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Author(s): Nicholas Georgescu-Roegen
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The Steady State and Ecological Salvation: A Thermodynamic Analysis

Nicholas Georgescu-Roegen

Strife is the source and the master of all things.

Heraklitus, *Fragm.* 43

THE STATIONARY STATE: A REVIEW:

Change is the greatest challenge for any student of actuality and the most bothersome element for any would-be architect of an ideal society. No wonder then that the state from which all relevant change is absent has offered to the scholarly mind a restful haven. For his republic, Plato prescribed that not only the size of population be kept constant (by treacherous infanticides if necessary), but also any tendency to change be nipped in the bud (*Laws* 740-741, *Republic* 424, 546). Even Aristotle, though rejecting on the whole the master's prescriptions, taught that the ideal state ought to keep the size of its population in accord with that of its land and avoid anything that may induce change (*Politics* II.ii, V.iii, vi-vii, VII.xiv). Naturally, if we can prevent change, we ensure everlasting social stability, a society nearest to immortality, as Plato dreamt (*Laws* 739).

The same idea underpins the recently revived version of an old theme of John Stuart Mill (1920 ed., IV. vi), according to which ecological salvation lies in a steady-state mankind. If the individual human is mortal, at least the human species can become immortal provided that mankind resolves itself to follow this advice, most cogently defended by Kenneth E. Boulding (1966) and especially by Herman E. Daly (1973).

Most economists, however, have always looked upon the advent of a stationary economy with immense disfavor. Adam Smith (1937, pp. 71-95) feared that such a state may come about because the tendency of profits to fall will stop any "further acquisition." It is in the progressive state, he argued, that the condition of the great body of people is the happiest. "It is hard, in the stationary, and miserable in the declining state . . . . The stationary is dull; the declining melancholy." He used the case of China to illustrate his idea that the general welfare depends not on the level of wealth, but on how wealth varies with time.

In contrast, David Ricardo (1951 ed., I, pp. 109, 119-122, IV, pp. 234, VII, pp. 16-17) argued that the stationary economy will come about only because of the pressure of population on food; at that time the size of population will reach its peak. He went on to express his hope that "we are yet far distant" from such an unpleasant situation.

Standard economists of latter days have gone even further in regarding the stationary state (which they equated with "stagnation") with great horror. They believe not only in the possibility of continuous material growth, but also in its axiomatic necessity. This heresy—the growthmania, as Ezra Mishan (1967) labeled it—has given rise to an immense literature in which exponential growth is taken as the normal state of affairs. But the intellectual relief derived from the absence of change explains the strange marriage of this philosophy and the unilateral attachment of the same economists to static analysis. The basic ingredient of this analysis is the stationary state (called also static or steady)—an economy in which production and consumption are carried on at the same rate day after day by some invariable (not necessarily self-identical) economic units.

There was still another reason why static analysis provided from the outset the foundation on which the new economics was to be erected. The unparalleled prestige which the mechanistic philosophy enjoyed among scientists and philosophers until well into the last half of the 19th century was the reason why neoclassical economics was conceived as a sister science of mechanics. The stationary state thus came to be viewed, however tacitly, as the sister concept of the mechanical static equilibrium (Georgescu-Roegen 1966, pp. 18-19, 1971, pp. 40-42, 1976b, ch. 1).

This development aggravated the confusion inherited from Adam Smith, Ricardo, and especially Mill, who all failed to clarify what they meant by stationary state. The situation led Robbins (1930) to argue that "stationary state" is surrounded by so much ambiguity that one should specify even the particular level of such a state. Moreover, he insisted on the strict distinction between the stationary state *reached as the ultimate equilibrium of an evolutionary (or even dynamic) process*—the old use of the Classical school—and the state that is stationary because its main factors (population and capital) *are not allowed to vary*—the analytical fiction of analytical economics.

