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THERMODYNAMICS OF QUALITY AND SOCIETY

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ABSTRACT

The developments of Thermodynamics over the last century (and in particular during the last three decades) have led to an *extra-ordinary* novelty: the introduction of a renewed concept of Quality (thus indicated by a capital Q) which is already inducing a profound revision not only in Classical Thermodynamics but also in several related disciplines. Such a recent conquest of science, in fact, shows a wide influence because it touches the most profound roots of our way of thinking and, consequently, of speaking, here understood as the most adherent way of expressing our thoughts.

Quality, in fact, is no more referred to as a simple "property" or a "characteristic" of a particular phenomenon, but it is now recognized as being any *emerging* "property" (from any physical process) *never reducible* to its phenomenological premises or to our traditional mental categories. Consequently Quality suggests we first modify our Logic, based on a cogent "necessity", in order to better understand its specific dynamics. At the same time Quality suggests we modify both our codified perspectives of looking at things and the pertaining traditional interpretations of experimental data. Thus Quality exerts a significant influence on some directly related disciplines such as Gnosiology and Epistemology.

In addition, the modifications induced at the corresponding level of Language (required to adequately describe the dynamics of Quality) do not only concern everyday spoken languages, but also the formal language represented by Mathematics, which is recognized as the most appropriate linguistic form adopted by science.

All the previous aspects, in turn, are adherently able to explain how and why Quality also promotes substantial modifications in our decisions and consequential actions, both at the individual, social and political levels.

Thus, after having summarized the most relevant consequences of the Quality concept in Thermodynamics, as a fundamental starting point for a new scientific Logic and its corresponding new Mathematics, the paper presents some practical consequences in selected disciplines of common interest. Particular attention is devoted to Economics, in the frame of an increasing process of globalization, in order to pave the way to those Quality *generative processes* which are really capable of promoting a sustainable development, both for technologically developed countries and for those under a progressive achievement of comparable levels.

In this respect the paper will show how Quality acts as an "orientor" and, at the same time, as an "attractor" for living (and also non-living) forms of organization. The associated concept of Ordinality is introduced in order to account for Quality-driven organization of both single components (i.e. Firms, Citizen, States, as well as National Societies) and the entire Human Society as a whole.

1. INTRODUCTION

From a conceptual point of view the paper can be substantially articulated in the following four parts: i) the introduction of a new concept of Quality in Thermodynamics; ii) its influence on our traditional way of *thinking* (Logic) and *speaking* (everyday language and Mathematics); iii) its main consequences in several disciplines, with special focus to Economics; iv) its fundamental influence in any *decision-making process* (acts & facts).

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1st PRINCIPLE:
$dU = \delta Q - \delta L$ $\Rightarrow$ Conservation of *ENERGY (En)*
Joule & Mayer (1841 -1848) $\Rightarrow$ *EXERGY (Ex)* *Z. Rant* (1955)

2nd PRINCIPLE:
$$dS = \frac{\delta Q_{tot}}{T}$$ $\Rightarrow$ Increasing of *ENTROPY (S)*
Carnot (1824)

3rd PRINCIPLE:
$$\lim_{T \to 0} \Delta S = 0$$ $\Rightarrow$ (Validity at low absolute Temperatures)
Nernst (1906)

4th PRINCIPLE :
$$dEm = d(cEm_e) + d(\gamma_i \Phi_i)$$ $\Rightarrow$ "Maximum Em-Power Prin *EMERGY (Em)* *H. Odum* (1984)
Boltzmann Lotka (*H. Odum*, from 1955 on)
(1886 -1922)

Figure 1. Principles of Thermodynamics with some Authors and dates of reference [6][a]

As far as the first aspect is concerned, Fig. 1 schematically lists the well-known Thermodynamic Principles progressively stated over the last two centuries. The First Principle leads to Conservation of Energy, whereas the Second Principle asserts the continuous increasing in Entropy. The latter can more usefully be replaced, especially in practical applications, by a physical quantity named Exergy, whose definition can be obtained through a linear combination of the first two Principles. The Third Principle (1906), which has a great relevance only at very low absolute temperatures, completes Classical Thermodynamics which, however, had already reached its almost definitive and systematic theoretical structure thirty years before its statement (in the 1870's).

The possibility for the further addition of a *Fourth* Thermodynamic Principle emerged soon after this period, especially as a consequence of interesting and problematic aspects which appeared in the application of the first two Principles to the analysis of *Biological Systems*. It was immediately clear that those Principles (although globally valid even in the case of living systems) could not be considered as being Laws sufficient to explain, by themselves, how and why organisms develop through self-organization processes, during which they decrease their Entropy, in open contrast with the surrounding universe. Those Principles are only able to "tell us that certain things cannot happen, but they do not tell us what does happen" [23].

Boltzmann (1886) first investigated the direct relationship between Classical Thermodynamics and the Evolutionary Theory of the organic world [1]. Lotka in 1922 reconsidered Boltzmann's initial ideas and, on the basis of a thorough analysis of wide

[a] The differential Emergy Balance Equation is carried out from the Global Emergy Balance, which does not represent, by itself, the formulation of the M. Em-P. Principle, but only the basic presupposition for its formulation [6,14].

classes of living systems, formulated the "Maximum Power Principle" and at the same time suggested it be considered a Fourth Principle of Thermodynamics [23]. Odum, in the early 1990's, after having introduced a new physical quantity termed Emergy [5], provided a more general formulation of Lotka's Principle in the form of the "Maximum Em-Power Principle" [8,9,10]. This asserts that "Every System tends to maximize the Flow of Processed Emergy" [6], where Emergy (contraction of the words *Em*bodied En*ergy*) is defined as the product of *Quality* (expressed by *Transformity*) by Energy *Quantity* (expressed by *Exergy*).

2. EVOLUTION TOWARD THE MAXIMUM EM-POWER PRINCIPLE

The evolution of the formulation of Maximum Em-Power Principle can be articulated in three steps: i) the original Boltzmann Maximization Principle (1905) could be termed as the Principle of "Maximum Power Competition" ([8], p.118) or, equivalently, in Exergy terms, the Principle of "Maximum *Exergy Inflow*"; ii) Lotka's Maximization Principle (1922), originally termed as the Principle of "Maximum Energy Flux", could alternatively be renamed (in Exergy terms) as the Principle of "Maximum *Exergy Flow through* the system" because "*energy flux* refers to the *available energy* (Exergy) absorbed *by* and dissipated *within* the system per unit time" ([23], p.185); iii) whereas the third step represents a real advance in Quality recognition and assessment (when compared to the previous formulations in Exergy terms). In fact, Odum's Maximization Principle introduces (and is also based on) original and fundamental elements, such as: the concept of Energy *network*, the concept of *transformation hierarchy* (different Energy Quality for different Energy forms) and above all, the previously mentioned definition of the new physical quantity *Emergy*, understood as:

Emergy = *Transformity* (Energy Quality) times *Exergy* (Energy quantity) (1).

