J. ENVIRON. SYS., Vol. 4(2), Summer, 1974

ENVIRONMENTAL IMPACT: PART 2–
Assessment for Twelve Selected Nations

DR. PETER NEWMAN
Environmental and Life Sciences
Murdoch University
Western Australia

AUTHOR'S NOTE

The model, presented in Part 1 for assessing environmental impact in a semi-quantitative fashion, is used to calculate the approximate damage caused by twelve selected nations. The major contributions to global impact are seen to be from USA and USSR but damage to national environments is greater in Western Europe and Japan. The two components of environmental impact, exotic energy use per capita and population density are used to explain this and to suggest an approach as to how the different problems of developing and industrial countries can be made. The exotic energy flow in these countries is compared with the energy flow of Paleolithic and early Neolithic societies and with natural ecosystem energy flow due to photosynthesis.

Introduction

A semi-quantitative parameter was developed to measure environmental impact or ecosystem damage based on the theory of disturbances affecting ecosystem succession, in Part 1. Such disturbances, as far as they are caused by man's activities, were shown to be directly or indirectly related to man's use of exotic energy. Environmental impact (I) was therefore defined as

$$\frac{\text{Exotic energy use (E)}}{\text{Area of environment (A)}};$$

this was further developed to show that

$$I = \frac{E}{P} \times \frac{P}{A}$$

where P is population, thus highlighting the two major components of

doi: 10.2190/1FVR-C4YJ-KUYW-98HJ
http://baywood.com

environmental impact as exotic energy use per capita and population density. In this paper the formula is used to assess the environmental impact of twelve selected nations chosen to illustrate a range in state of development, agricultural productivity, land mass, population size, and population density.

Method of Calculation

Certain clarifications are required to show what data are necessary in the calculation of this parameter for ecosystems the size of nations.

First, exotic energy use comes from two sources: the consumption of fuel and net imported food. For fuel consumption, data are readily available [1]; this includes sources such as nuclear and hydro but in the countries considered these were always less than 5% of the total, so fuel will generally be referred to as fossil fuels. A figure on total consumption of fossil fuels is necessary for the parameter, but for food, only net imported quantities are required, i.e., imports minus exports. As explained in Part I, food energy produced and consumed in an environment does not in itself lead to ecosystem damage, the steady state material cycles remain essentially in balance, and with no exotic energy available man is restricted to hunting, food gathering, and subsistence agriculture so that both his ability to damage the environment and his population density are considerably limited. Imported food energy means an increased scale of activities and population density are possible, i.e., a nation which imports food is increasing its environmental impact. In the same way, a nation that exports food energy can be said to cause a decrease in environmental impact, seen as the export of people, their waste products, and activities associated with and derived from the food energy. Environmental impact caused by the intensive agriculture required for a nation to export food, is accounted for by the fossil fuel consumption of agriculture. So, as far as damage to the environment from exotic food energy is concerned, it is necessary to find net imported quantities; such trade data are also readily available [2]. The import and export of machinery does not constitute a flow of energy of comparable magnitude to food, because although these materials contain a certain potential energy due to their negative entropy or information content, it is negligible compared to the quantities under consideration, e.g., the potential energy contained in a computer is only a minute fraction of the energy required to make it and to operate it [3]. Therefore total fuel and net imported food consumption accounts for the environmentally significant energy flow in a nation.

The second clarification necessary concerns the area of a nation. Man's energy using activities are concentrated in cities, agricultural areas and to some minor degree in recreational areas. In this study, area is taken to be the usable land area in a country, i.e., it does not include desert, tundra or mountain (rock) areas as these are considered to be subject to little pressure from man's energy and population. The highly specific flora and fauna of these regions in general has to cope with far greater natural disturbances than those from man, although recreational vehicles are beginning to change that [4]. Usable area is therefore taken to include all arable land, urban areas, permanent pasture and grassland, water areas and forest; data for this are easily available [5] except for urban areas, which need to be estimated.

Results

Environmental impact information was calculated for the twelve selected nations for the year 1969 and is presented in Table 1.

Discussion

The twelve countries are listed in Table 1 in terms of environmental impact on their own ecosystems. Before examining this it is worthwhile to discuss some of the component quantities, listed in the other columns, that were used for the final calculation.

