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Creation of a Global Emergy Database for Standardized National Emergy Synthesis

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ABSTRACT

Emergy evaluations at the national scale provide unique insight into the resource basis of economic organization. The existing framework for emergy analysis at the national scale is well-defined, with tables for quantifying and aggregating system inputs and computing indices to summarize condition (Odum, 1996). However, the processes of gathering raw data necessary for tabular synthesis, and applying consistent energy conversions and unit emergy values for translating physical flows to emergy units, have not been standardized. In addition, inconsistencies among data sources at the national level can confound comparative analysis between nations. We have developed a global emergy database containing the primary data, energy conversion ratios and unit emergy values needed to calculate national system flows for the year 2000 for 134 nations. Look-up tables of primary data were created from various international datasets, including GIS grid coverages for renewable flows. Look-up tables of energy conversion ratios and unit emergy values were developed from the literature and recent models estimating crustal element specific emergies and global soil transformities. The database incorporates a standardized template within which primary flows are calculated and aggregated into the emergy summary flows and indices. This template is dynamic, meaning updates to the raw data or transformities automatically propagate through to the final indices. The internal production, non-renewable extraction, and trade flows are analyzed in greater detail than with previous national analyses, and methods were developed for estimating the nonrenewable fraction of fisheries, forestry, soil erosion and water extraction. Formalizing data sources, line item detail, energy conversion calculations, and assignment of transformities to flows will strengthen the power and credibility of comparative national emergy analysis.

INTRODUCTION

Energy is the basis of ecological and economic systems alike and, therefore, provides a common numerator with which to assess the relative, and often hidden, contributions of nature's life support functions to human economic activity (Odum, 1971). However, energy flows driving system organization possess vastly different qualities, making direct comparison of physical units inappropriate. During the past several decades, *emergy* analysis has been refined to offer a systems-level evaluation tool that provides insight into the coupling of natural and socio-economic systems in common units that allow meaningful comparison. This approach to studying systems of interacting ecological and economic elements has been applied at many different scales in many parts of the globe to assist environmental decision-making and discern the real basis for wealth. A few representative studies among many, are Odum et al. (1987), Doherty et al. (1993), Ulgiati et al. (1994), Brown and

Ulgiati (1999), Odum et al. (2000) and Tilley and Swank (2003). At the national scale, emergy analysis provides unique insight into the resource basis of economic organization. The environment-economy interface for each country can be compared using indices of resource use and intensity, energy-based trade balances, and production sustainability (Brown, 2003; Brown et al., 2003; and Ko and Hall, 2003).

For reliable comparative analysis, it is essential to develop standardized methods. The framework for emergy analysis at the national scale is well defined, with tables for quantifying and aggregating system inputs and computing indices to summarize condition (Odum, 1996). However, the processes of gathering raw data necessary for tabular synthesis, selecting the level of line item detail (i.e. aggregation), and applying consistent transformity values for conversion of physical flows to emergy units have not been standardized. This paper summarizes the development of a standardized database compiling earth's material, energy, and money flows, aggregated at the national scale for the year 2000. The database, hereafter called the National Environmental Accounting Database (NEAD), provides an automated system that stores and supplies the necessary data, processes the data using standardized conversions, and computes the standard tables of line items, summary flows and indices. This tool will be immensely helpful for creating emergy accounts of individual nations, as well as providing fast, efficient and standardized sets of accounts for comparative purposes.

METHODS

General Database Structure

The organization of the NEAD is illustrated in Figure 1. Within Excel spreadsheets, primary raw unit data are compiled by country codes and linked to tables of energy content values and unit emergy values (UEVs) from the literature. All UEVs are set relative to the 15.83 E24 sej/year baseline (Odum, 2000). Emergy calculations are executed and organized according to the standard template format, with results loaded into forms which display the main emergy table, main table notes, and the summary flows and indices table. Worksheet files within the database are dynamically linked, allowing for rapid updating if changing source data, UEVs, or calculations.

Primary Data Acquisition

National emergy synthesis requires a wide variety of data from a multitude of sources. Compiling data for a single country can be time consuming, and conflicting data are frequently observed for the same flows. Data sources typically include atlases, statistical abstracts, international trade databases, nationally produced accounts, scientific literature, anecdotal information, and estimations where data are unavailable. For the NEAD, datasets were chosen based on the following criteria: global in coverage with values for most countries, availability of documentation and literature references, and publication/dissemination by a recognized organization. In addition, spatial coverages were chosen for renewable flows to allow for calculations within a GIS environment and future analysis at sub-national scales. Appendix A contains a list of the data sources and online locations for each of the primary data inputs.

Renewable Flow Coverages

Continuous data raster coverages of historical annual averages were utilized for solar radiation, rainfall, evapotranspiration, rain runoff geopotential, heat flow, and wind emergy determinations. Using ArcGIS software, cell values from the datasets noted in Appendix A were aggregated by national political boundaries with the zonal statistics tool. In order to approximate the chemical and geopotential of river inflows and outflows, a worksheet was constructed that tabulated elevation and discharge for 591 river gauge stations located near national borders. Unfortunately, in some cases, discharges that may be significant are not included due to the lack of station data in some areas. Updates will be possible if more gauge data become available.

Regarding tidal energy, only one data source was found with readily available tidal amplitude estimates and global coverage. Unfortunately, these estimates are fairly broad ranges of tidal heights, so the midpoint of the tidal amplitude range is currently used as the amplitude. The wave dataset noted in Appendix A is not currently used in the renewable calculations, as the values are maximum wave height, rather than the required average wave height. Again, the database will be updated upon discovery of more appropriate data sources.