Consequently his Maximization Principle does not refer to mere quantitative aspects represented by the sole Exergy (as Boltzmann's and Lotka's Principles do), but contemplates both *Quality* and *quantity*, now included in a *unique concept*.

At this stage, in order to account for Energy Quality or, better, for the Transformity associated to any form of Exergy, some special algebraic rules have to be taken into account. Such rules, illustrated in detail in [2], refer (among other things) to the basic *generative* processes (co-production, inter-action, feed-back) which characterize living systems and, in so doing, give rise to a *non-conservative* Algebra. This is exactly because Quality (to be accounted for) is no more understood as a simple "property" or a "characteristic" of a particular phenomenon, but it is recognized as being any *emerging* "property" (from any physical process) *never ever reducible* to its phenomenological premises or to our traditional mental categories. This achievement is already inducing a profound revision not only within Classical Thermodynamics but also within several related disciplines (referred to below in this paper). From a more general point of view, Quality at the same time suggests we first modify:

i) our *way of speaking*, not only at the level of everyday spoken language (in order to adequately express our thought), but also (and in particular) with respect to that formal language represented by Mathematics, which is recognized as the most appropriate linguistic form adopted by science;
ii) our *way of thinking*, in particular our Logic, traditionally based on a cogent "necessity", in order to better understand the specific dynamics of Quality. This also adherently suggests we modify both our codified perspectives of looking at things and the pertaining traditional interpretations of experimental data;

iii) our *way of acting*, in the sense that the previous aspects are able to show how and why Quality also suggests (and promotes) substantial modifications not only in our everyday decisions and consequential actions, but especially at the social and political levels.

This is why we will synthetically present the most fundamental novelties introduced by Quality at these three distinct (but also intimately related) levels, by focusing in particular on consequences in those disciplines (e.g. Energy, Economics, Environment, etc.) which are maximally involved in the perspective of a "sustainable development".

3. THE INFLUENCE OF QUALITY AT THE LEVEL OF SPOKEN LANGUAGE

For the sake of clarity we start from the language issue, understood in its widest sense: not only as a physical expression, but also (and especially) as a fundamental support to our thoughts. As a general introduction we may recall the famous aphorism of Medieval Logic which says: "If we do not speak exactly as we think, we end up by thinking exactly as we speak".

Quality in fact suggests:

i) The adoption of more appropriate *verbs*: these would clearly show the passage from *necessity* to the *absence of necessity*. For example: *to demonstrate* would more adherently be replaced by the verb *to ostend*; *to imply* by *to yield* (or *to give*); *to derive* by to *obtain*[1];
ii) A modified meaning of some basic *substantives*: "process", "system", "order", as a consequence of the passage from the traditional ill-defined concept of *quality* to that of *Quality*, have a specific and different meaning than in current use;
iii) A modified concept of *definition*: Quality in fact suggests the adoption of *over-definitions*.

Such a concept, more deeply analyzed in [6], can be here shortly illustrated with reference to the usual definition of "man" as "rational animal". This is in fact an example of the shortest definition, given in *two words* (because one word would represent only a synonym), in which the word "animal" acts as *genus* whereas "rational" as *species*. The sequential *priority* of the words, however, may also be inverted. This is not very frequent in English (unless in poetry, prayers and songs), whereas it is very common in neo-Latin languages. As a consequence of such an inversion, the considered definition acquires a new and much more profound sense[2].

Nonetheless, even in this case, the definition, which etymologically means "action concerning the boundaries", is always seen as a combination of two concepts clearly apt to *circum-scribe* each considered object (and thus to radically *isolate* it from the rest of the universe). Quality, vice versa, suggests that a definition is something more: it is an *interaction* between two concepts which generates an *excess of meaning* with respect to the two basic terms adopted (in this sense it represents an *overdefinition*). Thus, with reference to the previous example, we can recognize that "rational animal" only represents the *minimum* required to "isolate" a Man from all the other things. Man, in fact, is much more. He is also characterized (at least) by *will* and *affectivity*, which are

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[1] *To ostend* is a somewhat old-fashioned verb, but it exactly corresponds to the *ostensive method* adopted by Odum [4].

[2] A clear example can be represented by the difference between "divine love" and "love divine", thought of in the context of a love song: the meaning of former is rather evident, whereas the latter has the sense of "the same divinity has personified in (our) love".

never reducible to the initially adopted definition. Consequently, every overdefinition refers to something understood as being "not less than". Another example (taken from geometry) could be represented by a "square", which can never be reduced to the sole two generating sides. In fact it requires, at least, a third element: an *external perspective*, which allows us to see the genesis of a *superior order* entity ([6], p.178). These examples have been here recalled only because they can represent a valid support to the understanding of the transposition of the same "excess of meaning" both at *logical* and *mathematical* levels.

4. THE INFLUENCE OF QUALITY AT THE LEVEL OF LOGIC

At the logical level, Quality suggests the passage from a *coherent* Logic to an *adherent* Logic. Such a fundamental passage, extensively analyzed in [6], can be here synthetically illustrated as follows. Traditional Logic (especially in scientific disciplines) is based on the logical process termed as "deduction", which is assumed to be intrinsically "necessary". This means that, by starting from some given basic hypotheses (or premises), the conclusions (derived by means of such a deduction process) can never represent a real "novelty" with respect to the pertaining initial assumptions. In fact they are simply an explicit (and obligatory) articulation of the content already included in the same premises. As an example, we can think of all the geometrical properties of a "circle": these are nothing but the obligatory consequences (obtained by means of theorems) of its primary geometrical definition. Such properties are very useful for practical applications, but they do not represent, in actual fact, a real addition of "new" knowledge.

Fig. 2 shows the comparison between a coherent syllogism and an adherent syllogism. The former is thought of as a triangle two corners of which are positioned on the baseline of Basic Principles of Logic (identity, non-contradiction, causality). The third corner (conclusions) is hanging from this baseline due to constraining links represented by both the major and minor premises of the syllogism. The conclusion is obligatorily constrained in its position and, as a consequence, "necessary". In the latter case, on the contrary, the conclusion (the horizontal "beam") simply lies on the major and minor premises of the syllogism. These, in turn, as two "pillars", are well-planted in the ground of experimentally founded pre-*sub*-positions which sustain the structure from the *bottom*.

