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BIOECONOMICS: A PATH FOR A DE-GROWTH SOCIETY

ABSTRACT: The paper outlines the theoretical path which starts with the analysis of the thermodynamic and biological basis of the economic process as developed by N. Georgescu-Roegen, and leads to the discussion about the prospect of a de-growth society.
As highlighted by N. Georgescu-Roegen, according to the Entropy law, each productive activity causes the irreversible degradation of matter and energy. Therefore, an important conclusion can be drawn: the present primary goal of the economic process, i.e., an unlimited growth, does not take into account the finiteness of the ecosystem. Actually, we are facing both the problem of the exhaustion of resources and the risk of an ecological collapse, as the large variety of damages caused to the environment shows. The consequences of the economic development have questioned the capability itself of our economic and social organization to produce welfare.
The paper illustrates how de-growth can constitute an alternative prospect with respect to the existing models of development, in particular, the model of sustainable development, severely criticized by N. Georgescu-Roegen. Therefore, de-growth is a call giving voice to the urgency in the change of the present paradigm, in the Kuhnian sense, which constitutes the skeleton of Western society and culture. Such paradigm considers economic growth as the only way to produce welfare. In this regard, systemic epistemology has to be considered an ideal epistemological frame for the elaboration of ecological guidelines in order to implement the de-growth paradigm.

1. Economics and biology

The economic system is a subset of the biophysical world. As is well known, the human species lives as other species do, by taking low entropy from the natural environment and discharging it back into the environment as high entropy waste. Economy, society and environment are thus linked in a co-evolutionary relationship. In order to identify the various attributes of such relationship a multiplicity of theoretical approaches is needed. In particular, as many economists (Marshall, 1961, Georgescu-Roegen, 1971) have underlined, evolutionary biology can be a source of inspiration for relevant theories (Gowdy, 1994).
In this regard, considering the history of the development of economics and biology, it is also possible to trace several intellectual connections between the two disciplines. For example, C. Darwin and A. R. Wallace elaborated their theories about evolution through natural selection after reading the social and economic theories developed by T. Malthus. On the other hand, it was especially the Spencerian ideas of evolution through competition to spread in social

sciences. Actually, Spencer, not Darwin adopted the term 'evolution' and developed the principle of the survival of the fittest. Such ideas greatly influenced Marshall and Veblen, and still dominate in the contemporary economic thought: competitive selection is considered as the main force at the origin of economic change and evolution. In addition, further analogies between economics and biology can be discovered as both disciplines adopt concepts such as specialization, exchange, interdependence (Gowdy, 1997).

As above mentioned, the reasons for the existence of such analogies can be surely traced in the fact that both economics and biology deal with the life process. Therefore, although economic activity has moved far away from a direct contact with nature, the 'biophysical foundations of economics' has remained present in the background of economic theory. In this regard, A. Lotka (1956) clearly highlighted the belonging of the economic domain to the biological one : "Man's industrial activities are merely a highly specialized and greatly form of the general biological struggle for existence","...the laying bare and clearly formulating of the relations thus involved, in other words the analysis of the biophysical foundations of economics, is one of the problems coming within the program of physical biology". Particularly, Marshall claimed that 'The Mecca of the economist lies in economic biology rather than in economic dynamics" (Marshall, 1961). In his Inaugural Lecture (1895), he also criticized the abuse of mathematical models in contemporary economics, explaining that such models completely disregarded how change affects economic phenomena, which involve 'biologic concepts of growth". In this respect, he added: 'nature knows no absolute partition of time into long periods and shot; but the two shade into one another by imperceptible degradations (Marshall, 1961)'.

However, although the life process is essentially an unique one, biology has abstracted from the human economy, while neoclassical economics has taken into consideration exclusively the relationships among commodities and man.

In such regard, it is worth highlighting that any attempt to analyze a segment of reality is somewhat misleading, leaving out too many feedbacks existing between systems. Concerning this matter, Georgescu-Roegen accurately described how analysis cut actuality, which is seamless, into artificial and discretely distinct pieces in order to simplify its understanding; however, any unity of analysis presupposes a non-neutral operation of choice made by the observer (Georgescu-Roegen, 1971).

