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I. Introduction

In order to develop further Environmental Economics, and particularly Applied Environmental Economics, this paper focuses on three major topics. Welfare Economics is first concerned by means of the concept of External Effects and the policies for dealing with. Second, Environmental Economics is at issue through the concept of Environmental Externalities and the proposition of an enlarged economic paradigm. In a third step, the issue is on Applied Environmental Economics by means of the new concept of Energy Externality and the analysis for dealing with at the interface between systems of nature and society.

This article is thus an attempt to find a link between a human economy and its physical environment including an ecosystem and its external energy sources. The new concept of energy externality is proposed as an extension from the traditional concepts of external effects and environmental externalities.

II. External Effects and the Market Mechanism

An externality is defined as the case where a regular action of one economic agent (one consumer or one production-firm) incidentally affects the utility level of another consumer or the production possibilities of another firm in a way that is not reflected in the setting up of market equilibrium and in the definition of its optimality [Just et al. (1982); Pillet and Odum (1984)]. In general, policies for dealing with externalities are discussed regarding theoretical or applied welfare economics in terms of Pareto optimality, damage function, or social optimality. In the latter case, an externality is defined in a slightly different way, anticipating the most commonly encountered situation in policymaking—a compensation. A regular activity of any economic agent is said to generate a beneficial or a detrimental externality if that activity causes incidental benefits or damages to another consumer or producer, and no corresponding compensation is provided to or paid by that one who generates the external effect. In all those cases, external effects primarily indicate some market failure regarding either classical or neoclassical competitive price systems.

This section summarizes the formal definition of external effects in welfare economics, shortly recalls the common welfare policies in the presence of externalities, and outlines the special case of joint production of external diseconomies.
a) External Effects and the Pareto Optimum

In a perfectly competitive market, any single decision-maker cannot influence market prices and then any relevant event is subject to a market transaction. Externalities do not exist, or are ignored. Prices are equating marginal costs—there is no excess demand nor excess supply. As utility maximisers and profits maximizers, consumers and producers are satisfied in buying and selling goods. Thus, a competitive equilibrium exists, which is simply a set of prices such that all markets clear [Villet (1976); Just et al. (1982)].

As regards theoretical welfare economics, if such competitive equilibrium exists, it attains Pareto optimality. In other words, under required assumptions, competitive markets result in an equilibrium position from which it is impossible to find another allocation point without making someone worse off. Such a possible state of the economy is said to be a Pareto-optimal state, in other words a state which allows getting as much as possible for the society from its limited resources. This relationship between competitive equilibrium and Pareto optimality is a determinant one vis-à-vis the basic concept of economic externality insofar as a competitive economy will generally no longer attain a Pareto equilibrium in the presence of external effects.

To consider an example in consumption, let assume that the utility level of individual A depends upon the commodities he purchases, plus upon y₁ which is imposed upon him as an externality by individual B's consumption decision. A and B are maximizing their utility. Yet the effect of y₁ upon A's utility level is unpriced and will exist when

\[
\frac{\delta u_A}{\delta y_1} = \begin{cases} 
> 0 & \text{beneficial externality} \\
< 0 & \text{detrimental externality}
\end{cases}
\]

[2.1]

[Buchanan and Stubblebine (1962); Pillet (1976)].

b) Welfare Policies in the Presence of External Effects

External effects make sense in economics, first by their conceptual definition which statuates that a competitive equilibrium in the presence of externalities is Pareto suboptimal, and next by generating a move toward a new equilibrium point that will be Pareto optimum by means of welfare policy-making, especially regarding the application of a compensation principle to attain a social optimality. There are ways and means of doing it.

Internalization is an approach “commonly used to determine social optimality in the presence of externalities by considering all of the involved economic agents jointly, as for example, in a hypothetical merging of firms” [Just et al. (1982); see also Meade (1973)].

A bargaining process can be considered as another way of achieving an internalization and meeting a Pareto optimal competitive equilibrium. Such a situation confirms and matches up the approach of assignment of property rights in order to encourage the development of a market for the externalities.

To consider an example, suppose that a consumer-consumer externality exists between two individuals, i and j. Both of them are utility maximizers regarding Pareto optimality requirements. The market is a perfect competitive one.