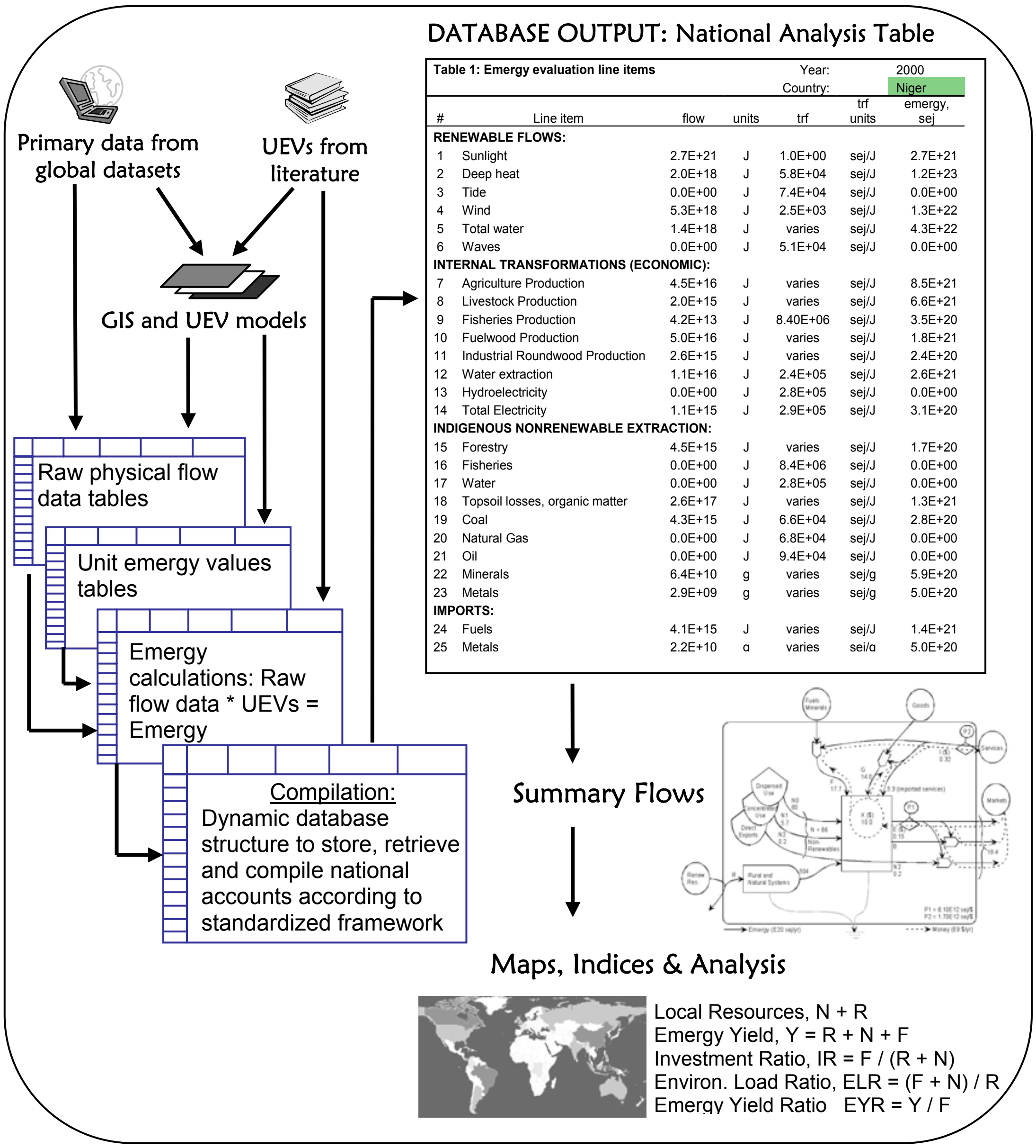

Table 1: Emergy evaluation line items Year: 2000 Country: Niger

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

Figure 1. *Schematic of the global emergy database.*

Unit Emergy Value Compilation

Unit emergy values (UEVs) are the crucial link between the energy, mass, or dollar value of a flow, and the prior emergy it took to produce and convey the flow to its present location. In the absence of a comprehensive set of location specific UEVs for every product and process in the globe, it is essential to use a standardized set of UEVs in order to perform a reliable comparative analysis of nations. With a few exceptions (soil and metals), previously computed UEVs were compiled from the emergy literature, with a heavy reliance on a transformity list compiled by Buranakarn (1997, unpublished data compilation).

Renewable flows were assigned UEVs from Odum et al. (2000). Agriculture, forestry and fishery internal production flows were assigned UEVs based on FAO commodity codes for 223 items, with UEVs compiled from numerous publications and documented within the database. Soil organic matter UEVs vary spatially over the global landscape and were calculated within a GIS model (Cohen et al., 2007a). Fuel production UEVs were compiled from various sources, documented within the NEAD. Metal UEVs originate from a model constructed by Cohen et al. (2007b) for 51 crustal elements. Mineral UEVs were compiled from Odum (1996) and Odum et al. (2000) for the 31 mineral items reported by the British Geological Survey. Trade commodities were assigned UEVs based on SITC1 classification at the four digit level (622 commodities). This standardized set of UEVs is organized into lookup tables which are dynamically linked to the main template, allowing for automatic updates if UEVs are refined or calculated for additional flows.

National Account Line Items

The line item format used for the NEAD is very similar to recent national accounts in the emergy literature, represented by an example template developed by Stachetti et al. (2003) which can be viewed at the following URL: http://www.emergysystems.org/tables.php. Some modifications were made and the current configuration of the line item table can be seen in Appendix B. Main features of the line item table are noted in the following sections.

Renewable flows

Due to its role in many of the emergy indices, one of the more important areas for standardization in the national accounting method is determination of the total renewable summary flow. The general procedure is to list all major renewable flows as line items, but to use only the largest value for Total Renewable Flow (R) (Odum, 1996). In recent practice, both the chemical potential of evapotranspiration and the geopotential of runoff have been listed as separate line items; however, these items are frequently combined before applying the criteria of largest renewable flow because summing these flows is not considered double-counting (Odum et al., 1988). To try to reduce confusion for the audience unfamiliar with emergy, as well as codify whether rainfall or evapotranspiration is to be used, all of the water calculations are performed prior to insertion into the main line item table, and are detailed in the notes section accompanying the main table. The resulting line item emergy value is called Total Water, the calculation of which considers chemical potential of rain, chemical potential of evapotranspiration, chemical and geopotential of rain runoff, chemical and geopotential of river inflow, chemical and geopotential of river outflows, and if the nation is landlocked or coastal.

The sequence of steps in the calculation of Total Water is shown in Figure 2. If a nation is landlocked, water runoff contributes geopotential energy to that nation only while within the national border. The runoff does not meet seawater within the nation, and thus does not provide chemical potential energy. Therefore, the Total Water line item for landlocked countries is the sum of the emergy of the chemical potential of the actual evapotranspiration (AET) flow and the emergy of the