About this matter, the philosopher of science Paul Feyerabend (1965) has provided a useful example: consider the relationship between the movements of molecules, at one level, and the concept of temperature, on another. Feyerabend asserts that although the concept of temperature can be associated with statistical mechanics and the movements of molecules, the kinetic theory cannot 'give us such a concept' as temperature, which relates to an interactive level above and beyond the combined movements of molecules. Consequently, it is an error to attempt to completely reduce the concepts of one science, relating to one systemic level, to those of another (Hodgson, 1997).

As far as the relationship among economy and biology is concerned, Georgescu-Roegen has to be considered a faithful follower of the ideas of Marshall and Lotka, who are often quoted in his works: '...if instead of artificially reducing the economic process to a closed mechanical system, as we have done ever since Jevons and Walras, we carefully consider all its material aspects, we must arrive at the conclusion that this process is only an extension of the biological evolution of the human species. Like any biological process, the economic process, too, cannot create or destroy energy matter. Both are irreversible processes because both are only consumption processes as far as their material nature is concerned (Georgescu-Roegen, 1971)'.

In this regard, Georgescu-Roegen sharply criticized the substantial error made by neoclassical economists deriving the foundations of neoclassical economics from physics, a science concerning the inorganic world. Actually, this economist considered economic domain as deeply rooted in the physics, chemistry and biology of human existence.

In Georgescu-Roegen's view, economy should be thus analyzed through a different approach, termed bioeconomics "The new discipline would merely include economics as a restricted domain, in the same way in which physical science includes mechanics.(Georgescu-Roegen, 1975)' For Georgescu-Roegen the term bioeconomics encompasses the relationships among humans as well as between humans and environment. Therefore, in such approach the unit of analysis should not be the economic process, or the behavior of homo oeconomicus, but the relationships between many systems, that is, between institutions, economic process and environment. In such a view, Georgescu-Roegen proposed also an interdisciplinary dialogue between parceled fields of knowledge with particular regard to economics and life sciences.

In order to establish a new alliance among nature and economic activity, Georgescu-Roegen referred to the Entropy Law claiming that economics concerns the study of the transformation of matter and energy realized by the human activity, while Entropy law is the natural law regulating such transformations (Zamagni, 1982).

Although there were some forerunners who concerned themselves with the relation of thermodynamics and economics, Georgescu-Roegen was the first to establish such theory analytically and systematically in economics: he adopted the entropy concept and applied it in order to describe the real nature and character of the economic process.

2. The Entropy Law

Thermodynamics can be defined as that scientific theory describing the processes involving heat transformations into other forms of energy (mechanical, chemical, etc..). In particular, Entropy is a term introduced by Rudolf Clausius as an indicator of the amount of energy that cannot longer be transformed into mechanical work. However, the second principle of thermodynamics was formulated in 1827 by Sadi Carnot, who studied the stem engines' working.

Carnot realized that a difference in temperature between the parts of a system is the essential condition to utilize energy in order to perform a mechanical work: particularly, the possibility of performing work depends on the heat transfer from a body at high temperature to a body at lower temperature. Yet any transfer of energy from high to lower temperature corresponds to a decrease of available energy utilizable to perform work. As the water cools, the steam engine is not longer able to work.

The above mentioned cases, that is, the availability of energy as mechanical work and the degradation of such energy, are referred to the following states:

1) the state of free, utilizable, or available energy for useful work (corresponding to a high temperature in water);
2) the state of unavailable, or bound, or closed energy (the temperature of the water having lost its heat).

Hence, an increase of entropy corresponds to a decrease in energy utilizable for mechanical work. These observations about energy behavior were summed up by R. Clausius as the second law of thermodynamics: in the world (as a closed system), entropy, that is the amount of unavailable energy, always tends to constantly increase (Dragan and Demetrescu, 1991).

Therefore, the second principle of thermodynamics points out a transformation, namely, the qualitative degradation of energy from available to unavailable.