Let the utility function of the first individual be given by

\[
 u_i = f(x_{i1}, ..., x_{in})
\]

[2.2]
and let his budgetary constraint be given by

\[ \sum_{k=1}^{n} p_k x_{ik} \leq m_i \]

where \( p_k \) is the price for \( k \) among \( n \) goods which have been already produced, and \( m_i \) the income of the individual \( i \). Assume, further, that the second individual, \( j \), faces a utility function which depends not only upon the commodities it purchases in the marketplace but is concerned with \( x_{i1} \), too; that is, \( x_{i1} \) is imposed upon it as an externality by the first individual's consumption decision. Thus we have

\[ u_j = f(x_{j1}, ..., x_{jn}, x_{i1}) \]

and

\[ \sum_{k=1}^{n} p_k x_{jk} \leq m_j \]

In general, individuals \( i \) and \( j \) maximize their utility regarding their budgetary constraint, as follows:

\[ \frac{1}{\lambda_r} \frac{\delta u_r}{\delta x_{rk}} \left| \begin{array}{l} x'_{rk} - p_k \{ \leq \} 0 \\ \text{iff } x'_{rk} \{ > \} 0 \end{array} \right. \]

with \( k = 1, \ldots, n; \)
\( r = i, j; \)
\( x'_{rk} = \) the current value of \( x_{rk} \) (that is, before any bargaining process);
\( \lambda_r = \) the Lagrangian multipliers (they express the marginal utility of \( i \)'s and \( j \)'s incomes).

Equation 2.6 makes sense as follows: As being measured regarding budgetary constraints, the marginal utility of any good \( (k) \) is lower than, or is equal to its price \( (p_k) \) if that good is not purchased; that is when \( x'_{rk} = 0 \), and it is equal to its price if it is purchased; that is when \( x'_{rk} > 0 \).

Yet, if

\[ \frac{1}{\lambda_j} \frac{\delta u_j}{\delta x_{i1}} \left| x'_{i1} \neq 0 \right. \]

Pareto optimality is not achieved. Obviously, the \( i \)th individual imposes a loss of utility on the \( j \)th individual in its choice of \( x_{i1} \) that is not reflected in the marketplace and is not considered in its utility maximization. In other words, the solution 2.7 represents a competitive equilibrium in the presence of the externality regarding a pure consumption case. But, because one loses, the Pareto criterion is not met.

Therefore, if

\[ \frac{1}{\lambda_j} \frac{\delta u_j}{\delta x_{i1}} \left| x'_{i1} < 0 \right. \]
individual \( j \) is facing an external diseconomy which is a Pareto relevant detrimental externality.

In general, as we already pointed out in equation 2.1, one can write:

\[
\frac{\delta u_i}{\delta x_{ik}} > 0 \quad \text{beneficial externality} \\
\frac{\delta u_i}{\delta x_{ik}} < 0 \quad \text{detrimental externality}
\]

with \( i \neq j \) among \( r \) economic agents, and \( k = \text{one of } n \) goods.

Thus far, bargaining is an approach used to determine social optimality in the presence of externalities when there is no governmental limitation on goods whose consumption or production leads to detrimental (or, beneficial) welfare effects.

Governmental welfare policies in the presence of market externalities can lead to various cases including compensatory payments [Turvey (1963); Pillet (1976), (1985)].

c) Joint Production of External Diseconomies

From another point of view, although the theory deals with individual firms or consumers in competitive microeconomics, the external effects may be quite general and hence more public and indivisible effects than private and excludable ones. In this sense, public goods are often associated with externalities because no individual's preferences for such non-excludable goods may be registered in the marketplace.

In the search for an optimal allocation of goods, the attempt is thus to consider large-scale external diseconomies as "bads" and then to include them in the setting up of the market equilibrium in a precisely analogous way we use to take into account goods or services. For this reason, one can consider externalities as joint productions parallel to the economic production in general [Whitcomb (1972); Pillet (1980)], matching up jointly produced external effects with public bads or goods because they have the same characteristic of not going through the market and of simultaneously affecting the utility functions of several individuals (consumption by one individual does not prevent consumption by another one). Hence, on the one hand, the analysis of those joint effects could be similar to that of public goods; on the other hand, however, the existence of permanent large-scale externalities leads us to carry welfare economics one step further, looking at external effects in terms of environmental externalities.

III. Environmental Externalities and the Extension of the Economic Paradigm to Include Environmental Links

External effects are essentially positive or negative, incidental effects affecting the utility or the production possibilities in a way that is not reflected in the marketplace nor considered in any profit or utility maximization. In general, they are considered as market shortcomings because a competitive economy will no longer attain a Pareto optimality in their presence.

Welfare policies such as compensating variations give rise to meet Pareto optimality in the presence of externalities. Unfortunately, as far as we relate external effects to some sort of public goods, they tend to escape from market clearing, appearing more and more as permanent rather than incidental external effects. Therefore, in a matter-of-fact way, the theory of economic externalities has to be drifted toward a tentative analysis of environmen-
ternal externalities; that is, toward effects that are related to the marketplace and to the environment as well.

One can define environmental externalities as the case where actions of economic agents affect the production possibilities of the economy and hence the flow of goods and services individuals can enjoy in a way that is not reflected in the marketplace but that is reflected in real, noneconomic terms.

In this sense, economic theory has drifted from a strict market duality between costs, and prices to that emerging problem that production and consumption are intimately involved with real, physical dimension of resources, goods, and services [see for example Daly (1968); Georgescu-Roegen (1971); Odum (1971); Pillet (1976); Ayres (1978); Tamanøi et al. (1984)].