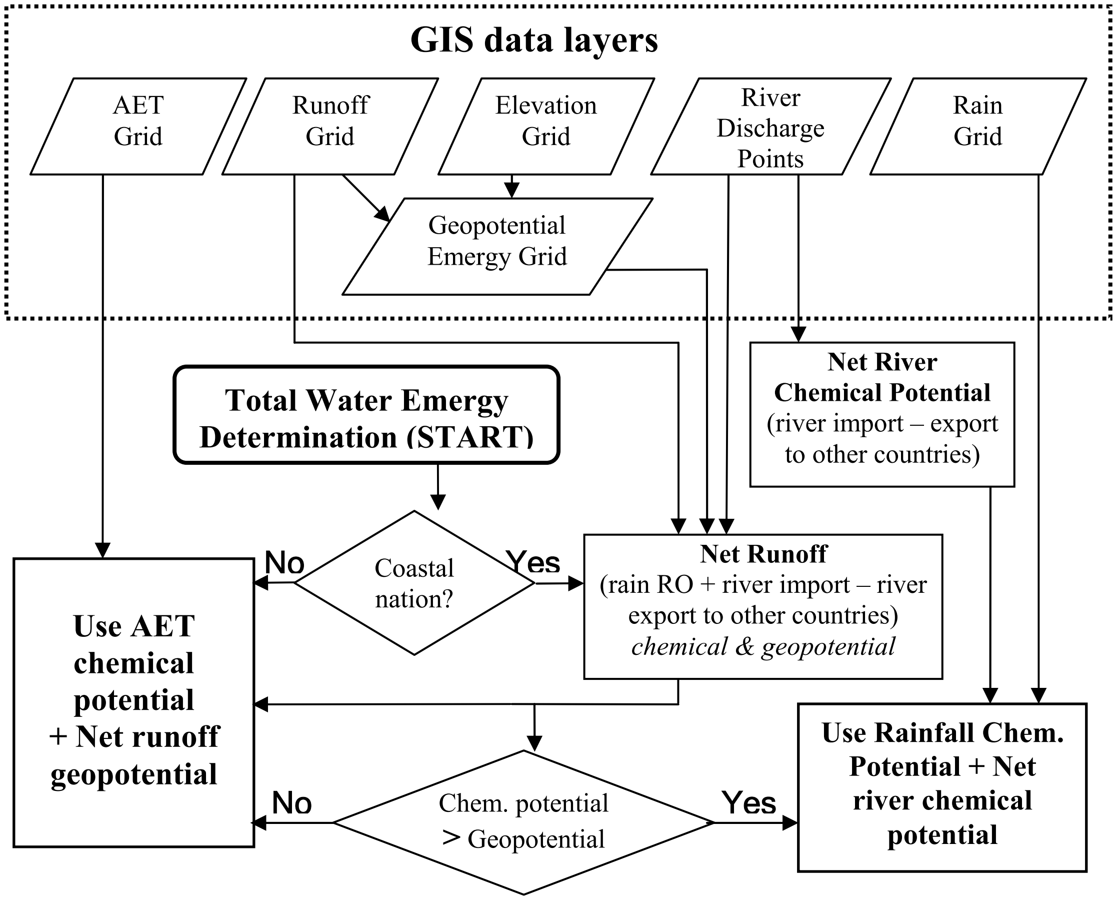

Figure 2. *Logic flowchart for determination of the renewable line item Total Water. AET = Actual Evapotranspiration.*

net geopotential of the runoff flow. The net geopotential is relative to sea level and includes the geopotential of the runoff flows from internal rainfall and any imported river flows, and subtracts the geopotential of runoff leaving the country through rivers. In coastal nations much of the runoff, including any river imports from upstream countries, is deposited at the coast and the chemical potential of the water relative to seawater contributes emergy to the nation. However, the emergy of the geopotential contribution of that runoff may be larger than the emergy of the chemical potential at the coast. In order to choose the largest flow and avoid double-counting, a sequence of steps was developed for determining the Total Water emergy flow for coastal nations by comparing the emergy of the chemical potential and geopotential of the net runoff. If the net runoff geopotential is larger, Total Water is calculated as for landlocked countries. If the net runoff chemical potential is larger, Total Water is the chemical potential emergy of rainfall plus the emergy of the net river chemical potential. The net river component accounts for contributions from river inflows at the border and removes the chemical potential of runoff leaving the nation over land.

With annual renewable water flow now represented by one line item, the largest flow from the main table may be chosen for total renewable flow. Another option is to sum the largest terrestrial renewable flow and the tidal flow if the country is coastal, as discussed by Campbell (2000). Campbell proposed that adding rain and tide will likely not double-count any of the three independent biospheric energy inputs (solar radiation, deep heat, gravitational attraction) because, relative to the time-scale of national economies, radiation is a negligible input to tide, deep heat is a long term input for tide, gravitational attraction is a negligible input for rain, and deep heat is a negligible input for rain. Accordingly, the current calculation in the NEAD adds the largest terrestrial renewable flow and the tidal flow to arrive at total renewable flow (R) for coastal countries.

Internal Transformations (Economic)

This section of the main table is similar to previous templates, with the addition of water extraction, and the creation of a heading title that tries to impart two caveats. First, line items in this section are not flows crossing the boundaries, and therefore are not included in the Total Use summary flow. Second, values do not represent production of plant and animal matter, but rather, the portion of production that is reported in published statistical tables, which is generally only the portion entering the realm of economic transactions.

For agriculture and livestock production, detailed mass to energy, and energy to emergy conversions take place for 120 FAO commodities before aggregating into the main line items. Though all 120 commodities do not have individual transformities yet, differentiation between items such as milk, eggs, chicken, beef, fruits, vegetables, sugar, grains, and nuts avoids assuming an average energy conversion and UEV for the whole line item aggregate. References and notes on energy conversions and UEVs are documented within the FAO commodity sub-table of the NEAD.

Indigenous nonrenewable extraction

This section of the main table contains line items for materials with use rates exceeding replacement rates. Non-renewable forest extraction, fishery extraction, water extraction, and topsoil loss are also known as "diffuse non-renewable" flows and "natural capital". The calculations for these line items are discussed in more detail in Cohen et al. 2007a.

The fuel, metal and mineral extraction line items are the concentrated non-renewable flows. The portion of extraction that undergoes upgrading within the national boundaries is included in the nation's total emergy use (N1), while any portion exported without transformation is excluded from total use (N2). A disaggregated list of minerals and metals is transformed to emergy units using individual UEVs before aggregating into line items. Fifteen UEVs from various sources are assigned to the 36 mineral commodities reported by the British Geological Survey (BGS), and 29 elemental metal UEVs are assigned to the 29 metal commodities reported by BGS. The model used to estimate elemental UEVs is discussed in Cohen et al. 2007b.

Imports and exports

The aggregate trade line items in the main emergy table represent extensive ranges of commodities, thus emergy estimates may improve greatly by performing emergy transformations with individual energy conversions and UEVs before aggregating to line item flows. Past emergy analyses often sum up the total mass within a line item (e.g., agricultural products or chemicals) and then apply an assumed average water content, and assumed average mass to energy conversion, and an assumed average UEV. Within the NEAD, a table was created based on the 623 commodities reported by the United Nations COMTRADE database (SITC-1 classification, 4-digit code level). Each commodity is assigned a UEV and, if the UEV is per joule, a mass to energy conversion. All conversion values are referenced, and substitutions are noted for commodities lacking a UEV. As more UEVs become available through the emergy research community, they will be assigned to the COMTRADE commodities table within the NEAD.

Summary Flows and Indices

Summary flows and indices calculated within the NEAD are typical of past emergy analyses and are shown in Appendix C.

RESULTS

The main product of the NEAD is a set of global tables with emergy values for line items, summary flows and indices for 134 countries (partial datasets for 223 countries). In order to look at individual countries, these tables are linked to spreadsheets which are configured as dynamic forms having the familiar national analysis format: the main emergy table of line item flows, a detailed notes section for the main table, the aggregated summary flows table and the emergy indices table. Upon typing a country name into the designated cell, the national forms update to the values located in the NEAD for that country.

Values for several of the emergy indices for the year 2000, extracted from the NEAD in January 2006, are presented in Table 1. Note that these values may change as newer data is incorporated. In addition to viewing tabular output, tables of values coded by country can also be linked to political boundary coverages in a GIS environment in order to produce maps of emergy flows. Figure 3 displays global maps of total emergy use, empower density, and emergy use per capita. Renewable use and electricity use as a fraction of total use are shown in Figure 4. The indices Environmental Loading Ratio, Investment Ratio, and Emergy to Money Ratio are shown in Figure 5.

Further results and initial analyses utilizing NEAD output can be found in this volume (Cohen et al., 2007a; Cohen et al., 2007c; King et al., 2007). These studies investigate global natural capital depletion and the relationship of emergy indices to published indicators of well-being.

DISCUSSION

The NEAD is a work in progress at a variety of levels. Most of the technical issues are resolved, but updates are expected due to the production of new global datasets by the scientific and economic communities, and the calculation of new transformities and refinement of emergy synthesis methodology by the emergy community. Standardizing calculations and documenting assumptions during development of the database has brought a variety of interesting issues to the surface that will benefit from further discussion and research. A few of these issues are highlighted below.

