KEEPING THE BOOKS FOR ENVIRONMENTAL SYSTEMS: AN EMERGY ANALYSIS OF WEST VIRGINIA

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Abstract. Emergy provides a general accounting mechanism that allows us to view the economy and the environment on the same income statement and balance sheet. This allows an auditor to verify the economic picture by checking it against a more complete representation of the flows and storages of real wealth as measured by emergy. In this study, we constructed emergy accounts for the state of West Virginia in 1997. The income statement showed annual production, consumption, and flows of emergy and dollars into and out of the state. The balance sheet evaluated the storage of emergy in some of the state's assets. Emergy indices were used to answer questions posed by managers and gain insight into the state's economic and environmental strengths and weaknesses. West Virginia has great wealth in nonrenewable resources (9E14 sej m^{-2} or 17 times the U.S. average). The investment ratio of emergy purchased outside to indigenous renewable and nonrenewable emergy was 2.2:1, which indicates a high potential for future development. However, the environmental loading ratio (14:1) was already 1.5 times higher than that found at an average location in the U.S. Twice as much emergy was exported as received and standard of living indicators showed that people have largely failed to benefit from their state's wealth. We propose that, just as in business, where decisions made using financial accounts ensure solvency; decisions governing the environment should be made based on an emergy accounting of activities, assets, and liabilities for the combined system of humanity and nature.

Keywords: environmental accounting, emergy analysis, West Virginia, management questions, environmental assessment

1. Introduction

For more than 100 years physical and social scientists have struggled with the problem of incorporating resource limitations and interactions into the formulations of economics using land, labor, energy, and other physical quantities (Martinez-Alier, 1987). This problem is central to the analysis and assessment of environmental systems. Environmental systems include the economic and social infrastructure and activities of humanity, as well as the storages, flows and processes of ecosystems. Most often

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efforts to incorporate the environmental basis for economies in assessments has centered on energy as a potentially unifying common denominator for accounting purposes, because it is both required for all production processes and incorporated in all products. Early efforts failed largely because none of the proposed energy-based accounting methods considered differences in the ability to do work among energies of different kinds (Odum, 1996; Campbell, 2001). This problem was solved by H.T. Odum and his colleagues in the 1980s through the development of the concepts of emergy and transformity (Odum, 1988). *Emergy* is the available energy (exergy) of one kind previously used up directly and indirectly to make a product or service. The unit of emergy is the *emjoule*, which connotes energy used in the past. *Transformity* is the emergy used to make a unit of available energy of a product or service. Emergy accounts for the environment and the economy are kept in solar joules, thus, transformities are expressed as *solar emjoules* (sej) per joule (J). *Empower* is emergy per unit time. Emergy is related to the system of economic value through the emergy-to-money ratio. The *emdollar* (Em$) value of a flow or storage is its solar emergy divided by the emergy-to-money ratio for the economy (Odum, 1996). Converting emergy flows to emdollar values redistributes the total money flow in proportion to the emergy flows in the system giving an Em$ value to all the products and work of nature and humanity. Odum's innovations established a medium (emergy) for environmental accounting that made it possible to express economic commodities, services, and environmental work of all kinds on a common basis.

Usually, records for the environment are kept in physical units such as pounds of pollutants discharged, tons of carbon fixed, or the numbers of species lost from an area, while the accounts for human activities are, for the most part, recorded in dollars. Neither accounting mechanism is able to adequately address the credits and debits of the other, in part because each uses different units, but also because dollars are not paid to the environment for its work. As a result, there is often a gap in the scientific assessments given to managers faced with solving complex problems having social, economic, and environmental consequences. Environmental accounting using emergy provides a way to bridge this gap. In this paper, we used emergy accounting to show how keeping the books on an environmental system (West Virginia) helped us identify problems and seek solutions at the macroeconomic level of a state's economy.

