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Materials, beyond Life Cycle Thinking

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Abstract – Materials have been central to the development of civilization, as they constitute the backbone of our society and of our technology, as all things are made of materials and all of them are made by tools mainly made of metals, and especially iron and steel. In modern language, they have become central to the sustainability of our society. Speaking about or measuring this relationship, however, is complex. Life Cycle Thinking is an important tool for doing this, but it was not developed with materials in mind and it focuses only on that small part of sustainability related to environmental impacts. Economic and societal issues require other methodologies and all these complementary visions have to be aggregated in order to report properly on sustainability matters. To advance towards such a new tool, called the New Metrics, an Initiative called SOVAMAT was launched 10 years ago and a Community has shaped up, binging together academics from a broad array of hard and soft disciplines, materials producers from metals to plastics, glass, paper/cardboard, concrete, carbons, wood, etc., and materials users, including meta-users who work on ecodesign, for example. The agenda of the Initiative is moving forward, improving existing methodology, extending it and aggregating various tools towards the final target of the New Metrics. The SOVAMAT Community meets regularly in annual seminars called Society and Materials or SAM. This paper explains the questions addressed by the Initiative and some of its early successes.

Mots-clés :
Matériaux ; ACV ; AFM ; nouvelle métrique ; analyse de durabilité ; initiative SOVAMAT

Résumé – Les matériaux, au delà de la Pensée Cycle de Vie. Les matériaux sont au cœur du développement de notre civilisation dont ils constituent la colonne vertébrale : en effet, tous les objets sont constitués de matériaux et la totalité d'entre eux sont fabriqués à partir d'outils et de machines constitués eux-mêmes de métaux et particulièrement de fer et d'acier. En langage moderne, les matériaux participent frontalement au développement durable. Parler ou mesurer cette relation est une démarche très complexe. La Pensée Cycle de Vie est un outil important pour ce faire, mais elle a été développée sans penser directement aux matériaux et elle s'intéresse d'abord aux questions d'environnement liées aux impacts des activités humaines. Les questions économiques et sociétales demandent qu'on ait recours à d'autres méthodes et les différentes visions complémentaires qui sont ainsi proposées doivent être rassemblées pour couvrir la totalité du sujet du développement durable. Pour faire avancer la conception de ce nouvel outil, qu'on appelle la Nouvelle Métrique, une Initiative nommée SOVAMAT a été lancée depuis 10 ans et cela a donné naissance à une Communauté, où on retrouve des universitaires de différentes disciplines, dures et molles, des producteurs de matériaux, métaux, plastiques, verre, papier/carton, béton, bois, etc., des utilisateurs de matériaux, y compris au niveau « méta » comme les spécialistes d'écoconception. Le programme de cette initiative avance, en améliorant les méthodologies existantes, en formulant des développements plus radicaux et en rassemblant différents outils qui constitueront ainsi à terme la Nouvelle Métrique. La Communauté SOVAMAT se réunit régulièrement dans le cadre de séminaires annuels appelés *Society and Materials* ou SAM. Cette publication explique les questions soulevées dans cette initiative, ses premiers résultats et ses premiers succès.

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This paper is intended to be a progress report on the *SOVAMAT Initiative*. It is centered on materials, because they are central in the way the material[1] part of society[2] operates and this has been true since mankind emerged from the dawn of prehis-

[1] The identity of words is not coincidental!

[2] Furthermore, prehistorians and anthropologists have long been pointing out that the material and cultural parts of society are very closely connected!

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Acronyms

CBA	Cost Benefit Analysis
CF	Carbon Footprint
CFD	Computerized Fluid Dynamics
CSR	Corporate Social Responsibility
EBITDA	Earnings before Interest, Taxes, Depreciation, and Amortization
EF	Ecological Footprint
EPD	Environmental Product Declaration (cf. FDES)
ETP	European Technology Platform
FC	Fuel Cell
FDES	Fiche de déclaration environnementale et sanitaire
FONDDRI	Fondation pour le développement durable et les relations internationales
GHG	GreenHouse Gas
GWP	Global Warming Potential
ICE	Internal Combustion Engine
IPP	Integrated Product Policy
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
LCFC	Liquid Carbonate Fuel Cell
LCT	Life Cycle Thinking
MFA	Material Flow Analysis
NOx	nitrogen oxide pollutants
PEMFC	Proton Exchange Membrane Fuel Cell
PM	Particulate Matter
POP	Persistent Organic Pollutant
REACH	Registration, Evaluation, Authorisation and restriction of CHemicals
RFDI	Radio Frequency Data Identifier
SAM	Society and Materials (seminars)
SAT	Sustainability Assessment of Technologies
SFA	Substance Flow Analysis
SLCA	Social LCA
SOFC	Solid Oxide Fuel Cells
SOVAMAT	SOcial VALue of MATerials
SOx	sulfur oxide pollutants

