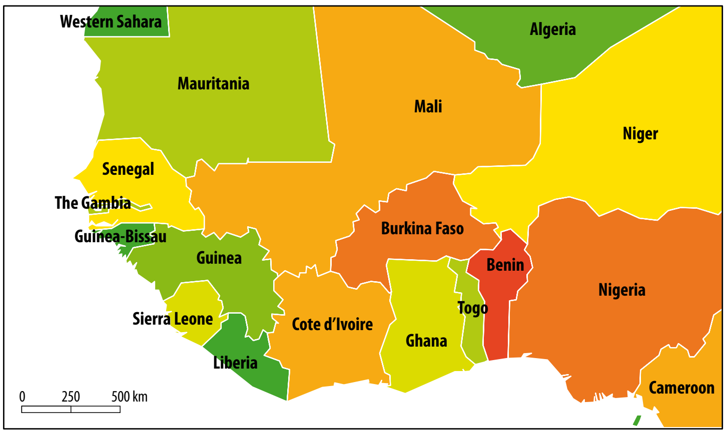


Country	Fraction of use locally renewable	Global rank
Mauritania	0.79	12
Mali	0.76	16
Niger	0.74	18
Burkina Faso	0.63	26
Indonesia	0.57	35
Nicaragua	0.56	37
Senegal	0.55	38
Brazil	0.5	43
China	0.26	69
Kenya	**0.26**	**69**
France	**0.16**	**84**
United States	**0.12**	**90**
Saudi Arabia	**0.09**	**97**
Sweden	**0.05**	**107**

FIGURE 7

Global map of natural capital depletion as a fraction of use (%N0), with West Africa inset. The table of values and global ranks (out of 134 nations) contains the five focal Sahelian countries and nine other comparison nations of varying size, location, and level of development.





Country	Fraction of use locally renewable	Global rank
Burkina Faso	**0.20**	**9**
Nicaragua	0.20	10
Niger	**0.14**	**21**
Mali	**0.14**	**22**
Senegal	**0.08**	**36**
Brazil	0.07	45
Mauritania	**0.07**	**46**
Indonesia	0.07	47
Saudi Arabia	0.03	71
Kenya	0.03	77
China	0.02	92
Sweden	0.01	104
United States	0.01	107
France	0.00	126

Total emergy use per capita provides considerable insight into the general well-being of populations. A high emergy-per-person ratio generally translates into a high standard of living; interestingly, though emergy per capita is correlated with GDP per capita, the emergy metric accounts for more than just monetary income, specifically the unpaid, direct wealth to people from the environment. As might be expected, West African countries fall below the global average levels, indicating a lower average well-being in general terms relative to other countries. What might not be expected is that metrics of human welfare, though generally correlated with resource use, tend to increase initially and then stabilize, suggesting that some level of resource reduction would not adversely affect measures of human welfare. Moreover, identifying nations particularly adept at creating human opportunity with constrained resource use become models for sustainable development. Nations that accomplish this appear to be Switzerland, France, Norway and Iceland.

Perhaps the most fundamental metric of long-term sustainability is the fraction of total use that is from renewable sources, as opposed to non-renewable sources (Figure 6). Globally, this value is ~30%, but strongly uneven across nations. Dryland countries rely significantly upon indigenous renewable flows. For instance, Mali, Mauritania and Niger obtain around 75% of their total emergy use from free environmental flows, while many western European nations derive less than 1% of their emergy use from these flows, operating instead principally on imported non-renewable emergy from outside the system.

Non-renewable resources can further be divided into concentrated non-renewable use (fuels, metals, minerals) and diffuse non-renewable use (extraction of water, forest, fish, and losses of soil organic matter at rates faster than they can be replenished). The West African nations rely on natural capital depletion for between 5–27% of total emergy use (Figure 7); potential shocks due to simultaneous depletion of natural capital, while relying on natural capital flows for system sustenance, represent a major policy challenge. Interestingly, nations that are strongly reliant on local depletion of natural capital tend to be classified as less developed. That the most developed nations obtain a small fraction (and also a relatively small magnitude) of their resources from non-renewable depletion of natural capital suggests both that they are better positioned to regulate depletion rates, and, perhaps more important, that they can export resource depletion to other parts of the world.

Electric power is a critical reagent in information and industrial societies; the flexibility, portability and generality of electricity as a flow of energy is the principal resource underlying technology and information. As such, the fraction of national resource use that occurs in the form of electricity is an excellent indicator of development status, and a useful benchmark for development trends over time. Electricity use as a fraction of total use highlights areas with relatively low development, such as Sub-Saharan Africa (~1%) versus places like Japan, USA and France, where that figure exceeds 15%. Trends are upwards for West African nations, but the pace of increase is slow. It has also been widely recognized that the use of fossil energy has been a catalyst for global and regional development. Fuel use as a fraction of total emergy use is lowest in sub-Saharan Africa (1–2%) and highest in Kuwait and Saudi Arabia (60% of total use).

