Emergy and the Issue of Forestry and Wood Production

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Introduction

Humans have been using natural resources (e.g., food, hydrocarbons, minerals, timber, etc.) from the environment generally in a non-sustainable way, which caused increasing concern, as this situation ultimately threatens humanity's well-being.
According to Odum and Odum (1981), one possible way to deal with our future depends on how humanity may be able to combine energy, economics, and the environment into one system. This way, understanding that energy causes and maintains the array of nature (human beings part of it), it will be possible to make better economic and political decisions, and individuals can choose how to live in a world they understand. A key for understanding so much complexity is to realize how energy affects and maintains dynamic systems (1981).
One of the reasons why ecosystems of the world are threatened is because market-based valuations do represent their importance to human life-support. Both, people and ecosystems provide services but only one of them gets compensated; meaning that money is only paid to people for their contributions, and not to ecosystems for their service (Odum and Odum, 2000). Properly accounting for these "free services" from ecosystems has been difficult, mainly because ecosystems are not fully represented in market-drive economies.
In order to conduct ecological accounting, a biophysical method based on the analysis of the embodied energy has been proposed. Over five decades of work on ecological and general systems theory by H.T. Odum culminated in his notion that embodied energy (or emergy) could be used to compare the work of nature with that of humans on a fair and equal basis. This chapter reviews the fundamental concepts of emergy analysis as given by H.T. Odum starting with his seminal work, "Environment, Power and Society" (Odum, 1971). The concepts are demonstrated by depicting the relationship between forests and people.

Energy Systems

As universally stated, energy "is the ability to cause work, and work is defined as any useful energy transformation" (Odum, 1996). And energy may be classified as whether it is potential or kinetic. Potential energy is stored energy that has the capacity to drive a process that transforms energy from one form to another. Kinetic energy is the energy of movement. Each body possesses certain amount of kinetic energy, which depends on the speed of its motion and mass.

Laws of Thermodynamics

- First law of thermodynamics: energy can neither be created nor destroyed. Energy is conserved during transformations. Energy that goes into a system must either come out or stay inside. For example in Figure 1 energy flows into the forest from several sources (i.e., sunlight, water, nutrients) and energy is converted into biomass and degraded energy (plants respiration).

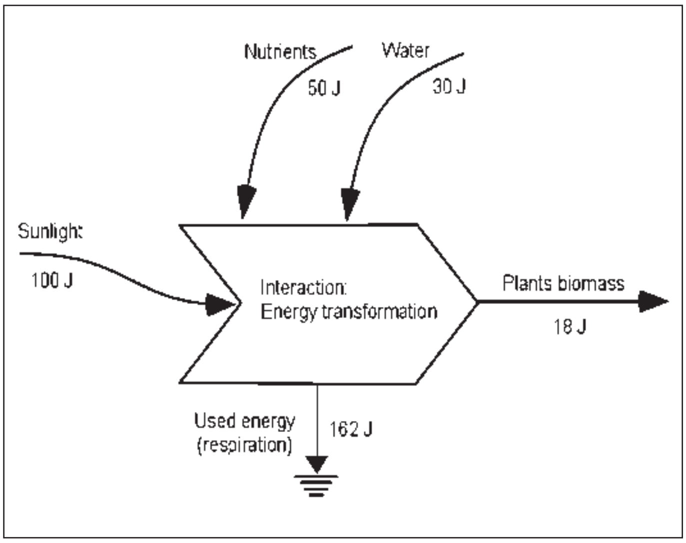

Fig. 1 - Example of a simple energy budget in the forest

- Second law of thermodynamics: all transformations of energy from one form to another leads to a loss in the ability of that energy to do work. Due to the second law, the ability of energy to work is lost, but according to the first law no energy is lost. This loss of ability results in an increase in entropy. The second law of thermodynamics tells us that the quality of energy is degraded every time energy is used in any process. This 'energy quality' has been named exergy.
  For example, the work of a tree in the forest results on most of its potential energy going into the soil when it is decomposed after dying. Some of its energy is retained as high quality genetic material (seeds) that were produced when it was alive and now they are young trees (Figure 2).