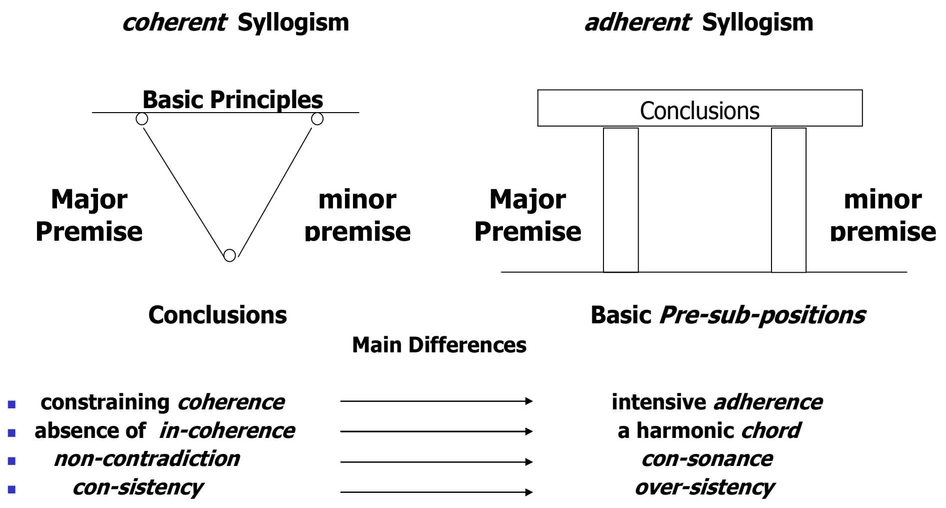

Figure 2. Comparison between a coherent Syllogism and an adherent Syllogism

The main differences are (see Fig. 2): i) the *constraining coherence* becomes an *intensive adherence*; ii) the *absence of incoherence* becomes a *harmonic chord*; iii) the *non-contradiction* transforms into *a consonance*; iv) *consistency* becomes *oversistency* (for ulterior details, see also [6]).

The afore-mentioned aspects can be now adopted as a "guide" to understand, by analogy, the linguistic and logical bases which suggested the definition of the "incipient" derivative concept.

4.1 Linguistic and Logical bases of the *incipient* derivative

Let us start from the traditional definition of the derivative of a function $f(t)$

$$\lim_{\Delta t \to 0} \frac{\Delta}{\Delta t} f(t) \qquad (2).$$

This may evidently be considered as being an "a posteriori" definition (e.g., let us think of the definition of velocity). In fact, although it is usually read from left to right, it is vice versa interpreted from right to left. In other words its meaning is based on a *reverse priority* of the order of the three elements that constitute its definition: i) the concept of function (which is assumed to be a primary concept); ii) the incremental ratio (of the supposedly known function); iii) the operation of limit (referred to the result of the previous two steps). Now we may ask: what happens if we interpret the sequence of symbols in expression (2) according to the same order as they are written (that is from left to right)?

Such a *direct perspective* gives rise to a new concept of derivative, the "incipient" derivative, defined as follows (for further details see [6,15]):

$$\frac{\tilde{d}^q}{\tilde{d}\, t^q} f(t) = \tilde{\lim_{\tilde{\Delta} t: 0 \to 0^+}} \circ \left(\frac{\tilde{\delta} - 1}{\tilde{\Delta} t} \right)^{\tilde{q}} \circ f(t) \qquad \text{for any} \quad q \in Q \qquad (3)$$

where: i) the definition is generalized to any fractional number q; ii) the "operator" $\tilde{\delta}$ generates the "translation" $\tilde{\delta} f(t) = f\left(t + \tilde{\Delta} t\right)$; iii) the sequence of symbols is interpreted according to a *direct priority*, that is in the same order as they are written (from left to right); iv) the sequence is also interpreted as a *generative interaction* between the three considered mathematical concepts[3].

It has been named "incipient" (or "spring") derivative because of some special properties which enable us to follow the evolution of the "product" of any generative process from the very beginning, in its "rising", in its "incipient" act of being born. These properties (which can thus also termed as "genetic" characteristics) can be easily illustrated with reference to the exponential function $e^{\alpha \cdot t}$. As an example, in the case of a fractional order (q = 1/2), the incipient derivative generates a new class of functions: the "binary functions"

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[3] The symbol " $\circ$ " represents a generalized form of product (termed as "circle product" [6, p. 178]), whose result accounts for both cardinality and Ordinality of the given "factors". For the sake of clarity, "cardinality" and "Ordinality" are defined in footnote (4), whereas an example of a "circle product" is given in footnote (5).

$$\frac{\tilde{d}^{1/2}}{\tilde{d}\,t^{1/2}}e^{\alpha\cdot t}=\begin{pmatrix}+\sqrt{\alpha}\\-\sqrt{\alpha}\end{pmatrix}\cdot e^{\alpha\cdot t} \qquad (4)$$

which can never be reduced to the traditional functions [15]. These "binary functions" are particularly useful to explain (among other things) the second rule of Emergy Algebra concerning co-production [19]. In fact they enable us to show that in such a generative process there is no "double counting" of the Energy involved. On the contrary, the resulting Transformity adequately accounts for the recognized genesis of an *excess of Quality* [ib.].

4.2 Main consequences on Mathematics

The introduction of the incipient derivative has several consequences on Mathematics, which can be synthesized as follows: i) *fractional* derivatives (and their associated differential equations) generate the new class of functions mentioned above ("binary", "ternary" functions, and so on), which are able to describe the *new* reality generated by a given process as being *one sole entity*; ii) all the differential equations (of integer and fractional order) written in terms of incipient derivatives are intrinsically *linear* [15, 20]; iii) all the solutions are always characterized by both *cardinality* and *Ordinality*[4]; iv) some traditionally "non-linear" differential equations (e.g. Riccati's and Abel's equations), when re-interpreted in terms of incipient derivatives, present *explicit* solutions in terms of "duet" functions, which are able to represents the "product" generated as a unique entity of *superior order*[5]; v) when incipient differential equations have explicit solutions in *finite terms and quadratures*, these are not affected by that "drift" phenomenon which characterizes the traditional a posteriori derivatives [15,20]; vi) the *exponential function* plays an extremely hinge role which is much more marked than in the case of ordinary differential equations (ib.).

5. INFLUENCE OF QUALITY ON SOME OTHER DISCIPLINES

The new concept of Quality, together with the adoption of a new Logic and an adherent formal language, opens new perspectives in several other disciplines. It is worth mentioning, for example, that in Celestial Mechanics both angular momentum and mechanical Energy do not conserve in the orbital movements of Planets. This can be clearly shown by considering the solution to the famous problem of Mercury's Precessions, now obtainable in terms of incipient derivatives [15,20]. This fact, in turn, has also a direct consequence on "Energy Conservation Principle", because mechanical

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4 Given a differential equation of any order, written in terms of incipient derivatives, its solution can always be represented as $[f(t)]^{l,(\frac{m}{n})}$ where: its *cardinality* is given by $[f(t)]^{l}$, that is the instantaneous value $f(t)$ raised to the power l (if present), whereas its *Ordinality* is expressed by the ratio (m/n), which is defined as the order of the basic fractional derivative $(1/n)$ multiplied by the non-linearity degree (m) of the considered generating equation.

5 An example of a "duet" function is given by the formal expression of those concepts concerning a "square" already mentioned at the end of par. 3. Let be $[l(t)]^{1,(1)}$ the Ordinal-cardinal representation of a side, thought of as being variable with time. The quantity $[l(t)]^{1}$ represents the traditional concept of length (as a real number), whereas the Ordinal exponent (1) represents the pertinent Ordinality, that is its physical-geometrical nature (as a segment). The "circle product" $[l(t)]^{1,(1)}\circ[l(t)]^{1,(1)}=[l(t)]^{2,(2)}$ yields, at the same time, both the *area* of the square $[l(t)]^{2}$ and its physical-geometrical nature (as a *surface*), appropriately represented by the Ordinality (2).