For example, as Georgescu-Roegen described, when a piece of coal is burned, its potential energy is dispersed as smoke and ash so that is not longer possible to utilize it for a mechanical work. In other words, this energy has degraded and cannot anymore be recycled (Georgescu-Roegen, 1971). Therefore, as above stated, entropy is an indicator of the quantity of unavailable energy. The natural state of things is a constant shift from order to disorder, from low to high entropy. Actually, according to such law, also the energy of the universe must permanently degrade (Dragan and Demetrescu, 1991).

As already underlined, Georgescu Roegen takes the Entropy law as the starting point of much of his work. In such regards, he claims that the problem of the exhaustion of natural resources and pollution, in one word the ecological problem, should be substantiated on a thermodynamic basis: economic thinking must change its basic model and reconstitute itself as bioeconomics in the light of the principle of entropy (Dragan and Demetrescu, 1991).

Actually, in Georgescu-Roegen's view, the natural and continuous process of energy degradation should be considered the main aspect in order to regulate the economy of the natural resources. Even though according to the first principle of thermodynamics energy can neither increase nor decrease, it degrades qualitatively, steadily passing from an utilizable to a non-utilizable form.

As Georgescu-Roegen points out in relation to the entropy law, the universe can be represented as a sand clock where the available energy in the upper part turns into unavailable as the contents in the upper part steadily fall into the bottom part of the sand clock. The only difference between the sand clock of the universe and an ordinary clock is that the former can never be turned back.

In such regard, the Entropy Law is an evolutionary law, i.e. according to Georgescu-Roegen's definition: " a proposition that describes an ordinal attribute E of a given system and also states if $E_1<E_2$ (E_2 follows E_1 in the ordinal pattern of E), then the observation of E_2 is later in Time than E_1 and conversely (Georgescu-Roegen, 1971)". In this framework, the attribute E plays the role of an evolutionary index of the system considered just like entropy in the view of Classical Thermodynamics.

In conclusion, the second principle of thermodynamics claims that any process can go only in one direction, that is from order to disorder. Entropy represents the time arrow: it is not possible to reverse the direction of time.
E. Schrödinger (1996) was the first to point out the relevance of the entropy law for the living beings claiming that life does exist by drawing low entropy from the surrounding environment. In particular, life is able to concentrate low entropy in part of the system although the overall level of entropy in the whole system does increase.
As above mentioned, in order to highlight the similarity among the economic and ecologic domain, Georgescu-Roegen emphasizes how both are ruled by the entropy law. Actually, Georgescu-Roegen stresses that humans, like other living beings, survive by absorbing low entropy resources flowing from the environment: therefore, all the activities of man and generally the economic process are inevitably an entropic phenomenon. Particularly, the basic inputs of production and consumption processes are drawn from the solar flow of low entropy and from the terrestrial stock. The material output is high entropy in the form of pollution and dissipated matter and heat (Georgescu-Roegen, 1971).
Therefore, the Entropy law emphasizes the evolutionary nature of the economic process as well as the place of human economy within the natural world: human civilization does transform matter within a closed system wherein the process of natural growth of entropy can be slowed down or hastened but it cannot be reversed. Thus, the bioeconomic paradigm has stressed the primacy of the *physis* for an understanding of the true nature of economy (Seifert, 1993). In addition, Georgescu-Roegen's approach has placed paramount emphasis on the inputs to the process (energy and energy resources, that is, low entropy) and on the output (pollution, that is, high entropy).

3. The Entropy Law's Implications

Beyond its value as a principle ruling the natural and, consequently, economic world, the entropy law in Georgescu-Roegen's theoretical construction has to be considered as a broad, almost philosophical concept. The analysis of the biophysical roots of the economic process is in first place a basic stage in order to avoid being trapped by anthropocentric myths such as technological optimism.
In fact, in Georgescu-Roegen's view, human beings will be saved by a new ethics and not by a technological revolution.
The economic process, as the life phenomena, is an unidirectional and open process depending on external contributions. Therefore, the material character of the economic process and its dependence on a limited environment demonstrates the fallacy of the main goal of the standard economics, that is unlimited growth.
Secondly, the Entropy law undermines the basis of any project of sustainable development or steady state proposed for mankind's ecological salvation: actually, every work performed must necessarily end with an entropic deficit.
Standard economists consider economy as a closed and circular process, an endless pendulum movement between production and consumption. In such framework the general reference point of neoclassical theory is an equilibrium

position of the system: change occurs only when exogenous occurrences do alter such equilibrium. Since change is not considered as endogenously originated, the source or nature of change are of little theoretical interest, even the distinction between quantitative and qualitative change are not explored. The alteration of an equilibrium is seen only in the frame of possible change in consumer preferences or as derived from innovations or creative pursuits. However, equilibrium analysis generally focuses on statements about the existence and stability of equilibria and is not concerned with the analysis of processes that move towards and away from an equilibrium position. It provides even less an endogenous account of the factors that have caused a motion (Dopfer, 1993).

