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Enterprise eco-watching and appraisal: asset modelling and sustainability assessment

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Abstract

At the millennium turnover, the ecology globalisation shows the impeding threats of over-depletion/pollution: the sustainable growth requires supply-chain visibility, resource bookkeeping and renovation planning. The lifecycle starts when the idea of a product is born and lasts until complete disposal after realisation and operation. In the musts' specification/analysis, the basic design (global plan, detailed design, assembly design, etc.) are followed by manufacturing, assembly, testing, diagnostics and operation, advertising, service, maintenance, etc.; then, disassembly and firing are scheduled, requiring reclamation and recovery, by re-cycling (material reprocessing) or re-using (part refurbishing). The present paper provides pilot clues for understanding the product-process agendas, using the **TYPUS** metrics and the ***KILT*** model, developed by the authors, in previous works.

Keywords: Lifecycle Management; Economy Globalisation; Ecology Globalisation; Sustainable Growth

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1. Introduction

The investigation aims at valuing the lifecycle-management, LCM, of all the deliveries (parts, machineries, facilities, services, consumables, etc.) on the entire lifecycle. Lifecycle starts when the idea of a product (service, etc.) sprouts and lasts until the disposal (or reuse, recycling) of the given item. In the first phases, there are the requirements gathering, analyses, planning (global plans, detailed plans, assembly plans, etc.), then comes the parts manufacturing (including assembly), testing, diagnostics and servicing is done. Control, advertising, sales and service (maintenance and repair, etc.) are parts of the LCM. Finally, when the product is worn out or becomes useless, there is the destruction (disposal) or reuse (e.g. disassembly of used, but useful parts) or recycling (e.g. melting again). These processes need to be modelled and at the design stage, depending on the complexity of the delivery [1], [2], [3], [4], [5].

The lifecycle-management shall appraise the ecological footprint (environmental effects, energy/material-consumption, CO_2 emission, etc.) of manufacturing and operation of different products and services. A known balance states: *a cup of coffee needs the consumption of 600 litres water, if everything is taken into account* (all included, from watering plants, to dish washing). The goal is clearly defined; the solving proposals are quite poor. The ***KILT*** model and **TYPUS** metrics are purposely specified, to make the analyses consistent [6], [7], [8], [9], [10]. The main goal is to model and quantify the complete delivery (products, by-products, trash and effects of them) of a firm and to model all the relevant steps of the LCM).

The transformation of the world socio-economic layouts requires unique changes, aiming at ‹sustainable development› by the well assessed new ‹extended enterprises›, having the lifecycle responsibility of the supply chain, under suitable accreditation and certification schemes. In connection, some notions and their relationships are worth to take a look at for the LCM point of view [11], [12], [13], [14], [15]:

- To use extended artefacts, defined based on the philosophy of the extended enterprise
- To discern between the services provided by a facility and the tangible supply chains
- To distinguish amongst the tangible and intangible value-added provided by a delivery

The future results will help to examine not only on-duty enterprises (defined as products); also the enterprises under design can be evaluated, taking into account several environmental, ecological, human and other issues of sustainable development or simply their eco-consistency.

2. Renewable and non-renewable stocks

The *ecology*, with the tied restriction on *spontaneous* changes, which, in addition, do not alter the existing equilibriums, is quite recent entry in the society scientific background, based on the otherwise impending threats of the over-pollution and over-consumption. The uncontaminated ‹nature›, as perfect model of virtue is recurrent image, rich of charm. The concept is, unhappily, rather entangled, having links with extraordinary numbers of facts affecting the humanity history. The involvedness of those notions depends on the *nature-culture* opposition, assuming that wilderness is primary state, and civilization is artificial modification. Such *nurture* conflict assumes that the bringing up (or fostering care from the nursery) modifies the inborn idyllic attributes. Men have the ‹civilisation› mission, if we trust the ‹anthropic principles›, in strong or weak form [16], [17], [18], [19], [20].