Energy is always an integrating part of *total* Energy. This, consequently, does not conserve. On the other hand such a result can be directly obtained by the same formulation of the Maximum Em-Power Principle, as already shown in [6, p. 65]. For the sake of brevity all the other disciplines analyzed in the light of the new concept of Quality are simply listed in footnote 6, with the indications of some pertinent references[6]. After this very synthetic panorama about the profound influence of Quality on some selected disciplines, we will now focus on its profound influence on Economics. To this purpose, we will start from the analysis of the fundamental concept of Externality.

6. ECONOMICS: THE CONCEPT OF EXTERNALITY

This concept, originally introduced by Marshall (1890), was conceived as an entity i) referable to *external origins* (*external*-ent*ity*); ii) with an intrinsic *positive* meaning: "*external economies*" [7][7] . Such external economies are not subjected to any compensation (and thus generally remain uncompensated for), whereas "external diseconomies" almost always represent additional costs for the Firm. This is why the term externality has been progressively used in the latter sense and is now prevailingly understood in a negative meaning (diseconomy) [12]. A possible "reward" for positive externalities could be researched for through the analysis of the relationship between transactions and externality.

6.1 Transactions and externality

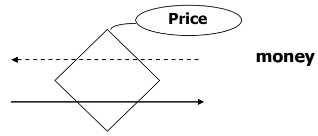
The theoretical reason for the above-mentioned "reward" could be based on a generalized definition of Externality [16], even more intensive, though always understood as "something" which: i) remains "outside the market transaction"; ii) refers to a "binomial" transaction; iii) depends on the sense of transaction. Externality could be then defined as: "Any transaction aspect that might have economic effects (immediate or future), even estimated only as a proxy, which are, in all cases, not included in the transaction price, not even remunerated or compensated for" [ib.]. Such a definition presents some advantages. For example it is able to include (even indirectly) some other economic subjects external to the considered binomial transaction. However it does not consider any "extra" aspect which could be referred to as a "vehicle" of Quality.

6.2 Externalities in a context of Quality

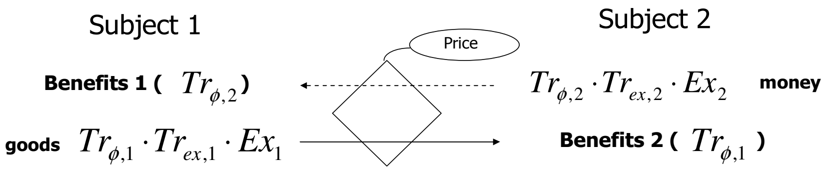
The concept of Externality, in a context of Quality, is no longer defined in negative terms (as a lack of compensation), but in positive terms: "as an excess of Ordinality". Let us start from the symbology adopted by Prof. Odum [8, p. 8] to represent a transaction (Fig. 3a).

[6] Quantum Mechanics [6,13], Electromagnetism [3,6], Chemistry [6,13], Biology [13,22], Gnosiology [6,13], Cosmology [6,13].

[7] "Those internal economies which each establishment has to arrange for itself are frequently very small as compared with those *external economies* which result from the general progress of the *industrial environment*".



(a)



(b)

Figure 3. Externality understood as an "excess of Ordinality" when analyzed in Emergy terms

We can easily recognize that money and goods (exchanged in counter current), when analyzed *in Emergy terms*, do not reduce their meaning to mere physical-economic concepts. In fact the Transformity which appears in Eq. (1) can be subdivided into two distinct factors

$$Tr = Tr_{\phi} \cdot Tr_{ex} \quad (5)$$

where Tr_{ϕ} (generative Transformity) accounts for the *Ordinality* "vehicled" by a given product/service, whereas Tr_{ex} (dissipative Transformity) accounts for the losses of Exergy used up during the generation process of the same product/service [6,19]. Consequently Emergy associated to any product/service (*i*) can be written as

$$Em_i = Tr_{\phi,i} \cdot Tr_{ex,i} \cdot Ex_i \quad (6).$$

Transaction (see Fig. 3b) then represents an exchange of different Emergies, both in terms of *cardinality* and *Ordinality*. Traditional transactions, on the contrary, do not account for those exchanged *Benefits* which are proportional to the *generative* Transformities $Tr_{\phi,1}$ and $Tr_{\phi,2}$ pertaining to the exchanged products [16].

As a consequence of an ever-present *disequilibrium* between the exchanged Emergies (and related *Ordinalities*), only when the two Subjects operate in consonance with the Maximum Em-Power Principle the transaction: i) becomes a true *transactive* interaction; ii) presents a reciprocal *increase* in Ordinality (as a consequence of an Ordinal-cardinal interaction).
In such a sense Externality can be defined as "the excess of Ordinality emerging from the transaction relationship".

7. INFLUENCE OF QUALITY AT THE LEVEL OF "FACTS": AN ADHERENT DECISION-MAKING TOOL

On the basis of the previous considerations, a consequential methodology has been developed to obtain an adherent decision-making tool. This was termed as *Four-Sector Diagram of Benefits* (FSDOB) because mainly based on the evaluation of the Benefits pertaining to the four distinct "Subjects" (or Sectors) which are usually involved in any productive process: Benefits to the *Firm* (deriving from the Production process), Benefits to the *Society* (deriving from the new Product generated), Benefits to the *Environment as a Source*, Benefits to the *Environment as a Sink*. The evaluation of Benefits considers both traditional economic benefits and *Ordinal* Benefits (that is those generating an excess of Ordinality). The latter, as illustrated in par. 5.2, are evaluated in Emergy terms (see Eq. (6)) in order to highlight those strategic decisions which are mostly adherent to the Maximum Em-Power Principle.

In addition, the method is able to account for the multiplicity and heterogeneity of the evaluation parameters required for the analysis of the considered System. These parameters in fact usually derive from different theoretical approaches and disciplines, specifically appropriate to different time-space scales of analysis. In this sense the method overcomes the most frequent limits of other methods, such as: i) a reduced field of analysis, due to the main goal of making the evaluation parameters sufficiently consistent with each other; ii) evaluations very often performed more in terms of possible *damages* to be *internalized* than in terms of *external benefits* to be *remunerated* (in particular those which are proportional to generative Transformities of products exchanged).

The method, described in detail in [17,18], can be synthesized as follows.