A comparison of the first two columns reveals that total exotic energy flow is primarily from fossil fuel sources but that exotic food energy is far from negligible. In the case of U.S.A. it is just a little more than 1% of the fuel energy, in other cases the exotic food is from 3% to 30% of the fuel energy, with most developed countries being around 10%. The extreme value for the U.S.A. would seem to be due to its high material consumption patterns but also its status as the highest net exporter of food, a status which could not be achieved without large fuel consumption by agriculture. These two columns also give some indication of the global dependence on fossil fuels, even in places like Afghanistan and Tanzania.

The total exotic energy flow can be viewed as a country's global environmental impact, as there is an implicit $\frac{E}{A}$ with A being global area. It represents the contribution of a country to global problems such as atmospheric CO_2 and particulates, chemical poisoning of the oceans, loss of genetic diversity on a global scale and so on [7], each directly or indirectly related to exotic energy flow as previously depicted. From this perspective U.S.A., U.S.S.R., U.K., and Japan are the worst offenders. Exotic energy flow per capita shows the global environmental impact of an average person from the selected nations. The six developed nations show an order of magnitude greater impact per person than the six developing nations. A useful comparison can be made with the energy flow used by an average person living without exotic energy sources, i.e., a hunter-gatherer or someone who lives by incipient agriculture. A value of 2,800 Kcals per day represents average survival needs involved in strenuous activities like hunting or farming [8] for such a person; thus over a year this person, in a steady state relation to the environment, would use approximately $10^6 \frac{\text{Kcals}}{\text{person-yrs}}$ of energy. Exotic energy flow is superimposed on top of this as the energy with which that person causes environmental damage. Therefore, the column containing exotic energy per capita, when divided by 10^6, indicates the

Table 1. Environmental Impact Information For 12 Selected Nations Using Data from 1969

Country	Fuel[b] energy 10^{12} Kcals/yr	Net[c] exotic food energy 10^{12} Kcals/yr	Total exotic energy (E) 10^{12} Kcals/yr	Exotic energy per capita (E/P) 10^6 Kcals/pers-yr	Population[d] (P) (10^3)	Area (A)[d] (Km^2)	% Useable Area[d]	Population density[e] (P/A) persons/Km^2	Environmental Impact (I) i.e. $\frac{E}{P} \times \frac{P}{A}$ (10^6 Kcals/Km^2-yr)
Netherlands	412.8	+ 28.1	440.9	34.3	12,873	40,844	99	318	10,898
U.K.	1,968	+105	2,073	37.3	55,534	244,013	95	240	8,959
Japan	1,991	+152	2,143	21.0	102,321	369,881	80	346	7,249
U.S.A.	15,063	−169	14,894	73.3	203,213	9,363,353	90	24	1,759
U.S.S.R.	6,950	− 62.4	6,888	28.6	240,567	22,402,200	70	16	450
Cuba	59.8	− 17.6	42.2	5.12	8,250	114,524	99	73	374
India	713.9	+ 37.4	751.3	1.40	536,985	3,268,090	80	205	287
Malaysia[a]	28.0	+ 5.5	33.5	3.72	9,000	131,313	95	73	272
Australia	439.9	− 44.2	395.7	32.2	12,300	7,686,810	70	3	92
Brazil	300.9	− 40.3	260.6	2.87	90,840	8,511,965	98	11	32
Afghanistan	3.0	+ 0.5	3.5	0.21	16,516	647,497	25	104	22
Tanzania	5.1	+ 0.3	5.4	0.42	12,926	939,703	98	14	6

[a] Data is for West Malaysia.

[b] Data on consumption of fuel energy was obtained from Reference 2 and converted into Kcals using 1 metric ton coal equivalent = 6.88 × 10^6 Kcals.

[c] Net exotic food energy, or food imports minus exports, was obtained from Reference 3 as dry weight; based on data from Odum [6] it was converted into Kcals using 1 metric ton food = 5.0 × 10^6 Kcals.

[d] Statistics on population and area were found in Reference 2 and percentage usable area from Reference 6 with an estimate of how much land was in urban use.

[e] Population densities are from Reference 2 with adjustments for usable land area.

incremental increase in energy use of an average person from these countries compared to a person in a steady state situation like a Paleolithic hunter; i.e., there is a range in increase from 73 times for U.S.A. to 0.2 times for Afghanistan.

To gain a full picture of the environmental impact of a nation on its own ecosystem requires the extra factor of population density as well as exotic energy use per capita. When these are multiplied, the order given in Table 1 results.