The ecologic fundamentalism clashes against the anthropic principle, in its *weak* form, too. These all have intriguing consequences. Actually, the man aspires to transcend the contingent nature, in view to justify the intrusion, through explicit acts and instances, to improve the surroundings. The hope might apply to the transcendent God; otherwise the dream relates to the evolution, and the struggle for life is expected leading to the best-fit winners. These pictures are recurrent vision, instituting the *progress* is fundamentalism of the

‹human capital› champions. It is, however, factual acknowledgement that the quality of the life is wholly *artificial* option.

Today, the *ecologism* encounters the damages of the industrial activity, founded on the manufacture transformation efficiency, making withdrawals from finite earth stocks, and piling up garbage and pollutant amounts, exceeding the natural recovery potentials. Hence, *natural* opposes to *artificial*, in view to limit dumping and contamination, moving back the growth rate at pre-industry figures. In the anthropic vision, the *nature* never opposes to the *man*, being, in reality, only helpful complement of the progress. Besides, the term ‹natural capital› is a recent designation, proposed by the ecology movements.

The designation is, nonetheless, notably effective, when the bookkeeping schemes are requested. The production of everything necessitates materials, compulsorily to be taken from somewhere. The balances split up the renewable and the non-renewable resources. The latter shall classify in term of (direct, instrument, etc.) usefulness, (express, ensuing, etc.) toxicity, (local, global, etc.) rarity, and so on, assuming the unidirectional flow from provisioning, to useful ends. The *point-of-sale* denotes the manufacturer's interest, leaving entire responsibility of the use, misuse and disposal to the purchasers. These irresponsible supply chains are made legal by the current bylaws, to be, in reality, better classified as superficiality or swindle. The description relies on an *economic* productivity, defined on manufacturing and exploiting the instant supply/demand balance in the materials' provision, with no worry for the context. The tax system follows similar logics: e.g., the VAT moves along the supply chain, charging the increments, utterly neglecting the correlated spoil amounts and effluence levels. As said, the method is faulty: the earth stocks will run out; the environment will turn lethal; only the today consumers (producers and buyers) profit.

The outlined remarks require revising the current attitude about the supply chains. The distinction between the tangible and intangible aspects of a delivery requires aiming at transformations maximising the value-added conferred by the latter; the following points deserve notice [21], [22], [23], [24], [25]:

- The intangibles, chiefly, relate to wily treatments of the ‹financial› and ‹technical› capitals
- The tangibles involve the ‹natural› capital by instrument/constituent role of the ‹human› one
- The business stability needs a model for the explicit evaluation of all the (four) capital assets
- The lawfulness requires an (example) metrics for the tangibles' appraisal, by legal metrology

The above four points stress again concepts widely examined: the need to give autonomy to the ‹natural capital›, in view that the visibility might motivate enhanced eco-consciousness; the manufacturers' responsibility on the product lifecycle, leaving aside the misleading restriction on the consumers. Both concepts are, perhaps, obvious, but are late in the awareness of many current operators, which prefer naive (actually, *egoistic*) simplifying assumptions, not to give visibility to the ecology cycle. On these points, more virtuous supply chains are deemed to establish, aiming at better balancing the available resources, not to permit the hoardings and lootings of confident profiteers.

2.1. Financial capital prospects

The ‹money› is ancient invention, providing the market efficiency, to replace the barter. The earliest settings addressed an impractical unit, a ‹pecus› say a *goat* (from which *pecuniary* means), suitably replaced by metal coins. The ‹money› is the substitute of goods, having *worth* standardised according to covenants and sanctioned by the ruling authority. It is not, by itself, *wealth*, but ‹instance› of *wealth*, readily becoming currency, for trade setups. The instrument role of the financial flows identify into bank and banking transactions, with the twin implementations:

- Credit management, creating venture companies, looking at profit through risk investments
- Debt management, offering loans at interest, originating asset-backed security engagements

The current economic globalisation sees the finance market encumbered by offers of *sovereign* debt, with governments exceeding the GDP and needing current loans for the current expenditures. The situation tempts speculative bubbles, in which the *structured* finance exploits creating *virtual* wealth, making profit from the indebtedness of the weaker actors. The *virtual* wealth manoeuvres deserve due deepening, but are out of the present interests.