Such conception is based on the mechanistic framework which economists borrowed long ago from physics, and which has never been revised in order to redress its basic omission, that of the Entropy Law. Once one considers that none of man's activities eludes the entropy law, the economic process appears in a very different light. For one thing, the process can now be recognized not to be circular and timeless, but irrevocable. It consists of the continuous and irreversible transformation of low entropy into high entropy. Since the economic process is in its nature irrevocable, Georgescu-Roegen also points out its place in history, particularly the way in which the present pattern of economic activity will affect that of future generations. Because the terrestrial dowry of ordered material structures, from which our resources of low entropy are drawn, is finite, every Cadillac or every Zim we make today, 'means fewer plowshares for future generations, and implicitly, fewer human beings too (Georgescu-Roegen, 1975)'

In such regard, the Entropy Law gets us to reflect to our present and our choices in relation to the possible ecological consequences, related to pollution and to exhaustion of resources and to the quality of life that the future generation will inherit. According to Georgescu-Roegen: "There can be no doubt about it: any use of the natural resources for the satisfaction of non-vital needs means a smaller quantity of life in the future. If we understand well the problem, the best use of our iron resources is to produce plows or harrows as they are needed, not Rolls Royce, not even agricultural tractors (Georgescu-Roegen, 1971)"

In such regard, due to the existence of pure time preference, even when it is possible to correctly incorporate social costs, private market forces will lead to their overexploitation. Market decisions are made by individuals at a point in time, and individuals would logically rather have something today than at some point in the future. 'Rational' decisions involving resource use made by individuals with finite lifespans at a particular point in time may be totally irrational for the human species (Gowdy, 1993). The problem of intergenerational equality is a crucial point stressed by Georgescu-Roegen and in such regard he admonishes 'love thy species as thyself (Georgescu-Roegen, 1975)'.

As a result, Georgescu-Roegen draws the conclusion that economic development, "is definitely against the interest of the human species as a whole if its interest is to have a lifespan as long as it is compatible with its dowry of low entropy (Georgescu-Roegen, 1975)'

4. The Fourth Law of Thermodynamics

In ‘Energy Analysis and Economic Valuation’ (1979), Georgescu-Roegen analyzes the role of matter in the economic process.
The problem of matter degradation had been scarcely taken into account in the pre-existing literature. In such regard, K. Boulding had stated that ‘there is no law of entropy increase for the matter (Bolulding, 1966)”
In Georgescu-Roegen’s view, on the contrary, the irreversibility, which is an aspect of the entropic processes (second principle of thermodynamics), applies also to the material transformations. In such regard, the author elaborated a fourth principle of thermodynamics considered controversial by many scholars. Such principle states that:

1) Unavailable matter cannot be recycled
2) A closed system (namely a system that cannot exchange matter with the environment) cannot work indefinitely at a constant rate.