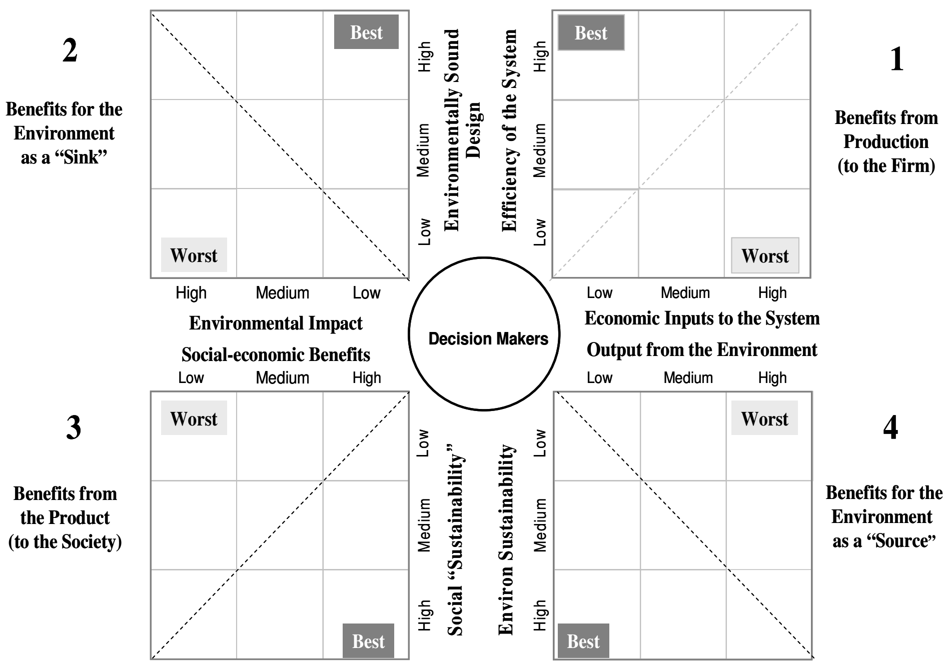


Figure 4. General structure of the Four-Sector Diagram of Benefits [17,18]

The four above-mentioned sectors are symmetrically set with respect to the center of the diagram (Fig. 4) because the decision maker ideally represents a sort of "referee" in equilibrating different needs and interests, often in contrast with each other. Such a graphic choice would also indicate that the four sectors cannot be considered as being independent from each other. In fact each sector is seen as a sub-System of a larger whole System characterized by a dynamic "circulation of Benefits". Each sector is thus identified by two axes which point out the fundamental features of its input/output properties respectively.

These, in turn, characterize the main interface relationships between adjacent sectors. In this respect it is worth pointing out that the axis termed as "Environmental Impact" offers a double possibility of reading: in terms of “damages”, when it is oriented toward the outside of the diagram, and in terms of “Benefits” in the opposite versus. In this latter case the pertinent “Benefits” do not correspond to the mere complementary value of the former, because in such a positive perspective *Benefits* have always a much larger impact than the *avoided damages*. As a direct consequence of such a second positive reading, an adherent equiverse orientation of the corresponding interface axis termed as “Social-economic Benefits” is adopted. This choice also confers a symmetric aspect to the diagram, which is particularly helpful in its interpretation.

The eight basic typologies (one per axis) also indicate that the whole evaluation can be represented in an eight-dimensional space. Each coordinate axis can be characterized by any number of indicators (even hundreds, in principle). However the case studies presented in this paper only consider five Indicators per axis (defined in Tab. 1).

Table 1. List of the adopted Indicators (I_y) subdivided by Sectors (where: i = generic axis of the diagram, for i = 1 to 8; j = sequential order of each selected Indicator in a given axis (i), for j = 1 to 5)

Sector 1 Benefits from Production (to the Firm)	I_{11} = Plant cost per unit power (€/kW)	I_{21} = Energy efficiency
	I_{12} = Fuel cost per unit product (€/kWhex)	I_{22} = Exergy efficiency
	I_{13} = Labour cost per unit product (€/kWhex)	I_{23} = Raw Energy conversion coefficient
	I_{14} = Maintenance cost per unit product (€/kWhex)	I_{24} = Transformity of the product (seJ/J)
	I_{15} = Cost of NOx uptake device per unit product (€/kWhex)	I_{25} = Profit Index
Sector 2 Benefits for the Environment as a “Sink”	I_{31} = Cogenerated heat / total heat supplied	I_{41} = Global Warming (CO2 release) (kg/MWh)
	I_{32} = Cost of CO2 sequestration and storage (€/ton)	I_{42} = CO2 Emission costs at a local level (€/kWh)
	I_{33} = Cost of NOx uptake (€/ton)	I_{43} = CO2 Emission costs at a global level (€/kWh)
	I_{34} = Reuse of uptaken materials (%)	I_{44} = Cost of NOx emissions (acidification) (€/kWh)
	I_{35} = Fraction of recycle after Decommissioning (%)	I_{45} = Cost of NOx emissions (via ozone) (€/kWh)
Sector 3 Benefits from the Product (to the society)	$I_{51} = \sum_{k=1}^{4} (\ )_k / Inv$ (economic benefit per unit Investment)	$I_{61} = \pi_4 / \pi_2$ (benefit to Economy / product cost)
	$I_{52} = EYR^*$ (process economic amplification)	$I_{62} = \pi_5 / \pi_2$ (Feedback benefits / product cost)
	$I_{53} = Tr_{pd} / Tr_{pc}$ (product benefit per typology of process)	$I_{63} = \pi_6 / \pi_2$ (I_{62} at net of local damages)
	$I_{54} = (F' \cdot EYR_f - Inv) / Inv$	$I_{64} = \pi_7 / \pi_2$ (I_{63} at net of global damages)
	$I_{55} = \pi_1 / \pi_2$ (Firm/citizen financial sustainability)	$I_{65} = \pi_8 / \pi_2$ (I_{64} at net of resource consumption)
Sector 4 Benefits for the Environment as a “Source”	I_{71} = ELR (Environmental Loading Ratio)	I_{81} = Emergy Density (seJ/m2)
	I_{72} = EIS (Emergy Index of Sustainability)	I_{82} = Non-renewable Emergy / Total Emergy
	I_{73} = Decrease of biodiversity (%)	I_{83} = Material Intensity, water factor (g/kWh)
	I_{74} = Area supporting the process (m2/MW)	I_{84} = Material Intensity, abiotic factor (g/kWh)
	I_{75} = Actual NOx emission / Law emission limit	I_{85} = Fraction of imported fuel (%)

Each selected Indicator is preliminarily normalized by adopting an appropriate reference value (specific to the typology of the processes investigated). In this way the comparison is made in terms of relative values, which indicate the “distance” between the *real* and the *reference* cases. Consequently, the “feasibility and acceptability” position of every investigated System is assessed with reference to the best technology available (pertaining to its specific class). Each position is then easily plotted on a multi-dimensional diagram (Fig. 4) according to the following procedure.

Each Indicator, once normalized, can be appropriately weighted in order to account for its specific influence. Such a weighting procedure allows the policy maker to choose the weight factors according to his specific needs (depending on priorities assumed). The only condition to be satisfied is that the sum of the specific weights ($w_{ij}^{(k)}$) respects the "closure" condition

$$\sum_{j=1}^{n} w_{ij}^{(k)} = 1 \qquad \text{for} \quad i = 1,2,...8 \qquad \text{and} \qquad k = 1,2,...m \qquad (7)$$

where i = axis, $n =$ number of selected Indicators, $j =$ sequential order of their corresponding weights, k = sequential order of the Plant each time considered.