2. Methods

We used two environmental accounting tools, the emergy income statement and the emergy balance sheet, to characterize the state's annual activities and stored assets, respectively. From this information we calculated emergy indices to help us understand West Virginia's condition with respect to the concerns of environmental managers. These concerns were expressed as a series of questions that are asked in the Discussion section and answered using the results of our analysis. The basic methods used in performing an Emergy Analysis of a state can be found in Campbell (1998). The diagrams in this study use the symbols of the Energy Systems Language (Odum, 1994) to describe components, pathways, interactions, and monetary transactions within the system.

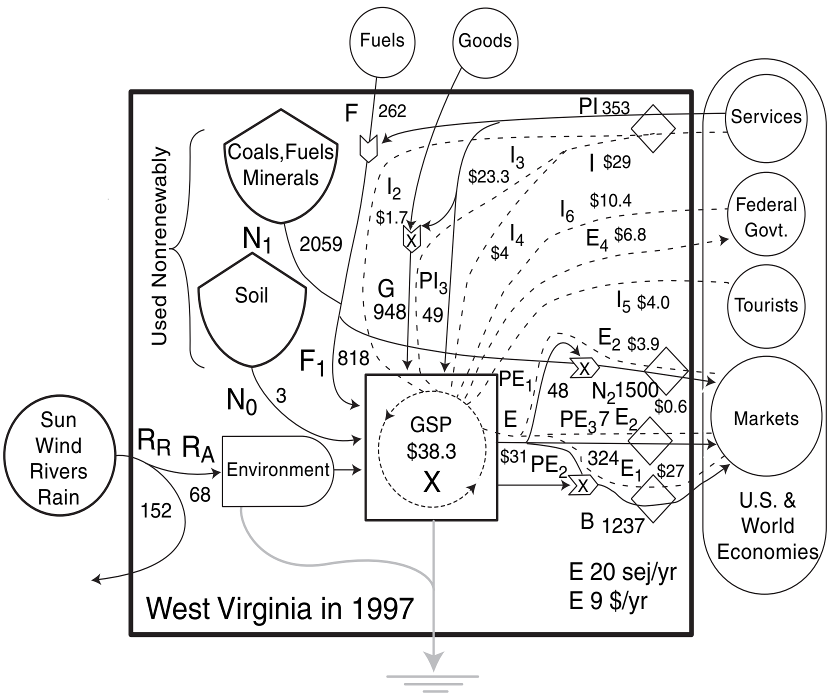

Figure 1. An aggregated energy systems diagram of the emergy resource base for the economy of West Virginia. Emergy inflows and outflows include: renewable resource inflows (R), purchased resources, i.e., fuels (F), goods (G) and services (PI), exports of goods (B) and services (PE_2 + PE_3). Money flows on the dashed lines (I's and E's) as a counter-current to emergy in exchanges (diamond symbols). The System contains interior storages of minerals (N_1), water and soil (N_0) and the lands and waters receiving (R_R) and absorbing (R_A) renewable resources. The circulation of money, X, is as a money wheel, GSP, within the box representing the state's economy.

The aggregated diagram of West Virginia (Figure 1) is a simplified representation of the system that emphasizes those components and processes that are of primary interest in answering management questions. More than one aggregated diagram may be constructed, depending on the questions to be answered and the scale of aggregation needed to answer those questions (Figure 2). Information is not discarded in the process of aggregation; instead, functionally similar storages and flows are grouped together to define variables important in calculating indices or of use in decision-making.

The emergy income statement includes the following tables: 1) renewable resources received and used within the state and the production based on the use of these resources, 2) instate production and consumption of nonrenewable resources, 3) imports into the state, and 4) exports from the state. The emergy balance sheet consists of a table of assets and liabilities based on the evaluation of storages and the displacement of stored renewable assets from their unexploited levels, respectively. The format for emergy analysis tables is illustrated in Table I.