Therefore, this law proclaims for matter what the second law of thermodynamics stated for energy. In particular, Georgescu elaborated such law for two main reasons:
1) the fourth law should have played a more relevant role than the Entropy Law for bioeconomics. Actually, being the Earth a closed system, that is isolated in relation to the matter but not in relation to the energy (because of the solar radiation), a principle of matter degradation and, contemporaneously the non-substitutability of matter and energy, would have implied more strict limits to the economic process than those connected to the second principle of thermodynamics.
2) the principle of matter degradation was the basis on which Georgescu-Roegen criticized the so-called ‘energetic dogma’, very popular in the 70s. Such dogma consists in the belief that with sufficient energy it would be possible to recycle any amount of matter, so that any material constraint to the economic growth would be removed.
Concerning such dogma, H. Brown claimed: ‘all we need in order to obtain whatever material we want, is adding enough energy to the system”
However, in Georgescu-Roegen’s view, the supporters of such dogma did not provide any plausible explanation to demonstrate how an operation of complete recycling could be possible if a sufficient amount of energy was available. Someone appealed to the Einstein’s equivalence among mass and energy: E=mc2, c being the speed of light in empty spaces, but such equivalence applies only to cosmic phenomena. On the Earth, man cannot transform energy into matter and produce matter thank to the availability of energy (Dragan and Demetrescu, 1991).
In addition, some theoreticians of resources hold that exhaustion of matter is impossible. In such regard, Georgescu-Roegen specifies that it is not matter, but only available matter which is in question: since available matter is subject to an irreversible entropic degradation, in the future such resource could become scarce.

Also the principle of the complete recycling has no basis: actually, a gratuitous recycling does not exist and it does not exist any production of commodities without waste.
In order to provide a specific argumentation to support such ideas Georgescu-Roegen explains that each work of any kind needs a material structure in order to be performed. Such material structure is subject to friction and, therefore, to degradation. Even if matter presents a granular nature it is wrong to state that with sufficient energy it would be possible to reassemble it. It would be possible, for example, to gather the unthreaded beads scattered on a carpet in a room or even in a stadium. This would require expending energy as well as time, but this operation might ultimately be performed (Dragan and Demetrescu, 1991).
However, consider the example of a bottle of ink sprinkled over the Atlantic. It would in principle be possible to reassemble the molecules of that bottle by expending sufficient energy. But for all practical purposes the exercise is impossible. Actually, according to Georgescu-Roegen: "complete recycling is impossible…Material objects wear out in such a way that small particles (molecules) originally belonging to these objects are gradually dissipated beyond the possibility of being reassembled (Georgescu-Roegen, 1981)'
Consider also a less trivial example. The loss of soil and vegetative cover as result of arable production and fuel wood collection is a widespread problem in many developing countries. In such case, once the damage is done, it is economically impossible to undo it: this form of irreversibility reflects indeed the fact that the cost of rehabilitation or restoration exceeds the resources available.
Therefore, the accomplishment of fully reversible material process as through the utilization of sufficient energy is beyond man's possibility also because such operation would require an infinite time. In addition, in order to support such operation, it would be necessary a material structure that, being subject to wear and tear either used or unused, will not have, in turn, an endless duration.
In conclusion, according to Georgescu-Roegen, the energetic dogma and the principle of complete recycling are the most characteristic corollaries of the belief that science will eliminate any technical difficulty, so that it will be possible to recycle all the waste and the physical environment will go on supporting an unlimited growth and development.

5. The Controversy about the Fourth Principle

As already highlighted, the Fourth principle of Thermodynamics has been considered as wrong on a theoretical level. The first criticism to such principle appeared in a paper by Ayres and Miller claiming that: "Georgescu-Roegen's assertion that intrinsically scarce materials cannot be recovered (regardless of energy expenditure) from average rocks and the ocean is just plain wrong (Cleveland, Ruth, 1999)."
In 1993 a more articulated criticism was elaborated by some physicians (Bianciardi et al., 1993) stating that the 4^{th} principle is not consistent with the framework of physical laws: "Georgescu-Roegen's statement is very important from the stand point of analysis of physical processes, or even ethics, but it is

false in the field of physical laws where the author intended it to stand. Let us recall that any physical law must be expressed as a precise relation between measurable physical quantities. This has been to date one of the cornerstones of the scientific method, and Georgescu-Roegen cannot claim to have intended a physical law outside this methodology. Any new law should be consistent with the existing framework of the science we are dealing with, unless some major change is proposed to the framework itself in order to remove the inconsistency"

Some years ago, Ayres returned on the topic: 'Despite counter examples in nature, it has been argued that, as a consequence of the second law of thermodynamics, total recycling is impossible for an industrial society. In this paper it is shown that there is no such limitation (Ayres, 1999)'.

