LIFE-CYCLE, ENVIRONMENTAL AND SOCIAL CONSIDERATIONS - SUSTAINABILITY

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Contents

Summary

The chapter inquires about the possibility of expanding the meaning of "optimal system" beyond its engineering limits: in other words, it explores the possibility of including environmental, monetary and social externalities in process optimization procedures (as discussed in *Optimization Methods for Energy Systems* and *Design and Synthesis Optimization of Energy Systems*) either as independent variables or as constraints of some sort. We shall see that the answer is affirmative, provided new methods are developed for the proper "weighing" of variables rather different from the usual engineering "process variables". In essence, the analysis must be expanded both in space and in time, considering the entire ecosystem as the proper control volume and the life-cycle of the system as the relevant time-scale. We shall examine Embodied Energy Analysis, Life Cycle Analysis (LCA), the Cumulative Exergy Content (CEC) Method, Emergy Analysis and Extended Exergy Accounting (EEA), and see how they treat the internalization of externalities. We discuss LCA, CEC and EEA in more detail, because they seem to be more useful under several respects. Dealing with "global" optimization inevitably raises the issue of Sustainability, which we also address. Our conclusions are that strong sustainability is *approximately feasible in human timescales*, but requires a major shift in both the resource mix and the end-use consumption standards. Furthermore, a sustainable state being a long-term goal, the transient must be planned and steered using decision-support tools similar to Exergy-based LCA or EEA.

1. Introduction

In the last part of the XX Century, humankind has become increasingly preoccupied with problems related to the environment we live in, our "Biosphere". A combination of "natural" evolutionary factors and human interventions brought about a series of new problems, forcing us to investigate the complex interactions of our species with the biosphere and suggesting that our entire "environment" (the world in which we live) may be pushed into a "catastrophic" (in a bio-geological, rather than human, sense) transition towards a different evolutionary pattern. The problem, broadly stated, can be expressed as follows: "Are the present patterns of human development irrelevant for the natural course of the geological evolution of Planet Earth or have the magnitude of the Human/Nature interactions reached a limit beyond which natural cycles are perceptibly affected by human intervention?" In other words, is the Earth being "modified" globally and on geological timescales by the presence and behavior of its dominant living species? Present evidence shows that the cumulative behavior of the human race is indeed affecting Earth's chemical and energetic balances: less clear, and presently hotly debated due to its extremely far-reaching implications, is the extent of these "human effects" and the ways to mitigate the situation. Oddly, in spite of the fact that the debate mostly concerns physicists, biologists, chemists, economists, sociologists and philosophers, it is the engineers that might have the key to it, perhaps not in the sense of "solving" the problem (though this could also be possible, as we shall try to argue below), but definitely in reducing the human influence on the planet's evolution.

To deal with such issues, we must expand the horizon of our investigation to encompass the entire human society and its "surroundings" (in an extended sense).This leads to a problem that has preoccupied industrial and energy planners for almost 20 years, becoming a hot focus of attention for the broader public opinion only in the last decade or so: *sustainability*. This chapter is organized as follows: we discuss first the extension of the concept of "Optimal System" (Section 2), arguing that it is necessary to factor into the analysis *in a quantitative fashion* the effects of finite plant life, those related to the life-cycle of the products and materials used by the processes and disposed of in due course, and those related to the associated environmental externality, i.e. the costs of the pollution originated by the placement of a process in a previously undisturbed ecological niche. Extending our range a little further, we then briefly consider the associated social externality, i.e. the costs of the integration of the productive structure into the human community (local and at large). Finally, we discuss material cycles (inputs and outputs) to judge whether and to which extent they may affect the planetary balance.

In Section 3, we describe some of the new tools required for a correct analysis of the expanded problem: first, the Life Cycle Assessment paradigm is discussed in detail, together with its logical extension, Exergetic Life Cycle Analysis. Then, we address Embodied Energy Analysis and its more advanced counterpart, Szargut's "Cumulative Exergy Content" method. At this point, we present a brief critique of today's dominating economic theory, the so-called Neo-Classical Economics (NCE), with the purpose of exposing some of its limitations and pitfalls. This introduces the last two paradigms discussed here, the strongly holistic *Emergy* Analysis and the Extended Exergy Accounting method, both based on the negation of the validity of the three basic assumptions of NCE.