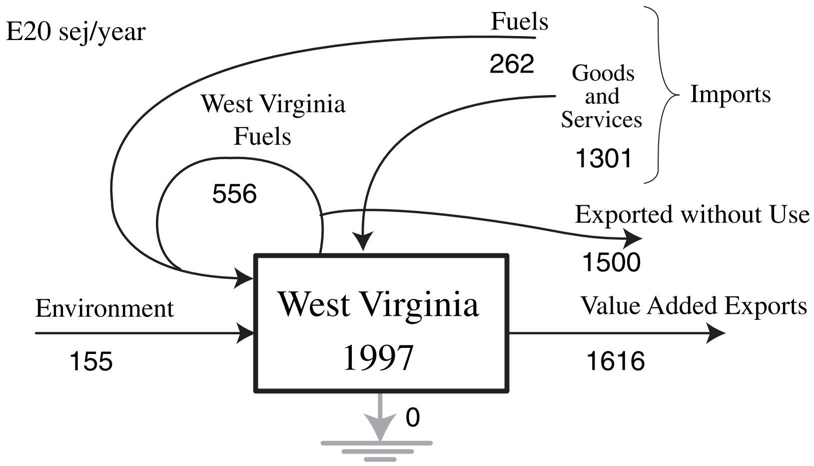

Figure 2. An input-output summary or "three-arm" diagram of West Virginia's environmental and economic emergy flows.

Campbell et al. (in review), give a list of sources for the information used in this study. Raw data on mass flows was converted to energy using standard physical formulae (Odum, 1996) and then multiplied by the appropriate transformity to get emergy. When it was convenient, the emergy per unit mass was used to convert data on mass flows to emergy. Also, when appropriate, the dollar value of some flows was converted to the average emergy of the human services purchased by multiplying the dollar amount by the emergy to dollar ratio for the United States in 1997. Information from the completed emergy accounts was combined to create a summary table of flows. This table was used to evaluate the aggregate diagrams (Figures 1 and 2) and create emergy indices to compare systems and to suggest alternatives that may deliver more emergy, be more efficient, or more equitable. Emergy indices have been listed and defined in many publications including Odum (1996), Campbell (1998), and Brown and Ulgiati (2001) to name a few.

Table I. Renewable Resources and Production for West Virginia in 1997.

Note[1]	Item[2]	Data[3] J, g, $, ind/yr	Units	Emergy/Unit[4] sej/unit	Emergy[5] E20 sej	1997 Emdollars[6] E6 Em$
Renewable Resources						
1a	Sun, incident	3.07436E+20	J	1	3	252
1b	Sun, absorbed	2.64395E+20	J	1.16	3	252
2	Wind Kinetic Energy	3.58E+17	J	1470	5.3	431
3	Earth Cycle of uplift and subsidence	1.38757E+17	J	33700	47	3833
4	Rain, chemical potential energy received	3.32273E+17	J	18100	60	4946
5	Evapotranspiration, chemical potential absorbed	1.56E+17	J	28100	44	3599
6	Rain, geo-potential on land	3.66E+17	J	10300	38	3090
7	Rain, geo-potential of runoff	6.59777E+16	J	27200	18	1471
8a	Rivers, chemical potential energy received	9.05596E+16	J	50100	45	3731
8b	Rivers, chemical potential energy absorbed	2.89648E+14	J	50100	0.15	12
9a	Rivers, geo-potential energy received	4.9870E+16	J	27200	14	1117
9b	Rivers, geo-potential energy absorbed	2.05821E+16	J	27200	5.6	459
Production Using Renewable Resources						
10	Agricultural Products	1.76038E+16	J	30300	5	439
11	Livestock				28	1475
	Beef	3.69547E+15	J	680000	25	2060
	All other livestock	4.22689E+14	J	792000	3	274
12	Fish Production	7.21649E+11	J	1961800	0.014	1
13	Hydroelectricity	4.09E+15	J	156000	6	523
14	Net Timber Growth	2.10E+17	J	20600	43	3546
15	Timber harvest	2.29E+16	J	68700	16	1290
16	Ground water	9.49E+14	J	159000	2	124