Also Georgescu-Roegen's pupil, Kozo Mayumi, in the paper 'Fourth Law of Thermodynamics and the Flow-Fund Model' did claim that: 'Georgescu-Roegen's formulation is not compatible with the framework of thermodynamics (Dragan et al., 1993)'

The argumentation proposed by Mayumi deserves a further explanation: Mayumi compares the thermal exchange among the Earth and the external space to a Carnot's cycle: "It is possible to construct a closed engine which will work in a complete cycle, and produce no effect except the raising of a weight, the cooling of a heat-reservoir at a higher temperature and the warming of a heat-reservoir at a lower temperature. This is nothing but a Carnot engine. The Carnot engine (with a fluid) is a closed system because heat can be exchanged during two isothermal processes (expansion and compression) through the base of the cylinder. If our economic process is set aside, the earth our abode, can be regarded as a big (closed) Carnot engine with the sun (a heat-reservoir at lower temperature) and the outer space (a heat –reservoir at lower temperature). There is the meteorite fall. But it consists of highly unavailable form of dust. The amount of particles that escape the gravitational field is also negligible. The amount of heat produced by consumption of fossil fuels is about one twenty thousand of the amount of the solar radiation reaching the earth. The amount of geothermal heat is about one six thousand. Therefore these can be ignored (Mayumi, 1993)'

However, even if biologists and ecologists have supported the possibility of a complete recycling referring to the biogeochemical cycles (carbon cycle, oxygen cycle, nitrogen cycle, ecc.), a complete recycling must be considered technologically unrealizable.

Even if natural cycles, based on the flow of solar energy, bring about the temporary generation of high concentrated materials contradicting with the principle of the degradation of matter and such argumentation has been often reported as a definitive proof, some authors disagree (Cleveland and Ruth, 1997, Ayres, 1999): "It is the hugeness of each of such stocks to cover on short period the amount of matter continuously leaving the cycle. One of the revealing signs is that all the carbon deposited at the bottom of the oceans as calcium carbonate will not be included in the carbon cycle, and this is only an element of lesser disturbance in the global circulation of the environmental carbon.'

Another relevant phenomenon which contradicts Georgescu-Roegen's assertion on the irreversibility of the material degradation is the process of photosynthesis

opposing to the entropic degradation. According to Tiezzi (1996): "Photosynthesis contrasts the entropic degradation, according to the classical physics, since it tends 'to order' the disordered matter: plants absorbing disordered matter (dispersed water and carbon dioxide), through the solar energy, organize it and create complex structures. Photosynthesis is the process that, capturing solar energy and diminishing the Planet's entropy, can be considered the high road of the biological evolution.'
In such regard, also Georgescu-Roegen acknowledges that plants can slow down the entropic degradation, capturing the solar energy. Anyway, despite photosynthesis the total entropy (organism and environment) does increase.
In conclusion, although the fourth law of thermodynamics cannot be considered as a physical law as Georgescu-Roegen believed, the phenomenon of degradation of the matter is empirically relevant for several processes on the border among economics and ecology. However, heterogeneity, which characterizes matter (and the same technology), makes it extremely difficult to express a general evaluation on the amount of matter degraded at the end of a given process. Each related conclusion concerning this matter cannot leave out of consideration scale and time characteristic of the process.

6. Bioeconomics and Sustainable Development

According to the sustainable development's perspective growth and development are presented as compatible with respecting environmental constraints. In such regard, economists like R. Costanza and H. Daly specified: "We differentiate the concepts of growth (material increase in size) and development (improvement in organization withous size change)'. However, in Georgescu-Roegen's view, since every work ends with an entropic deficit, it is difficult to imagine how the prospect of a sustainable development could be realized. Particularly, the economist defines sustainable development as "one of the most toxic recipes (To J. Berry, 1991)" and "a more beguiling snake oil than the steady state (To J. Berry, 1991)".
Actually, as already highlighted, Georgescu-Roegen believes that economic activity must not merely cease to grow, but will eventually decline. In particular, Georgescu-Roegen appeals to a new ethic as a possible foundation of a renewed economic action. Such new ethic should lead to a spontaneous auto-limitation of the consumptions. In such regard, it is worth observing that recently several thinkers (Bonaiuti, 2005, Latouche, 1992) have underlined the inadequacy of the utilitarian individualism as an ethical foundation of the Western society.
In fact, the risk of an environmental collapse has highlighted the incompatibility among the principle of utility maximization and Nature's limits.
As a consequence, Georgescu-Roegen sharply criticizes also the two prevailing approach for a sustainable development, that is the neoclassical approach and H. Daly's one.
Concerning Daly's approach, based on the constancy of the natural capital, the most relevant flaw is the omission of the Entropy law and the attempt to apply a model in order to measure the natural capital through a monetary index: the