The necessity for this distinction seems hard to conceive. The geometrical concept of "square," for example, is one and the same, regardless of whether we refer to a perfectly rigid body or to the limit of an elastic quadrangle subject to some dynamic forces. Whether any actual geometrical form can be a square is, obviously, a completely separate issue. One may very well deny—as Al-

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The author is Visiting Benedum Professor of Energy Economics at West Virginia University, Morgantown, WV 26506. The paper was completed while he held an Earhart Foundation Fellowship and served as Distinguished Professor of Economics at Vanderbilt University.

fred Marshall, in particular, did (Robbins 1930, p. 200)—that the stationary state resembles nothing of the real world. All analytical fictions have this defect. However, Daly's insistence on the distinction between "stationary" and "static" is the pivot of the rationalization of ecological salvation through the steady state. The stationary state as conceived by the Classical economists, especially by Mill, is so elastic that it may be adjusted with almost no conspicuous ado to almost any necessity of an argument.

MECHANICAL PENDULUM vs. THERMODYNAMIC HOURGLASS

There are several regrettable consequences of the adoption of the mechanistic epistemology by standard economics. The most important is the complete ignorance of the evolutionary nature of the economic process. Being erected as a sister science of mechanics, standard theory has no room for irreversibility any more than mechanics has. The standard analysis of the market is all based on complete reversibility from one equilibrium to another. Alfred Marshall and a very few others excepted, economic theorists reason as if an event (e.g., a drought or an inflation) left absolutely no trace on the economic process (Georgescu-Roegen 1966, pp. 64-66, 171-183, 1971, pp. 126-127, 338). The conception of the economic process as a merry-go-round between production and consumption also led to a second regrettable omission—that of the role of natural resources in that process.[1]

To get to the root of all these troubles, we need only observe that according to the mechanistic epistemology, the universe is only an enormous dynamic system. It moves, therefore, in no special direction. Like a pendulum, it may move equally well in the reverse direction without violating any mechanical principles. Even the dead could rise to live a life in reverse and die in birth. The sore fate of the mechanistic epistemology was sealed more than a century ago, as thermodynamics compelled us to take notice of the irrevocable irreversibility that dominates the physical world at the macro level.

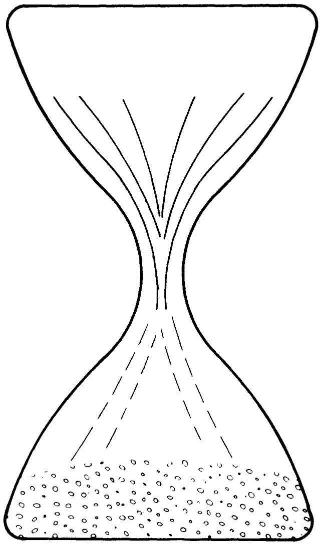

Fig. 1. The hourglass of the universe.

To tell the story of thermodynamics in a plastic way, let the hourglass of Fig. 1 represent an *isolated* system, i.e., a system that exchanges neither energy nor matter with the outside. Let the stuff inside that hourglass represent matter-energy. As in any well-insulated hourglass, the amount of this stuff remains constant at all times, which takes care of the First Law of Thermodynamics. Also, as in any hourglass, the stuff continuously pours down from the upper into the lower half. But two important features distinguish our plastic representation from an ordinary hourglass.

First, as the stuff pours down, it changes its quality. The stuff in the upper half represents *available* matter-energy, i.e., matter-energy in the form that can be used by us humans as well as by all other life-bearing structures of this planet.[2] The stuff in the lower half represents matter-energy which is *unavailable* in this sense. Second, the hourglass of the universe can never be turned upside down. These two special features express the essence of the Second Law of Thermodynamics, namely, that in an isolated system available matter-energy is continuously and irrevocably degraded into the unavailable state. Thermodynamic equilibrium is achieved when all matter-energy ultimately becomes unavailable. If we now note that entropy is an index of the relative level of unavailable matter-energy, we may also say that the entropy of an isolated system continuously increases to a maximum.

Two observations are now called for. First (ignored, if not denied, by the conventional literature), the entropic transmutation occurs in the same direction as the stream of our consciousness, i.e., parallel with our lives. Without this clarification, we cannot possibly speak of the increase of unavailable matter-energy. Second, isolated systems present only a small interest for us. If we set aside the case of the whole universe, isolated systems are set up (with some degree of tolerance) only in laboratories. All the rest are nonisolated subsystems of the universe.