tory: they deserve a special epistemological treatment in the way that their connection to society is described and it is not sufficient to brand them as commodities, especially since many of them are not, in the economic sense of this word. The point is that Life Cycle Thinking does not fully address the issues of which materials are part and that some new approaches, going beyond Life Cycle Thinking, need to be invented; and that this is actually already under way.

1 What is SOVAMAT?

SOVAMAT[3] means "SOcial VALue of MATerials", a concept that was put forward several years ago [1–4] to emphasize the point that materials have played a broad and important role in the economy and in the history of mankind, which cannot simply be addressed in terms of their environmental footprint without losing too much of the complexity of the real world.

2 Sustainability and sustainable development, etc.

The concepts of *sustainability* and *sustainable development* have also become quite familiar across the power spectrum that extends from economic players to society stakeholders, governments and international bodies. Complementary concepts are also used in this context, such as that of *Life Cycle Thinking* (LCT) and *Sustainability Assessment of Technologies* (SAT) [5, 6].

The overarching rationale is to portray human activities in a way that acknowledges

[3] Acronyms are defined in a table at the end of the text. Please look them up there, if it did not seem necessary to define them in the text.

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the complexity of the systems within which they are at play. All the concepts mentioned above do indeed address this question, but from the standpoints of specific stakeholders and are therefore slightly biased [7].

The *sustainability approach* is a very general and positive statement about where mankind ought to go if it wants to survive in the long term and, at the same time, an implicit acknowledgment that governance rules can indeed be formulated that can steer society in that direction. The approach also implicitly posits that the world is strained under constraints that have to be pro-actively balanced in order to avoid some kind of fracture in the fabric of society, a statement reminiscent of Malthusian doctrine and of the Club of Rome studies [8,9]. It stands therefore on the common ground between political ethics – "we ought to manage the world under conditions that will leave it functional for our grandchildren" – and political and management science in their longer-term, most strategic forward planning – "let's just do it!".

Life Cycle Thinking is an approach that has been induced from LCA, a tool and methodology developed to regulate the generation of new products and services in the market economy.

3 LCA, apologia and criticism

The LCA approach looks at the function of a product or a service (the "functional unit") from the transversal standpoint of the value chain in which it is inserted. It has thus forced economic players, who usually interface aggressively through markets, to work together and to exchange enough information to integrate an environmental vision in their activities, i.e. to introduce the idea of an environmental value into an economic world where the economic cost does not always factor in an environmental cost – what economists call the non-internalization of the environmental externality. In the background of the sustainability concept also lies the *precautionary principle.*

In practical terms, a car, analyzed as a functional unit (e.g. an automobile which is used for 100 000 km), is now specified under many public policies by its tailpipe emissions (e.g. 120 g of CO_2 per km). Such a car can be designed by reducing its weight, which can be accomplished in many different ways, such as using wood, cardboard, aluminum, magnesium, plastics or carbon fiber composites rather than the most common material today, steel, or changing the power train and thus steering away from fossil fuels, etc. Some of these solutions are not practical because of cost or safety standards, but any material that passes these tests can in principle be "the" solution. This is where LCA comes in, as the carbon footprint of a car is not simply its tailpipe emissions, but also what happens before and after the car is used to provide the service of mobility: the production and the end-of-life phases will be quite different if steel, aluminum or plastics are used. As a matter of fact, once cars change from ICE automobiles to electric or FC cars, then their tailpipe emissions will be virtually zero and the production and end-of-life phases will become the only ones worth considering! Even today, when cars have become light and nifty in order to meet these tailpipe emission standards, the use phase is no longer the main phase in terms of the carbon footprint. This simply means that tailpipe standards have outreached their usefulness now that car technology has achieved its present state of the art. This is a good case to show how useful the LCA approach can be and also an argument to generalize the approach and to speak of *Life Cycle Thinking*.