Section 4 discusses the application of the tools to practical problems, and Section 5 addresses the "problem" of resource scarcity, much debated in scientific and popular circles alike. Our aim is to establish whether and to what extent this problem is relevant to the survival of humankind. At this point, our thesis will already be clear (let us anticipate here that we believe that a sustainable society is indeed possible on geological timescales, provided certain strong measures are taken to modify human attitudes and expectations), so we discuss the "Spaceship Earth" paradigm as a "cellular" example of a sustainable society. Finally, Section 6 describes a "feasible" sustainable society: we try here to formulate the problem of its attainability in a rational and well-posed form.

2. Extension of the Concept of "Optimal System"

Theme 3 is concerned with Energy Conversion Systems ("ECS"), and has dealt with their "optimization": we say that an ECS is optimal under certain constraints if it delivers its "product" with the minimum use of "resources" (materials, energy and capital). Previous chapters have treated both technical, economical and environmental optimization problems: we have learned how to use Thermo-Economics to construct an informed judgment about the optimality of an ECS, based on a proper combination of a monetary measure (for capital) and of an energetic measure (exergy, for resources). We have learned that it is possible, though under somewhat more stringent assumptions, to factor into this judgment (a portion of) the apparent environmental damage by "internalizing" additional "Environmental Costs" (externalities) and reducing them to equivalent monetary costs. Nowhere in Thermo-economics, though, do we find mention of a functional correlation between Environmental, Labor and Capital costs, or of their common dependence on social factors (this issue is usually left for Sociologists). Furthermore, with very few exceptions that address the problem only at a scale local to the plant, neither have we heard about including into the accounting procedures the expenditures (of resources, capital and labor) that pertain to the life cycle of the product or of the very same plant.

2.1. Including the Effects of a Finite Plant Life

Traditionally, analyses of energy systems consider only the "active" (i.e. operative) phase of the plant life. However, in an extended approach addressing long-term issues, it is absolutely necessary to consider that a power plant has a finite life and to include the impacts associated with the end-of-life of the system. In fact, decommissioning may have very significant environmental (and social) impacts (consider for example nuclear and hydroelectric power plants, steel-processing plants, etc.).

2.2. Including the Effects of the Life-cycle of the Product

If the scope of our analysis is expanded a little further, the overall assessment of any energy system should take into account its full life cycle. This includes both the already mentioned downstream steps of the chain (end-of-life, decommissioning), as well as all of the upstream steps, in particular the environmental impact, resources and energy consumption related with the production and use of materials needed to build and operate the plant. For fossil-fueled systems, this includes for instance the fuel extraction and its transportation to the plant. For nuclear power systems, it includes the impacts related to the total fuel cycle. In fact, a life-cycle approach is the only suitable method to assess renewable energy systems. For example, solar photovoltaic systems produce zero emissions during their operational phase, and a life-cycle assessment is the only way to account for the upstream phases of the preparation of the semiconductor material and of the production of modules, *where emissions may occur*. Furthermore, it can also calculate the impacts related to the rest of the system (i.e. support structures, electronics, integration in buildings, etc.) as well as those related to the recycling of the modules at the end of their operational life. *In spite of some subjective aspects in its formulation that must be dealt with from a methodological point of view, a global life-cycle analysis is the only comprehensive and coherent way to compare different energy technologies.*

2.3. The Environmental Externality

Until a few decades ago, environmental remediation expenses were not considered a component of the cost of a product. *It took a long time for Legislators to include provisions that make polluters responsible* for the consequences of the pollution they caused. The topic is far from being satisfactorily resolved and is still subject to debate, because of the very high interests, both genuine and vested, at stake. Generally speaking, modern regulations force producers to include in the production costs of a commodity either the real costs necessary to remedy the environmental damage if, when, and where it occurs (like the environmental insurance against oil spillages from ships), or some nationally or internationally accepted "pollution tax" (like the carbon tax or the direct taxation of waste products). From a *global point of view*, and in spite of the substantial advances made under the pressure of an increasing public awareness, the following problems remain open:

- For most pollutants, the exact damage assessment on a scale larger than local is essentially unknown or at least subject to debate;
- The complex interactions between different pollutants are difficult to assess on a global scale;
- *The very same definition of "pollution" should be revised, and taken to mean "every substantial human alteration of the existing state of the environment". Notice that this brings some problems of scale (what does "substantial" mean?) and must also be meant in dynamic terms (because the "state of the environment" changes naturally even in the absence of human intervention).*

Let us consider some unquestionable facts:

- *The environmental resource base is finite*. Therefore, we must preserve and, where possible, restore the integrity of natural systems (soils, water, air, and biological diversity) that sustain both economic prosperity and life itself.
- *There are limits to the carrying capacity of the planet*. Since there are unmistakable signs that we are indeed approaching this limit (in what sense, see Section 5), it is illusory to think that technological "progress" will improve our resource-exploitation efficiency so much that we may remain below that limit indefinitely: we must instead reduce our physical demands on all life-support systems.
- *Economic growth is not a panacea for diminishing environmental quality*, unless our idea of the future is few hundred million individuals living brutally on a desert planet (the so-called "Mad Max model" from the1985 movie). A high *pro-capite* income is useless if the resource base is reduced below sustenance.