global system is composed by a limited stock of resources subject to a continuous entropic degradation. Therefore, the natural capital degrades both in relation to its heterogeneity and in relation to its non-renewable components. In addition, nature is not economically measurable: such measurement cannot exhaust all the qualitative information regarding ecosystems.
The neoclassical definition of sustainable development, based on the constancy of natural capital and the substitutability among natural capital and produced capital is even less acceptable than the former. In particular, the two forms of capital do have qualitatively different functions: the former supports life, the latter production (Daly, 1990). In addition, the interactions among economic system and environment do originate several qualitative transformations: actually, substitutability among factors can be implemented only in the case of reversible systems.
As a result, both the neoclassical approach to the sustainable development and Daly's approach based on the constancy of the natural capital present relevant epistemological limits as they are both characterized by the project to cardinally and unidimensionally measure sustainability. In such regard, Georgescu-Roegen fully understood the evolutionary character of the relationship among biological and economic system. Such evolutionary character cannot be comprehended through a static concept like the constancy of the natural capital.
In conclusion, according to both bioeconomics and the recent developments of the complex system theory, an interdisciplinary and complex approach to sustainability should avoid to reduce the ecological dimension to the economic one. In such regard, ecology and the related system epistemology provides us with a conceptual frame adequate to the comprehension of the nature as an interdependent network of relations to which man and any human activity, including the productive one, belong. As already highlighted, contemporary economic theory sees the world as a mechanical, deterministic system. By contrast, contemporary ecology sees any particular configuration of an ecosystem, as one of the many possibilities depending on initial conditions, historical accidents, or random self-organizing quirks. Therefore, metaphors from ecology can lead to important insight regarding the co-evolution of the economy, society, and the environment.

Actually, only taking our stand on the interpretation of the ecosystems as auto-organizative webs, we can elicit a set of principles, identifiable with the ecological principles, that can be used as guidelines for the realization of sustainable communities (Pignatti e Trezza, 2000).

7. Economics and ecosystem

Particularly, between economic and ecologic systems there are some discrepancies which makes the coexistence of the two systems impossible.

The first contrast consists of the incompatibility between a stable component, free from quantitative growth such as ecosystem, and an ever-growing component, the productive system. The entrepreneurial system utilizes an energetic source created by man and variable at will, that is, capital in the form of money. Such a system is characterized by the linearity of the processes near the equilibrium. The energetic source, money, is both the cause and result of the productive process whose work is based on a recursive cycle.

Consequently, the capital is invested and returns to aliment a continuous growth which makes the accumulation of profits possible. In such regard, the economic growth, is necessary to prevent an economic collapse. On the contrary, ecosystem depends on a constant energetic source, solar energy, which allows the system to stay at a steady state far from the equilibrium. Therefore, after an initial phase of growth it remains in a stationary condition for and indefinite period. Consequently, the economic system cannot continuously expand without overcoming the biosphere carrying capacity and, thus, irreparably altering its cycles.

A further contrast between economy and ecology arises from the fact that nature is cyclical, but our industrial systems are linear. The biological systems composing ecosystem, as mentioned above, utilize solar energy to keep low their internal entropy. In this way, they can keep the biosphere thermodynamic structures in activity, developing in order to utilize as much of the energetic flow originated from photosynthesis as possible. The paths through which the nutritive substances are continuously recycled are the ecosystem retroaction loops.