2.2. Technical capital prospects

The man controlled industrial cycles are recent conquest. The *industrial* revolution is considered to be typical outcome of the *capitalism*, especially promoted by venture companies backed by nation-state, which are entitled to pursue public and private profits. Widespread exploitation of *artificial energy* is primary technological innovation; the stream power is original enabler. The *industrial* revolution, being recent achievement, has throughout descriptions. The ‹industry› defines as the business establishment, which nicely exploits structured work-organisation and the facility-integration.

Its meaning is: branch of trade or manufacture, assuring productive efficiency; or: diligence and habitual employment in useful activities (*industrious* is equal to *diligent*). The industrial *revolution* has turned the old (third) meaning, in the other two. The process is somehow mirror of the one pursued by the word ‹culture›, from the land cultivation, to the people instruction. All round, the ‹technical capital› has, up today, the prime driver of the progress.

In its original form, the industry has been based on the *scientific* work-organisation and the *economy of scale* through the mass-production. The robot technologies have brought out the *intelligent* work-organisation and the *economy-of-scope*, by one-of-a-kind manufacture. The *industry* patterns undergo changes; *the variations amplify the opportunities, as it was the* case, with the *agricultural* revolution, compelled to move at *natural* life pace.

The industrialism has promoted the affluent society and consumerism. The drawbacks are well assessed; they open impending threats to the earth progress. The manufacture process concerns *non-renewable* resources. The irreversible transformations deteriorate the surroundings, with damages to the bio-sphere. The changes towards the *intelligent* work-organisation depend on integrating computer engineering tools. These are recognised as key help ‹to dematerialise›, and relevant support for the ‹natural capital› bookkeeping.

Once made clear the negative aspects of the industrialism, the search for remedies shall start. The total suppression of the material goods is non-sense. The burning up of inanimate stuffs is standard process to carry on the vital cycles. The resort to *artificial* energy highly (and selectively) speeds up the consumption rates, but again, the simple suppression of the option is gibberish, not to wipe out the current quality of life. The doable remedies are, quite sadly, only partial and temporary [26], [27], [28], [29], [30]:

- To augment the tangibles' productivity, obtaining larger output, while lowering the native exploited input (by process effectiveness and recovery/reclamation closure)
- To discover suited ‹to re-materialise› cycles, renewing the amount of useful earth stocks, at artificial rates (‹robot age› technology transformations)

The success of remedies will not aim at the unlimited progress, rather at *bounded-growth*, linked to *weak* anthropic bio-sphere's duration forecasts. The current engineering concerns aim at how improving the resource effectiveness. They include a mix of opportunities, such as the following:

- To reinvent the manufacture cycles, under resource-manager liability
- To avoid waste, planning closed-flows, chaining outputs into inputs
- To deliver functions, replacing goods, under unified overseeing
- To invent domotics, optimising the energy controlled delivery
- To supply lifecycle-service, doing maintenance and refurbishing

- To perform reverse-logistics, up to mandatory recovery targets

The example list show already well understood businesses, which are deemed expanding in the near future. The ‹to re-materialise› remedy is longer term issue, involving, most likely, the agricultural ideas, to deal with animated resources, and to exploit suitable bio-mimicry transformations, which enable the related self-reproduction capacities. It is now not possible abolishing the industrial products, as, in the past, these did not remove the land produces. The remedies aim at finding out conservative tracks and replacement means, according to suitably planned restoring/remediation criteria.

The doable remedies have the extra imperative trait of urgency. The climate changes hurry up the need of lowering the contamination, starting by the CO_2 emission. This comes from the oxidization processes, including the ones of animal life. The earth atmosphere is highly oxidising, having the 21% of oxygen. Some 4.5 billion years ago, the atmosphere was highly reducing. The actions of photo-synthesis moved towards the today balance; without, the CO_2 would become dominant. The current composition is only marginally stable: at higher O_2 concentration, self-combustion establishes (by 24% of O_2). Besides, the living beings needs energy, and mainly exploit the $2H_2 + O_2 => 2H_2O$, highly exothermic reaction, which allows reaching to life-suited temperature.