[1] Note. Each item number corresponds to a footnote in a table where raw data sources are cited, assumptions stated, and calculations shown. The footnotes in this paper reference calculations presented in Campbell et al. (in review).
[2] Item. The name of the item is listed.
[3] Raw Data. For each line item the raw data is given in joules, grams, or dollars.
[4] Transformity. Transformities have been calculated for many items (Odum, 1996; Campbell et al., in review). Transformities in this paper are referenced to the planetary baseline, 9.26 E+24 sej y^{-1}, from Campbell (2000).
[5] Emergy. The solar emergy is the product of columns three and four. It can either be an emergy flow (sej y^{-1}) or an emergy storage (sej). The notation E20, used in engineering and computing, means 10^{20}.
[6] Emdollars. This number is obtained by dividing the emergy in column five by the emergy/money ratio for the country or state in the selected year (1.22 E+12 sej/$ for the United States in 1997). The monetary unit depends on the country under analysis.

3. Results

The evaluated energy systems diagram of the macroscopic characteristics of West Virginia is shown in Figure 1. Pathways and interactions show the activities related to resources (e.g., production, consumption, import, export and the accompanying economic exchanges).

The emergy flows represented in the Figure 1 were further aggregated into an input-output summary or "three-arm" diagram. The three-armed diagram shows the environmental system simply as a black box receiving emergy from the local environment on the left, purchasing emergy from the main economy at the top, and then using this emergy to make products for export leaving from the right side. Used or degraded energy exits from the bottom of the box and carries no emergy (Odum, 1996). This simple picture was slightly more complex for West Virginia because much of the purchased emergy was from indigenous sources and a large fraction of the state's mineral production was exported without first being used in the state's economy. Many emergy indices can be calculated directly using these two figures. For example, using Figure 2 the investment ratio of emergy purchased outside to indigenous emergy use is (1301+262)/(155+556) or 2.2:1.

3.1 The Emergy Income Statement

The emergy income statement for West Virginia is given in Tables I–IV. The emergy and emdollar evaluations of the renewable natural resources and products of West Virginia in 1997 are shown in Table I. The numbered notes given in column one of Tables I through VI refer to calculations and documentation found in Campbell et al. (in review) and at *http://www.epa.gov/aed/research/desupp3.html*. The chemical potential energy of rain on land was the largest renewable emergy source (60 E20 sej y^{-1}) followed by the chemical potential energy delivered to state borders in river flow (45 E20 sej y^{-1}). The largest emergy in renewable energy production in West Virginia in 1997 was timber growth (43 E20 sej y^{-1}).

Coal dominated energy and emergy production and consumption within the state in 1997 (Table II). The second largest production of energy and emergy was in electricity (98% of which was generated from coal[3]). Petroleum was the second largest energy consumed followed by natural gas and electricity. However, when these energy flows were multiplied by their transformities, electricity was the second largest emergy used followed by petroleum and natural gas.

Table II. Production and Use of Nonrenewable Resources for West Virginia in 1997.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E20 sej	1997 Emdollars E6 Em$
Fuels and renewables used in a nonrenewable manner						
17	Coal Production	4.64E+18	J	39200	1819	149089
18	Coal Used in the State	9.9E+17	J	39200	388	31810
19	Natural Gas Production	1.9E+17	J	47100	89	7335
20	Natural Gas Used in the State	1.7E+17	J	47100	80	6563
21	Petroleum Production	9.2E+15	J	53000	5	400
22	Petroleum Used in the State	2.3E+17	J	64700	149	12198
23	Electricity Production	3.3E+17	J	196000	647	53016
24	Electricity Used in the State	9.4E+16	J	196000	184	15102
25	Clay	1.5E+11	g	1.9E+9	3	244
26	Sand and Gravel	1.7E+12	g	1.3E+9	22	1796
27	Limestone	1.2E+13	g	9.8E+8	118	9680
28	Sandstone	8.6E+8	g	9.8E+8	0.01	1
29	Soil Erosion of agricultural areas	4.0E+15	J	72600	3	238