In simple terms, LCA has made it possible, for example, to estimate the global CO_2 emissions of a car driven for 100 000 km and not simply g of CO_2 per km, nor kg of CO_2 per ton of steel or of plastics. It stops, however, at the point of estimating the global emissions of all the cars of the Clio II series, of all the cars put on the market in 2009, or of all the cars running in 2009. It does not say anything either as to the full impact of these on global GHG emissions. It also leaves out the cost related to achieving better results, although derivative methods, such as LCC or LCM, make attempts at doing this [10].

Life Cycle Thinking is being promoted by the European Commission as a way to move beyond the selfishness of economic

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players. It is a tool developed to maintain a vision of the public good in the supposedly unruly economic markets, alongside other tools such as REACH, which focuses on protecting human health from artificial molecules, or the IPP or many other rules that aim at steering society towards a more balanced relationship with the environment, the ecosystem and life in general.

SAT is another new approach, the target of which is to ensure that new technologies will not jeopardize society's future well-being nor its sustainability – hence its name. The standpoint is one of diffidence to new technologies and reflects a vision of the precautionary principle, probably a conservative one; it is also an optimistic statement of what can actually be accomplished by political governance in terms of specifying technologies before they can be fully developed or implemented. One can, however, seriously wonder if our present world would exist, complete with the technologies it has mastered and trivialized, if such methods had been used when these technologies were first brought to use. One might even argue that these political approaches are connected with *relativism* as a way to explain science and technologies.

LCA is by far the most developed tool available to quantify such approaches and thus tends to upstage other methodologies. Probably typical of this rivalry among tools is the fact that they are developed by groups of researchers who identify themselves as belonging to a "Community", e.g. the LCA Community vs. the MFA Community. This is why Sustainability has often become more or less synonymous to Life Cycle Thinking. This is a typical bias of doers versus thinkers, of people who put a premium on action rather than on more critical and careful progress.

Another criticism of these goodwill approaches of political scientists, administration managers and bureaucrats is that they assume that the total is the sum of its parts. A sustainable world would thus be the result of sustainable technologies, producing sustainable products and delivering sustainable services, all produced by businesses and people engaged in Life Cycle Thinking under the guidance of enlightened public bodies issuing governance rules to make the world sustainable.

4 Critical appraisal of sustainability?

The real world might not be fully responsive to such a vision, akin to a degree of wishful thinking, and it might be necessary to acknowledge more complexity in its fabric in order to steer it in the proper direction, i.e. towards a better world for future generations under the constraints of a finite environment – as much as this can be accomplished.

Failure to do so would lead to what is conservatively called *rebound effects*, which are unexpected consequences of policy decisions, governance rules, and tools and methodologies imposed outside of their natural domain. Rebound effects may overcome the direct effects sought by a particular policy and thus turn into *perverse effects*.

An example of a rebound effect in the materials world is related to the *recycled content* concept, a provision introduced in several EU directives to foster recycling, based on an idea that sounds anchored in practical sense and specifies a minimum amount of recycled material in any material used to produce cars. The steel people are particularly unhappy with this rule as applied to automobiles, for example, because they claim in good faith that more than 95% of the steel used in cars is recycled, but not necessarily to make new automobiles. The system of reference in which this recycling phenomenon ought to be analyzed is thus not the car cycle but the steel cycle: there is absolutely no doubt that steel ought to be recycled, and plastics and aluminum as well, but not necessarily steel or plastics or aluminum from old cars in new cars: this would constrain the economy beyond its current optimized practice and drive costs up to levels that would be unacceptable to everyone, first of all to car consumers. Even more ironically, some products made with almost 100% recycled content would end up in landfills or be incinerated, a rather poor value creation for society!

Another example is related to oil refinery technology. An LCT approach applied to automotive fuels, for example, seems to favor

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diesel against gasoline, in terms of energy efficiency, GHG emissions, air pollution (except very fine PM), etc. However, there is a minimum amount of gasoline that a refinery has to produce from crude oil so that a complete switch to diesel fuel would overreach its purpose and eventually have a worse ecological footprint than the *statu quo ante.* Similarly, the recycling of obsolete oil should not lead to the disappearance of new oil, since some has to be produced by a refinery: 100% reuse/recycling would mean that a refinery would produce a waste. . . made of new oil!

5 Complexity analysis

One way to introduce the complexity of the real world into these approaches is to acknowledge that there is not a single sustainability issue but rather several similar questions that depend on the system in which they are raised. Paramount is the notion of scale, i.e. of micro- or macro-economic decisions or policies.

One might actually accept the idea that sustainability is a global concept that only applies to the world as a whole and to a time extending far into the future, but not necessarily to all of its parts.