At the risk of overgeneralization, we can say that the root of the problem lies in the fact that present Environmental Economics is overwhelmingly micro-economics, its emphasis being placed on the correct internalization of environmental costs to arrive at *product prices that reflect the producers' marginal costs*. As correctly noted by some economists (see for instance Herman Daly, 1996) the real issue ought to be instead how to internalize externalities so that *product prices reflect full social marginal opportunity costs.* Such an internalization is possible in practice only if we can convince all segments of society to equitably share environmental costs and benefits, so that both the polluter and the depleter are forced to pay a proper penalty. One powerful tool is a (revenue neutral) taxation shift from income (value added) to throughput (the commodities to which value is added). This shift could be supplemented for social equity with a stiff income tax on very high incomes and a negative tax on very low incomes in order to maintain progress. The "Exergy Tax" as well as the "Renewable Energy Incentives" is a step in this direction. Even "Pollution Trading Permits" can be considered a displaced and hidden form of such taxation. It is clear that, to correctly assess our options and priorities for the near and far future, we need additional analysis tools to somehow “price” environmental damage.

2.4. The Social Externality

In the last two centuries, first Classical economists and then Neo-Classical as well have made a banner of the concept of *growth*. In this context, the term refers to an increase in the physical scale of the cumulative matter/energy flow that sustains the economic activities of production and consumption of commodities. For a single Company and for Nations alike, “to grow” means “to quantitatively increase the physical scale of one’s throughput”. Notice first that unlimited growth is denied by our assertion that the Environment is finite: even if we think of colonizing other planets, the best we can hope for is delaying the instant in which we will reach the limiting capacity of the System. Some economists and energy planners contend that by pushing technology to higher levels, we can effectively keep the same growth rate by “modifying” the type of load we impose on the Environment: this is the rationale behind underwater farming, water desalination, biologically-modified cultures, etc. Even if a limited amount of such a growth is, with enough ingenuity, possible, ethical and social limits may render it undesirable. If we extend our solution space to include “social” variables, four additional propositions arise that limit the desirability of growth:

- *The desirability of growth financed by the **consumption** (=**annihilation**) of geological capital is limited by the cost imposed on future generations.* One *kg* of resource used up irreversibly today has a certain and known monetary present-worth. By the concept of discount rate, we know that the same *kg* (if untapped today) will be worth e^{ni} in n years from now. For a constant 5% discount rate, its future worth doubles roughly every 13 years and 10 months. Will a hypothetical “future generation”, say in 100 years, be able to value that very same *kg* 148 times its present worth? Or, are we able to ensure our descendents that, for each *kg* we use today, we “generate” 148 *kg-equivalent* of the same resource for their future use?
- *The desirability of growth financed by takeover of habitat is limited by the reduction of bio-diversity due to our excessive altering of other species’ habitats.* Economic growth requires “more space” for humans and their activities. Necessarily, this *invades* the space used by other species. We have enough examples at present of how the extinction or near-extinction of a species affects, with a domino-like effect, an area much larger than the one the extinct species used to live in. The imposition of some limit on habitat takeover based on the calculation of the use value of the endangered species is however practically impossible. Once we have established that a continuing expansion of the scale of the human economy is inconsistent with maintaining bio-diversity and ecological life-support systems, a possible simplified approach would be that of allowing a limited takeover of the habitat of other species, and then penalizing such takeover by a purely “environmental levy“ (i.e. neglecting the social cost of reducing bio-diversity).
- *The desirability of aggregate growth is limited by its self-canceling effects*. It has been argued that absolute wants (those we feel independently of the condition of others) are not insatiable. Relative wants (those we feel only because their

satisfaction makes us feel superior to others) are indeed insatiable. To quote John Stuart Mills, "men do not desire to be rich, but richer than other men". In industrialized countries, on the average and neglecting for a moment the "islands" of urban poverty, increments in well-being are largely a function of changes in relative income. In this case, growth is unable to increase welfare in the aggregate, or at least that portion of the welfare that depends on relative position. This is clearly an attitude problem, and raises formidable educational and socio-political issues, because economic growth, environmental protection and social equity ought to be seen as interdependent, mutually balancing national goals, but in practice policies to achieve these goals, instead of being integrated, frequently conflict.