Table III. Imports to the West Virginia Economy in 1997.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E20 sej	1997 Emdollars E6 Em$
30	Coal	2.32E+17	J	39200	91	7454
31	Petroleum	2.173E+17	J	64700	141	11532
32	Natural Gas (Received at State Border)	1.97E+18	J	47100	928	76055
33	Iron Ore	4.41E+13	J	60800000	27	2198
34	Alumina/Bauxite	2.19E+13		14700000	3	264
35	Services Embodied in the Goods	2.50E+10	$	1.22 E+12	305	25000
36	Material in the Goods	Various	J or g	Various	948	77705
37	Services	4.0E+09	$	1.22E+12	49	4000
38	Tourism	4.0E+09	$	5.72E+12	229	18754
39	Federal Government	1.04E10	$	5.72E+12	595	48761

The largest emergy imported to West Virginia was carried by the materials in goods (Table III). Ignoring the large flux of natural gas, which passes through the state, the second and third largest emergy imports were the services embodied in those goods and the emergy in petroleum fuels. The state imported some coal for electric power generation, alumina and bauxite for aluminum production and iron ore for steel production. Tourist dollars spent in West Virginia generated an emergy flow within the state greater than that imported in petroleum.

Coal accounted for the largest amount of emergy exported (Table IV) followed by the emergy of the materials in exported goods, electricity, and the services embodied in the goods exported. Coal and electricity generated from coal accounted for 63% of the emergy exported. West Virginia is also an important state for transporting natural gas as indicated by the large emergy flows of natural gas received and delivered at state borders. We assumed that West Virginia exports the natural gas it produces in excess of consumption.

Table IV. Exports from the West Virginia Economy in 1997.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E20 sej	1997 Emdollars E6 Em$
40	Coal	3.82E+18	J	39200	1497	122741
41	Natural Gas (Production Exports)	6.65E+15	J	47100	3	257
42	Natural Gas (Delivered at state border)	2.08E+18	J	47100	980	80302
43	Electricity	2.35E+17	J	196000	461	37754
44	Steel	2.00E+12	g	3380000000	68	5541
45	Services Embodied in Goods	2.72E+10	$	1.22E+12	372	30492
46	Material in Goods	Various	J or g	Various	776	63798
47	Services	5.80E+08	$	1.22E+12	7	580
48	Migration (net emmigration)	9851	Ind.	Various	17	1424
	Preschool	131	Ind.	3.3E+16	0.04	4
	School	7052	Ind.	9.2E+16	7	535
	College Grad	2327	Ind.	2.7E+17	6	526
	Post-College	341	Ind.	1.3E+18	4	360
49	Federal Taxes	6.85E+9	$	1.22E+12	84	6850

Table V. Assets of West Virginia in 1997.

Note	Item	Data J, g, $, ind/yr	Units	Emergy/Unit sej/unit	Emergy E20 sej	1997 Emdollars E6 Em$
49	Forest Biomass	1.04E+19	J	28200	2933	240393
50	Coal	1.42E+21	J	39200	556640	45626230
51	Petroleum	1.19E+17	J	53000	63	5170
52	Natural Gas	3.13E+18	J	47100	1474	120839
53	People	1816000	Ind.	Various	3837	315570
	Preschool	21952	Ind.	3.3E+16	7	602
	School	1181525	Ind.	9.2E+16	1089	89587
	College Grad	383808	Ind.	2.7E+17	1054	86686
	Post-College	51036	Ind.	1.3E+18	656	53929
	Elderly (65+)	159518	Ind.	1.7E+17	270	22183
	Public Status	18160	Ind.	3.9E+18	700	57568
	Legacy	792	Ind.	7.7E+18	61	5015

3.2 The Emergy Balance Sheet

Table V shows the emergy stored in some of West Virginia's economic, environmental, and social assets. By far the greatest stored wealth in West

Virginia is in its coal reserves. The second largest storage of emergy is in the knowledge held by its people (Odum, 1996). Also, there are large accumulations of wealth in the forests and natural gas reserves.