Thus, to make the world sustainable, it might be necessary to conduct unsustainable policies in parts of the world for part of the time: it is thus generally acknowledged, as far as Climate Policy is concerned, that developed and emerging countries should not be submitted to the same constraints on GHG mitigation in the short term even if they would have to converge eventually, to give a chance to the emerging countries to raise the standard of living of their people and not to restrict it to fighting a phenomenon which they did not create.

The question of what constitutes a sustainable world is indeed complex.

On the one hand, the optimum of a system is not necessarily the aggregation of the optima of each of its parts.

On the other hand, what ought to be the optimizing function is not necessarily obvious: an economic function such as the EBITDA of a business, an environmental function such as a minimum ecological footprint, or a social function, such as zero unemployment? Or a more abstract objective, such as long-term survival of a species as is the rule in the biological world, where the concept of an optimal yield has absolutely no merit?

Another factor is that the whole may be much more than its parts. Thus, the social value created by steel is much more than the added value of the steel industry itself. Similarly, CO_2 emissions due to one ton of steel are much less than the amount of emissions that are saved by new steel grades used in a car, etc.

6 Sustainability and systems

To follow this line of thinking, let us give some thought to the *systems* that ought to be considered:

- there is first the *micro-economic system of the consumption markets*. This is the system for which LCA was initially developed. These markets are very competitive and communication among value-chain partners was often poor or nonexistent prior to the introduction of LCA. LCA is the most commonly used tool to deal with this system: it makes it possible to assess competing products or services by comparing them from a range of indicators, usually impact categories: the LCA tool thus deals with the complexity of the organization of the value chain and with the consequences in time that are caused by the initial creation of the functional unit (FU). It is a tool meant for marketing people on the one hand, and for consumers on the other, i.e. a tool for dealing with some of the micro-economic aspects of the consumption market.
  LCA, however, focuses on negative impacts and does not value positive ones.
  Moreover, it looks at the contribution of one functional unit and does not in any way propose a solution for aggregating impacts due to a whole family of products during the time they stay on the market or for aggregating several generations of products together.
  LCA also adds up impacts of the whole value chain, assuming additionality, which is not always the case: e.g. SOx

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emissions in a South American mine, in a Chinese steel mill and of a car used in Europe simply do not add up physically; what actually adds up is the total local emissions in a region of Brazil or China, but LCA does not yet usually take this on board.

Global impacts such as GHG emissions or energy consumption are rather well described, but most of the other impact indicators point to problems (e.g. too much SOx altogether) rather than to physical accumulations (too much SOx in a region, leading to a serious acid rain concern there).

The time frame is also narrowly confined to the instant: one functional unit, one product used from now on, not another similar product, not a new version that will be commercialized next year or later.

- there are also *macro-economic systems*, where the aggregation may be done on various scales, global (planet) or regional, such as:
  - the total national or world market for the functional unit, which is the relevant system for estimating the impact of the FU. One car may be polluting beyond the emission standards but this would not matter that much if there was not a mass market for this model: aggregation is therefore necessary and there is no standard tool for doing it, except, to some extent, consequential LCA.
  - the total energy market is a very complex system as it involves many different resources, usually split into fossils and renewables. But more involved situations exist, where different kinds of energy are mixed in order to produce fuel, such as biofuel – a mixture of solar energy and fossil fuels used to grow the agricultural, silvicultural or aquacultural feedstock, fertilize and transport it to fuel production plants, or oil shales which need heat and hydrogen, thus requiring so much energy that it is planned to produce it from a nuclear power plant. In the latter case the gasoline produced by such a scheme would actually be mainly a transformation of nuclear energy, whereby shale oil would play the role of a raw material (like iron ore for steel), rather than of an energy resource!
  - the total materials market is also a complex system that involves primary materials and secondary ones (recycled) as well as reused parts (cf. the 3R agenda, for *Reuse, Reduce, Recycle*). It also includes materials such as wood which are grown from biomass. There are major materials, on the one hand, such as steel, concrete, non-ferrous metals, wood, glass and plastics, and minor ones, on the other hand, such as lithium, platinum, etc. There are no outstanding issues with resource availability of the major materials, but minor ones do exhibit some. For example, the future of alternative powertrains for automobiles depends on the availability of platinum for FC cars and of lithium for electric cars, at least in the short/middle terms, until other FC technologies (LCFC? MOFC?) become more attractive than PEMFCs and other battery options than ion-lithium ones become available, if they ever do! Most "high-tech" products depend on a critical material and their future and the scope of their market extension might be controlled by the access to this material (e.g. gallium in LEDs or solar cells, germanium in infrared lenses and solar cell concentrators, indium in flat panel displays and photovoltaics, tellurium in solar cells, etc. [11, 12]). The issue of handling sensitive waste also comes up, for example in the case of low-consumption light bulbs [13], which exhibit low energy needs, but raise issues about the way end-of-life should be carried out. All of these are classic cases that call for a broad approach, balancing and weighing competing constraints.
  - global impacts such as GHG emissions, which are so global that they embrace the whole planet as the relevant ecological system.
  - impacts of other air emissions, such as NOx, SOx, particulate matter,