Concerning renewable emergy flow, the decision to add tide to the largest terrestrial renewable flow is tentative, and the argument for doing so is presented in several papers from prior proceedings (Campbell, 2000; Campbell et al., 2005). Another aspect of determining the renewable base, also discussed in the Campbell papers, is spatial resolution. The ideal situation for comparing national renewable flows would have all nations with equal areas, though in reality, national boundaries produce extreme differences in area. The global database, with its geographic renewable coverages, may provide a good launching pad for researching the effect of scale and resolution on determining renewable flows for any system.

Another area of concern is the determination of the summary flow "exported without use" (N2). The N2 summary flow highlights nations exporting concentrated resources, such as fuels and metals, rather than upgrading them within the boundaries, and consequently attracting additional outside investment. Emergy trade imbalances are often associated with such flows of largely unrefined metals and fuels (Odum, 1996). Generally, exported flows of raw metals, minerals, and fuels (N2) are not included in the total use equation, $U = R + N0 + N1 + \text{Imports}$ (Odum, 1996). However, in the NEAD, N2 becomes particularly important because it determines the value of N1 (concentrated use). N2 (export) must be used to derive N1 (use) due to the lack of a global data source which reports the fraction of fuel, metal and mineral production that is used within national boundaries. Currently, the

Table 1. Selected indices from global emergy database, extracted January 2006.

Country	U E22 sej/yr	U/A E11sej/m^2/yr	R/U	Elec/U	EMR E12	IR	ELR	EYR
United States	1889.2	20.6	0.12	0.20	1.9	1.41	7.29	1.71
China	1285.6	13.8	0.26	0.10	11.9	0.33	2.83	4.03
Mexico	917.8	47.7	0.04	0.02	15.8	3.09	21.51	1.32
Russia	742.3	4.4	0.35	0.11	28.6	0.10	1.86	11.33
Japan	710.8	189.7	0.03	0.13	1.5	2.25	34.75	1.45
Brazil	707.7	8.4	0.50	0.05	11.8	0.12	1.00	9.58
Canada	598.9	6.6	0.51	0.09	8.4	0.48	0.95	3.07
U.K	545.1	225.6	0.44	0.06	3.8	0.95	1.29	2.05
India	533.4	17.9	0.28	0.09	11.4	0.17	2.53	6.90
Germany	525.3	150.4	0.01	0.10	2.8	10.12	99.76	1.10
Australia	482.8	6.3	0.49	0.04	12.4	0.14	1.04	8.17
Spain	455.3	91.1	0.02	0.05	8.1	0.64	41.24	2.57
South Korea	415.2	422.9	0.24	0.06	9.0	1.36	3.24	1.74
Italy	414.0	140.8	0.02	0.07	3.9	2.12	60.32	1.47
France	382.2	70.1	0.16	0.11	2.9	4.58	5.19	1.22
Indonesia	310.0	17.0	0.57	0.03	20.6	0.19	0.74	6.39
Argentina	291.7	10.7	0.79	0.03	10.3	0.08	0.26	12.83
Netherlands	217.4	641.7	0.04	0.05	5.9	11.20	22.72	1.09
Belgium	209.5	691.9	0.00	0.04	9.2	5.34	323.1	1.19
South Africa	207.2	17.0	0.08	0.09	16.2	0.16	11.65	7.25
Thailand	183.0	35.8	0.10	0.05	14.9	0.62	8.69	2.61
Ukraine	165.4	27.4	0.07	0.09	52.9	0.31	13.07	4.20
Malaysia	161.7	49.2	0.26	0.04	18.0	0.90	2.87	2.11
Iran	160.9	9.8	0.22	0.07	15.6	0.15	3.61	7.72
Turkey	150.0	19.5	0.10	0.08	7.5	1.08	9.29	1.93
Peru	148.8	11.6	0.34	0.01	28.0	0.06	1.93	17.41
Poland	134.4	44.1	0.03	0.09	8.2	0.71	37.29	2.40
Zimbabwe	123.6	32.0	0.05	0.01	171.6	0.04	19.36	27.20
Ireland	119.3	173.2	0.63	0.02	12.6	0.46	0.58	3.19
Chile	112.2	15.0	0.20	0.04	15.0	0.23	3.98	5.37
Venezuela	103.8	11.8	0.38	0.08	8.6	0.13	1.64	8.45
Colombia	98.6	9.5	0.61	0.04	11.8	0.14	0.63	8.26
Portugal	94.4	102.7	0.04	0.04	8.9	0.85	23.07	2.18
Austria	91.5	111.0	0.03	0.06	4.8	1.57	31.04	1.64
Saudi Arabia	91.1	4.6	0.09	0.13	4.8	0.39	10.35	3.58
Bangladesh	88.0	65.7	0.85	0.02	18.1	0.13	0.18	8.97
Sweden	84.8	20.6	0.05	0.16	3.5	3.00	19.31	1.33
Kazakhstan	82.8	3.1	0.16	0.06	45.3	0.12	5.17	9.10
Philippines	80.6	27.0	0.19	0.05	10.6	1.04	4.34	1.97
Norway	68.3	22.2	0.33	0.16	4.1	1.00	2.04	2.00
Pakistan	65.9	8.5	0.17	0.09	10.3	0.42	4.89	3.37
New Zealand	62.2	23.2	0.63	0.06	12.0	0.26	0.58	4.91
Czech	62.0	80.3	0.01	0.09	11.2	1.83	77.81	1.55
Switzerland	61.0	153.5	0.03	0.09	2.5	27.76	31.65	1.04
Greece	57.7	44.1	0.03	0.08	5.1	2.53	29.60	1.39
PNG	57.1	12.6	0.71	0.00	167.1	0.31	0.40	4.19
Kenya	49.7	8.7	0.26	0.01	47.5	0.09	2.86	12.25
Egypt	49.4	5.0	0.08	0.14	4.8	0.52	12.17	2.93
Nigeria	49.3	5.4	0.39	0.03	11.7	0.37	1.55	3.68
Finland	48.4	15.9	0.04	0.16	4.0	3.31	23.26	1.30
Denmark	48.1	113.4	0.04	0.07	3.0	5.70	21.83	1.18

Table 1. (continued)