Table VI. Summary of Annual Emergy, Dollar, and Emdollar Flows for West Virginia in 1997.

Note	Letter in Fig. 2	Item	Emergy E20 sej	1997 Dollars E9 $	Emdollars E9 Em$
54	R_R	Renewable emergy received (Tab. 2, 3+4+8a)	152		12.46
54	R_A	Renewable emergy absorbed (Tab. 2, 5+7+8a+8b)	68		5.55
55	N	Nonrenewable source flows	2059		168.77
56	N_0	Dispersed Rural Source	3		0.24
57	N_1	Mineral Production (fuels, etc.)	2056		168.52
58	N_2	Fuels Exported without Use	1500		122.95
59	F	Imported Minerals (fuels, etc.)	262		21.48
60	F_1	Minerals Used ($F+N_1-N_2$)	818		67.05
61	F_2	In State Minerals Used (N_1-N_2)	556		45.57
62	G	Imported Goods (materials)	948		77.70
63	I	Dollars Paid for all Imports		29	
64	I_2	Dollars Paid for Service in Fuels		1.7	
65	I_3	Dollars Paid for Service in Goods		23.3	
66	I_4	Dollars Paid for Services		4.0	
67	I_5	Dollars Spent by Tourist		4.0	
68	I_6	Federal Transfer Payments		10.4	
69	PI	Imported Services Total	353		28.93
70	PI_1	Imported Services in Fuels	21		1.72
71	PI_2	Imported Services in Goods	283		23.20
72	PI_3	Imported Services	49		4.02
73	B	Exported Products (goods + elec.)	1237		101.39
74	E	Dollars Paid for Exports		31.1	
75	E_1	Dollars Paid for Goods		26.6	
76	E_2	Dollars Paid Fuel Exported		3.9	
77	E_3	Dollars Paid for Exported Services		0.6	
78	E_4	Federal Taxes Paid		6.85	
79	PE	Total Exported Services	379		
80	PE_1	Exported Services in Fuels	48		
81	PE_2	Exported Services in Goods	324		26.23
82	PE_3	Exported Services	7		5.74
83	PE_4	Emergy Purchased by Tourists	228		18.69
84	PE_5	Emergy Purchased by Federal $	203		16.64
85	X	Gross State Product		38.3	

3.3 Emergy Indices

Table VI summarizes the flows of emergy and dollars that characterize the West Virginia economy. It lists all of the quantities needed to calculate the emergy indices presented in Table VII. Key emergy indices that characterize the state are the emergy to money ratio (5.72 E12 sej/$), the investment ratio, (2.2:1), the environmental loading ratio (14:1), the ratio of exports to imports (2.0:1), and the ratio of emergy in electricity use to the total emergy used (0.084).

Table VII. West Virginia Emergy Indices for 1997.