Environmental load

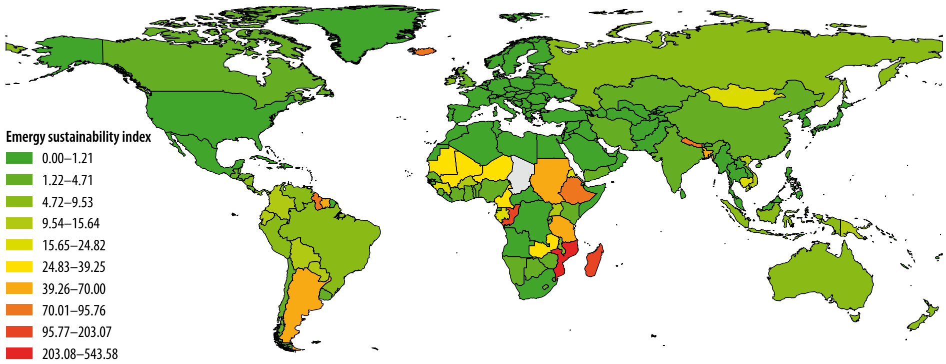
The ratio of non-renewable (both local and imported) to renewable use, called the Environmental Loading Ratio (ELR), reflects pressure put upon local environmental systems to absorb impacts and process waste flows associated with resource use intensification, and is a measure of potential pollution pressure. Using this index, most of sub-Saharan Africa has comparatively low pollution pressure (ELR < 1), with the exception of Botswana, South Africa and Kenya. In contrast, the ELR for Germany, Israel, and Belgium approaches or exceeds 100:1.

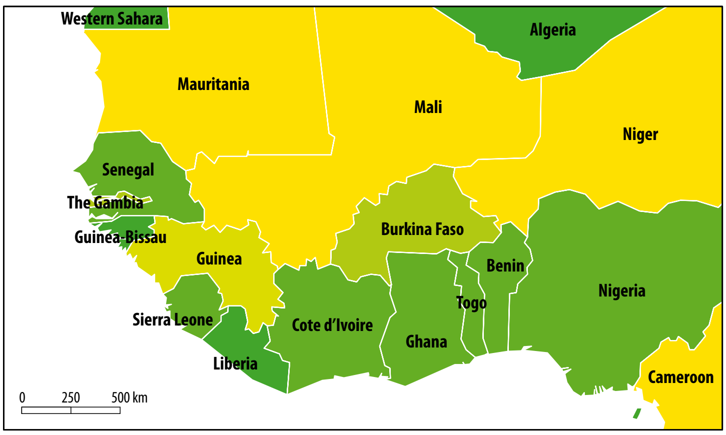
A second aggregate index, the Emergy Investment Ratio (EIR), quantifies the degree to which a national economy is dependent on external investment for its resource base. It is a ratio of imported to indigenous sources, whether renewable or non-renewable. This metric measures the degree of participation in globalization and degree to which locally available resources are sought after by the global system. It is notable that in sub-Saharan Africa, only Nigeria, Benin, Cote D'Ivoire and Lesotho have values comparable with the global average (~1.6). Nations with high values, which are those most strongly dependent on the global economy for resource acquisition, include Japan, Sweden, Switzerland, Netherlands and Italy, with values as high as 10. The Sahelian nations have values around 0.1.

The Emergy Sustainability Index (ESI) is a measure of sustainability in terms of the goal of minimizing environmental load while encouraging development. That is, a nation may be considered sustainable only if it can simultaneously facilitate development and reduce environmental degradation. Countries typically regarded as highly sustainable (e.g., Sweden) have very low Emergy Sustainability Index

FIGURE 8

Global map of the Emergy Sustainability Index (ESI).





Country	Sustainability index ESI = EYR/ELR	Global rank
Mauritania	**31.22**	**17**
Niger	**31.04**	**18**
Mali	**30.92**	**19**
Burkina Faso	**10.02**	**33**
Brazil	9.53	34
Indonesia	8.64	36
Nicaragua	6.69	41
Senegal	**4.71**	**45**
Kenya	4.28	46
China	1.42	67
Saudi Arabia	0.35	92
France	0.23	98
United States	0.23	99
Sweden	0.07	111

values, indicating poor resource sustainability, largely because they rely heavily on non-renewable energy resources (Figure 8). Mali, Mauritania, Niger and Cameroon, by contrast, have relatively high values, primarily due to their comparative dependence on renewable use fractions. As non-renewable resources decline in importance (due to depletion or protection), economies with larger portions of their resource basis supported by indigenous resources, particularly renewable resources, are less likely to exhibit serious shocks and dislocations of populations. While sub-Saharan Africa is not typically considered sustainable from the perspective of global human welfare, the globe's current reliance on emergy flows three times greater than the annual renewable supply is profoundly unsustainable.