Country	U E22 sej/yr	U/A E11sej/m2/y	R/U	Elec/U	EMR E12	IR	ELR	EYR
Madagascar	44.1	7.6	0.84	0.00	113.6	0.03	0.19	38.05
Mozambique	43.7	5.6	0.93	0.01	118.7	0.03	0.07	38.38
Romania	39.4	17.1	0.14	0.12	10.6	0.94	6.40	2.06
Zambia	39.4	5.3	0.52	0.01	121.6	0.03	0.94	36.84
Vietnam	39.2	12.0	0.65	0.06	12.5	0.21	0.53	5.74
Morocco	37.1	8.3	0.19	0.04	11.1	0.77	4.25	2.30
Bolivia	37.0	3.4	0.62	0.01	44.1	0.17	0.62	6.76
Iceland	37.0	36.9	0.85	0.02	43.9	0.07	0.17	16.00
Hungary	36.9	40.0	0.02	0.10	7.9	4.69	49.53	1.21
Sudan	35.4	1.5	0.73	0.01	30.7	0.05	0.37	21.17
Israel	34.3	168.8	0.00	0.11	2.9	12.35	295.2	1.08
Ethiopia	33.4	3.0	0.83	0.00	55.5	0.05	0.20	19.49
Algeria	33.0	1.4	0.12	0.07	6.1	0.45	7.28	3.20
Bulgaria	32.3	29.2	0.06	0.10	25.6	0.53	15.55	2.88
Ecuador	31.2	11.3	0.61	0.03	19.6	0.15	0.65	7.68
Slovakia	28.8	59.1	0.03	0.08	14.2	2.20	38.10	1.45
Tanzania	28.0	3.2	0.78	0.01	30.8	0.07	0.28	14.61
Kuwait	24.9	139.5	0.01	0.12	6.9	0.32	82.10	4.16
Gabon	24.5	9.5	0.40	0.00	48.7	0.03	1.49	32.35
Belarus	24.0	11.5	0.06	0.13	23.0	6.31	14.95	1.16
Cameroon	22.9	4.9	0.73	0.01	24.7	0.08	0.38	13.23
Nepal	22.3	16.3	0.85	0.01	41.8	0.08	0.18	13.46
Uruguay	19.9	11.5	0.38	0.04	9.9	0.23	1.61	5.39
Ghana	19.9	8.6	0.31	0.04	40.0	0.36	2.25	3.79
Guatemala	19.7	18.2	0.37	0.02	10.4	0.40	1.67	3.51
Syria	18.7	10.2	0.06	0.12	7.6	0.17	15.71	6.72
Jordan	17.9	19.4	0.01	0.04	21.1	0.50	78.74	3.00
Tunisia	17.7	11.4	0.04	0.05	9.1	1.46	25.31	1.68
Serbia &	16.5	16.1	0.13	0.20	15.0	0.47	6.55	3.14
Panama	16.2	21.4	0.61	0.03	16.2	0.28	0.64	4.54
Cote d'Ivory	15.2	4.8	0.50	0.02	14.3	0.42	0.99	3.38
Libya	14.8	0.8	0.16	0.13	4.3	0.35	5.44	3.85
Armenia	14.1	49.6	0.03	0.04	73.7	0.09	38.54	12.54
Guyana	14.0	7.1	0.85	0.01	196.1	0.06	0.18	16.62
Slovenia	13.4	66.4	0.06	0.08	7.1	5.71	17.00	1.18
Cuba	12.8	11.5	0.19	0.11	4.6	1.25	4.33	1.80
Cent. Afr. Rep.	12.7	2.0	0.94	0.00	139.6	0.01	0.06	110.2
Costa Rica	12.6	24.9	0.38	0.05	7.9	0.82	1.66	2.22
Suriname	12.4	7.7	0.84	0.02	159.1	0.08	0.20	13.75
Trin.&Tobago	11.9	231.7	0.03	0.04	14.5	0.92	30.97	2.09
Namibia	11.8	1.4	0.46	0.02	34.1	0.30	1.19	4.37
Croatia	11.4	20.3	0.09	0.12	6.2	3.32	10.04	1.30
Mongolia	11.2	0.7	0.62	0.03	118.8	0.08	0.62	12.92
Jamaica	11.2	103.1	0.03	0.05	14.5	0.73	33.54	2.37
Oman	10.9	5.2	0.31	0.07	5.5	0.60	2.20	2.66
Guinea	10.8	4.4	0.60	0.01	35.4	0.08	0.67	13.67
Paraguay	10.8	2.7	0.72	0.02	14.0	0.25	0.39	4.95
Botswana	10.8	1.8	0.42	0.02	21.6	0.34	1.37	3.93
Turkmenistan	10.4	2.1	0.14	0.07	21.2	0.20	6.03	6.05
Nicaragua	10.3	8.6	0.56	0.02	26.2	0.23	0.79	5.31
Cambodia	10.1	5.7	0.78	0.00	30.1	0.16	0.29	7.10

Table 1. (continued)

Country	U E22 sej/yr	U/A E11sej/m²/yr	R/U	Elec/U	EMR E12	IR	ELR	EYR
Honduras	10.0	8.9	0.41	0.04	16.9	0.32	1.44	4.15
Lithuania	9.9	15.2	0.08	0.10	8.9	4.90	12.03	1.20
El Salvador	9.8	47.5	0.22	0.04	7.5	0.78	3.64	2.28
Congo	9.4	2.8	0.90	0.01	29.2	0.05	0.12	22.30
Mali	9.3	0.8	0.76	0.00	38.0	0.11	0.32	9.86
Azerbaijan	9.1	10.6	0.10	0.19	17.3	0.22	8.80	5.59
Uganda	9.0	4.5	0.65	0.01	15.7	0.13	0.54	8.43
Senegal	8.6	4.5	0.55	0.02	19.7	0.35	0.83	3.88
Yemen	8.5	1.6	0.37	0.03	10.0	0.37	1.68	3.68
Lebanon	8.3	81.0	0.04	0.10	5.0	20.55	23.69	1.05
Mauritania	6.8	0.7	0.79	0.00	75.1	0.13	0.27	8.50
Latvia	6.7	10.6	0.20	0.09	9.4	2.09	3.97	1.48
Estonia	6.6	15.3	0.10	0.10	12.8	5.21	8.97	1.19
Sierra Leone	6.1	8.5	0.57	0.00	96.0	0.52	0.77	2.93
Macedonia	5.9	23.7	0.04	0.11	16.4	0.69	23.02	2.44
Niger	5.8	0.5	0.74	0.01	32.5	0.10	0.35	10.89
Burkina Faso	4.9	1.8	0.63	0.01	22.5	0.20	0.59	5.96
Togo	4.8	8.7	0.22	0.01	35.8	0.26	3.57	4.82
Guinea-Bissau	4.6	16.3	0.97	0.00	202.7	0.02	0.03	49.20
Benin	4.2	3.8	0.45	0.02	18.8	0.39	1.23	3.57
Cyprus	4.1	44.6	0.02	0.07	4.7	10.82	59.14	1.09
Albania	4.0	14.7	0.22	0.14	10.5	1.25	3.56	1.80
Malawi	3.7	3.9	0.55	0.03	21.1	0.19	0.82	6.30
Eritrea	2.7	2.3	0.74	0.01	36.4	0.20	0.35	6.06
Belize	2.5	11.1	0.34	0.00	33.3	0.39	1.96	3.55
Moldova	2.4	7.2	0.10	0.21	18.7	5.17	8.78	1.19
Rwanda	1.9	7.7	0.36	0.01	11.1	0.21	1.75	5.69
Swaziland	1.4	8.4	0.21	0.07	10.4	3.27	3.76	1.31
Lesotho	1.4	4.6	0.53	0.02	16.2	0.74	0.88	2.36
Burundi	1.2	4.8	0.39	0.01	17.3	0.20	1.58	5.93
The Gambia	1.1	11.3	0.76	0.01	26.7	0.27	0.32	4.73
Djibouti	0.8	3.5	0.43	0.02	14.4	1.26	1.33	1.79
Avg. of nations	120.2	42.7	0.34	0.06	27.9	1.58	15.20	7.38

U = total emergy use, U/A = use per area, R/U = fraction renewable, Elec/U = fraction electricity, EMR = emergy to money ratio in US$, IR = investment ratio, ELR = environmental load ratio, EYR = emergy yield ratio.

NEAD estimates N1 as the sum of fuel, metal, and mineral production, minus exports identified as N2. The difficulty arises in the need to allocate individual commodities as N2 flows. How do we distinguish between refined and unrefined commodities for the purposes of emergy analysis? How much added value does it take to remove a mined ore from the N2 aggregate and report it as used in the source country?