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targeted molecules (POPs, dioxins, etc.), of discharges to water and soil, etc., which do not aggregate at a world level (a regionalization of the impact is needed) but ought to be aggregated anyway on the appropriate scale related to the physical ecology of the phenomenon.
  - economic positive impacts, such as the contribution to GDP, growth, job availability and creation, etc.
  - all of these embrace a problem at a global, aggregated level typical of what geographers do, or macro-economists dealing with aggregated data such as a national accounting system.

There are no specific tools to deal with these various issues, except that MFA is an already fairly developed tool for materials accounting, which has the potential of being used in a larger context as some teams have started to do [14].

- there are also *time dimensions or temporality systems,* which come up when dealing with problems extending over time, because of long life cycles or indefinite recycling, or when the future is at the core of the analysis like in future studies or prospective:
  - the way that LCA deals with time is rather paradoxical, as the concept of the life cycle is central in the approach, but the method remains static in that most parameters describing the context, technologies, impacts, etc. are uniquely chosen and frozen in time. There is an attempt at introducing a time dimension by considering past, present or future values of the main parameters (cf. *attributional vs. consequential LCA),* but this falls short of a full dynamic, time-dependent picture that would be necessary to deal with problems that do have a real time extension. Dynamic LCA raises issues related to the functional unit and therefore it is debatable whether it is still a kind of LCA or already a different methodology, a "new metrics". Other names are popping up in the literature, such as prospective LCA, predictive LCA, meso-LCA, macro-LCA; dynamic MFA is also under development [15]. Note also that the various kinds of time that need to be taken on board for such an analysis amount to considering time as multi-dimensional, an interesting concept!
  - *Future Studies* require a very plastic view of the world in which a study is conducted with a strong time-dependency, usually embodied in scenarios that amount to different time lines. Future studies are usually carried out by economists who follow the methodology of prospective and find little help in existing methodologies such as LCA or MFA, which are anyway foreign to their culture. Future studies are used in strategic marketing for the shorter-term projections and in studies related to social sciences or, quite often lately, to Global Warming for the longer-term projections. While the LCA of a car makes perfect sense, the discussion of transportation and mobility over the next 50 to 100 years cannot be carried out with LCA alone and needs a more encompassing approach – in terms of models, powertrains, fuels, connection with the urban structure, etc. – with a strong time evolution dimension.
  - it is not coincidental that many of the concepts that need to be factored into the various temporalities are similar to storylines found in science fiction literature or in physics' new holistic theories. All try to deal with the same complex issues with their own approaches and, as the number of models available to human intelligence is limited, we may learn from them!
- there are also *social and societal issues* which do not simply boil down to quantitative indicators of the type that is being developed, for example, by SLCA[4]:
  - mimicking LCA approaches, one can wonder how the world would be without cars, or without steel, or

[4] These are more *management chart* kinds of indicators, which refer to a steady-state context, where business development has to stay on track with respect to a business projection.

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without aluminum, or health services, or... intuitively, it seems obvious that removing one of the above from our present society would change it very deeply and probably for the worse. Goods, materials and services therefore have a positive social value, i.e. they bring benefits that go beyond their immediate role in the system to which they belong. Steel, for example, beyond being part of cars, construction, machines, packaging, etc., is so closely central to the core of the technology of our times, even of our history, that it is basically one of the backbones of society and therefore of the well-being and of the survival of its inhabitants. Jared Diamond makes this very clear in his ambitious book called *Gem, guns and steel* [16].