Emergy and money

Among the most important aspects of analysis of systems using environmental accounting is that the method does not depend on money flows. Money pays for human service *only*, and, as such, is not adequate for inference of ecological value where nature's work is provided free to human systems. However, while there is significant utility in trying to reduce the influence of money in determining the value of natural systems, it is imperative that the two methods of valuation be fundamentally compatible and at least partly interchangeable.

Figure 9 shows the relationship between energy and materials (solid lines – "real wealth") and money (dashed lines). The transaction is defined by the price, depicted as a diamond regulating both flows; the price is a function of market forces of demand and supply. Money flows only to services, either directly or indirectly for the services of embedded in goods. The work for production, which couples natural capital, environmental work and the purchased inputs, is not reflected in the price. As a result, goods for which free ecosystem services represent a high proportion of the work necessary for production are undervalued by price; the degree of undervaluation decreases with the number of economic transformations.

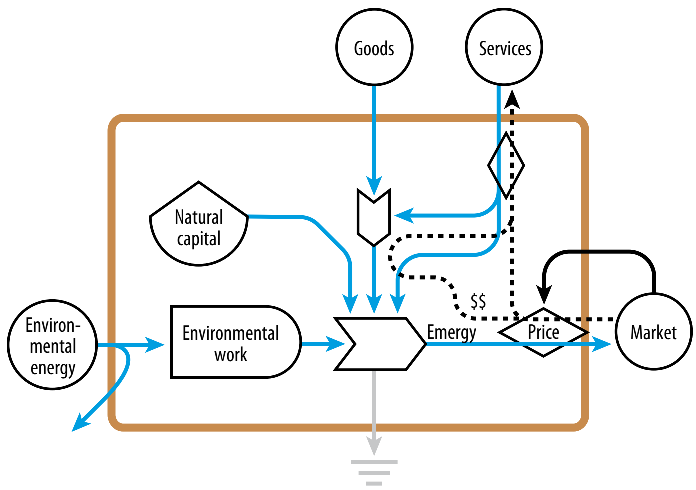
It follows that market exchange of resources will tend to overuse resources that require little labour to acquire. Moreover, the relationship between money and environmental resource is not fixed; the emergy in raw resources (e.g., minerals, agricultural commodities), that is those with less human value added, tends to require relatively little money, whereas processed goods require more money for the same quantity of emergy. This observation yields important insights about both the flow of money and social equity.

Similar issues arise when nations trade resources; nations exchange money for flows of goods and services on the global market. Because prices generally are fundamentally distorted with respect to the environmental work required for the production of goods and services, this exchange may have significant resource consequences, structurally disadvantaging one country over another. One outcome of thinking about trade in units of environmental work is the ability to consider the balance of trade on a non-monetary basis, and examine structural sources of inequity embedded in the financial system, both between national trading partners and among commodities.

Key to doing this is the computation of the Emergy Money Ratio (EMR), which relates the environmental resource basis of a nation to its economic productivity as measured by gross domestic product. In other words, the EMR describes the unit price (in US dollars) of emergy or "real wealth". It permits comparison of environmental and economic work in equivalent monetary units, facilitating improved interpretation, since emergy units are unfamiliar. We generally observe that more industrialized countries tend to have lower Emergy Money Ratios, signifying a low price associated with environmental work, whereas West African countries have considerably higher Emergy Money Ratios than the global average (Figure 10). The global average EMR is 2.6×10^{12} sej/$;

FIGURE 9

The relationship between biophysical work embodied in production and the money paid for a product. Money flows (dashed lines) pay only for human services; products that are relatively highly dependent on nature's work are, therefore, undervalued.



only Japan and the US are lower, while the Sahelian nations have values between 10 and 30 times higher.

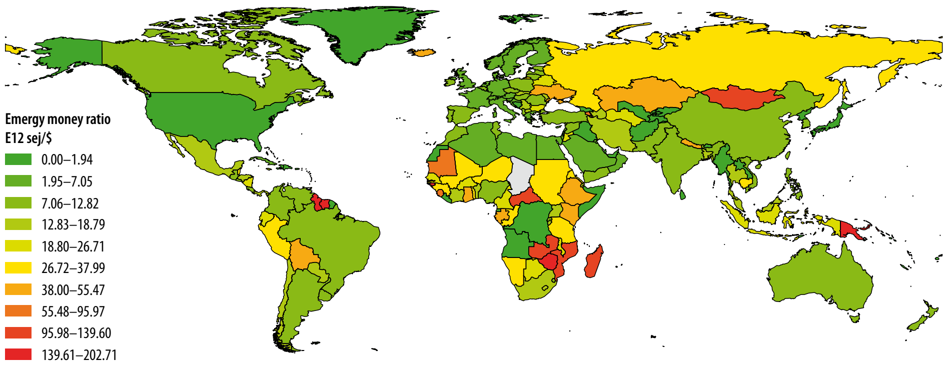
The EMR values are informative by themselves, but offer additional insight into the environmental resource equity of international transactions. We compute a metric of inequity called the Emergy Exchange Ratio (EER), which compares the resource purchasing power of a standard unit of currency between two nations. The EER is essentially the ratio of EMR values for trading nations; values different from 1 indicate structural disadvantages when the two nations engage in financially balanced trade. Among the most disadvantaged nations in this regard are those in sub-Saharan Africa; whereas the United States, Switzerland and Japan are among the main benefactors from this structural trade inequity. As an example, our analysis shows that Niger is structurally disadvantaged when trading with the global economy because the resources necessary to generate revenue are 10-fold higher than the resources it receives in return. That is, in order to generate an equivalent monetary value, Niger appropriates a greater amount of environmental work.