First, abstract models of environmental externalities are overviewed. Then, the proposition of an extension of the economic paradigm to include environmental links is briefly presented.

a) Abstract Models of Environmental Externalities

Individuals are not only satisfied in buying and in selling goods in the marketplace. As a branch of welfare economics, environmental economics deals with nonmarket services or disservices associated with economic production and consumption processes that are intimately involved with real, physical materials and energy. The common view on this subject is that the existence of such externalities is now inherent to the economic use of materials and energy—though perhaps once it was not. In other words, unlike economic externalities, which were potentially internalized in a way or another, environmental externalities are pro-

![Diagram of Environment and Economy: Daly's Model](image)

![Diagram of Environment and Economy: Ayres-Kneese General Equilibrium Model](image)
duced as far as are economic goods and services. Finally, they have to be integrated in the
general economy more than to be internalized in a Pareto optimal market equilibrium.

An early attempt to formulate this problem from an economic viewpoint seems to have
been that of Daly (1968). According to him, consider a simple input-output model figuring
some basic relationships between the main economy and the environment (see Figure 1).

The first sector of this matrix (sector A) represents the economy acting upon the en-
environment, for example in rejecting waste materials of a vast variety of kinds. Sector B
focuses on the economy as a classical production/consumption ageless machine only subject
to effective demand. Money is the “working fluid” of this machine and any transaction
between individuals or firms is subject to an accounting identity between income and ex-
penditures plus any changes in stock (savings, reserves). Sector C deals with natural re-
sources direct supply and waste assimilation from the environment as well as adverse effects
upon economy. In contrast with sector B, sector D focuses on long period environmental
work. Unlike sector B, which is concerned with economic goods and services, sectors A,
C, and D deal with environmental goods (zero price) or bads (negative price)—though
negative prices are nonobservable ones. This is one particular way of showing some basic
interrelationships between the economy and the environment and to outline the inherent
presence of environmental externalities.

Other attempts focused on input-output models in which the environment was treated
as a distinct sector subject to what has been known as the materials/energy balance principle
[cf. Kneese, Ayres, and d’Arge (1970); Før Sund (1972); Noll and Trijonis (1971)]. This
principle states that the laws of conservation of matter and of energy “guarantee that the
sum total of all waste flows to the environment from the economy must be equal to the sum
total of all resources originally extracted from the environment” [Ayres (1978) p. 31]. This
rule makes sense regarding sectors C plus A of the Daly’s model (Fig. 1). The rule applies
to the main economy as well as to regions, individual communities, industries, firms, or
environmental protection agencies. Nowadays, materials/energy balance principle as such
is in doubt [Pillet (1985)].

As an example of a general equilibrium model including environmental externalities,
the Ayres-Kneese model is a production-consumption input-output model associated with
an environmental sector, both of them being subject to a balance of all physical flows (see
Figure 1). Two successive transformation matrices are involved: a resource/commodity
matrix and a commodity/product matrix. Goods are distinct from services; the latter involve
no physical inputs. Goods produced by the economic sector are priced as are raw materials
extracted from the environment. Waste flows from the final consumption carry a negative
price (based for example on a fee for disposal). Recycling is allowed for.

Other models of environmental externalities are concerned with the search for optimal
policies for economic growth in the presence of resource constraints and a degradable envi-
ronment [see for example Måler (1974)].

In general, only simple theorems are generated through those models and other ones
of the same kind. In particular, it is postulated that in the presence of environmental ex-
ternalities, the utility function depends both upon the level of consumption and on the
accumulated stock of pollution which, in turn, is a function of current consumption devoted
to pollution abatement and of current waste flows. A materials/energy balance principle is
allowed for, but only implicitly appears in the model in pointing out the importance of
balancing both economic and physical grandeurs. Unfortunately, their high schematic construction does not allow to obtain actual numerical solutions nor includes energy constraints and energy quality. In this way, they are abstract models that keep environmental economics too closely related to theoretical welfare economics.

b) Extension of the Economic Paradigm to Include Environmental Links

From a classical, positive economics viewpoint, a single stage mapping is required, which goes from factors of production to marketable goods and services. This stage is optimized by means of some functional relationship between economic output and factors of production—land, labor, or capital. From a neo-classical welfare economics viewpoint, optimization is concerned with a two stage transformation: from factors of production to goods and services, and then to utility or welfare. In addition, the theory of welfare economics recognizes the possibility of substitution between different goods and services not only as regards market-allocated ones, but also regarding non-market-allocated goods and services (i.e., public goods, as well as economic and/or environmental externalities). This sequence is optimized by reaching competitive equilibrium and Pareto optimality both in production and in consumption. The mechanism involved here determines the production, the consumption, and the distribution of commodities. Social optimality is required when externalities exist.