The today atmosphere has the 0.05% CO_2 (78% nitrogen, 1% argon). Bigger CO_2 emissions have rising side fallouts (greenhouse effect, etc.), altering the biosphere equilibrium. The real dynamics depends on multiple factors. Several models are in use, to simulate potential scenarios. The control of the CO_2 emission is critical request, to preserve the rather peculiar earth habitat, having negligible CO_2, on spite of the highly oxidizing atmosphere. The environment-industry will become tomorrow key business, which adds to the entrepreneurial developments. The innovation is a technical capital challenge.

3. Shop-floor modelling: industrial approach

The manufacture activity cannot be suppressed, even if the transformation of raw materials based on *artificial* energy is paradigmatic example of consumerism and natural capital decay. When planning for remedies, we need looking at apt models, in keeping two fundamental demands [31], [32], [33], [34], [35]:

- To recognise that the natural capital use requests refunding of all the withdrawals
- To assess and to bill the materials costs, with resort to fair legal metrology schemes

The former is outlined in the following; the latter is considered in the later **3.3** point.

3.1. The KILT model

The refunding needs synthetic models, defining the manufacture process. The portray links the delivered quantities, $\boldsymbol{Q}$, to the four capital assets: technical $\boldsymbol{K}$, financial $\boldsymbol{I}$, human $\boldsymbol{L}$ and natural $\boldsymbol{T}$; earlier models limit to financial $\boldsymbol{I}$ and human $\boldsymbol{L}$ capitals. Simple relations are in use to link the instant $\boldsymbol{Q}$ or the incremental $\Delta\boldsymbol{Q}$ values:

$$\boldsymbol{Q}^{\circ} = \alpha_o \boldsymbol{I}\,\boldsymbol{L}\,; \qquad \boldsymbol{Q}^{*} = \gamma_o \boldsymbol{K}\,\boldsymbol{I}\,\boldsymbol{L}\,\boldsymbol{T}$$

$$\Delta\boldsymbol{Q}^{\circ} = \beta_o \boldsymbol{I}\,\boldsymbol{L} - \beta_I \boldsymbol{I} - \beta_L \boldsymbol{L}; \qquad \Delta\boldsymbol{Q}^{*} = \delta_o \boldsymbol{K}\,\boldsymbol{I}\,\boldsymbol{L}\,\boldsymbol{T} - \delta_K \boldsymbol{K} - \delta_I \boldsymbol{I} - \delta_L \boldsymbol{L} - \delta_T \boldsymbol{T}$$

The know-how $\boldsymbol{K}$ innovation and the tangibles $\boldsymbol{T}$ bookkeeping have non negligible effects. All the contributed technical $\boldsymbol{K}$, financial $\boldsymbol{I}$, human $\boldsymbol{L}$ and natural $\boldsymbol{T}$ capitals are included, to supply overt account of tangibles and intangible effects. The tetra-linear dependence assumes to operate nearby equilibrium assets. With optimised choices, the negative extras of the incremental balances accomplish the sensitivity analyses, separately giving the individual asset contributions.

In the $\boldsymbol{K}\,\boldsymbol{I}\,\boldsymbol{L}\,\boldsymbol{T}$ model, lacking one contribution, the balance is lame, and the reckoned productivity figures, untruthful or meaningless. The analyses investigate the piling up invariance against the resort to non-proprietary technologies, or to off-the-market loans, or to work out-sourcing or productive break-up.

The tetra-linear dependence means the equivalence of assets alone, and their synergic cumulated action. The company return is optimal, when the (scaled) factors are balanced; the current scaling expresses in money the four capitals (the output ***Q*** has proper value, with the four inputs homogeneity). The return vanishes or becomes loss, if one contribution disappears. The loss represents the imbalance between constituent (know-how, money, work out-sourcing, bought semi-finished parts, etc.) flows.