With the increase in detail of disaggregated trade data (COMTRADE) used in the database, the transition from raw to upgraded material is difficult to demarcate. Consider the upgrade of bauxite to alumina powder to aluminum ingots within national boundaries. If the ingots are considered upgraded due to the processing in country, and thus not identified as N2, they will be included in the total use equation even if they are exported. Additionally, dispersed non-renewables (N0) can also be exported with little to no transformation, such as logs and whole fish. Should these also be included in N2? This is clearly a feature of the NEAD, and emergy accounting in general, requiring additional examination. Currently, the NEAD assigns a code for N2 to crude oil, coal, and natural gas exports, exports named as ores by COMTRADE, and exports located in the unrefined minerals section of the

COMTRADE database. The NEAD is easily updated to accommodate any refinement concerning items "exported without use".

Concerning the assignment of UEVs, the adoption of previously computed UEVs represents an important implicit assumption within the NEAD. There are often structural differences in the production of commodities (e.g. maize production between the United States and Sub-Saharan Africa)

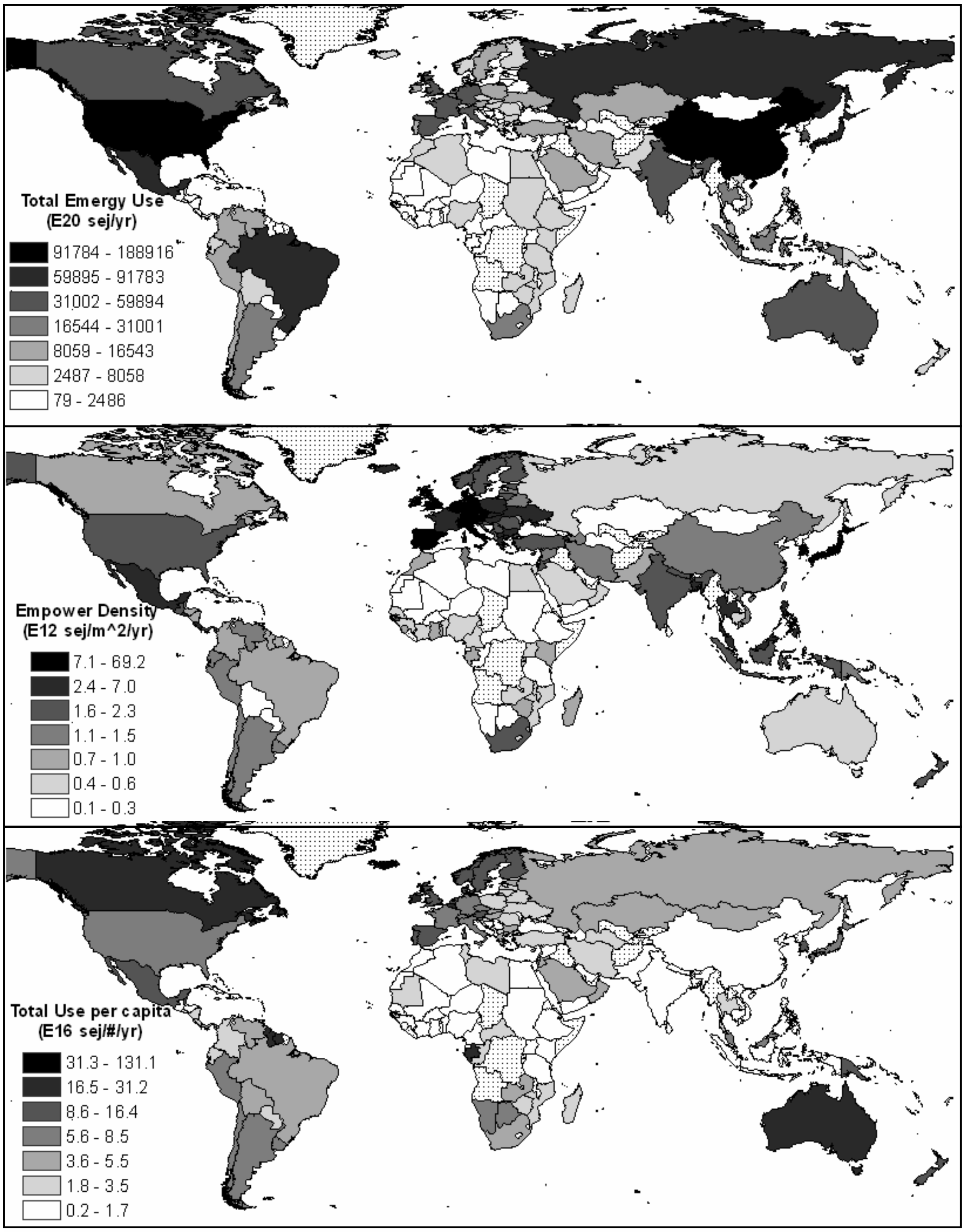

Figure 3. *Global maps of total emergy use, use intensity per area (empower density), and use intensity per capita for the year 2000. Stippled nations have incomplete data.*

that would render the assumption of UEV uniformity problematic. In general, UEVs vary only to a minor extent between parallel processes producing the same output. However, the fact that both environmental and economic goods are produced under different conditions with different transformation methods suggests that, where possible, local UEVs are computed for important inputs to a system under study. For standardized analysis of 134 national systems, this is not possible; as such, the results of this work should be treated as a first estimate of the resource basis of nations.

Despite the issues surfacing in this attempt to further standardize national emergy accounting, the formalizing of data sources, line item detail, mass to energy conversions and assignment of UEVs, surely improves the utility, reliability and credibility of comparative national analysis. In the past, individual country emergy accounts have been constructed item by item. Over the years, enough countries have been completed to enable enlightening comparative assessments (Odum 1996; Huang 1998; Brown, 2003) though methods, source data and year of the national accounts often varied. Not only does the automation, and standardization of the NEAD drastically reduce the time required to produce an individual country emergy table, but it also enables the generation of emergy data and documentation for almost every country. Further, a format now exists for the entry of data from additional years, so that time series will also be possible to the extent that historical data are available, and as future production and trade data are implemented.