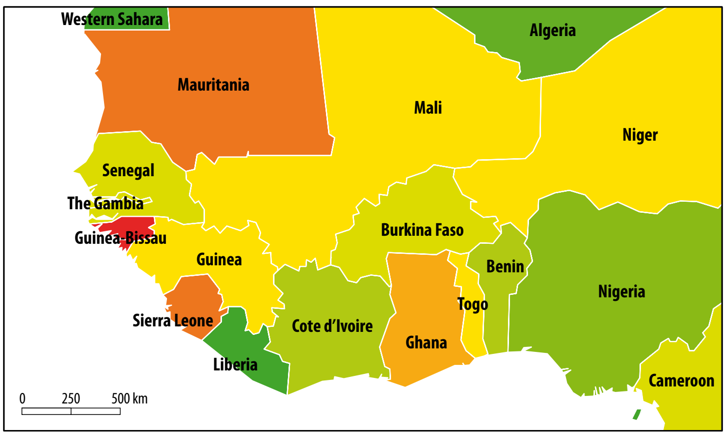
The structural conditions that lead to inequity in trade (when trade is made based on monetary balance) are frequently assessed in economics using a measure called Purchasing Power Parity (PPP). We found a strong positive relationship between Purchasing Power Parity and Emergy Exchange Ratio, suggesting that variability in PPP is at least in partly due the comparative resource basis of money among nations.

Despite the benefits that international trade confers, less developed countries tend to be resource exporters, while highly developed nations tend to be resource importers; this serves to widen the gap in resource endowment over time. One policy implication is that trade agreements could be made more consistent with the real wealth that traded commodities represent, and compensation to resource exporting countries made to more accurately reflect the value of exported goods.

FIGURE 10

Global map of the Emergy Money Ratio (EMR = Total Emergy Use/GDP)





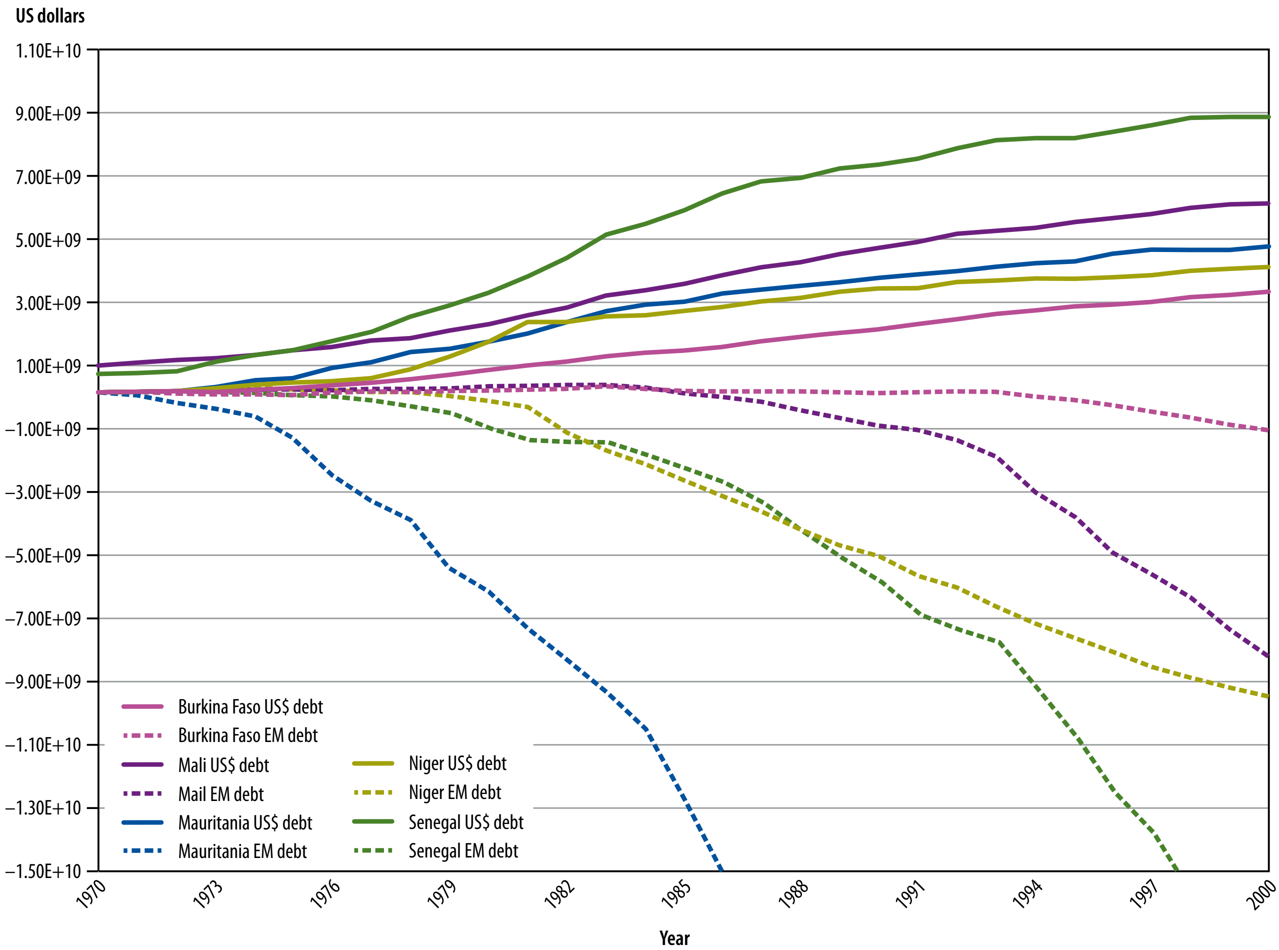
Country	Emergy money ratio USE/GDP, E12 sej/$	Global rank
Mauritania	**75.06**	**12**
Kenya	47.50	17
Mali	**37.99**	**23**
Niger	**32.45**	**29**
Nicaragua	26.18	37
Burkina Faso	**22.53**	**41**
Indonesia	20.64	46
Senegal	**19.69**	**47**
China	11.90	77
Brazil	11.76	79
Saudi Arabia	4.83	117
Sweden	3.54	127
France	2.92	129
United States	1.94	133