The Netherlands, U.K., and Japan have the greatest impact because they have both high exotic energy use per capita and high population density. These countries are characterized by environments which are almost totally modified by man, with little natural vegetation and few free-living animals, i.e., the ecosystem diversity is reduced so that most energy and material flows are directed towards man and his activities. This results in a highly productive environment and it can also be quite beautiful but this is at the expense of high pollution levels and little natural flora and fauna. Also natural ecosystems with low diversity and high entropy are usually biologically unstable [9]; the meaning of this for a national ecosystem is uncertain but the instability being shown today in high technology [10] and energy intensive agriculture [11] could certainly give some indication.

U.S.A. and U.S.S.R. have high exotic energy use per capita but their low population density due to large areas of usable land, means that overall national environmental impact is not so severe. This does not mean that isolated areas are not heavily damaged, especially in areas of high population density where pollution levels are notoriously bad. So, as far as public health aspects of environmental damage are concerned, U.S.A. and U.S.S.R. may well be as bad or worse than those countries above them; however it is interesting that these two countries which contribute the most to global environmental impact have comparatively fewer problems over their own total environment than in western Europe and Japan.

India is a classic example of a country with extremely low exotic energy use per person (third lowest) but its population density means that environmental impact is increased considerably. It is worthwhile to compare India and U.S.A. as is done in Table 2.

Table 2. Comparison of U.S.A. and India for Relative Components of Environmental Impact

	(E/P)	*(P/A)*	*(E/P × P/A)* i.e. *(I)*
U.S.A.	52	1	6
India	1	8.5	1

Even though an average American uses fifty-two times more exotic energy than an average Indian, the eight-and-a-half times greater population density of India means that the estimated overall environmental damage of U.S.A. is only six times that of India. Problems from sewage-polluted rivers and overgrazing have the same overall effect on ecosystems as industrial effluents and highways. A similar but not so extreme situation holds for Cuba and Malaysia as in India.

Brazil and Australia have low environmental impact in their ecosystems due to the large areas of land that are still untouched, Brazil's higher population density being balanced by Australia's higher exotic energy use per person.

Afghanistan and Tanzania are examples of developing countries that have minor environmental damage, with Afghanistan's almost negligible exotic energy per capita being magnified relative to Tanzania by the effects of a large population and small usable area. The problems of these types of countries, however, are not so much from environmental impact due to man, but more in not being able to cope with the impact of the environment on them through disease and famine. Their dilemma can also be seen using the present model. Exotic energy flow indicates not only man's damage to ecosystems but also his degree of control over the environment, so in countries which are characterized by an extremely small exotic energy flow per capita, the only other way to gain some control over their environment is with population density—thus people are seen as the major source of energy, e.g., for producing food and fighting disease. This gives an insight into why family sizes are so much bigger in these areas and why a transition to smaller families occurs when a higher state of industrial development is achieved, i.e., exotic energy per capita is increased making less people-energy necessary. A demographic transition achieved in this way can easily backfire though, due to the time-lag in exploding populations giving rise to severe resource and environmental problems from the burgeoning population pressure [12].

A comparison between the countries listed in Table 1 and the minimal level of environmental impact by man in a steady state situation can be deduced from the following data: subsistence level energy for a person, as estimated previously, equals $10^6 \frac{\text{Kcals}}{\text{person-yr}}$, and population density for tribes of hunter-gatherers has been estimated as 0.1 persons/km^2 [13] (although this figure varies to some degree with the habitat it is essentially constant) [14]. The environmental impact of Paleolithic man is therefore estimated as approximately $10^5 \frac{\text{Kcals}}{\text{Km}^2\text{-yr}}$ and the countries in Table 1 range in comparison of their environmental impact from 100,000 times to 60 times that of a Paleolithic population living at a steady state subsistence level. An increase of population density by a factor of ten is provided by subsistence agriculture [14] thereby giving an environmental impact of approximately $10^6 \frac{\text{Kcals}}{\text{Km}^2\text{-yr}}$ for early Neolithic man (pre commerce).

A further comparison in energy flow can be made between the selected countries and natural ecosystem energy flow fixed by photosynthesis over a particular area. Table 3 gives an average set of values for the photosynthetic

Table 3. Ecosystem Energy Flow Due to Photosynthesis, Based on Odum [6]

Gross primary productivity (photosynthesis) in $\frac{\text{Kcals}}{\text{Km}^2\text{-yr}}$ (X 10^6)	
Desert and Tundra	200
Grasslands and pastures	2,500
Dry forests	2,500
Coniferous forests	3,000
Non-mechanized agriculture	3,000
Moist Temperate forests	8,000
Mechanized agriculture	12,000
Tropical forests	20,000

energy passing through an ecosystem[6] revealing that the exotic energy flows of many nations fall within the same range. With this scale of activity it is small wonder that man is causing such severe damage to his environment.