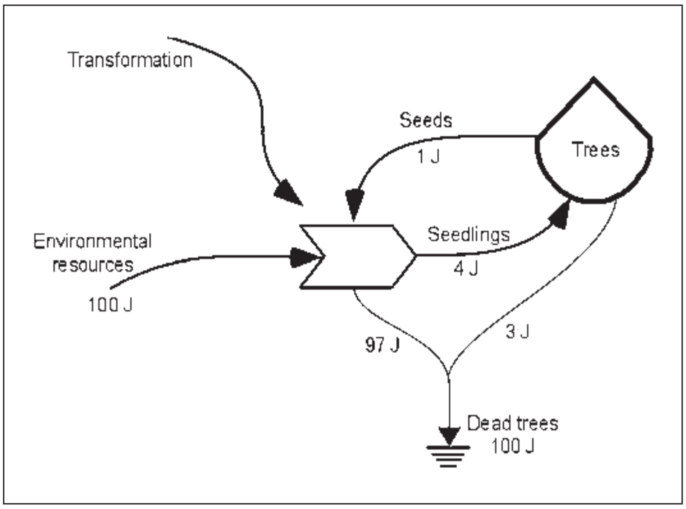

Fig. 2 - Example of a simple degradation of energy in the forest

- Third law of thermodynamics: absolute zero exists. Entropy at absolute zero is zero. As heat content approaches absolute zero (-273ºC) molecules are in crystalline states, and the entropy of the state is defined as zero.

Energy comes to our planet from the sun as ultra-violet radiation, visible light and near-infrared radiation, where it heats the seas, produces plant food, and indirectly generates winds, waves, and geologic uplift. It also made the ancient biomass that is today's coal and petroleum. Processing information from books, newspapers, television, and internet requires that energy be used.

Some activities, like education seem like small energy consumers because they apparently involve only people and not many fuel-using machines, but the energy involved in all the educational activities is large. Maybe because we are used to thinking of energy as physical work, we do not realize that the thinking process uses energy too. Much energy goes into educating the mind and maintaining the body to support the mind.

Different kinds of energy can be associated and/or compared using conversion factors which show how much of one kind of energy is equivalent to how much of another kind of energy (Odum and Odum, 1981). Connecting different kinds of energy, we can associate many parts and visualize complexity in a simple way. This is called the "systems" approach. In this approach, diagrams are used to visualize the systems, and from the diagrams calculations are made about flows and storages (Odum, 1996).

Energy Hierarchy

The concept of energy hierarchy refers to the fact that it takes more energy of one kind to generate another, higher quality form of energy. Sunlight, for example, is considered a dilute form of energy while others, like gasoline, and firewood, are concentrated forms of energy. In other words, many joules of available energy of a certain kind are required in a transformation process to produce a unit of energy of a higher quality form.

Odum utilized an analogy to explain energy transformation hierarchy: "*A hierarchy, such as a military organization, has many units of one kind (privates) that contribute to and are controlled by a unit at a higher level (corporals). Similarly, many corporals contribute to and are controlled by a unit at the next level (sergeant), and so on*" (Odum, 1996 pp. 18). Hence, one unit of dilute energy cannot be used in the same way as one unit of concentrated energy, and since it takes energy to concentrate energy, we must degrade some energy to concentrate what is left. Many units of dilute energy are needed to form one unit of concentrated energy. For example, four joules of coal are required for one joule of household electricity and 1,000 joules of sunlight maybe required to make one joule of wood.

According to Odum and Odum (1981), the total energy required for a product is the embodied energy in that product, which was the starting point for the development of emergy (spelled with an M) analysis as a new field of study.

What is Emergy?

The word emergy is a contraction of the term "embodied energy". The term was introduced in 1987 by D.M. Scienceman who also used emergy to refer to the concept of "energy memory" (Scienceman, 1987). As a systems concept, emergy was defined as "***the sum of all energy of one form needed to develop a flow of energy of another form, over a period of time***".