Yet, from a "materials/energy" balance principle viewpoint, the economy is a set of unidirectional transformations "that convert raw materials and natural resources (both renewable and nonrenewable) into "final" goods and services" [Ayres (1978)]. In this sense, economic products are not physically "consumed," but provide "services" before being discarded as partially recyclable wastes.

Thus, it seemed appropriate from this new point of view to develop environmental economics as a somewhat more elaborate economic paradigm: "A more complex (but also more realistic) sequence of mappings from exhaustible or renewable natural resources to finished materials and forms of energy; then to material products, and structures (this includes capital goods); then to (abstract) services, and finally utility" [Ayres (1978), p. 67]. In this enlarged economic paradigm, the first two stages imply physical transformations, but also involve human labor and capital as well as labor-saving materials like fuels, electricity, fertilizers, and so forth. The latter two transformations are not physical in nature, but their inputs include labor as well as material products generated in the previous stage. However, as regards services, they are non material ones. It follows that what comes in as material inputs now is converted into wastes. Finally, utility is maximized as in welfare economics, "in principle, by suitable allocation of incomes among consumers and of expenditures among pure final services" [Ib., p. 68], although pure services are concerned with shadow prices.

In general, according to the "physical" principle at work in this revised economic paradigm, each given level of utility or each finished material can be derived from various processes, each different from another and not from a unique, irreducible set of materials, or energy inputs. The environment appears as a new, quasi-sector of the economy.

Unfortunately, the models proposed in this field look like unfolding charts of a somewhat inert system, without any generation of particular design, or dynamic network.
IV. *Energy Externality and Environment Economic Interfaced Systems*

With sections II and III, we have sought an understanding of externalities in welfare economics and in environmental economics.

As a third step, we deal now with energy externalities in environment economic systems. Energy externality is a particular concept belonging to the general notion of external effect.

Energy externalities may be defined in first instance as energy systems-oriented externalities; that is, as indirect contributions to economic vitality from environmental work or services. On the one hand, their real basis is external to market decision-makings. On the other hand, it is an interface concept which relates external contributions or limits from the environment to the economic system of production and consumption of goods and services, and reciprocally. They mainly are macro-level effects [Pillet and Odum (1984), (1985)].

We deal first with the method of energetics and with energy circuit language and diagrams. Then, we pay attention to energy externalities in environment economic interfaced systems. Finally, we will turn to applied environmental economics with the help of a case study.

a) The Method of Energetics

This paragraph focuses on energetics as an approach of the physical, external basis of the economy. Dealing with systems and not specifically with elementary, isolated, chemical processes (as taxonomy did as regards extended accounting models), energetics may cover complex sequences of mappings from energy sources to dispersals of both materials and energy, including environmental work as well as economic activities.

A system may be defined as “a group of parts that are interacting according to some kind of process, and systems are often visualized as component blocks with some kind of connections drawn between them” [Odum (1983), p. 4]. As an example, the connecting lines of any box diagram may represent the interplay of the different parts of the process portrayed. Unfortunately, simple box diagramming does not make understandable either processes or even simple mechanisms. That is, systems are wholes that have emergent properties from the interaction of parts.

A system is characterizable with the quantities it stores. The quantities can vary with time. Such variables are called state variables “since they describe the state of the system while it is varying”. When inflows and outflows become balanced, an open system becomes constant and is in a steady state. The production firm equilibrium as it is used for example in economics refers here—as it also does in engineering—to a closed system with constant storages.

Now, to facilitate understanding the combination of parts into systems, one has recourse to any qualitative or quantitative, vague or clear, spoken or written symbolism; that is, to many systems languages, as different as are English, French, Japanese, differential equations, Forrester diagrams, Probability diagrams, Graph theory, or Art. As far as we are concerned with the economy as a system of transformations related to environmental work and hence
intimately involved with physical principles, we at once have to choose and are chosen by energy as a passageway and the energy language as a way of representing systems of environmental and economic transformations—and even systems generally—because all real facts are accompanied by energy transformation. In particular, as Odum states, “the performance of real word systems as quantitatively measured is the basis for evaluating the reality of the concepts” of the energy circuit language [Odum (1983)].

The energy language is a circuit language inasmuch as it keeps track of flows of potential energy from sources going into storages or into work transformations and finally into degraded form as used energy leaving the system [Odum (1983)]. Potential (or, available) energy is “that capable of driving a process with energy transformation from one form to another”. Work is any energy transformation driven by potential energy (availability). In general, part of the energy transformed into another type is going into a used form “that no longer has potential for further work”. Sources from outside supply available energy which in turn provides “the means of keeping systems generating work”. Finally, storages within the system constitute potential energy capable of driving work processes. Thus, from a passageway viewpoint, energy circuit language pathways literally represent pathways of energy flow. As regards the measurement of the pathways, the rate of flow of energy is now usually expressed in Joules per unit of time.