International debt

We apply the concept of trade equity to international loans. In order to generate international currency to make their debt payments, West African countries (and indeed most of the developing world) export large quantities of local environmental capital, either in the form of mined resources, agricultural commodities or otherwise raw goods. For example, each unit of currency borrowed represents purchasing power in the global market, but to service that debt Niger appropriates approximately 12 times the environmental resource for repayment. Loan interest serves only to exacerbate the problem. When loans and debt service are put in units of environmental work, the need for debt relief becomes clear. When debt repayments are compared in emergy units, all five of the targeted West Africa nations have repaid their loans, and have indeed become emergy creditors (Figure 11). This is most pronounced for Mauritania and Senegal, who officially owe $4.8 and $8.9 billion, respectively, but have overpaid by $77 and $18 billion respectively if the flows are examined in emergy units. This conclusion supports recent debt relief efforts for these nations. The general framework for assessing inequity is expected to imply the same conclusion for all of sub-Saharan Africa.

FIGURE 11

Official debt (in US$) and emergy debt (also in US$ adjusted by EMR).



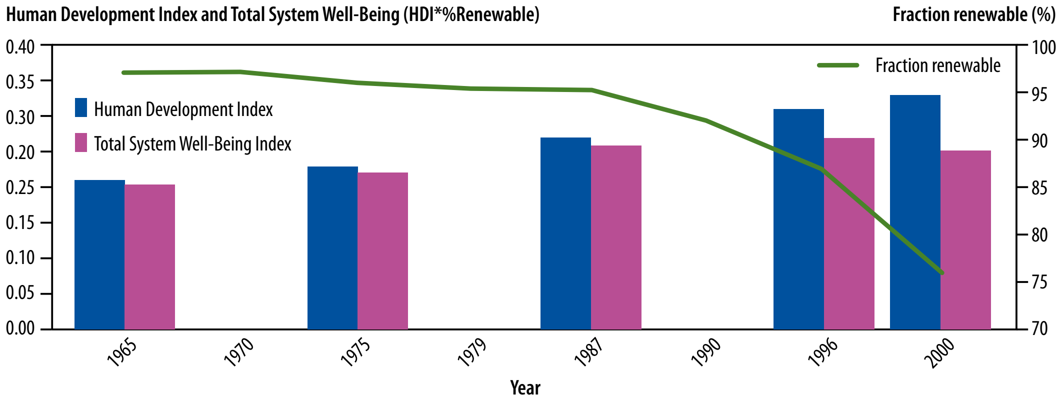
Time trends in poverty, resources and human well-being

We examined trends in various emergy metrics over time for the five Sahelian nations between 1965–2000. In general, trends indicate increasing total resource use and increasing reliance on non-renewable sources of emergy for the generation of economic product. However, paralleling trends globally, the emergy use per capita has been systematically declining, both overall and in comparison with the global average.