The emergy synthesis method was introduced by H.T. Odum in the 1980s with the aim of taking into account energy from different sources that participate in a process and allowing their comparison on a common basis. The problem of multi-quality inputs is solved by transforming them to an equivalent of energy of a single quality, which is usually solar energy (Tilley, 1999; Tilley and Brown, 2006). In other words, emergy expresses the cost of a process or a product in solar energy equivalents. The basic idea is that solar energy is our ultimate energy source and by expressing the value of products in emergy units, it becomes possible to compare different kinds of energy (Jorgensen *et al.*, 1995; Laganis and Debeljakb, 2006) using transformity. Howard T. Odum, based on the "Principle of Maximum Energy Flux" developed by Lotka (1922), proposed the "Fourth law of thermodynamics" as the Maximum Empower Principle (Odum, 1971). It states that self-organizing systems tend towards the maximization of useful power. This sometimes has been interpreted as increasing efficiency, but this may be the selection criteria of choice when new energy sources are scarce.

What is Transformity?

Like with emergy, the concept of transformity was first introduced by D.M. Scienceman in collaboration with Howard T. Odum. Scienceman (1987) proposed that the phrases, "energy quality", "energy quality factor", and "energy transformation ratio", all used by H.T.Odum, be replaced by the word "transformity".
Transformity is defined as "***the emergy of one kind required to make a unit of energy of another kind***". For convenience, all types of contributing energy are expressed in units of solar energy that would be required to generate all the inputs (Odum, 1996). For example, if 3 solar emjoules (sej) of sunlight and 1solar emjoule (sej) of nutrients are required to produce 1 joule (J) of wood, the transformity of wood is 4 sej/J.

What is Empower?

Empower is "***the flow rate of emergy***". According to Scienceman (1987), the time rate of change of emergy is empower, analogous to power that is the time rate of change of energy. Maximum empower therefore is the maximum flow rate of emergy.
Maximum empower has been proposed by Odum as a corollary of the maximum power principle suggested by Lotka in 1922 when he described the maximum power principle as an organizational law of evolution (Lotka, 1922; Odum, 1971).

Definition of a System

The word system refers to entity/objects, real or abstract, that function as a whole by the interaction of each and every component/element into organized parts. Thus, a subsystem is a set of elements which is a system itself and a part of a whole system.
Some examples of systems are: a house, which is a system of water pipes, electrical wires, rooms, building materials, and so on. A forest is an ecological system consisting of trees, soils, chemical cycles, wildlife, and microorganisms interacting so that the forest as a whole is sustained, and each of the major divisions of the forest constitutes a subsystem. Looking with greater detail, a tree has component cells and tissues which are also systems since they too have parts, the microscopic components of living cells. There are systems within systems within systems. Since we cannot consider everything at once, we must decide at what scale we are going to work. A convenient way to clarify the simplifications that humans need in their window of attention is the use of systems diagrams (Odum, 1998).
Systems Diagrams and Energy Flows
Systems diagrams can be used to represent the main inflows and outflows of energy. Figure 3 is a simple system diagram showing how the energy for wood production comes in with sunlight, rain, nutrients, the work of the logging company, the machinery, etc.; and how most of this incoming energy leaves the system as timber and dispersed heat which spreads out into the surroundings. The timber that goes out of this system has a higher grade of energy than the standing tree and in this form is useful to man.
Energy systems diagrams may be helpful for a better understanding of the laws of thermodynamics.

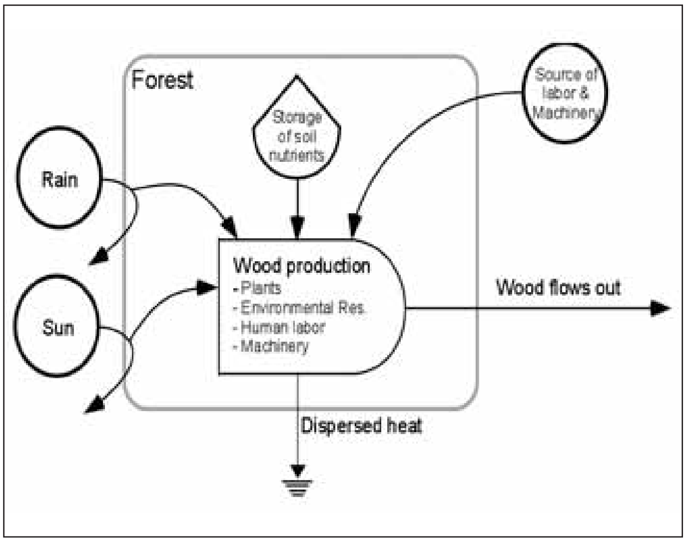

Fig. 3 - Energy flows necessary for a forest to produce wood *Redrawn from Odum and Odum, 1981*