OPEN AND CLOSED SYSTEMS

The *open* subsystem can exchange both matter and energy with its environment. Obviously, the entropy of such a system may either increase or decrease. The open steady system presents a tremendous interest simply because living organisms seem to be so constituted. But although the highly interesting results originated by L. Onsager and expanded especially by I. Prigogine have cast much light on the physical aspects of biological phenomena, we are still very far from a satisfactory comprehension of that field (Katchalsky and Curran 1965, p. 235).

The greatest care must also be observed in applying these results to ecological issues. Because the famous Onsager equalities for an open steady state represent a detailed (rather a delicate) balance among the numerous vectors of the system, an open steady state is as far removed from actuality as a reversible system. Also, the beautiful theorem of Prigogine, according to which the entropy produced by an open system reaches its minimum when the system becomes steady, is improperly invoked by some advocates of the steady-state mankind. The theorem does not say, as they claim, that the production of entropy by an open steady state is necessarily smaller than that produced by a nonsteady one.

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[1] The only environmental factor which appears in the standard theory of production is land in the Ricardian sense, that is, indestructible space. Mill (1920 ed., p. 22) seems to be the last economist of repute to share explicitly the old view of William Petty, that labor is the father and nature the mother of wealth (Georgescu-Roegen 1966, p. 22).

[2] Because of the patently anthropomorphic scaffold, thermodynamics constitutes a peculiar science (see footnote 5, p. 268). But thermodynamics has also a wrap of mystery, for it still does not tell us whether or not its laws are valid for extraterrestrial forms of life. It is well to point out that the famous paradox of Maxwell's demon bears on this very issue; hence, the arguments claiming to have resolved it are perforce unavailing (Georgescu-Roegen 1966, pp. 80-81, 1971, pp. 187-89).

On the other hand, no systematic objection seems available against the idea that, conceivably at least, the economic process may be a steady state as long as the resources of available matter and energy are accessible with the same ease (which can hardly be the case forever in actuality). But even this admission would not vindicate the thesis of ecological salvation by the steady state. The earth is not an open, but a *closed* subsystem, i.e., a system that exchanges only energy with its environment.[3] Such a system may be represented plastically by the circular coil exchanging only energy with the universe hourglass (Fig. 2). The amount of matter within the system, represented by the circular thick arrow, remains constant at all times.[4]

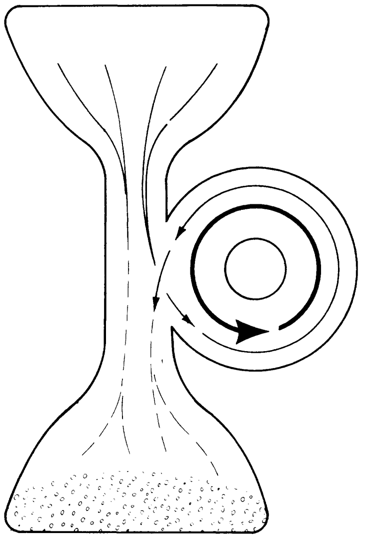

Fig. 2. A closed steady subsystem.

The Problem of Entropy

Even though the closed system constitutes the theoretical foundation of classical thermodynamics, the problem of whether such a system may be a steady state has not been (to my knowledge) examined systematically. Perhaps the general feeling has been that as long as enough available energy is forthcoming, there is no limit to the amount of work that can be performed. This very idea now dominates our thoughts on the entropic problem of mankind. For its justification, one is likely to refer to the fundamental formula of classical thermodynamics for closed systems, $dU = \Delta Q - \Delta W$, where dU is the internal energy of the system, Q the amount of energy received as heat, and W the amount of work performed by the system. For a steady state, $dU = 0$; hence, $\Delta Q = \Delta W$. Any given task, therefore, can be performed by a corresponding amount of energy.

The usual thermodynamic manual illustrates the formula $dU = \Delta Q - \Delta W$ with the aid of an ultrafamiliar apparatus involving a piston. Classical though this argument is, it ignores some crucial facts. One omission was recently pointed out by Silver (1971, pp. 29-31): not all energy can be converted into effective work; part of it, being work against friction, is always converted into dissipated thermal energy.