Then the weighted average of each axis ($\bar{w}_i^{(k)}$) is evaluated by assuming that all the normalized Indicators have, as a basic reference level, the same weights (namely, $w_{ij}^{(k)} = 1/5 = 0.20$). By taking into account that the decision maker will probably adopt a differentiated distribution of weights, we also calculate the maximum (positive and negative) variations ($\Delta \bar{w}_i^{(k)}$), with respect to the previous values, in correspondence to a predefined margin of confidence (defined as the ratio between the maximum and minimum modified weights, always in the respect of condition (7)). In our case studies the value of 500% was adopted. On the basis of the values obtained (see Tab. 2 and Tab. 3), a summary diagram can be consequently drawn (Fig. 5).

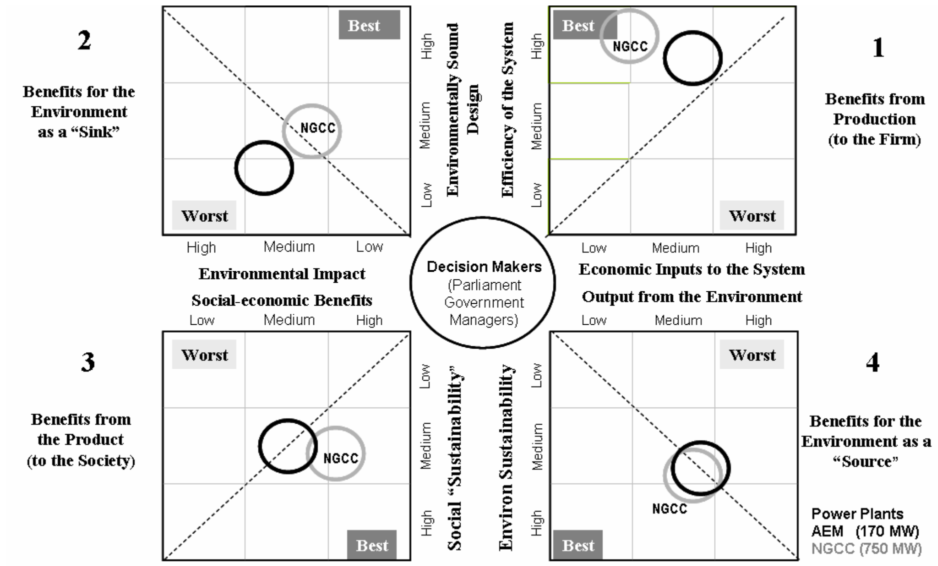


Figure 5. Four-Sector Diagram of Benefits for Co-productive Power Plants. AEM is a conventional cogeneration plant, based on a steam turbine coupled to a gas turbine, run by the private Company AEM, while NGCC is a modern plant run by the national electric Company ENEL, based on a more innovative natural gas combined cycle. Both plants are located in Northern Italy [17]

The barycentres of the "circles" represent the average values $\bar{w}_i^{(k)}$. The inner radius ($\bar{r}_g$) corresponds (in the scale adopted in the diagram) to a maximum variation evaluated at a *global* level and defined as follows

$$\bar{r}_g = \max\left(\left(\sum_{i=1}^{8} \bar{w}_i^{(k)} / 8\right) \cdot \left(\sum_{i=1}^{8} \Delta \bar{w}_i^{(k)} / 8\right)\right) \qquad \text{for} \quad k = 1,2 \qquad (8),$$

whereas the outer radius ($\bar{r}_l$), defined as

$$\bar{r}_l = \max(\bar{w}_i^{(k)} \cdot \left|\Delta \bar{w}_i^{(k)}\right|) \qquad (i = 1,2,..8\,;\ \ k = 1,2\,) \qquad (9),$$

represents (in the same scale) a maximum variation evaluated at a *local* level.
A particular advantage of the methodology consists in its intrinsic “stability”. In fact the two radii are usually very close to each other. As an example, the case study illustrated in Fig. 5 refers to the comparison between two co-generative production plants, carried out from previous analyses supported by ENEA. Tab. 2 and Tab. 3 show the values of the adopted Indicators together with their reference values (in brackets), the values of the weighted averages previously mentioned and their (positive and negative) percentage variations.

The case study illustrated in Fig. 5 suggested, among other results, that an improvement of the Environmental Impact factor can be obtained only on the basis of a different technology, independent of fossil fuels. This result stimulated an application of the method to the analysis of Hydrogen technologies [18], by starting from the strategic positioning of Molten Carbonate Fuel Cells (MCFCs) with reference to the NGCC Power Plant analyzed in the previous case study.

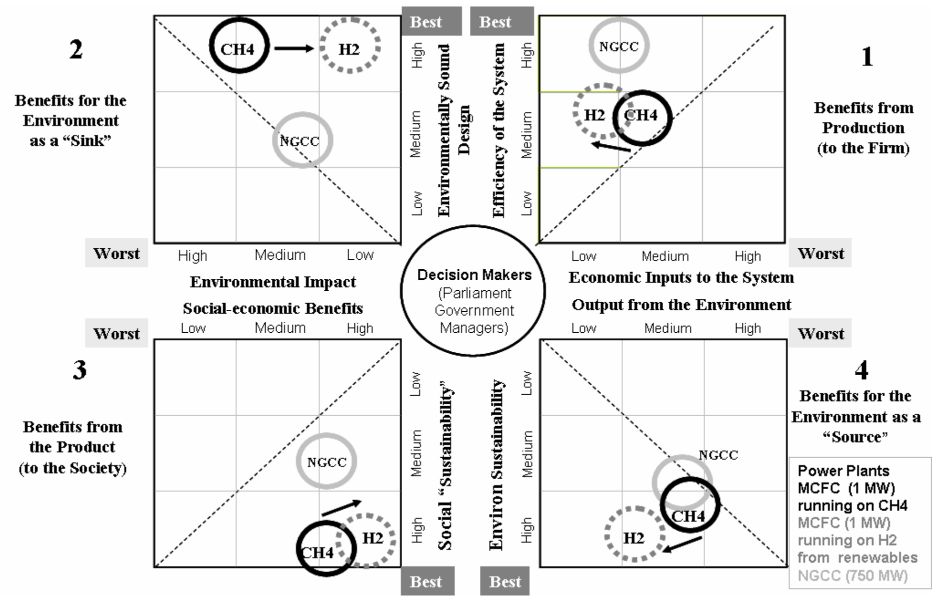


Figure 6. Four-Sector Diagram of Benefits applied to the analysis of Hydrogen Technologies [18]

As shown in Fig. 6, the same method can also represent a valid tool to decide well-calibrated “incentives” (to the Firm) in order to favor the shift (indicated by arrows) from MCFCs to renewable-hydrogen MCFCs. Such incentives, in fact, are nothing but an anticipated “remuneration” of Externalities (understood as an excess of Ordinality) that the State recuperates (in monetary terms) because of a consequential increase in economic activities induced by those primary externalities, in a *non-zero sum* circular process.

The previous case studies have been here synthetically recalled only to show that the method, now in the process of application to the analysis of “sustainability” of progressively larger cities (e.g. Rome), can also be usefully adopted to compare two (or more) distinct countries.