In order to accomplish a complex work, many kinds of high-quality energy are required. And currently, we tend to think of the energy requirements in terms of fuel use, ignoring the contribution from nature and human beings, without realizing that the energy used in services and in obtaining the material may be larger than that of the fuels in many processes. Let's consider for example the energy required to make a piece of wooden furniture (a chair for example); which will include the energy involved in growing the tree, operating and maintaining the equipment for timber process, the energy used in manufacturing, operating and maintaining the machinery (Figure 4).
If we consider energy as a universal measure for all kinds of work performed by humans and nature, and agree that everything that happens is an expression of the flow of energy in one of its forms, then we can apply the basic laws of energy to all processes of nature and human beings, including economics, culture, and aesthetics.

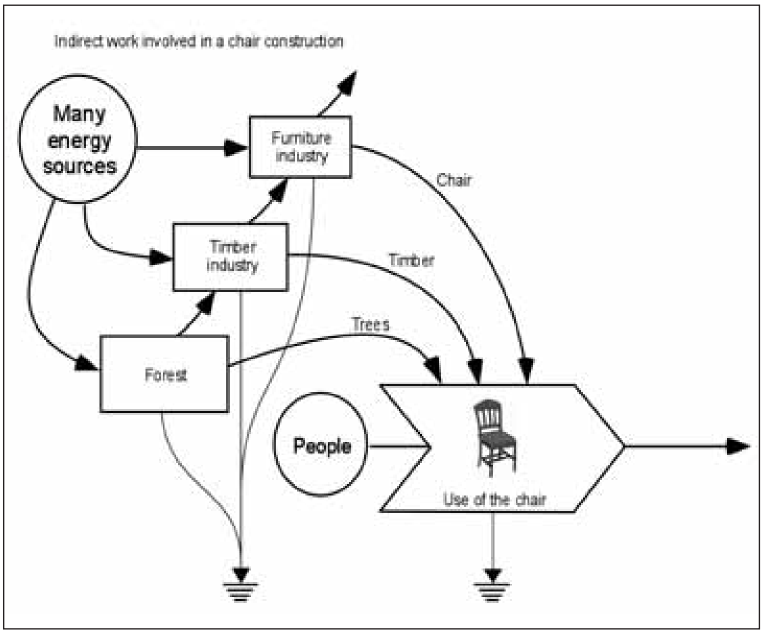

Fig. 4 - Energy flows required to manufacture a wooded chair *Redrawn from Odum and Odum, 1981*

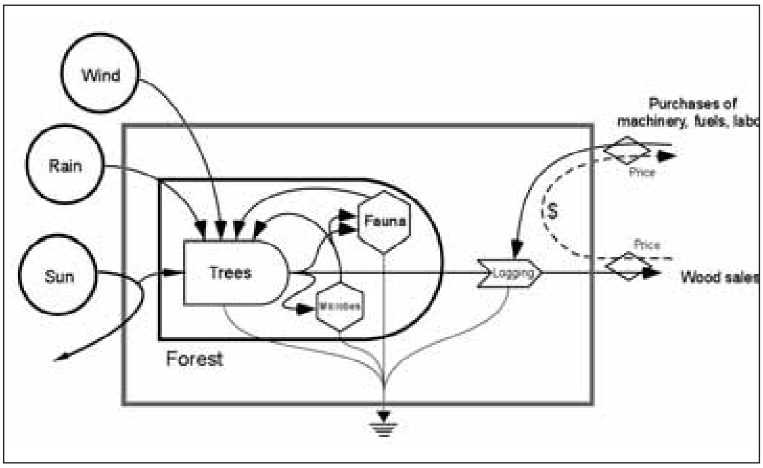

Fig. 5 - Work of a forest that supplies wood

According to Odum and Odum (1981) all the different sources of energy constitute the real basis of the economic system and are commonly named as externalities because these inflows come from outside the money circle.
Energy Flows without Money Flows
Figure 5 is an energy system showing a forest that supports people selling wood. Money is exchanged between people as a medium for keeping track of the exchange of wood and the services related to the provision of it. However, money is not exchanged between the parts of a natural ecosystem.