- *The desirability of aggregate growth is limited by the degradation of moral standards resulting from the very attitudes that foster growth, such as excessive emphasis on self-interest and a self-asserting "need-to-grow" dogma. On the demand side of commodity markets, growth is often stimulated by greed and intensified by the ever present advertising industry. On the supply side, some technocrats proclaim the possibility of limitless expansion without offering a credible justification for this belief, and often show a disturbing tendency to discard or question even proven facts that contradict their outlook.*

A substantial distinction must be made between *growth* (quantitative increase by assimilation or accretion of materials) and *development* (qualitative improvement). Commonly, the concept of economic growth is expressed as "growth in GNP", but GNP in fact conflates (and confuses!) these two totally different concepts, and furthermore also hides some of the information content about the reality underlying these concepts. Growth is not sustainable in a finite environment. Development, though, may well continue for geological times, probably as long as the human race survives as a species. We can, thus, anticipate one of the findings of Section 6: *sustainable development is development without growth;* that is without an increase of the material and energy flows of the System beyond the regeneration and absorption capacities of the "Environment" (Planet Earth or whatever). Progress means development, not growth.

In such a context, population control and consumption patterns become key issues. Population must be stabilized at a level consistent with the capacity of the Earth to support its inhabitants at a "decent" level of *pro-capite* wealth. Even if we cannot precisely quantify "decent life", it is important to assert this principle, and leave the discussion on life quality standards open. Some difficulties arise here: different *cultures* have different views about the way population and consumption are to be controlled, and migrations or free trade with free capital mobility tend to drive people from low-GNP, high population density to high GNP, low population density Countries. The current thrust toward economic globalization is compatible with global population control only if we could establish some sort of World Population Authority, which in turn opens the door to delicate political problems. *The issue is so complex and has so far-reaching consequences that it is very unlikely that a compromise between supporters of contrasting views may be reached in the short run.*

The global patterns of consumption must be consistent with a steady improvement in the efficiency with which society uses natural resources. This raises a politically sensitive issue: low-GNP Countries question the imposition of stricter limits on their industrial development, which they perceive as unfair. In fact, we have reached the present state of affairs because of the exponential growth brought on by the uncontrolled industrialization of today's high-GNP Countries. Why should now the weaker be denied access to higher standards of living? It is clear that what is needed is *a simultaneous strong reduction in the levels of consumption in high-GNP Countries and a strict control of the rate of growth of low-GNP ones.*

Population control and reduced consumption, joined by greater sharing (an educational problem!) can also help eliminating poverty, another sensitive social issue.

2.5. Material cycles

The importance of material flows for the production of commodities is often downplayed by economists, who point out that on the average only about 10% of the GNP accounts for the extractive and reclaiming sectors. From the perspective of an Energy Engineer, this is an example of the "fallacy of misplaced concreteness": even if the aggregate monetary worth of these two sectors is a relatively small fraction of the GNP, what would happen if there were zero material input flows? Our economy, and indeed our entire Society, is based on the transformation of raw materials into commodities and services. *Even if the extraction and reclaiming sectors account for only a small portion of the GNP, they make the remaining activities are possible.*

In what follows, we treat separately renewable and non-renewable flows, because their "economics" are different.

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Biographical Sketches

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He received a Master in Mechanical and Electrical Engineering from UDR1 in 1972. From 1972 to 73, he was a Research Assistant at the Chair of Turbomachinery in the same University. From 1973 to 75, he worked as Research Engineer in the Research and Development Division of BMW, Munich, Germany, where his tasks included the design, development and testing of advanced i.c. Engines.

After returning to UDR1 as a Senior Research Assistant from 1975 to 1978, he enrolled in the Graduate School of Mechanical Engineering with major in Thermal Sciences at the Rutgers University, New Brunswick, NJ, USA, where he was granted his Ph.D. in 1981.

From 1981 to 1985 he was Assistant Professor at Catholic University in Washington D.C., USA, teaching Thermal Sciences.

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He has been post-doctoral Marie-Curie research fellow at CMER/INSEAD working on the “Applicability of Life-Cycle Assessment (LCA) to Management for Eco-Efficiency with specific reference to Energy Technologies”.

Dr. Frankl's background is in semiconductor physics. He holds a PhD in "Energy and Environmental Technologies" from the University of Rome. His thesis on "LCA of Photovoltaic (PV) Systems" has obtained the 1st Italian National Award Premio ENEA Energia e Ambiente, 1998.

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