In the bi-linear model, the tangibles ***T*** (utilities or commodities) are attainable without limits. They do not affect the manufacture business; the affordable growth trend is undefined. The changes in technology, knowledge or know-how, simply, rescale the productivity of tangibles, processed along the material flow. The *new* model presumes the direct concern of the sustainability bounds for energy saving, pollution avoidance, natural goods preservation, and the likes. These bounds require introducing the figure of the resource *efficiency*. The replacement of material goods is cost to society, with non-negligible environmental impacts, which shall be paid by the benefits holders (and not poured out on third people and future community).

The earlier dependence on the financial ***I*** and human ***L*** capitals is result, perhaps, of the dialectic opposition between plant owners and labour. Yet, the neglect of the tangibles ***T*** factor is surprising, as the manufacture duty has no output, without materials and energy. The addition of the intangibles ***K*** is characteristics of the ‹knowledge› paradigms, and an earlier entry could have been devised from the ‹new economy›. With the manufacturer's lifecycle responsibility, the explicit role of ***K*** and ***T*** needs to emerge, since the companies' profitability will become critically dependent on how these factors are balanced. The ***T*** *vs*. ***K*** dialectic opposition is tomorrow challenge.

The scaled ***T***-factor measures the ‹natural› capital use/misuse, with annexed allegations. The technology ***K*** concern has fallouts at the design, production and sale phases, and, in the manufacture business, is dealt with, for *trade fairness*, by quality engineering rules. The *quality* standard, ‹conformance to specifications›, binds design (technical specifications files), to delivery approval testing. Anyway, the technology ***K*** comes as primary transformation factor, affecting the manufacture process throughput.

The productivity bookkeeping is merged into global ***Q*** assessments, to provide synthetic pictures, with visibility of the four capital assets, as the enterprise's function/facility champions. The manufacture shop-floors generate value chains, providing ***Q*** guesses based on the market requests, including the welfarism charges (***L*** factor), according to the enacted rules, and, from now on, the ecologic fees (***T*** factor), following, e.g., the in-progress EU directives. With the ***K I L T*** model, the four manufacture assets easily apply, without modifying many assessed traditional habits.

3.2. Tangibles' productivity

The environment protection is man's right at universal range, with outcomes to safeguard the future generations, not today, represented by efficient political parties or governmental agencies. The democratic consensus or international agreements results deprived of justifications, whether limited to place the interests of the today citizens before. The *fair* socio-political approach, put forward by the ‹knowledge› paradigms, compels protecting the (without voice) generations to come, by compensation ways, such as [36], [37], [38], [39], [40]:

- To create a tax system, which consolidates the wealth corresponding to the withdrawal accomplished from the natural capital, following deposit/refund-like arrangements
- To forbid natural capital withdrawals that exceed quotas, roughly equal to the reverse logistics recovery, or (hopefully) to the bio-mimicry stimulated generation, in view to keep the original natural capital level, by neutral yield

The first way is formal, since, transforming different capitals, the equivalence criteria are, at least, ambiguous. The second, if coherently applied, faces decay limitations, and today runs into the life quality

decrease, towards the thrifty society. It is, moreover, possible to merge the two ways, using the *deposit-refund* choice as first instance, thereafter keenly researching innovative technologies, out of reverse logistics, which perform active *replacing* resources and full eco-remediation, to achieve neutral yield of the *inherited* natural capital.

Many unanswered questions exist (e.g., in terms of comprehensiveness). The EU environmental policy looks aiming at united way. The bookkeeping of the tangibles' decrease and pollutants' increase becomes primary demand, with, as side request, the assessment of the restoring onerousness. So, closed-cycle economic/ecologic processes are prerequisite of the manufacture markets to come. The analyses need to be quantitative, to make meaningful comparisons, fulfilling the assessments by recognized standards. The consistent closed-cycle appraisal brings to concepts such as the below new metrics (or similar equivalent standards).

3.3. Eco-watching and appraisal

The ***T*** factor, in any case, is essential figure to be monitored, using appropriate standards: the **TYPUS**, *tangibles yield per unit service* is example metrics. The measurement plot covers the entire materials supply chain, from procurement, to recovery, so that every enjoyed *product-service* has associated eco-figures, assembling the resources consumption and the induced fallouts, requiring remediation. The results are expressed in money, resorting to arbitrariness in establishing stock-replacing prospects. The point is left open, but, it needs to be detailed to provide quantitative (legal metrology driven) assessment of the "*deposit-refund*" balance.