Energy circuit language is used to portray typical subsystems units (producers, consumers) as well as systems of larger scale like a farm, a tropical agriculture, forests, fisheries, industrial plants, cities, regional systems of landscape and human settlement, or a national economy. In addition, it reflects the laws of energy. The conservation law (the First Law) declares that energy is neither created nor destroyed in a system. Thus an energy system

![Figure 2. Autocatalytic Unit Maximizing Power](image)

A storage and a feedback loop are contained along with the sink by which heat is dispersed as available energy is degraded. Autocatalytic loops may be found in consumer units as well as in producer units.

The hexagon symbol means a consumer unit in energy circuit language [Odum (1983), adapted].
displays energy flows through it from outside and out again. The Second Law requires heat
dispersal from all storages and all processes. Thus reservoirs as well as process symbols
display energy drains that denote used energy leaving the system through the heat sink.
The maximum power principle (or, the Fourth Law) works as a major design principle in
explaining much about the structure and processes of systems [cf. Odum and Pinkerton (1955),
and Odum (1971, 1983)]. What is observed in natural systems "is a feedback of energy from
storages to stimulate the inflow pathways as a reward from receiver storage to inflow source"
[Odum (1983) cf. Figure 2]. As formulated by Lotka, this principle suggests "that systems
prevail that develop designs that maximize the flow of useful energy". From a phenomeno-
logical point of view, a feedback loop allows the circuit to learn. Thus, feedback designs
may be called autocatalytic. An autocatalytic unit can be developed if the energy flow avail-
able is sufficient to surpass the flow of depreciation from the storage in the loop. If it is
not the case, energy degrades without work transformation and then without developing
any autocatalytic loop (e.g., diffusion of a concentrated substance into a more dilute state).

The Third Law regards absolute zero (Kelvin) and leads to entropy definition.

Then, autocatalytic units as well as pathways, storages, interactions or sources, need
symbols other than writing as a way of communicating. Visual symbols like the hexagon,
the arrow, the tank, the interaction symbol, or the circle can be grouped into patterns by
means of energy diagrams. Boundaries are represented in an energy circuit diagram by
boxed lines. Symbols and conventions of the language will be introduced as needed. Those
visual symbols are the units of the energy circuit language. Once grouped into patterns,
they make sense as energy diagrams. Those diagrams have energy as well as mathematical
meanings. They have been arranged by H.T. Odum according to system's ecology. They
are used as protocols for visualizing energy systems.

Paying attention to the design of energy systems, consider still the arrangement of energy
sources by quality. Flows of energy develop characteristic webs of energy transformation,
feedback interaction, and recycling. As a result, the webs form a hierarchy of converging
transformations. Yet, different kinds of energy are involved that are of different quality.
The quality of one kind of energy is measured by the embodied energy of one type required
to develop another type in the work transformations. That other type is then characterized
by its energy of the first type. Emergy is a new name proposed for this measure by D.
Scieneceman and H.T. Odum [Odum (1985)]. Available energy used for control (feedbacks
of transformed energy) is dependent on embodied energy, too. Thus energy systems dia-
agrams must show energy quality. It is recognized by the position of symbols which con-
sequently display hierarchical patterns and control.

The concept of successive energy quality transformations may be illustrated by means
of ecological food chains despite the fact that real systems form webs rather than chains—
however, the energy changes are similar—(cf. Figure 3). Energy comes in from an outside
source (solar energy), supports the phytoplankton (producer), is transformed through zoo-
 plankton and so forth through small and then large fish (consumers). Stated in other words,
"at each step much of the energy is used in the transformation and only a small amount is
transformed to a higher quality one that is more concentrated and in a form capable of spe-
cial actions when fed back. Declining energy is accompanied by increasing quality" [Odum,
(1983); see Figure 3]. In this sense, flows of low-quality energy are abundant and widely
dispersed. Distinct units are small in size. On the contrary, flows of high quality energy
Figure 3. Actual Energy and Solar Transformity
(a) decrease of total energy flow in successive transformations; (b) increasing energy quality;
(c) spatial hierarchical characteristics;
(d) transformity [Odum (1983), adapted].

(although less in total energy flow) are more concentrated. Individual units are of larger size and the territory from which they receive energy and feed it back is larger. Thus, spatial convergence accompanies quality hierarchy (see Fig. 3c).

The notion of energy quality is a decisive one regarding the external, physical basis of economic-ecologic systems. On one hand, energy sources driving such systems will be arranged in order from low quality (on left) to high quality (on right). On the other hand, we need a measure of energy quality. A measure of energy quality is provided by deriving energy transformation ratios from energy chains such as that shown in Figure 3b. An energy transformation ratio may be defined as “the ratio of energy of one type required to develop another type of energy in a transformation” [Odum (1983)], what defines the transformity of one type of energy in another [Odum (1985); see Figure 3d]. Transformity is a new name proposed for this measure by D. Scienceman and H.T. Odum. Such a concept is useful for describing energy patterns. Thus, if we want to compare energies of different types regarding energies involved either in their formation or their effect, they may be converted into equivalents of the same type (e.g. solar energy) by means of the appropriate energy transformation ratio (or, transformity); that is, by multiplying their actual energy content by
their solar energy transformity. Then one can calculate the emergy of any type of energy at each step of the chain (or, of the system). As a result, “the more transformation steps there are between two kinds of energy, the greater the quality and the greater the solar energy required to produce a calorie or, a joule of that type” [Odum (1983), p. 15]. Emjoule (emJ) is the unit of emergy. Emergy of different types of energy is evaluated in solar emjoules. Transformity is expressed in emJ/J.