Table 2. Characteristic Parameters of AEM Power Plant in the case study analyzed in [17]

Sector	Axis	I_{i1}	I_{i2}	I_{i3}	I_{i4}	I_{i5}	$\bar{w}_i$
1	**1**	**848 (325)**	**4.0E-2 (2.0E-2)**	**9.1E-4 (1.0E-4)**	**2.47E-4 (2.0E-4)**	**n. a.**	**0.55 +16% -16%**
1	**2**	**89.6 (90.0)**	**43.2 (60.0)**	**89.6 (90.0)**	**1.84E5 (1.0E5)**	**1.54 (2.00)**	**0.80 +9% -11%**
2	**3**	**0.11 (0.30)**	**n. a.**	**n. a.**	**n. a.**	**5.0 (30.0)**	**0.28 +18% -11%**
2	**4**	**447 (300)**	**4.34E-2 (1.5E-2)**	**1.74E-1 (5.4E-2)**	**1.73E-2 (5.4E-3)**	**5.2E-4 (1.5E-4)**	**0.61 +8% -20%**
3	**5**	**2.54 (3.50)**	**12.04 (20.00)**	**1.18 (2.00)**	**15.04 (30.00)**	**0.11 (0.50)**	**0.53 +7% -26%**
3	**6**	**0.29 (1.00)**	**1.70 (2.00)**	**1.58 (2.00)**	**1.03 (2.00)**	**0.35 (2.00)**	**0.52 +24% -28%**
4	**7**	**12.7 (10.0)**	**0.56 (0.10)**	**n. a.**	**2.96E4 (1.50E4)**	**6.58 (60)**	**0.59 +7% -11%**
4	**8**	**3.0E15 (7.5E13)**	**0.93 (0.9)**	**604 (1500)**	**182 (300)**	**90.0 (80.0)**	**0.57 +13% -6%**

The weighted average ($\bar{w}_i$) is given by $\bar{w}_i = \sum_{j=1}^{5} w_{ij} \cdot F\left[\left(\frac{I_{ij}}{I_{ij,r}}\right)^{\alpha}\right]$, where $\alpha = 1$ if $\frac{I_{ij}}{I_{ij,r}} \leq 1$, and $\alpha = -1$ if $\frac{I_{ij}}{I_{ij,r}} \geq 1$

Table 3. Characteristic Parameters of NGCC Power Plant in the case studies analyzed in [17,18]

Sector	**Axis**	I_{i1}	I_{i2}	I_{i3}	I_{i4}	I_{i5}	$\bar{w}_i$
1	**1**	**379 (325)**	**2.78E-2 (2.0E-2)**	**1.31E-4 (1.0E-4)**	**4.94E-4 (2.0E-4)**	**n. a.**	**0.31** **+13%** **-11%**
1	**2**	**78.4 (85.0)**	**55.6 (60.0)**	**78.4 (85.0)**	**1.01E5 (1.0E5)**	**1.19 (2.00)**	**0.87** **+6%** **-9%**
2	**3**	**0.24 (0.30)**	**n. a.**	**n. a.**	**n. a.**	**5.0 (30.0)**	**0.48** **+18%** **-19%**
2	**4**	**347 (250)**	**2.50E-2 (1.5E-2)**	**9.96E-2 (5.4E-2)**	**9.90E-2 (5.4E-2)**	**3.0E-2 (1.5E-4)**	**0.42** **+8%** **-15%**
3	**5**	**2.56 (3.50)**	**18.95 (20.00)**	**3.42 (4.00)**	**27.10 (30.00)**	**0.05 (0.50)**	**0.71** **+13%** **-35%**
3	**6**	**0.12 (1.00)**	**1.40 (2.00)**	**1.36 (2.00)**	**1.22 (2.00)**	**0.98 (2.00)**	**0.53** **+14%** **-24%**
4	**7**	**65.64 (10.0)**	**0.11 (0.10)**	**n. a.**	**3.68E4 (1.50E4)**	**3.57 (60)**	**0.63** **+11%** **-11%**
4	**8**	**2.54E16 (7.5E13)**	**0.99 (0.90)**	**781(1500)**	**140 (300)**	**90.0 (80.0)**	**0.56** **+13%** **-6%**

The weighted average ($\bar{w}_i$) is given by $\bar{w}_i = \sum_{j=1}^{5} w_{ij} \cdot F\left[\left(\frac{I_{ij}}{I_{ij,r}}\right)^{\alpha}\right]$, where $\alpha = 1$ if $\frac{I_{ij}}{I_{ij,r}} \leq 1$, and $\alpha = -1$ if $\frac{I_{ij}}{I_{ij,r}} \geq 1$

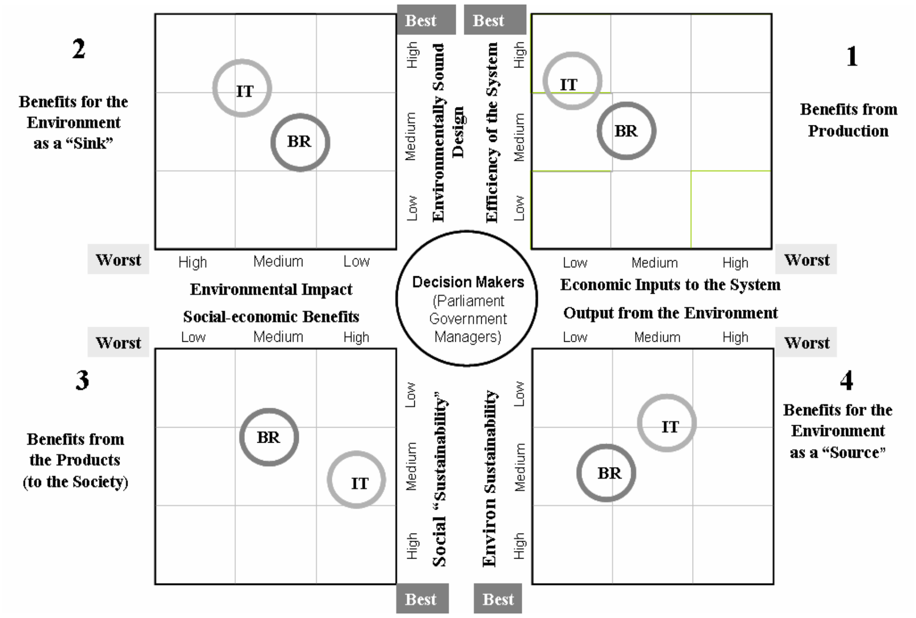


Figure 7. Four-Sector Diagram of Benefits "conceptually" drawn (in absolute terms) in order to show its potential adequacy for a comparison between Countries (unpublished manuscript by the author)

Fig. 7, in fact, represents an (ideal) comparison between Italy and Brazil, made in absolute terms. In such a case, however, FSDOB is much more useful when used in relative terms, in order to point out the *disequilibrium* between countries as a consequence of international trade (Fig. 8).