Economics

Most of the energy involved in developing the wood is in organic matter production based on the solar energy, the soil nutrients system, and the weather. Money is involved only in the last stages of the wood harvest and sale. Money in this case, like in most of the cases related with natural resources use, measures only the work of people, not the work of the forest. There should be a means to include energy as a measure of value of the wood that accounts for all contributions to the product, including those of forest, the loggers, people providing services, and those of nature.
Prices
Price is the ratio of money flow to goods flow. Money always flows in opposite direction to the flow of goods and the price can be set based on the costs of goods, costs of operations and the expected profit. Often the price is determined by markets. In order to make a profit, the amount of money the company pays for its costs must be lower than the money the company receives for its sales. Market prices are also regulated by demand or supply. In the case of wood, for instance, the amount of wood that people want to buy is called the demand and the amount of wood the logging company has to sell is called the supply. When there is more supply than demand, prices go down but if there is more demand than supply, prices go up (Odum and Odum, 1981).
Figure 5 shows also the relationship between the contribution from the environment and the economy. For wood production, the environment contributes with fuels, soil, air, water, sunlight, wind, etc., and the economic system contributes by feeding back goods, services, equipment, and fuels.

The price of wood does not recognize how valuable the environmental input is to the economy because it does not indicate how much of the main economy's money flow comes from the external inflow (from the forest). That is why the only way that the real value of an external input to the economy can be calculated is through the emergy evaluation.

Why Use Emergy?

Most people use money to judge the values of products for sale so money is everywhere to acquire goods and services. Money flows in circles while energy flows through a system generating work and ultimately it degrades to a form that is no longer capable of driving work. The flow of energy makes possible the circulation of money, and the manipulation of money can control the flow of energy. According to Odum, we must understand something about money and energy and their relationship in order to understand the economic system and the way energy affects it.

By now, it is clear that both energy and money are used to measure value and that energy and money flow in opposite directions (Figure 5). As wood produced on a forest goes to a town, people pay the logging company money that goes back to the extraction of wood. The logging company uses money to buy machinery and fuels from the town, sending the money back to town to pay for it.

This relationship forms a loop, where money circulates around and around and energy flows in as high grade potential energy and is used to maintain the structures of the wood-producing forest and town; however, as described before in the thermodynamic laws, most of the energy necessarily goes out as low-grade dispersed heat (Odum, 1971).

Human economic systems can produce materials and fuels to support populations and cultures. However, human beings are only a small part of the great biosphere (including: forests, oceans, mountains, valleys, land, rivers, and the atmosphere). Ultimately, it is not just human beings and their money that determine what is important; it is the world's energy. It would make, therefore, more sense to measure everything by the flow of energy, since only in this way nature can account for its contribution. In our example about logging, the money received by the timber company for its products pays only for the human work and the cost of using machinery but not for the work of sun, rain, soil, and wind.

Ratio of Energy to Money

Money can go around only if energy flows through the system to support the work that money buys.

The more work is done for each dollar that circulates, the more truly valuable the dollar is. Accounts for production systems based on natural resources cannot be kept in dollars alone, because environmental systems are based on the work of both humanity, which is paid for by a counter flow of dollars, and the work of ecosystems, for which no money is paid but energy can be used as a common denominator for quantifying all these flows.

Converting flows of energy and money into emergy puts the work done by humans and the environment on the same scale, so that economic and environmental flows are directly comparable. As stated by Brown and Ulgiati, emergy analysis is an accounting of social, economic and environmental flows in common terms on an objective basis (Brown and Ulgiati, 1999).

Emergy accounting may provide to environmental managers tools similar to those used by financial analysts to make business decisions. The development of emergy analysis will make possible for decision makers to examine and commensurate economic and environmental accounting data before making policy decisions about environmental systems.

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