Therefore, as an approach to deal with environment economic transformation processes, energy systems analysis allows us to make up real world’s own material. Sometimes simple models will be built that are easily retained in the mind for overviews. Sometimes more complex models will be displayed for example for computer simulation of real events. Sometimes very complex models will be drawn in order to meet inventory needs regarding everything known about a system. “Sometimes modeling is considered as an art because of the individuality, creativity, and essence of experience that may go into selection of what is included” [Odum (1983), p. 91].

b) Energy Externalities in Environment Economic Interfaced Systems

This is one of the first attempts to deal with energy externalities at the frontier of energetics and economics [see Pillet and Odum (1984), (1985); Kiker and Odum (1984); Pillet (1985)]. It is the first one as regards some general theory of externalities. Energy externalities may be defined as indirect and even recognized contributions from the physical environment including an ecosystem and its external energy sources to the economic sphere. The new concept of energy externality is used for understanding, evaluating and predicting the real external energy basis of economic processes. It makes sense in environment economic interfaced systems. We can cite solar energy, including rain and wind, water, topsoil, biomass, and natural ecosystems generally as energy externalities.

In this paragraph, interfaced relationships between environmental work and economic processes are first discussed. Then energy externalities are presented.

Typical interfaced relationships between environmental work and economic processes can be viewed as shown in Figure 4. From an energetic point of view, such systems relate high-quality information as a processor of lower-quality basic energy. Moreover, it drains low-quality energy, fitting it with imported, purchased, higher-quality one, what opens ways to coping with efficiency criteria. This constitutes a kind of chain or web reaction of economic information and energy. In addition, concentrated mineral fuel energies that support industry raise questions of more efficient environmental feedbacks as well as future return to use of the renewable energies. Feedback controls are of prime importance regarding maximum power principle. In fact the traditional formula for adjusting prices omits any reference to external energy sources as well as to environmental services, for money only accompanies part of the flows. These environmental input supply services are not bought.

Therefore, for coupling economic activity to environment, a feedback loop is first needed. A simple connection means that the economic activity drains some of the product, as fisheries or forestry do (see Figure 4a). But “the chain that produces the items of economic use is thus stressed, and its position as a competitor for energy inflow is decreased” [Odum (1983)]. Continuing interfaced relationships require a feedback loop (see Figure 4b) that amplifies the chain that is used “as much as the use is a drain”. Traditional agriculture and oyster
Figure 4. Feedback Loop for Coupling Economic Activity to Environment

(a) use is a drain; economic activity may decrease and competitors increase; (b) a feedback loop maintains chain of use.

Culture generally satisfy to such feedbacks that maintain chain of use competitive and economic activity stable [Odum et al. (1983)]. On a larger scale, the "suido" control feedback which realized this relationship between the forests, rivers, and human society during Japan's 17th Century, is another example [Murota (1984)].

Getting back to Figure 4, one can see in first instance that we may emphasize on control of the economy from an energy system viewpoint and not only as a drain from environment to economy. Second, economic price does not provide sufficient information in an environment economic model. It is often far away from the realities of any environmental control of the economy as well as from feedback controls from the economy to the environment. Any work/labor interface is intimately involved in transformations from low-quality energy to higher-one regarding a whole system. Human labor involves energy work; so the real basis of economies is outside the money measure but participates in the economic output; that is, as energy externality. Thus, maximization must regard the whole system and not only the resulting dollar while seeking for understanding relationships between money and energy. Circulation of money with real buying power may be said maximized when the whole systems power is maximum. A new word for energy/dollar ratios is here tentatively
proposed: monergy, though more discussion would be required in comparing and unifying macroenergetic and macroeconomic fields as regards monetary theory [Schmitt (1975)].

As regards the second law and its application in environment economic systems, heat dispersion is not accidental, but essential, as Schrödinger (1955) and many others stressed it [Georgescu-Roegen (1971); Tsuchida (1982); Tamanoi et al. (1984)]. Energy systems have
the ability to discard the entropy increase into their surrounding environment. Materials and energy are involved into a continuous and irreversible entropic degradation. However, according to systems ecology, once used up, energy cannot be used anymore while matter can be recycled. Georgescu-Roegen (1982) is wrong in joining up matter to energy. Matter is never used up. A particular system can lose it in dispersing it locally, but matter is finally recycled by larger natural systems. It can be reused if there is available energy. As regards economic systems (see Figure 5), they lose materials, but these materials are soon recycled according to the activity of external, natural systems. Such a view makes sense at the interface between environmental and economic systems. In this sense, the second law implies that we consider a human economy as a system subject to depreciation, requiring large energies, and in close interface with microscopic structures as well as with complex natural systems. Environmental contributions from energy sources and low-entropy materials to the economy may be considered as an external gain of order—what may appear as a fundamental definition of what we call energy externality.