Note	Name of Index	Expression	Quantity	Units
85	Renewable Emergy Received	R_R	1.52E+22	sej y^{-1}
86	Renewable Emergy Used	R_A	6.8E+21	sej y^{-1}
86	In State Non-renewable	$N_0 + N_1$	2.059E+23	sej y^{-1}
87	Imported Emergy	F + G + PI	1.563E+23	sej y^{-1}
88	Total Emergy Inflows	R_R + F + G + PI	1.715E+23	sej y^{-1}
89	Total Emergy Used	$U = R_A+N_0+F_1+G+PI$	2.190E+23	sej y^{-1}
90	Total Exported Emergy	$B+ PE +N_2$	3.116E+23	sej y^{-1}
91	Emergy Used from Home Sources	$(N_0+F_2+ R_A)/U$	0.29	
92	Imports-Exports	$(F+G+PI)-(B+PE+N_2)$	-1.55E+23	sej y^{-1}
93	Ratio of Exports to Imports	$(B+PE+N_2)/(F+G+PI)$	2.00	
94	Fraction of Use, Locally Renewable	R_A /U	0.031	
95	Fraction of Use, Purchased Import	(F + G + PI)/U	0.71	
96	Fraction Used, Imported Service	PI/U	0.16	
97	Fraction of Use that is Free	$(R_A+N_0)/U$	0.032	
98	Ratio of Purchased to Free	$(F_1+G+PI)/(R_R+N_0)$	13.7	
99	Environmental Loading Ratio	$(F_1+N_0+G+PI)/(R_R)$	14	
100	Investment Ratio	$(F+G+PI)/(R_R+N_0+F_2)$	2.2	
101	Use per Unit Area	U/Area	3.51E+12	sej m^{-2}
102	Use per Person	U/Population	1.21E+17	sej/ind
103	Renewable Carrying Capacity at Present Standard of Living	$(R_R$ /U)*(Population)	126,042	Ind.
104	Developed Carrying Capacity at Same Living Standard	8(R/U)(Population)	1,008,336	Ind.
105	WV State Econ. Product	GSP	3.83E+10	$/yr
106	Ratio of WV Emergy Use to GSP	U/GSP	5.72E+12	sej/$
107	Ratio of U.S. Emergy Use to GNP	U/GNP	1.22E+12	sej/$
108	Ratio of Electricity/Emergy Use	El/U	0.084	
109	Ratio Elec. Prod./Emergy Use	Elp/U	0.295	
110	Emergy of Fuel Use per Person	Fuel Use/Population	3.39E+16	sej/ind
111	Population		1.816E+6	Ind.
112	Area		6.236E+10	m^2

4. Discussion

Standard accounting tools such as the income statement and balance sheet are used to document the financial health of business and it is no less important that we develop and test similar tools to assess the condition of environmental systems. Emergy accounting provides the means to keep the accounts for the economy, society, and the environment on the same income statement and balance sheet. Information from the emergy accounts for West Virginia was used to answer questions posed by environmental managers that are given below.

4.1 Questions from Environmental Managers

The following questions were derived from interactions among the scientists and environmental managers, who are the authors of this paper, with the help of others who are listed in the Acknowledgments: 1) “What is the current level of economic investment in relation to West Virginia’s resource base? Is this level of investment sustainable?” 2) “What is the net exchange of real wealth between West Virginia and the nation?” 3) “What are the causes for any imbalance?” 4) “What actions can be taken to address the imbalance, if it exists?” 5) “How does West Virginia’s standard of living compare to other states and the nation?” 6) “Who benefits most from the use of the state’s resources?” 7) “How self-sufficient is West Virginia?” 8) “How can we manage the environment and economy of West Virginia to maximize the well-being of humanity and nature in the state and in the nation?”

4.2 Summary of Findings

In this section the findings of the West Virginia emergy evaluation are used to answer the managers’ questions. First, the question number is given and then relevant information from the analysis is presented.

1) West Virginia’s low investment ratio (2.2:1) and high environmental loading ratio (14:1) show that it is in a precarious position as a state with enough nonrenewable resources to support further economic development while currently suffering from the degradation of its renewable resources due to past and present economic activities. Development pressures can be expected to continue in the future, because West Virginia’s below ground assets, 9E14 sej m^{-2}, are 17 times greater than at an average location in the U.S. (Odum et al., 1987). The high environmental loading ratio indicates that further industrial development may not result in an improvement in the overall quality of life experienced by most West Virginians without major programs to restore and protect the environment. Only 9% of the current population can be sustained at the 1997 standard of living on the state’s renewable resources alone.