One of the more interesting trends that we observed was in a metric that tracks the total well-being of the national economic system (Figure 12). This ratio, which we quantify as the product of the fraction of renewable emergy multiplied by the UN's Human Development Index (HDI), both of which vary between 0 and 1, requires attention to both social and environmental considerations in the definition of well-being. The HDI combines measures of life expectancy, literacy, educational attainment and GDP per capita. The Total System Well-being Index (TSWI) developed here adjusts HDI for the degree of reliance on locally renewable resources, so that a high value indicates more sustainable development. TSWI provides a measure of efficiency of resource use. Nations which have a high TSWI score (which include Iceland, Argentina, Suriname, Guyana and Ireland) are generating human welfare predicated on more renewable resource basis. The Sahelian nations are generally in the lower half of TSWI globally and values have been declining over the period of record. This suggests that increases in the HDI have been outpaced by the increasing dependence on non-renewable emergy. Moreover, the rate of decline appears to have increased over the last decade. Comparable data are not available for all 134 nations, but we propose that an analysis of trends for that larger sample size could be exceedingly useful for sustainability benchmarking.

FIGURE 12

Time series of the UN's Human Development Index (HDI), fraction of total use from renewable sources (% R) and their product (referred to as the Total System Well-beingIndex) for Mali between 1962–2000.



Valuing the global depletion of natural capital

One of the principal insights of national-scale environmental accounting is the role of ecosystem stores and services in the generation of wealth. Amongst the key policy challenges of the 21st century is protecting natural capital stores so that future generations can benefit from the services they provide. Soil erosion, deforestation, over-fishing and over-use of water resources are well-documented resource-management challenges; placing these flows in emergy units (Figure 13) and contrasting these flows with other sectors of the economy can aid in providing some scale to the magnitude of the resource loss (Figure 14). Declining natural capital was observed to represent an annual cost of over $1.5 trillion in 2000. Soil erosion was the largest cost (~$640 billion annually), but all four declining stocks represent significant stocks.

In addition to quantifying the global losses and the losses accruing in each nation, we quantify the fraction of total resource use from natural capital. We observe several interesting trends; notably, natural capital use in nations at the high and low end of the sustainability spectrum (measured using ESI) is small

FIGURE 13

National emergy flows of natural capital in E20 sej/yr for A) soil loss, B), water overuse, C) overfishing and D) deforestation.

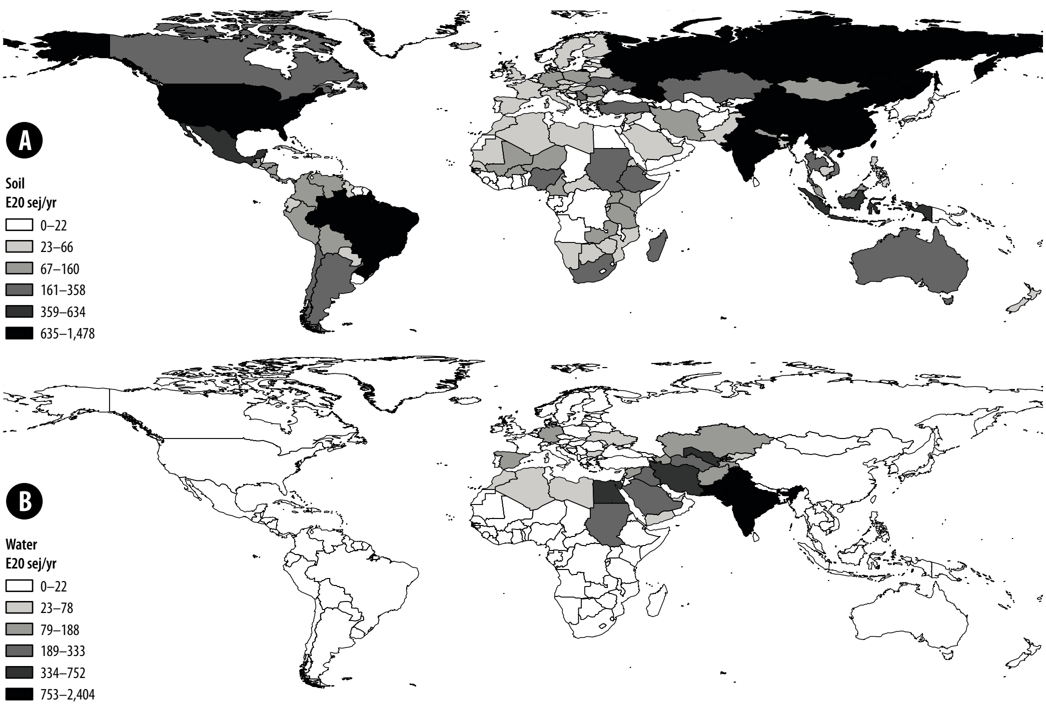


FIGURE 13 *continued*

National emergy flows of natural capital in E20 sej/yr for A) soil loss, B), water overuse, C) overfishing and D) deforestation.

