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Econophysics and bio-chemical engineering thermodynamics: The exergetic analysis of a municipality

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HIGHLIGHTS

- Econophysics is very powerful to support municipality policies.
- Bioeconomics plays a fundamental role for new perspectives in economy.
- Biochemical engineering thermodynamics highlights the role of irreversibility and exergy.
- A link between econophysics and biochemical engineering thermodynamics is obtained.

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ABSTRACT

Exergy is a fundamental quantity because it allows us to obtain information on the useful work obtainable in a process. The analyses of irreversibility are important not only in the design and development of the industrial devices, but also in fundamental thermodynamics and in the socio-economic analysis of municipality. Consequently, the link between entropy and exergy is discussed in order to link econophysics to the bio-chemical engineering thermodynamics. Last, this link holds to the fundamental role of fluxes and to the exergy exchanged in the interaction between the system and its environment. The result consists in a thermodynamic approach to the analysis of the unavailability of the economic, productive or social systems. The unavailability is what the system cannot use in relation to its internal processes. This quantity result is interesting also as a support to public manager for economic decisions. Here, the Alessandria Municipality is analyzed in order to highlight the application of the theoretical results.

1. Introduction

In the analysis of the thermodynamic behavior of open systems, irreversible processes represent one of the fundamental topics of investigation in thermodynamics. Indeed, the studies on irreversibility are important not only in the design and development of the industrial devices [1], but also in the studies related to biomedical applications [2,3]. The studies on irreversibility are very interesting in thermodynamics because they allow us to write the dissipation terms by using entropy generation and, consequently, to express the usual inequality by means of equations [1,3–9].

In 1824, Carnot [10] introduced an ideal engine operating on a reversible cycle without dissipation. This engine converts the absorbed heat in work and, apparently, it has no irreversibility. Carnot proved that [10,11]:

1. All ideal engines operating between the same two thermal baths (thermal reservoirs) of temperature T_1 and T_2, with $T_1 > T_2$, have the same ideal efficiency $\eta_C = 1 - T_1/T_2$.
2. Any other engine, operating between the same temperature, has an efficiency η such that it is always $\eta < \eta_C$.

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Carnot's conclusions represent the existence of a definite limit for any conversion of the heat into the kinetic energy and work [10,11]. Just to develop the analysis of dissipative processes, Clausius [12,13] introduced a new thermodynamic quantity, named entropy [12,13].

Science and technology are considered fundamental to the growth and socio-economic development of countries; indeed, technological development has impact on income distribution, economic growth, employment, trade, environment and industrial structure [14,15]. The 1992 Earth Summit stipulated that countries at national level as well as governmental and non-governmental organizations at international level should develop indicators of sustainable development in order to support countries in making decisions on sustainable development [14].

At all levels, the role of science and technology is fundamental; scientific knowledge and technologies are the basis to challenge economic, social and environmental problems in order to avoid unsustainable conditions. The analysis of technological processes can be developed using a thermodynamic approach for the whole system and for all its interactions both internal to the process and external to the environment and society. The results consist of a quantitative evaluation of the flows of matter and energy which occur in the system and of the consumption rate of the available resources. This information can represent a fundamental support to policy planning and resource management [15].

In order to evaluate the technological level and the advanced level of industrial processes some indicators must be considered. Every company applies different production processes, which cause different carbon emissions or environmental impact, therefore as regards the environmental effects, the process itself results more important than the product obtained. In order to analyze both the environmental impact and the technological level acquired by the countries several indicators can be introduced. These can be defined as in Ref. [15] "an aggregate, a quantitative measure of the impact of a 'community' on its surroundings (environment)". It implies that:

1. The ecological indicators must be applicable to any "community";
2. They are aggregated because it cannot be limited to a single individual;
3. They consider only the effects produced on the environment that surrounds the community under examination.

From this definition it follows that the community and the environment must be considered as two separate, but interacting systems [15]. The consequent properties of the environmental indicators can be summarized as follows:

1. They must be evaluated using unambiguous and reproducible methods under a well defined set of fundamental assumptions;
2. They must be expressed by a numeric expression whose results can be ordered in an unambiguous way;
3. They must be calculated on the basis of intrinsic properties of the community and of the environment;
4. They must be normalized in order to compare different communities or environments;
5. They must be defined on the basis of the accepted laws of thermodynamics.

Sciubba analyzed in detail a lot of indicators and pointed out their limits in Ref. [15]. Here his results are summarized according to the most used environmental indicators:

1. MTA (Material Throughput Analysis or Material Inventory Analysis): it is an indicator based on the assumption that the lifestyle of a community can be measured by the global equivalent material flow used to produce the commodities on which it thrives. The method involves highly disaggregated accounting of the material inputs/outputs and it requires detailed knowledge on production processes. Moreover, it does not use the second law of thermodynamics;
2. EEn (Embodied Energy): it is an indicator which obtains a direct measure of environmental impact. The amount of energy used to construct a product, in terms of resources and work done, is evaluated, but it does not include any measure of the quality of the energy flows considered;
3. The tranformity: in the Emergy Analysis the energy accounting is considered, but the fundamental assumption is that the only input form of energy is the solar radiation. All other flows of matter and energy are related to equivalent solar energy necessary to obtain them. This evaluation is carried out using a proper set of coefficients, the transformities. It does not include any measure of the different quality of the energy flows.

Now, we must consider that energy is a thermodynamic property which characterizes any state of a thermodynamic system in relation to a reference state. It is a conserved quantity in relation to the universe (the system and its environment), and its total value is always constant [16]. So, its physical meaning is related to its variation, which is the value and the causes of the useful work. Consequently, any change in a system is no more than a transition between two states.
On the other hand, the exergy of a system is the maximum shaft work obtainable by the system in relation to its specified reference environment, which is considered infinite, in equilibrium and it is specified by fixing its temperature, pressure and chemical composition [16]. The exergy was introduced [17] by Carnot [10], even if only implicitly, as a fundamental concept of the thermodynamics [18–22]. But, Gibbs [21] was the first to define explicitly the available work, even if also Tait and Lord Kelvin have defined a quantity similar to Gibbs' one [22], but they did not improve the concept [17], while the Gibbs approach was the basis of a great number of developments [23–27].

In 1889, Gouy and, in 1905, Stodola, independently, proved that the lost exergy in a process is proportional to the entropy generation [25–29]. Gouy's results were used in a great number of analyses of irreversibility [30–69,15,70].

Exergy is a quantity defined in relation to a reference, the environment [16,71,72]. It is defined as the maximum amount of work obtainable by a system as it comes to equilibrium with its reference environment. So, it represents a measure of the