The second regards the speed of the transformation. Certainly we cannot launch a rocket by heating the propelling gas with one match flame after another.

The last and the most fateful omission is that, because no conversion of energy is achieved without material support, friction dissipates not only energy but also matter. The wear-and-tear of most apparatuses during a single experiment may be imperceptible, but that is no reason to ignore it. In the long run or at the immense scale of the "world engine," the dissipation of matter reaches palpable proportions. All around us there is oxidation, chipping, blowing, and washing away, etc. There are no everlasting material structures because matter just as energy continuously and irrevocably dissipates.

However, let us not fail to realize that, in addition to the natural entropic degradation, dissipation of matter and energy is aggravated by all consumer creatures, especially by humans.[5] Topsoil everywhere is washed out into the oceans mainly as a direct consequence of the Entropy Law. However, by consuming food or burning wood, for example, far away from where they have been produced, man heightens immensely the dissipation of both matter and energy.

Matter Matters in Closed Systems

Since in a closed system available matter becomes increasingly scarce, why not use (one may suggest) the inflow of available energy to produce matter by the Einstein equivalence $E = mc^2$? The answer is that even in the fantastic engine of the universe matter is not created from energy *alone* to any significant extent; instead, huge amounts of matter are continuously converted into energy.[6] There is now on earth less uranium, for example, than there was millions of years ago. However, the number of copper molecules or of other such stable elements is now the same as when the earth was formed.[7]

Further, could not available energy help us to solve the material scarcity in another way? With a refrigerator we can separate again the hot from the cold molecules interdiffused by the melting of the ice cubes in a glass of water. We should be able to undo also the diffusion of matter and reassemble the molecules dissipated from a worn out penny or an automobile tire.

This idea of complete recycling is now highly popular; it is, though, a dangerous fallacy. Ecologists, as a rule, have been feeding it by describing with delightful diagrams how oxygen, carbon dioxide, nitrogen, and a few other vital chemicals are recycled by natural processes driven by solar energy. If these explanations pass muster it is because the quantities of the chemical involved are so immense that the entropic deficit becomes conspicuous only over long epochs. Some carbon dioxide, we know, ends up as calcium carbonate in the oceans, and the phosphorus in numberless skeletons of dead fish tends to remain dispersed on the bottom of oceans.

Having in mind the statistical interpretation of thermodynamics, one may argue that we can certainly reassemble the pearls of some broken necklace scattered over the floor. Is not recycling just such a type of operation? To see

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[3] There certainly is the meteorite fall. But although its amount may seem substantial (150,000 tons per year), in relative terms it is negligible; most of it is just dust. The material particles that may occasionally escape the gravitation pull are even less important.

[4] The fourth case—the system that exchanges only matter with the outside—is factually impossible, for any matter in motion carries kinetic energy.

[5] By now we all know that only in thermodynamics, of all branches of physiochemistry, life does matter. The green plants slow down and the animals speed up the entropic degradation. But even the plants cannot convert all solar radiation into effective work; that would defeat the Entropy Law.

[6] In nuclear reactors, plutonium-239 is produced from a substantial material base—uranium-238 or uranium-235—and some energy.

[7] See footnote 3.

the error in extrapolating from the molar to the molecular level, let us suppose that the same pearls are first dissolved in some acid and the solution is spread over the oceans—an experiment which depicts what actually happens to one material substance after another. Even if we had as much energy as we pleased, it will still take us a fantastically long, practically infinite time, to reassemble the pearls (Georgescu-Roegen 1976b, ch. 1).

This conclusion recalls a point taught by the introductory chapters of all thermodynamic manuals: All processes moving with infinitely small speed are reversible, because with infinitely small speed there is practically no friction. However, such a slow motion takes a practically infinite time. This is in fact the analytical reason why reversibility is not possible in actuality. It also is the analytical reason why matter cannot be recycled completely.