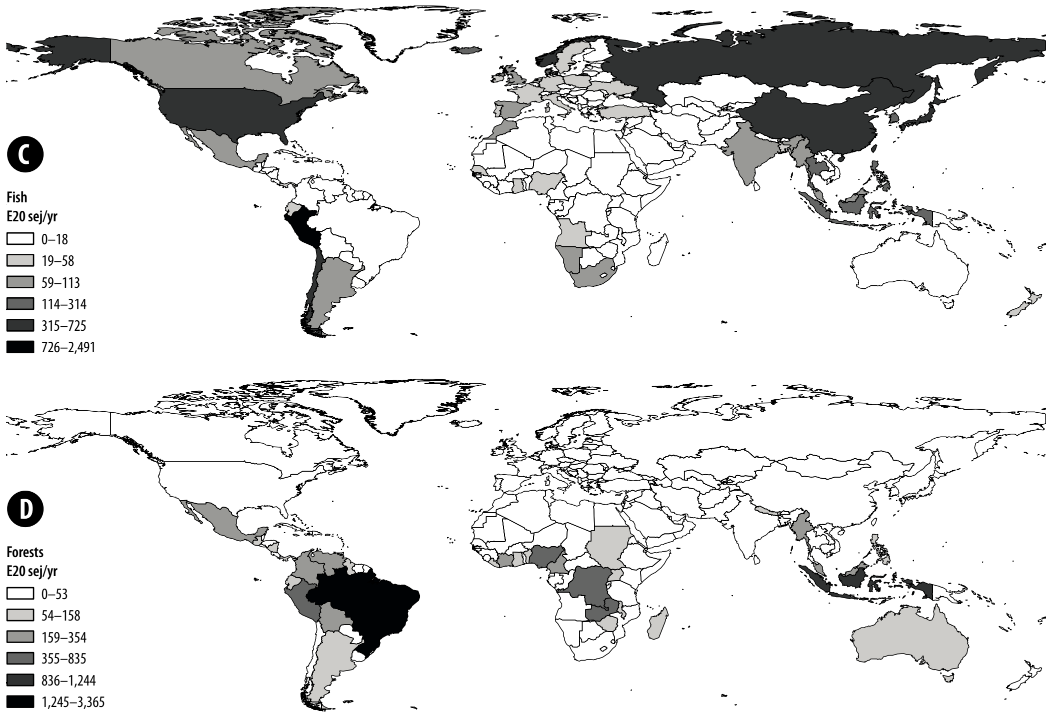


FIGURE 14

Summary of global costs of depletion for each natural capital stock examined. Cost estimates (imputed from global ratio of emergy and money flows) are in billions of US$ in 2000.

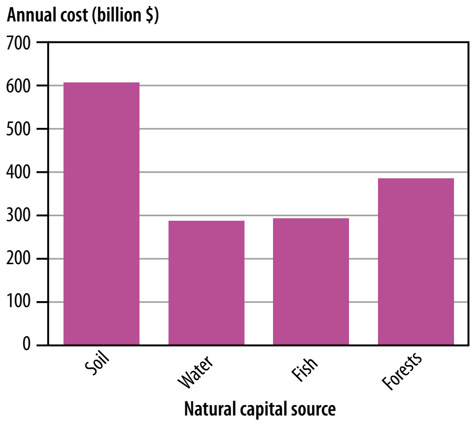
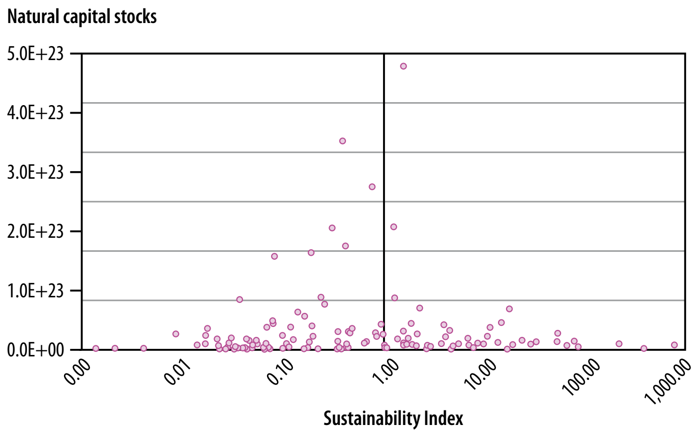


FIGURE 15

National-scale natural capital depletion as a) % of total use and b) total emergy flow vs. the Emergy Sustainability Index (ESI).



compared to total use, while the fraction is largest for nations at intermediate sustainability (Figure 15). This suggests that wealthiest nations (typically those lowest on the sustainability spectrum) protect their natural capital, perhaps by exporting environmental load, while the most sustainable nations haven't yet abused these resources. We also observe a strong inverse correlation between GDP and natural capital use.