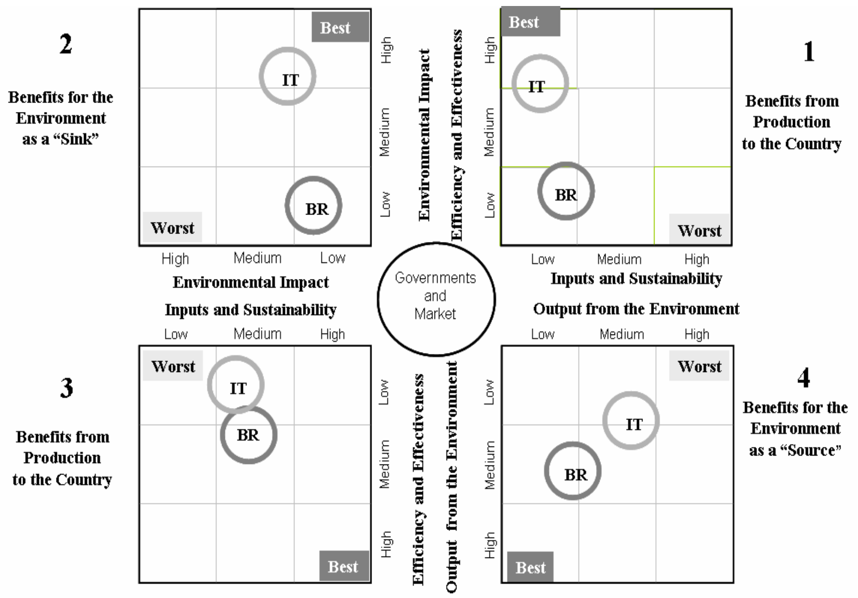


Figure 8. Four-Sector Diagram of Benefits referring to the same case in Fig. 7, now drawn in relative terms because in this form it is more "apt" to show the Disequilibrium between Countries as a consequence of International Trade (unpublished manuscript by the author)

In fact, as clearly shown by Emergy Analysis [9], this is one of the major reasons for the increasing in-equity between countries. As a further step, we could also think of the analysis of North-South disequilibrium (ideally "sketched" in Fig. 9).

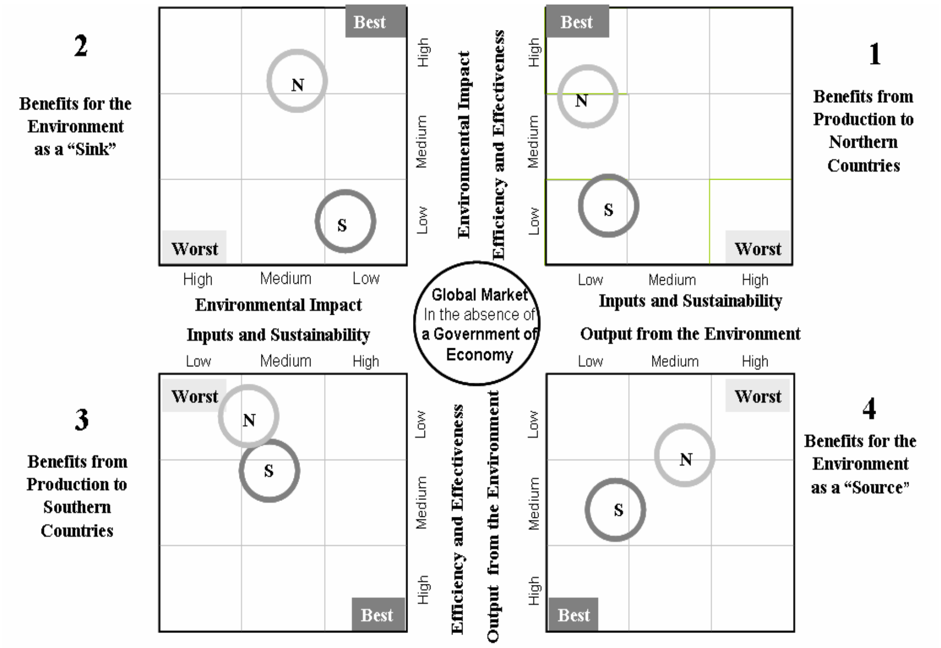


Figure 9. Four-Sector Diagram of Benefits, simply drawn by "analogy" to the case in Fig. 8, so as to point out North-South Disequilibrium for International Trade (unpublished manuscript by the author)

In such a context it becomes extremely clear that, if the analysis of international trade is performed in terms of the traditional concept of Externality (though made intensive), this means that the latter is still thought of in negative terms, that is with reference to a "lack" (or not) of a compensation. The key concept, instead, is that of an "excess" in terms of Quality, that is an "extra" of superior Ordinality, *never ever reducible* to the sole action of one subject or the other or to their "sum". What's more the genesis of such an excess of Ordinality can be now adequately modeled in mathematical terms by means of two new classes of functions exactly emerging from the mathematical formulation of the Maximum Em-Power Principle: the "binary" and "duet" functions. These functions in fact suggest that a given action is in reality generative (that is, it transcends the various terms of the relationship) only when it is not unilateral, either in reflexive terms or in purely altruistic terms. Only under such conditions, does an "excess" of Quality emerge from the relationship: that is an "extra benefit" which goes far beyond the "generator" and "generating" subjects. This is because the *Benefit* "generated" takes on some special properties which, although founded on the genetic characteristics of the "actors", intrinsically vehicle a superior Ordinality. This contributes to the generation of a higher level of "organization" in the Whole System. This is also the fundamental reason for sustaining that there exists, in Economics, a *dynamic circulation of "extra" Benefits*.

Such an aspect can progressively be pointed out, in an even more marked way, always on the basis of the Four-Sector Diagram of Benefits. In fact, the previous case studies represent only a preliminary step of analysis, because the previously four sectors can progressively be seen as interacting in the form of more and more structured "duet" functions. These in fact are characterized by an *internal priority* (with reference to the relationship considered in itself) as well as by a *time priority* (with reference to a dynamic analysis of the same relationship). It is also evident that the description of the System analyzed may contemplate, in principle, a higher number of sectors, interrelated to each other by means of more general functions ("triplet" or "quartet" functions). This would lead to a much more unitary description of the Economic System under consideration (especially in the case of the entire World) and, in spite of its (only apparent) Complexity, we could (and also should) make decisions even more orientated toward the genesis of the *Maximum Ordinality Excess*.

8. CONCLUSIONS

The introduction of the physical quantity termed *Emergy* (Odum, 1984) based on a new concept of *Quality*, the associated enunciation of the *Maximum Em-Power Principle* (Odum, 1990's) and its subsequent formulation in adherent mathematical terms ([14]) represent the general reference and the appropriate linguistic-mathematic tools for a renewed description of the surrounding World. In particular, they are able to lead to a new way of *thinking*, *speaking* and *acting* in order to maximize the level of Ordinality (i.e. harmony) among Human Societies and, in addition, between Man and the Environment. As Prof. Odum showed by adopting his *ostensive method*, it is not strictly "obligatory" to follow such indications. It is only a question of …… *enticement*, *fascination*, *charm*.

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