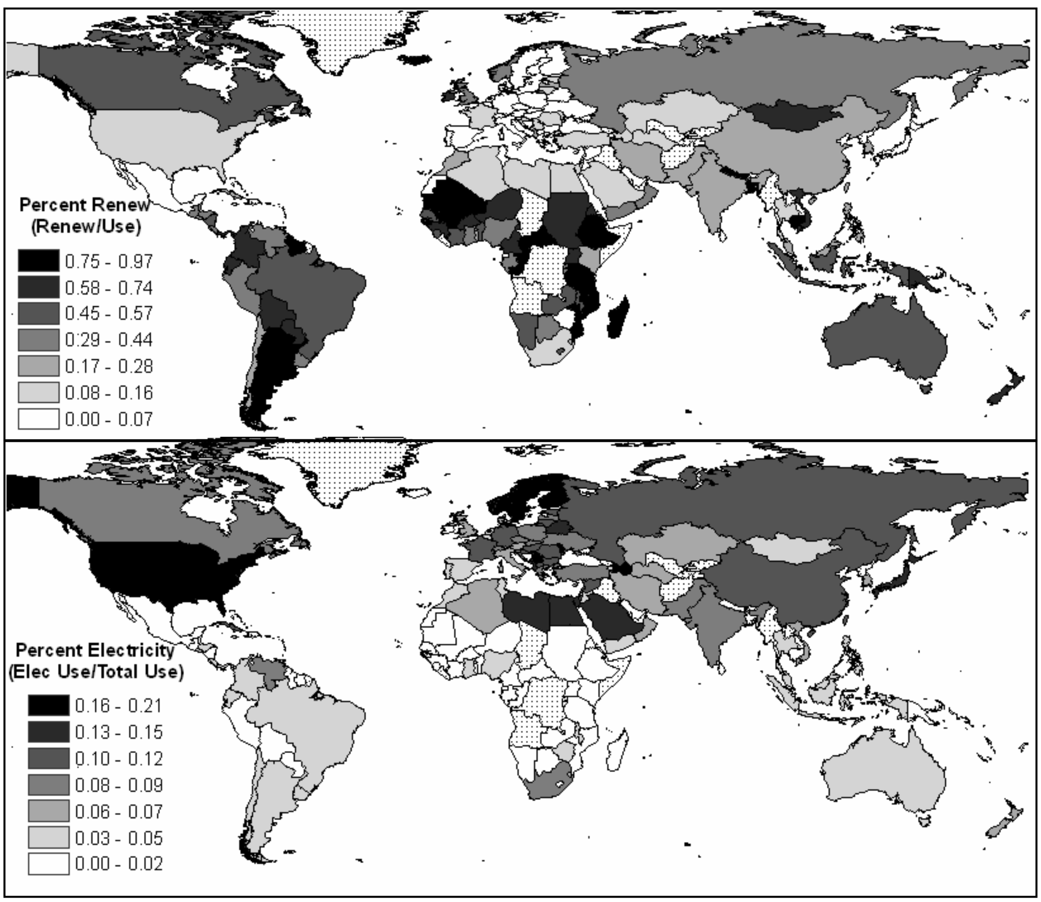

Figure 4. *Global maps of the renewable use fraction and electricity use fraction of total use for the year 2000. Stippled nations have incomplete data*

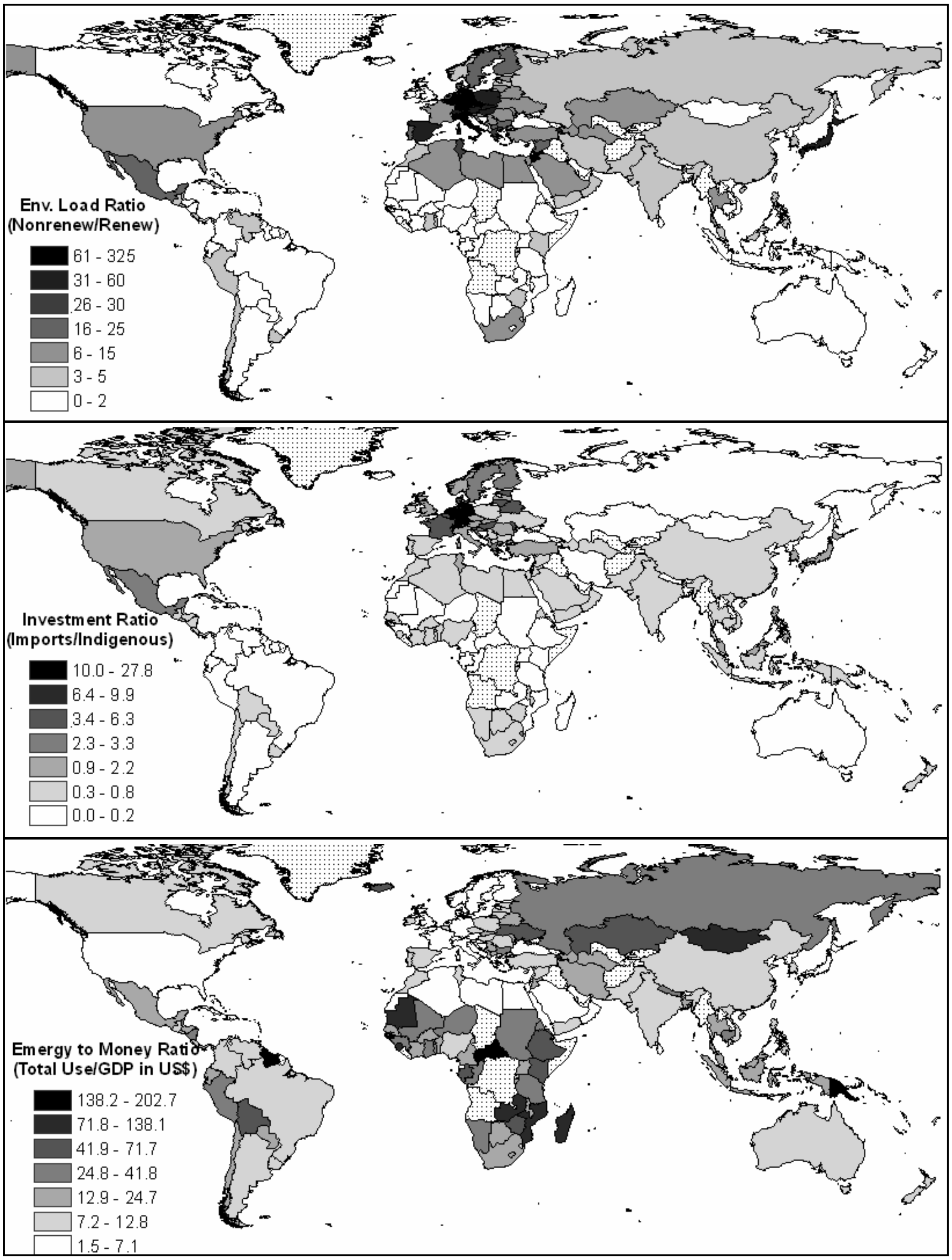

Figure 5. *Global maps of Environmental Loading Ratio, Investment Ratio, and Emergy to Money Ratio (using US$ equivalent) for the year 2000. Stippled nations have incomplete data.*

Interesting applications that may arise from this emergy information system include development of energy and emergy-based trade matrices, trade inequality measures, clusters of energy resource bases, development benchmarks, sustainability indicators, experimentation with calculating the renewable emergy base, and hierarchical studies of environment-economic subsystems of the planet. Some initial research findings based on the data produced can be found in this volume. The global emergy database provides efficient, standardized emergy analysis at the country level, and will be a valuable tool for generating insight to an increasingly connected set of interacting environment-economic systems across the globe.

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APPENDIX A. Datasets used in the global emergy database.