A FOURTH LAW AND THE ECONOMIC ENGINE

One consequence of the foregoing observations about matter is that something is amiss with the concept of *net energy* as a measure of efficiency (Cottrell 1955, Odum 1973). If ten tons of coal can be mined by using only the equivalent energy of one ton—we are told—we gain a net energy of nine tons. By the same token, any mining yields some *net matter*, but some *negative net energy*. A power plant, on the other hand, yields a *negative net matter.*

The obvious rub is that, since both energy and matter are involved in any operation, the only concept applicable is that of *global accessibility.* A straight flow-fund model (Georgescu-Roegen 1971, ch. 9, 1976b, ch. 9) will clarify this notion and, moreover, will provide an analytical basis for explicating the symmetrical role of matter in any physical process (Georgescu-Roegen 1976a).

The diagram of Fig. 3 represents the global flow circulation between the environment and the economic process. The latter is divided into six aggregate subprocesses: cE, producing controlled energy (e.g., electricity or gasoline); cM, producing controlled matter (e.g., steel ingots); K, producing capital equipment; C, producing consumer goods; R, the recycling industry; and Hh, the households. The primary input flows are eE and eM, environmental energy and matter. The final output flows of the economic process are dE, dissipated energy; dM, dissipated matter; and W, waste (e.g., crushed rock or nuclear garbage).

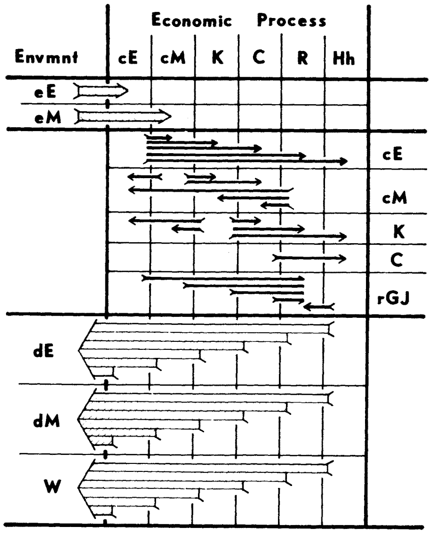

Fig. 3. The global flow circulation (no scale is implied) between the environment and the economic process. Key: cE = controlled energy; cM = producing controlled matter; K = producing capital equipment; C = producing consumer goods; R = the recycling industry; Hh = households; eE = environmental energy; eM = environmental matter; dE = dissipated energy; dM = dissipated matter; W = waste; and rGJ = "garbojunk." See text for explanation.

In addition, all economic activities produce "garbojunk," rGJ, which is neither dissipated matter nor waste, but *available* matter which, however, is not in a shape useful to us. It includes such things as broken bottles, old newspapers, worn out automobiles or clothes. And the point that can hardly be emphasized too much is that we can recycle only garbojunk; *dissipated matter is not recyclable.* R recycles all garbojunk, including its own, so that it has no such output flow.

The flow diagram brings home several important points. First, no economic system can survive without a continuous inflow of energy *and* matter; in particular, it cannot be a closed steady state. Even if all W could be recycled,[8] the dissipation of matter would still prevent the capital fund from being kept constant. Indeed, the maintenance of the transitory funds—the people *and* their detachable limbs (the capital equipment)—is the only material aim of the system, even though the real product of the entire activity is the mysterious immaterial flux of life enjoyment.

Two important conclusions emerge from the foregoing analysis. The first, which interests mainly the economist, is that, since energy and matter cannot be reduced to a practical common denominator, we cannot decide on purely physical grounds which of two processes performing the same task is more efficient, if one uses more energy, the other more matter. This decision remains *economic.* One should all the less think of reducing economic value to a physical coordinate. Economic value is related to low entropy of both matter and energy, but not equivalent to it (Georgescu-Roegen 1966, pp. 93-94, 1971, pp. 282-283). The roots of economic value lie in low entropy and the drudgery of work (another immaterial flux).

Because of its broader relevance, the second conclusion may be set forth as the Fourth Law of Thermodynamics (Georgescu-Roegen 1976a): *In a closed system, the material entropy must ultimately reach a maximum.*[9]

Jonathan Swift once argued that "whoever could make two ears of corn, or two blades of grass, to grow . . . where only one grew before, would deserve better of mankind . . . than the whole race of politicians" (Swift 1914 ed., XII, p. 176). The above law teaches us that to make just one blade of grass grow on the same spot year after year on end would be a miracle (Georgescu-Roegen 1971, p. 302).