The metrics is self-sufficient standard, aiming at the natural capital intensive exploitation. The supply chain lifecycle visibility needs monitoring and recording the joint economic/ecologic issues, giving quantitative assessment of all the input/output materials and energy flows. The new tax system has to operate on these data, establishing consumption rates at the input, and pollution rates at the output, to obtain the "wealth equivalent" of the overall impact (as for the first mentioned way).

When a metrics, such as **TYPUS**, is adopted, conservative behaviours are soon fostered. The ecologic bent of the taxing systems becomes enabling spur, to turn the ‹knowledge› paradigms towards environmental friendly goals. The **TYPUS**, *tangibles yield per unit service*, metrics can take follow schemata. The objective is to look after capital conservative arrangements, notably, as for the *natural* assets. In different words, the objective is saving the wealth (the *capital*), and to tax the consumption (the *imbalance* of the natural resources).

Today, the eco-fee evaluation is quite obscure, due to political biases. It leads to taxing schemas, which draw from the whole capital, more than in proportion to the *actual impact* (net depletion combined to pollution). The eco-protection, switched into the individual consumers' business, is starting point, to look for higher efficiency, over the whole supply chain, from provisioning to recovery, using *all-comprehensive* effectiveness criteria, singly dealing with each capital asset (tangibles' productivity included).

Tomorrow, the natural capital bookkeeping will be standard routine of the knowledge society. Today, the *economic* accounting to detect unlawful habits (crime, repression, etc.) is obvious practice, affecting personal liability. Similarly, the thought-out *ecological* accounting needs to develop into steady rehearsal, in view to charge the actual consumers (to the advantage of third people and future generations). With the ‹knowledge› paradigms, the tax regulation restructuring is required, because the socio-political aspects management becomes relevant contribution to effectiveness. The bigger question is how to distinguish the community's, from the individual's duties.

The solution offered by the (western world style) capitalism is noteworthy issue. The personal liability is consequence of the independent freedom to organise the exclusive fortune. In place of shared figures, the

individual accountability offers rewards through competition. The averaged taxation of input/output materials and energy flows is simple, being linked to nominal parameters, limiting the control to out-of-all quantities (provisioning and land-filling). This is local communities business, with visible fees refund, depending on the efficiency of the average balances. The *ecological* accounting through the **TYPUS** metrics is more tangled affair, needing to address each single supply chain, with pace wise check. The competition shifts at that level, and the lifecycle manufacturers' responsibility is viable bookkeeping charge (under registered overseeing). At least, this is fair practice, deserving attention.

4. Conclusions

The goal of this work is the technical, ecological, environmental and social examination of the lifecycle (LC) of any product (consumable, service, production) using the **TYPUS** metrics and the ***K I L T*** model. The lifecycle starts when the idea of a product is born and lasts until complete disposal, through realisation and operation. Our real goal is to give some means and tools to calculate different values which correspond to different phases of the product lifecycle. We specially emphasise re-use and re-cycling as important LC phases, due to moving toward water, energy and raw material shortages. As for product we mean anything which is used by simple users (a car, a cup, a bike, or a part of them, etc.), or which is used by dedicated users to produce or manage other products (a machine tool, a robot, a house, a test environment, etc.), or which is used to manage everything else (a firm, a factory, a ministry, etc.). We differentiate between simple products and extended products and between tangible and intangible parts (aspects) and service is taken into account as a product, too.

The **TYPUS** metrics and the ***K I L T*** model tell that the delivery of a firm can be calculated with a seemingly simple multiplication of four main factors, as Knowledge (innovation), Investment, Labour (human capital) and Tangibles (materials), scaled by appropriate constants and additional factors. Delivery means the goal-products, side effects (water consumption, CO_2 disclosure, etc.). Based on these calculations real data can be given on effects, side effects and 2nd, 3rd order side effects of products and productions, e.g. CO_2 emission can be properly evaluated.

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