In concrete form, one can first consider as energy externalities the ultimate sources that generate economic processes through pathways of action that are indirect and even unrecognized. As shown in Figures 4 and 5, externalities are unrecognized values; that is, external, nonpriced contributions to the main economy.

Second, as a concept, energy externality deals with the evaluation, by means of indices and ratios, of external environmental contributions to the main economy or of economic miscontributions regarding the environment. This energy externality evaluation procedure deals with the measurement of environmental effects within environment economic systems. It is based upon energy transformation networks, energy quality and hierarchy. It concerns all flows and reserves within environment economic systems; that is, environmental, nonpurchased inputs as well as economic inputs which are purchased in the marketplace. Evaluating energy externalities means considering environmental contributions to the economy as well as economic processes and products on an equivalent ability-to-do-work, what economic evaluation procedures cannot do, and what entropy theory does not consider in this way.

Getting back to the point, the vitality of any economy does not deal only with the productive work of people (labor) and machines. Human labor involves energy work. It depends also upon the productive work and the carrying capacity of natural processes of the environment. So useful production work includes that of natural systems interfaced with the main economy and that of people from inside the economy. There is a hidden relationship between energy basis and economic products. As regards the marketplace, environmental contributions are external ones. Because money only regards human labor, it does not measure the productive inputs of the environmental work that ultimately participates in the vitality of the economy and contributes to the gross national product at the interface between environmental work and human labor.

Hence, the work of environment involved in developing the economic production is an external contribution not measured by the money, which is only a measure of the national income. However, through the remuneration of the human labor, money has the power of purchasing all goods so produced. It is its only power. So we cannot carelessly put cash value on such environmental capital goods. However, because nature and humanity are interfaced with each other, we can try to match at this point two different evaluation pro-
The question is: How much energy externalities contribute to the economic product. In order, for example, to gain an overview of any national or regional economic basis, one must examine both kind of productive inputs, those from nature's work and those from the labor of humans. Money as a measure of national or regional income only accompanies part of the inputs to an economic process. Going further, after all inputs and storages are evaluated in energy units, they may all be put on a dollar basis by their proportionate effect on the total money that measures the national income.

Last, energy externality works as a measure of the embodied energy (emergy expressed in equivalent solar Joules; that is, emjoules) entering an economic process and must be involved in the ratio of emergy to dollars (monergy) within the web generated by environment economic systems along with the proportion contributed as a feedback from high-quality economic quantities (fuels, goods, services, equipments, and so forth). Such an monergy ratio is often higher where a rich resource is being processed into the economy. “Although the energy/dollar ratios vary along the pathways of the web, the overall ratio of total embodied energy to dollars circulating through the most valuable consumer sector provides a useful index of the economy as whole and a means for evaluation of the feedbacks of high-quality goods and services from the terminal sectors” Odum (1983). Therefore, energy externality may be a tool for evaluating the external, energy basis of economic systems and subsystems as well as for evaluating energy and economic yield systems.

In summary, to combine money and energy is a capital feature of the energy externality approach by means of the energy method. Let's now pay attention to a case study.

c) Energy Externality and the Economy of Switzerland

The part the concept of energy externality has to play at the interface between energetics and economics is to evaluate external environmental effects upon the economic sphere. By extension, it is concerned with economic impacts upon the environment. It is a key principle regarding applied environmental economics as well as environmental macroeconomics.

On a macro-level, energy externality analysis takes place in an energy analysis overview of a nation, the task in this paragraph. We try here to draw a somewhat novel energetic overview of the Swiss economy, featuring its typical energy externality [for more details, see Pillet and Odum (1984)]. In that analysis, energies of the environment, reserves and trade are included, representing all flows and reserves in embodied solar equivalents (emergy—see Figure 6).

After an energy diagram was drawn, the actual energy storages and flows were estimated and multiplied by their solar transformity (emJ/J). This calculation converted all storages and flows into emergy (expressed in emJ) for comparison and evaluation of contributions to the economy of different storages and flows. Flows are aggregated in Table I. Main categories are summed up in Figure 6. Finally, various indices are calculated [for details, see Pillet and Odum (1984)].