FROM THERMODYNAMICS TO ECOLOGY AND ETHICS

Almost anyone nowadays is likely to expatiate to his heart's content on the connection between thermodynamics and ecology. But, as we have seen in more than one case, just to air the textbook teachings does not suffice to explain what happens in the world engine, let alone to probe the various ecological prescriptions coming from all directions. Probing Mill's thesis is a case in point.

An economy consisting of "a constant *physical* wealth (capital) and a constant stock of people (population)," as defined by Daly (1973, pp. 14, 153),

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[8] Some waste may be eliminated. The crushed rock produced concomitantly with shale oil could, conceivably, be pressed back into place. However, some oil might then be no longer accessible. Such facts of life are totally ignored by those who preach that we can tailor the environment according to our wishes (Johnson 1973).

[9] The case of a single chemical element brings to mind Gibbs' famous paradox.

is a steady state, which may be either closed or open. The closed state is excluded by the law enunciated above. If open, the state can be only quasi-steady, because Onsager's relations cannot all be satisfied exactly. It further presupposes a quasi-constant accessibility to natural resources.

For the longest part of its history, mankind has in fact lived in such a state, in the traditional village communities which are not quite extinct yet. An industrial society, however, is constantly confronted with a decreasing accessibility to matter-energy in use. If this decrease is not counterbalanced by technological innovations, capital must necessarily be increased, and people must work harder if population is to remain constant. In this direction, there is a limit to the capacity of work as well as to the need for food and comfort. If innovations make up for the decrease, capital cannot remain constant in some definite sense. The weightiest difficulty is that such innovations cannot go on forever in a closed system.

The overpraised and oversold technological developments of our own era should not blind us. From the viewpoint of the economy of terrestrial resources—the basis of mankind's industrial mode of life—most innovations represent low entropy squandering. The razor that can wholly be tossed away when the blades become dull or the mountains of photocopied material discarded without even being glanced at pale in comparison with mechanized agriculture and high-yield variety (Georgescu-Roegen 1971, p. 302, 1976b, ch. 1, 3). "Bigger and better" automobiles, golfcarts, lawnmowers, etc., forcibly mean "bigger and better" resource depletion and pollution.

It is this growthmania, in the ultimate analysis, that Mill and the modern advocates of the steady state want stopped. But they have somehow reasoned as if negating growth produced a stationary state. Probably, as economists they could not think also of a declining state. And curiously enough, most arguments in favor of the steady state work even better for this other state (Georgescu-Roegen 1976b, ch. 1).

By Daly's own admission (1973, pp. 154-155), the steady state thesis has nothing to say about either the size of population or the level of the standard of living. A thermodynamic analysis again makes it clear that the desirable size of population is that which can be fed by organic agriculture alone.

Nevertheless, Mill's thesis teaches us a great lesson. "The struggling to get on; . . . the trampling, crushing, elbowing, and treading on each other's heels which form the existing type of social life," in his words, should cease.

To achieve this dream, we may begin with a minimal bioeconomic program which should take into account the fate of not only our contemporary fellow men, but the future generations as well. Economists have preached for too long that we should maximize our present gains. It is high time that people realized that the most rational conduct is *to minimize regrets.* Any piece of armament or a two-garage car means less food for the hungry of today and fewer plowshares for some future (however distant) generations of humans like ourselves (Georgescu-Roegen 1971, p. 304, 1976b, ch. 1, 3).

A new ethics is what the world needs most. If our values are right, everything else—prices, production, distribution, and even pollution—has to be right. At first, man has heeded (at least in a large measure) the commandment "thou shalt not kill," and later "love thy neighbor as thyself." The commandment of this era is "Love thy species as thyself."

Even this commandment, however, would not put an end to mankind's struggle with the environment and with himself. The duty of academia is to help attenuate this struggle and not to delude others with ideas beyond the power of human science. This is responsibility with humility—the bioethics of Van Rensselaer Potter (1971).

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