There are no tools to analyze a world with cars vs. one without them and thus to estimate the "social value" of cars, although methods based on CBA (Cost Benefit Analysis) could probably be applied, in a way similar to how N. Stern estimated the cost of Global Warming [17]. Describing a world without steel would be even more difficult: the effort has been made in the past by British Steel in a promotional movie called *A World Without Steel,* where high-rise buildings were shown to sway in the wind, because of the use of materials of lower stiffness than steel's, and surgeons had to do a messy job using stone knives rather than steel scalpels...

A simple method is available to provide quantitative estimates; the IoU curves which establish the connection between GDP and amount of steel used, both per capita (an example is shown in Fig. 1; there are other ways of plotting this). The extreme left part of the curve, where it intersects with the horizontal axis, gives the GDP of a world without steel, which would be a major reversal to prehistory. More to the point, the values before, at the maximum and after that maximum give the connection between growth, maximum growth in emerging countries and maintenance of the standard of living in a developed country [18].

– another example from the social/political domain is the counter-season agriculture that has become a large economic sector in Chile (for vegetables) or Kenya (vegetables, flowers), a system that has been built to negate the seasons for consumers in the Northern hemisphere. Consumers today seem ready to pay the extra price due to the long-distance shipping that the practice involves. However, new tools such as the *carbon footprint (CF)*, which is mainly based on LCA methodology, would make it very clear to the consumer that the practice has a high ecological cost in addition to the hefty market price.
What decision ought to be taken based on this rather obvious statement, which, incidentally, can be made without calling on the heavy methodological machinery of calculating a carbon footprint? Should we cut the habit altogether in the North, in the name of a green political philosophy and thus maybe drag producers from the South into bankruptcy? Or shouldn't we proceed differently, fostering a more transparent debate that weights all the elements of this complicated equation?
This is another example showing that oversimplification of a complex issue, or the denying of its complexity, errs! In that case, simple, CF-type indicators seem more harmful than helpful: a qualitative argument, organized around a storyline written in long words, would seem best.
– business, in connection with the business ethics trend that stems from the US business culture [19], is federating a view of sustainable development that is expressed by the annual publication of CSR reports [20], by business organizations such as the WBCSD [21] and by a lively teaching fashion in business schools. What is at stake there is a commitment of

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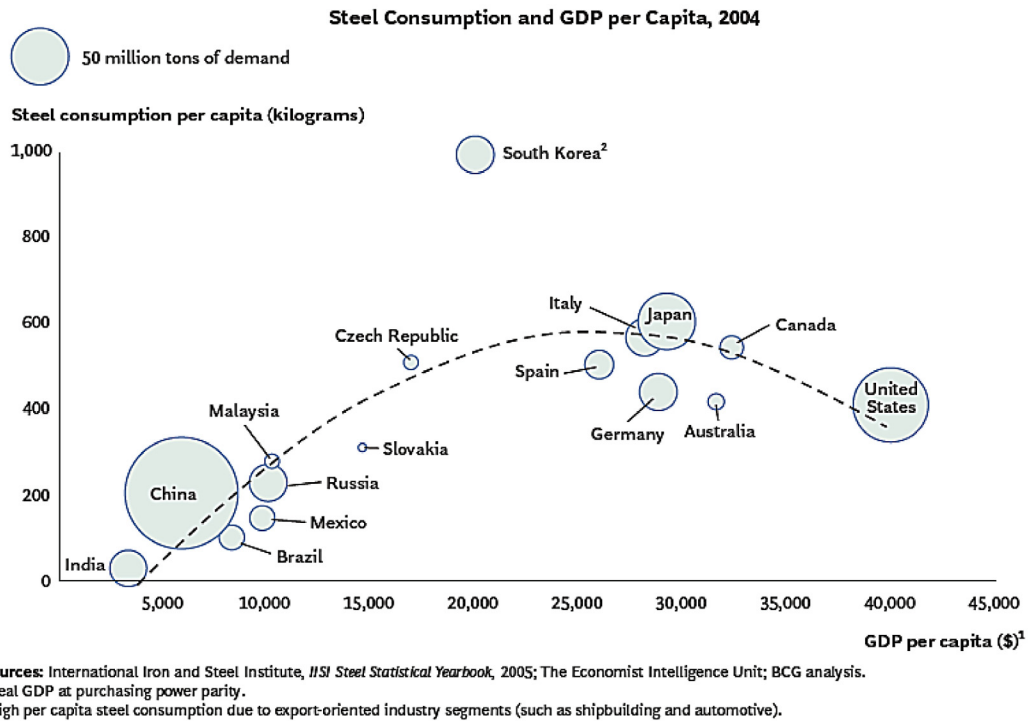


Fig. 1. Connection between per capita steel consumption and GDP.

business to act as a corporate citizen in its local community and to promote values and push initiatives which are disconnected with standard business targets as expressed by neo-classical and liberal philosophies and aim at improving the social context of its employees and of local communities. When this kind of initiative is directed at the poor, in an effort to integrate them in the supply chain as suppliers, distributors or consumers, it is known as *inclusive business* [22]. The conceptual key of all these various initiatives is that an economic activity extends beyond its normal business duties, which is a rather obvious understatement.