Being open systems, all the ecosystem organisms produce waste, but what is waste for one species can be a resource for another. In this way, waste is completely recycled and the whole ecosystem is freed from it. Furthermore, all the natural processes of the living being end with dissipation of thermal energy at low temperature in the surrounding space, hence, they do not interfere with the ecosystem processes. On the contrary, the production system exploits resources and elicits from them products and waste: the products are put into the markets and sold to the consumers who, in turn, produce waste. This waste is recycled only in small parts. As the waste is completely external to the biological functions, it is in most cases toxic. It increases biosphere entropy both in relation to the condition which has determined its organization and in relation to the maintenance of its steady state. Consequently, modification occurs in the concentration of environmental elements, disarticulating biosphere cyclical processes. As a result, the biosphere disorders and looses its capacity of auto-organization, homeostasis and resilience.

In order to be sustainable, the production processes which are nowadays using the biosphere as a sink should be cyclical, as are the natural processes (Pignatti e Trezza, 2000).

A further element to be considered is that, while the economic space is determinable by measurable quantities within the price system, the ecosystem is identified with very heterogeneous parameters, depending on both matter and energy. Moreover, according to a systemic view, it has to be pointed out that hierarchical levels characterized by emerging properties are present in the ecosystem. When considering such interconnected qualitative hierarchies the issue of incommensurability arises. It is impossible to reduce the multiplicity of the descriptive domains related to the ecosystem to a unitary synthesis and, consequently, estimate the economic value of the planet, using the economic system metric.

Thereby, alternatives of choice concerning the environment have to be chosen on the basis of multiple criterions and, hence, such choices are difficult to identify. Ecosystems consist of an auto-organizing system which shifts within unknown attractive basins and follows unpredictable trajectories. This, together with the complexity of the functional relationships, determines an actual impossibility of controlling the retroactive effects caused by the anthropic impact (i.e. bovines are vegetarians but it is not possible to predict what would happen if the were fed meat, that is, the Spongiform Encephalopathy uncork). It is necessary to consider that, due to the interconnections linking the elements of every system, both social and natural, the damage is seldom delimited. Consequently, in the environmental protection it is always preferable to act according to prudential criterions, aimed at eliminating the losses before the processes (Luzzatti, 2004).

In conclusion, the environmental problem has to be considered as a systemic problem: nature builds systems by adapting parts in the wholes, and in turn, wholes as parts of major wholes. As a consequence, natural norm does not consist of the existence, presence or absence of any particular system, but in the optimal functioning of the sets containing all the subsidiary subsets. Natural norm applies to the set of relations to which the system refers. Such set of relations establish the ultimate constraints of each subsystem's liberty. Most systems obey such constraints conforming to the energy chain and the information process of the environment. Through the market economy and industrial processes preponderancy, only human species are allowed a simple subsystem to reach dimensions so wide to threaten ecosystem's survival (Laszlo, 1972).

Such considerations illustrate a fundamental fact: managing a social system - a firm, a city, an economy – meant to establish optimal values for the system variables. On the contrary, the attempt to lead any single variable to its maximum values, in any case causes system's destruction.

Conclusions

The present conflict between ecosystem and productive system can be faced only by modifying one of the terms implied in the issue. Since the biosphere is not modifiable, unless it is destroyed, in order to provide a resolution to the environmental problem, it is necessary to change the current production system. Development has to be limited in order to avoid its irreparable interference with the biosphere. With respect to the problem, Georgescu-Roegen claims that a new and alternative economic theory is required. Such theory, termed bioeconomics, which aims at a de-growth society, considers both the characteristics of the living complex system and the cyclical transformation to which such system is subjected (Pignatti e Trezza, 2000).

In this new framework, also the environmental economist figure, whose main duty is to implement the prescriptions related to the environment, must change.

The social scientist in particular has to acquire an overall overview of the relationships that link the economic field to other disciplines. For example, it would be substantive to possess notions about the environmental sciences, with particular stress on the living organization study or the evolution, and notions about thermodynamics, which allow us the comprehension of the material aspect of the economic process (Luzzatti, 2004).

According to a rational ideal it seems apparent that the social system should adapt to the ecosystem requirements as soon as possible and, consequently, address its economic activity. In the past, the industrial revolutions were founded on a myth: subduing nature. Thus, water courses have been harnessed, until an atom has been harnessed, too, by nuclear energy. Today, the new challenge for science and economics is to insert us in the nature logic, in its great cycles, so as not to perturb it.

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