The picture is summarized in Figure 1 showing Paleolithic and early Neolithic man's energy use, photosynthetic energy flow, and how each nation fits into the range with its exotic energy flow.

A blueprint for the future optimization of the human condition must include both the ability to use and cope with the environment and the ability to enjoy it with minimum repercussions from its damage. This must mean that countries to the left of Figure 1, like Tanzania and Afghanistan, should be given assistance to increase their per capita exotic energy flow; countries like India in the same way,

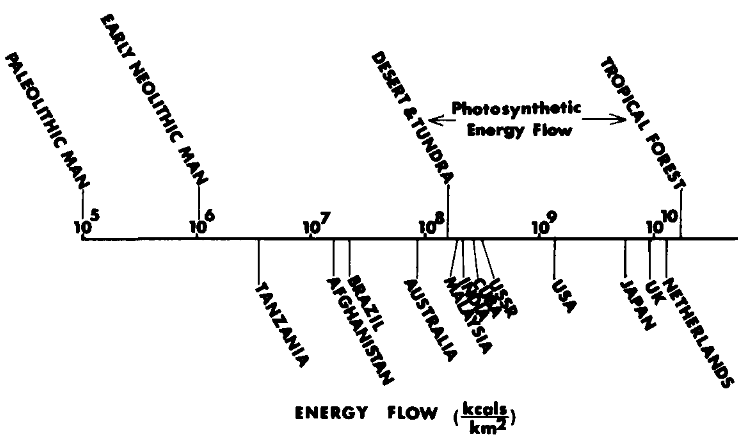

Figure 1. Comparison of exotic energy flow (1969) for selected nations with the energy flow of Paleolithic and early Neolithic Man and of natural ecosystems due to photosynthesis.

but they must also make great efforts to control their population as it threatens severe environmental deterioration. Those countries like the Netherlands, U.K., and Japan to the right of Figure 1, must exercise extreme control over their population and their exotic energy use; together with the other high exotic energy per capita developed countries like U.S.A., U.S.S.R., and Australia. The most obvious way for these countries to optimize the global human condition is to cut down their own wasteful use of exotic energy and encourage the wise use of energy in developing countries. Now that energy (food and fuel) is no longer cheap or readily available it is essential that there be careful management of energy use from an economic and environmental perspective.

As environmental deterioration can also be seen as decreasing the ability of the environment to support future generations through irreparable losses of soil, waterways, and other non-renewable resources, it is possible to see this analysis not only in terms of optimizing the human condition but also as essential steps in the future survival of mankind [15].

ACKNOWLEDGMENT

The author wishes to thank Professors Paul R. Ehrlich, John P. Holdren and J. W. M. La Riviere for valuable suggestions in the development of this paper.

REFERENCES

1. *Statistical Yearbook, 1970*, United Nations, New York, 1971.
2. *Yearbook of International Trade Statistics–1969*, United Nations, New York, 1971.
3. M. Tribus and E. C. McIrvine, *Scientific American*, 225: 179, 1971.
4. J. Carter Luther, *Science*, 183: 396, 1974.
5. *FAO Production Yearbook 1970*, United Nations, New York, 1971.
6. E. P. Odum, *Fundamentals of Ecology*, 3rd Ed., Saunders, Philadelphia, 1971.
7. MIT Report, *Man's Impact on the Global Environment*, MIT Press, Cambridge, Massachusetts, 1970.
8. N. Pace, *Environmental Biology and Medicine*, 1: 165, 1971.
9. R. Margalef, *The American Naturalist*, 897: 357, 1963.
10. G. Rattray Taylor, *Ecologist*, January, 1974.
11. W. C. Paddock, *Bioscience*, 20: 16, 1970.
12. P. R. Ehrlich and A. H. Ehrlich, *Population, Resources, Environment*, 2nd Ed., Freeman, San Francisco, 1972.
13. L. L. Cavalli-Sforza and W. F. Bodmer, *The Genetics of Human Populations*, Freeman, San Francisco, 1971; J. B. Birdsell, *American Naturalist*, May-June, 1953.
14. E. S. Deevey, *Scientific American*, September 1960.
15. P. R. Ehrlich and D. C. Pirages, *Ark II*, Viking Press, New York, 1974.