Variable	Dataset	Accessed through…	URL for dataset
Land area	The World Factbook	Central Intelligence Agency	www.cia.gov/cia/publications/factbook/
Net solar radiation	Earth Radiation Budget Experiment	Digital Atlas of the World Water Balance	www.ce.utexas.edu/prof/maidment/gishyd97/atlas/atlas.htm
Continental shelf area	Global Maritime Boundaries Database	UNEP, GEO-3 Data Compendium, 1.1	geocompendium.grid.unep.ch/
Tidal range	Typology Data Set	Land-Ocean Interactions in Coastal Zone	www.loicz.org
Number of tides	Typology Data Set	Land-Ocean Interactions in Coastal Zone	www.loicz.org
Rainfall	Wilmott grid V.2.01	Center for Climatic Research	climate.geog.udel.edu/~climate/html_pages/download.html
Evapotranspiration	Ahn and Tateishi, AET grid	UNEP, GEO Data Portal, GNV183	www.grid.unep.ch/data/data.php?category=atmosphere
Elevation	ETOPO5	National Geophysical Data Center	www.ngdc.noaa.gov/mgg/global/etopo5.HTML
Rain runoff volume	UNH/GRDC Composite Runoff Fields	Water Systems Analysis Group, UNH	www.grdc.sr.unh.edu/index.html
River flow at border	GRDC discharge database	Global Runoff Data Center	grdc.bafg.de/servlet/is/1035/?lang=en
Wind speed	Climate Research Unit CL 1.0	Climate Research Unit	www.cru.uea.ac.uk/~timm/grid/CRU_CL_1_0.html
Coastline length	The World Factbook	Central Intelligence Agency	www.cia.gov/cia/publications/factbook/
Wave height	Typology Data Set	Land-Ocean Interactions in Coastal Zone	www.nioz.nl/loicz/welcome.html
Heat flow	Global Heat Flow Database	International Heat Flow Commission	www.heatflow.und.edu/index2.html
Ag. & livestock production	FAOSTAT	Food and Agriculture Organization	faostat.fao.org/
Fishery extraction	FIGIS	Food and Agriculture Organization	faostat.fao.org/
Nonrenew fisheries	FAO Fisheries Technical Paper 457	Food and Agriculture Organization	ftp://ftp.fao.org/docrep/fao/007/y5852e/y5852e00.pdf
Wood extraction	FAOSTAT	Food and Agriculture Organization	faostat.fao.org/
Wood biomass per area	IPCC report, Table 3A.1.4	Intergovernmental Panel on ClimateChange	www.ipcc-nggip.iges.or.jp/public/gpglulucf/
Annual forest extent lost	Global Forest Resources Assessment 2000	UNEP, GEO-3 Data Compendium, 1.1	geocompendium.grid.unep.ch/data_sets/forests/nat_forest_ds
Water extraction	AQUASTAT database	Food and Agriculture Organization	http://www.fao.org/ag/agl/aglw/aquastat/main/index.htm
Hydroelec. production	International Energy Annual 2004	Energy Information Administration	http://www.eia.doe.gov/iea/
Electricity consumption	International Energy Annual 2004	Energy Information Administration	http://www.eia.doe.gov/iea/
Gas, coal, oil production	International Energy Annual 2004	Energy Information Administration	http://www.eia.doe.gov/iea/
Metal , mineral production	World Mineral Production, 1999-2003	British Geological Survey	http://www.mineralsuk.com/free_downloads.html#WMP
Soil organic matter content	WISE (version 2)	ISRIC	http://www.isric.org
Soil degradation	GLASOD database	ISRIC	www.grid.unep.ch/data/grid/soils.html
Gas, coal, oil, elec. trade	World Energy Database	EIA, International Energy Annual 2001	www.eia.doe.gov/emeu/world/main1.html
All other trade flows	COMTRADE	United Nations Statistics Division	unstats.un.org/unsd/comtrade/default.aspx
GDP	UNCDB	United Nations Statistics Division	http://unstats.un.org/unsd/cdb
Tourism expenditure	UNCDB	United Nations Statistics Division	http://unstats.un.org/unsd/cdb

APPENDIX B. Line item organization of main emergy table.

RENEWABLE FLOWS

1 Sunlight
2 Deep heat
3 Tide
4 Wind
5 Total water
6 Waves

INTERNAL TRANSFORMATIONS (ECONOMIC)

7 Agriculture Production
8 Livestock Production
9 Fisheries Production
10 Fuelwood Production
11 Industrial Roundwood Production
12 Water extraction
13 Hydroelectricity
14 Total Electricity

INDIGENOUS NONRENEWABLE EXTRACTION

15 Forestry, net loss
16 Fisheries, net loss
17 Water, net loss
18 Topsoil losses, organic matter
19 Coal
20 Natural Gas
21 Oil
22 Minerals
23 Metals

IMPORTS

24 Fuels
25 Metals
26 Minerals
27 Food & agricultural products
28 Livestock, meat, fish
29 Plastics & synthetic rubber
30 Chemicals
31 Finished products
32 Machinery & transportation equipment
33 Other refined goods
34 Electricity
35 Service in imports

EXPORTS

36 Fuels
37 Metals
38 Minerals
39 Food & agricultural products
40 Livestock, meat, fish
41 Plastics & synthetic rubber
42 Chemicals
43 Finished products
44 Machinery & transportation equipment
45 Other refined goods
46 Electricity
47 Service in exports
48 Tourism

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APPENDIX C. Summary flows and indices reported by the global emergy database.

Code	Summary Flows	Description
R	Renewable sources	Largest terrestrial renewable flow + tide
N	Nonrenewable resources from within	Sum of indigenous nonrenewable extraction
N0	Dispersed nonrenewable	Sum of forestry, fishery, soil, water extraction
N1	Concentrated nonrenewable used	Sum of fuel, metal, 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 other imported goods & electricity
I	Dollars Paid for Imports	Service in Imports, $ value
P2I	Emergy of Services in Imports	Service in Imports($) * World emergy to dollar
F_e	Exported Fuels and Minerals	Sum of fuels, metals, minerals exported
G_e	Exported Goods	Sum of other exported goods & electricity
E	Dollars Received for Exports	Service in Exports, $ value
P1E	Emergy of Services in Exports	Service in Exports($) * Country emergy to dollar
X	Gross Domestic Product	Use UN statistical data
P2	World emergy/$ ratio	Total Global Emergy Use / Gross World Product
P1	Country Emergy/$ ratio	National Emergy Use / Gross Domestic Product

Code	Indices	Computation
IMP	Imported emergy	F_i+G_i+P2I
U	Total emergy used, U	N0+N1+R+F+G+P2I
EXP	Total exported emergy	F_e+G_e+P1E
%Indig.	Fraction emergy use from indigenous	(NO+N1+R) / U
EXP:IMP	Export to Imports	$(F_e+G_e+P1E) / (F_i+G_i+P2I)$
%R	Fraction used, locally renewable	R/U
%purch	Fraction of use purchased	$(F_i + G_i + P2I) / U$
%serv	Fraction of use, imported services	P2I / U
%free	Fraction of use that is free	(R+N0)/U
Conc.:Disp.	Ratio of concentrated to dispersed	$(F_i+G_i+P2I+N1) / (R+N0)$
U/A	Emergy Use per area	U / area
U/#	Use per person	U / population
R/A	Renewable Emergy Use per area	R / area
R/#	Renewable Use per person	R / population
CC	Renewable carrying capacity	(R/U) * population
%elec	Ratio of electricity to use	(el)/U
fuel/#	Fuel use per person	Fuel / population
IR	Investment Ratio, imports/indigenous	$(F_i+G_i+P2I) / (R+N0+N1)$
ELR	Environmental Loading Ratio	$[(F_i+G_i+P2I)+N0+N1] / R$
EYR	Yield ratio, (total use / imports)	$U / (F_i+G_i+P2I)$
ESI	ESI, Emergy sustainability index	EYR / ELR
%soil	Soil loss/use	Soil loss / U
N0/Use	Fraction of use, depleted natural capital	N0/U

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