2) Emergy accounting showed that West Virginia supplies a large emergy subsidy to the nation. In 1997 West Virginia exported twice as much emergy as it received in return, resulting in an imbalance of 1.56 E23 sej y^{-1} or 71% of the annual emergy used in the state. In contrast, the monetary exchange between West Virginia and its trading partners was more balanced. The dollar value of West Virginia exports exceeded imports by $2.1 billion, which was 5.5% of the Gross State Product (GSP) and the ratio of the dollar value of exports to imports was only 1.07:1.

3) The emergy of coal exported without use accounted for almost all of the difference between imports and exports. 4) West Virginia received

3.56 billion dollars in net transfer payments from the federal government, and while this money was 170% of the dollar value of the excess exports, it made up only 13% of the existing emergy deficit when converted to emergy using the West Virginia emergy to dollar ratio. The question of the equity of exchange between West Virginia and the nation needs to be resolved.

5) Quality of life as measured by the emergy use per capita appears to be high, but many social indicators are depressed (CVI, 2002). This paradoxical state could occur if the benefits of high emergy use fail to reach the majority of people due to unusual or anomalous conditions. Two such conditions exist in West Virginia, which may explain the paradox: a) Much of the emergy used in the state is heavily concentrated in power generating centers and urban areas making electricity and chemical products for export. b) In contrast, 58% of the people live in rural areas and many of these people do not receive much benefit from the intense empower flows of the developed areas. Another indicator, the ratio of the emergy in electricity use to total emergy use, shows the standard of living in West Virginia to be 50% lower than the average for the United States, North Carolina, Maine, Texas, and Florida (Campbell et al., in review). Social and economic quality of life measures (CVI, 2002) reinforce the emergy data (e.g., the state was 49th in per capita income in 1997).

6) The quantities and destinations of coal and electricity exported show that much of the annual emergy flow in West Virginia supports the higher standards of living found in surrounding regions receiving these resources. Also, the benefits of past economic activities within the state have not contributed proportionately to the standard of living of the people when compared to many other states and the nation (Campbell et al., in review). Absentee ownership of much of West Virginia's vast coal and timber resources appears to have been a factor in the historical impoverishment of the state (Clarkson, 1964; Rice, 1985). The bottom-line of this emergy analysis is that, at present as in the past, more real wealth is taken from the environment and people of West Virginia than is returned.

7) Removing the large emergy exports of coal and electricity from the exchange balance makes West Virginia look like a typical emergy importing state such as Maine or North Carolina, which have similar support from home sources (Campbell, 1998; Tilley, 1999). Without these exports, imported emergy exceeds export by 12.6%. By exporting coal and electricity West Virginia provides energy independence and a high stan-

dard of living for neighboring regions and the nation, while the state's economy as a whole is very dependent on the national economy and many West Virginians live in poverty. The state's potential for self-sufficiency in a lower energy future (Odum and Odum, 2001) may be more accurately shown by the fact that 68% of 1997 energy use in the state was supplied from home sources and 83% of the coal mined was exported. With coal reserves that will last 300 years at the current rate of use, West Virginia is potentially one of the nation's more self-sufficient states.

4.3 Emergy Accounting and Environmental Decision-Making

Financial managers have a clear goal in overseeing the operations of a business—to maximize profits and shareholder value. Energy Systems Theory provides a parallel maximal principle, which managers should consider in making decisions on environmental policy. In this method, policy outcomes are compared based on the total environmental, economic, and social empower realized under each alternative. The maximum power (empower) principle (Lotka, 1922; Odum, 1996) indicates that those systems which maximize empower in their networks will be the ones that prevail in evolutionary competition with alternatives. Emergy accounting and simulations allow scientists to quantify the empower relations among environmental systems with alternative designs. Maximizing empower for the entire system gives a clear unified criterion for decision-making and provides an answer to the eighth question given above. The wide-spread use of this criterion by environmental managers may help society avoid the expense of costly trials and errors, which are often required under present decision-making methods.

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