– there is a strong need for social scientists of all "religions" to flesh out this social dimension of sustainability, which is very much talked about but is usually dealt with by non-social scientists, and, more often than not, by the LCA community itself.
– *the ecological systems* that are behind many of the environmental indicators, used in LCA, for example, need to be modeled in a more rigorous and scientific way:
– the *Global Warming Potential* (GWP), probably the strongest of the LCA indicators, which is at the core of most of the analyses carried out and of the decisions taken on the basis of this methodology, has been developed by the IPCC to compare the effect of greenhouse gases on Global Warming and not different products during their life cycle. For example, why use the 100-year GWP when modeling a building whose life is 60 years, the materials of which will be recycled once or more times? Why assume that the ecosystem response will remain the same over this period of time (the life cycle), when climatologists think that the biosphere and hydrosphere sink efficiency has been divided by 2 in the last 10 years? [23–25].
– *Eutrophication* or *Acidification* are commonly aggregated over a product's life cycle, even though, due to the globalization of the economy, we are

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adding emissions in Brazil – where the iron mines are located, in Japan – where the cars are made, then in the US – where the cars are used, which simply does not represent the physics of what actually happens: NOx, SOx, etc. simply do not travel all over the world. The indicators, in such a case, are thus not scientific constructs but policy targets, which may arguably be fine, hic et nunc, but hardly satisfy the physical properties of indicators that can be accrued over space and time and thus used in a reasonable way for making important and lasting decisions. Solutions are known and are being worked out along the line of better ecological models and of regionalizing the analysis. But they are not implemented yet in commonly used tools.

  - the data necessary to calculate these indicators are not very transparent, they depend on tools that use "proprietary" and non-transparent data, and are not published with an indication of their uncertainty that would allow proper parameter studies, with a systematic indication of the uncertainties of the conclusions.

- *prices*, when there is a market or regulators to define them, are a rather good measurement of the value of a product or a service, as they actually result from a negotiation between the producer/service provider and consumer. They embody a global value, which includes some social and environmental values, beyond the pure economic one, even if internalization of externalities is still partial. On the other hand, there is not much *economy* in LCA – short of switching over methodology to LCC, and this is an imbalance that needs to be corrected.
- last, there is the *political world of national or international organizations*, which sets the pace and aims at regulating and steering the way non-market issues, mostly environmental but also social ones, are handled. These organizations are pushing a sustainable development agenda, which is clearly part of their mandate to re-establish a balance between the 3 "pillars" in a world that is mostly dominated by economic forces[5]. But they also extend their zeal beyond this and decide on the methodologies that are to be used. The connection of the UN (UNEP) with the LCA community – *the SETAC Life Cycle Initiative*, is one such example [26] and so is Life Cycle Thinking advocated by the European Commission and instrumentalized by the JRC [27] in connection with the IPP directive [28].

7 Sustainability tools

Available *sustainability methodologies and tools* are summarized in Table 1.

They are to the issue of sustainability, or rather to the relationship between the ecosystem and society[6], as engineering is to hard sciences, medicine to biology, management to economics or political science to history, an applied version of a more abstract, theoretical, ambitious and global approach to knowledge and understanding. They are part of a larger context and confusion is possible among stakeholders, who are focused on action, of confusing tools with science and thus of sliding into a metonymous or synecdotic view of the world!

The table does not provide any classification among these tools, for example in terms of bibliometric data. If the relevant research had been conducted, it would probably show that LCA is by far the main tool in terms of publications and of practical use in the regulatory and in the business worlds. Probably but not certainly, as these subjects are treated by many different fields, which do not easily connect together and whose practitioners function in separate communities.