Policy recommendations

The five focal West African countries are extremely vulnerable to potential shocks, due to the fact that their economies are strongly reliant on natural capital flows while simultaneously depleting their natural capital. Large and immediate investments in sustainable natural resource management are vital to the economic and environmental security of these countries. The main priority for investment is in improved soil management in all five countries, while in Senegal sustainable fisheries management is also of high priority. One key implication of our analysis of natural capital depletion costs is that soil erosion figures prominently in each nation as a hidden, but significant annual cost to society. We estimate, for example, that soil erosion is equivalent to $1.2 billion (in 2000 currency) across the five nations (led by erosion in Burkina Faso), a hidden cost equivalent to nearly 10% of the combined GDP of those nations. These fluxes are comparable in magnitude to the economic value of national exports from the five nations, underscoring both the severity of the problem, and the utility of the emergy approach in being able to place these disparate flows in common units for comparison.

Central to achieving goals of sustainability and equity is support for recent policies that result in immediate and total debt relief, since when exports of natural resources are accounted for, all five focal nations have not only repaid their debts but have become emergy creditors to developed nations. Equally important is the need for vigorous restructuring of trade agreements to address the gross disadvantage that West African nations face when trading with developed countries. West African nations export up to 10 times more resources than they receive when trading with developed nations. Trade agreements must be made more consistent with the real wealth that traded commodities represent, and ensure that compensation to resource exporting countries accurately reflect the value of the exported goods. Maximizing the processing of natural resources in country will also contribute to redressing the trade emergy imbalance.

Increased emergy use, including greater use of fossil fuels and electricity generation, will be an essential component of the development of the focal nations. Environmental pollution due to industrial development is currently of lower priority for the focal countries than natural resource management, but preventative measures are strongly recommended to ensure environmental loads stay low as these countries develop.

Further policy studies are warranted to establish why the focal countries have lower values of human development index than would be predicted based on their resource use, and to investigate how some countries manage to generate a relatively high level of human well-being using a relatively low level of non-renewable resources or total resources per person. Indeed, using our Total System Well-beingIndex, which combines social welfare and environmental sustainability, could provide a policy benchmark. Nations with high values provide model systems for development without compromising environmental sustainability, and nations with upward trends are model systems for policy initiatives and development priorities.

For the rest of the world there is much policy revision to be achieved. The globe's current reliance on emergy flows that are three times greater than the annual renewable supply is profoundly unsustainable, and efforts to live within the planet's means should be amongst the grand policy challenges of this century. Many developed nations, in particular, derive less than 1% of their emergy use from renewable flows, operating instead primarily on imported emergy from outside the system. These imported resources are often obtained from less developed countries under inequitable trade conditions in terms of emergy exchange, in effect exporting resource depletion to other parts of the world. Developed country economies are also in effect extracting resources from poorer developing countries by receiving debt repayments at inequitable Emergy Money Ratios. In many developed countries Environmental Loading Ratios are also high, detracting from sustainable development.

Countries should gauge their development progress based not only on measures such as the human development index and economic performance, but also in terms of the degree to which their total resource use is derived from renewable as opposed to non-renewable energy sources, and on environmental loads. This work has provided a framework and database system with which to monitor these additional indicators to provide a more holistic evaluation of total system well-being and sustainability. National environmental accounting tracking systems should continue to leverage the massive improvements in whole-earth surveillance technologies that can help parameterize and refine the simple models used in this study. This kind of integrated thinking – economy, society, environment – when implemented on a project-by-project and policy-by-policy basis, and evaluated at the national scale via high quality standardized data, could be used effectively to judge development strategies and learn efficiently from successes and failures.

Over the past several decades, increasing human population, economic development, and emergence of global markets, have resulted in immense pressures on land resources, and these pressures are expected to intensify further over the next few decades. It is essential for sustainable policy that the costs of degradation of ecosystem services associated with development be incorporated into decision making and are not considered to be free. There is a growing need to include natural capital and ecosystem services in national accounting.

This report presents an environmental accounting framework based on a biophysical approach to quantifying values of ecosystem services. The foundation of the method (emergy analysis) is our understanding of energy and material flow through systems. Accounting for basic physical flows of energy and materials transformed in both environmental and economic processes permits a direct linkage with monetary valuation of environmental services and natural capital.

Detailed environmental accounting of 134 national economies is presented, with a strong emphasis on the dryland countries of West Africa, where the rural poor are especially dependent on land resources. Environmental accounting is used for: (i) understanding the comparative resource basis of nations, (ii) determining the value of global losses of natural capital, (iii) quantifying links between a nation's resource basis and indicators of human welfare, and (iv) examining implications of biophysical valuation on international trade and debt.

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