Monergy for Switzerland in 1982 was calculated from the chemical potential energy of rain, nonrenewable indigenous reserves, hydroelectricity used within the country, imported fuels, minerals, goods and services, and the Gross National Product (GNP). The Swiss monergy in 1982 was .72 E12 emJ/$, lesser than the German one (2.45 E12 emJ/$ in 1979), and than the US one (2.6 E12 emJ/$ in 1980). This suggests that for every dollar that an
In this sense, monergy is an index of the service intensive economy of a country in the matching of its energetic and economic dimensions at the interface between nature and humanity.

Emergy in international trade is given in Figure 6. Emergy of imports and exports were calculated from the energy flow of the minerals, from fuels and goods, added to the service energy (labor, paid in dollars) multiplied by the emergy/dollar ratio of the USA (Table I). The Swiss economy is highly export-oriented although the money balance of payments shows a rather low .4 billion dollars benefit in 1982. On an emergy basis, however, the trade ratio shows a considerable net gain; imports were 3.5 times the exports.
TABLE I. SUMMARY FLOWS FOR SWITZERLAND

<table>
<thead>
<tr>
<th>Letter in Figure 6</th>
<th>Item</th>
<th>Emergy E20 emJ/y</th>
<th>Dollars E9$/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>Renewable sources used (geopotential)</td>
<td>86.75</td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td>Nonrenewable sources flow within the country</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_0$</td>
<td>dispersed rural source</td>
<td>32.76</td>
<td></td>
</tr>
<tr>
<td>$N_1$</td>
<td>local wood used</td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>Imported minerals and fuels</td>
<td>308.97</td>
<td></td>
</tr>
<tr>
<td>$H$</td>
<td>Local hydroelectricity used</td>
<td>98.3</td>
<td></td>
</tr>
<tr>
<td>$G$</td>
<td>Imported goods</td>
<td>110.63</td>
<td></td>
</tr>
<tr>
<td>$P_2I_0$</td>
<td>Imported services</td>
<td>78.16</td>
<td></td>
</tr>
<tr>
<td>$I$</td>
<td>Dollars paid for imports</td>
<td>34.3</td>
<td></td>
</tr>
<tr>
<td>$E$</td>
<td>Dollars paid for exports</td>
<td>34.7</td>
<td></td>
</tr>
<tr>
<td>$P_1E_0$</td>
<td>Exported services</td>
<td>56.0</td>
<td></td>
</tr>
<tr>
<td>$B$</td>
<td>Exported products, transformed within the country (electr., machines)</td>
<td>82.24</td>
<td></td>
</tr>
<tr>
<td>$X$</td>
<td>Gross National Product</td>
<td>102.4</td>
<td></td>
</tr>
<tr>
<td>$P_2$</td>
<td>Ratio embodied energy to $\xi$ of imports (emJ/$\xi$) (US monergy)</td>
<td>1.84 E 12 emJ/$\xi$</td>
<td></td>
</tr>
<tr>
<td>$P_1$</td>
<td>Monergy of country</td>
<td>0.72 E 12 emJ/$\xi$</td>
<td></td>
</tr>
</tbody>
</table>

Source: Pillet and Odum (1984); adapted.

In general, Switzerland send 3.5 times less emergy out of the country than it actually imports, one of the reasons why Switzerland is prosperous from an economic viewpoint.

V. Conclusion

In the theory of externalities, it was shown how to derive a better understanding of external, environmental effects regarding the economic sphere. A new concept of energy externality has been proposed from the traditional concept of external effect.

On the one hand, a somewhat more general theory of externalities may be considered in accordance with three successive concepts: external effects, environmental externalities, and energy externality. Specific theory, definition, diagraming, modeling, field, principles, and application are summarized in the Summary Table.

On the other hand, according to the method of energetics, first formulated by Howard T. Odum, new tools and keys toward applied environment economics as well as environmental macroeconomics may be considered as operating ones. As a matter of fact, there is a need today toward an accurate understanding of the relationship between the economy and the environment considered as interfaced systems. In supplying missing ingredients in understanding and predicting the vitality of national economies and economic processes generally the concept of energy externality appears as a key dimension in environmental economics.

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### Summary Table: General Theory of Externalities: Three Basic Concepts

<table>
<thead>
<tr>
<th>Concept</th>
<th>Theory</th>
<th>Definition</th>
<th>Diagraming</th>
<th>Modeling</th>
<th>Field, Range</th>
<th>Principles</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic, Market Externalities (1950)</td>
<td>Welfare Economics; Marginalist Theory</td>
<td>$\frac{1}{\lambda_i} \frac{\partial u_j}{\partial x_{ik}} &lt; 0$</td>
<td>Graph</td>
<td>Functional Interrelationships; Perfect Competitive Market Micromodels</td>
<td>Nonmarket Measurement of Utility</td>
<td>Utility or Profit Maximization under Budgetary Constraint; Pareto Optimality (Compensative Variations)</td>
<td>Incidental External Effects; Nonmarket Welfare Measurement and Policy-making; Cost-Benefit Analysis</td>
</tr>
</tbody>
</table>
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