[5] e.g.: the Earth Rio Summit, the Global Compact, the Earth Charter, Agenda 21, the Human Development Index (HDI) of UNDP, the Environmental Sustainability Index (ESI), the Environmental Performance Index (EPI) of the World Economic Forum(WEF), the Genuine Progress Index (GPI)), the EU Sustainable Development Strategy (SDS), the Grenelle environmental laws in France

[6] the *technosphere* as opposed to the biosphere; cf. also the concept of *urban metabolism* often used by industrial ecology

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Table 1.

Acronym	Methodology or tool	Comments
ABM	Agent-Based modeling [29]	Related to the physics of Emergence and to the *self-organizing* concept
	Biodiversity indicators	Ruled by the UN Biodiversity Convention [30], biodiversity is considered as an ecological service in Industrial Ecology
CF	Carbon Footprint	A new family of indicators proposed to provide consumers with a "carbon price" to balance the usual price in their decision to buy a product or a service
CSR	Corporate Social Responsibility	The activity of a corporation in this area is reported in a special report, which has often replaced the Sustainability Report.
CBA	Cost Benefit Analysis	
DfE	Design for the Environment, Ecodesign	A new field in design, introduced to account for environmental constraints besides economic ones
dLCA	Dynamic LCA	
EL	Ecolabeling	
	Economics tools	
E-MFA	Energy-MFA	
EE	Environmental Economics	
EA	Environmental Accounting	
	Environmental Economics tools	
EIA	Environmental Impact Assessment	
EMS	Environmental Management System	
	Environmental Report	Chapter added to the Annual report then a report of its own standing published independently. Corporate world.
EP	Equator Principles	
EA	Exergy Analysis	
FCA	Full Cost Analysis	
GP	Green Procurement	
SEEA 2003	Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003	See NA
HIA	Health Impact Assessment	
IA	Impact Assessment	
IOA	Input Output Analysis	Leontiev matrices
ICM	Integrated Chain Management	
	ISO 14000	
LCA	Life Cycle Analysis	
LCC	Life Cycle Costing	
MFA	Material Flow Analysis	
M-LCA	Macro-LCA	
NA	National Accounting	See IOA
NAMEA	National Accounting Matrix With Environmental Accounts	An OECD tool
PIOT	Physical Input–Output Tables	

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Table 1. Continued.

PS	Product Stewardship Prospective (Future Science) tools (Delphi, etc.)	
3R	Reduce, Reuse, Recycle	A waste hierarchy commonly used in Industrial Ecology
SIA	Social Impact Assessment Social Science tools (surveys, etc.)	
SA	Stakeholder Analysis	
SFA	Stock and Flow Analysis	
SEA	Strategic Environmental Assessment	
SFA	Substance Flow Analysis	
SA	Sustainability Appraisal	
SA	Sustainability Assessment Sustainability Report	Evolution of the environmental report. Corporate world.
SAT	Sustainable Assessment of Technologies	
TA	Technology Assessment [31]	More general than SAT and more mature in terms of methodology

Here is an attempt at classifying them:

- in the beginning are the academic, basic sciences, such as physics, physical chemistry, ecophysiological science, toxicology, sociology or economics. They have their own methods to produce their own version of the truth and to carry out their own research, such as surveys in sociology or partial equilibrium models in economics.
- then come the tools. . .
- some tools are meant for economic activities which are related to *mass production* and therefore to *mass consumption*. LCA is clearly part of this, with its microeconomic approach centered on a single kind of product/service/functional unit with a (partially) global view of the total value chain as described by its life cycle. The basic reason why it makes sense to perform an LCA is that the subject of the study will be mass-produced/consumed and therefore that the effects of this production/consumption will add up significantly on a society-wide scale. Derivatives of LCA tools, such as LCC, LCM and SLCA, belong to the same category. The methods focus on producing quantitative indicators rather than on weaving a storyline. The main criticism of these tools, on principle, is that they do not provide any aggregation of their results, that their integration of temporalities is insufficient and that their connection to social sciences, from economics to sociology, is weak. They also focus on negative impacts and leave aside positive ones. An important practical criticism is that they rely on imperfect data, do not always provide an estimate of uncertainties or a parameter study, and sometimes focus on very small differences between scenarios that are neither significant nor particularly relevant. They also usually compare scenarios (through methods such as system expansion, allocation, partitioning), so that physical quantities are not always conserved (Lavoisier's law), something which makes the critical understanding of their conclusions difficult.

LCA has been internalized by policy-making as the Life Cycle Thinking approach.

Health assessment tools also belong to this category. They describe the danger or the innocuity of a consumer good. Mass production of health assessment statements has been made possible and compulsory by European regulations such as the IPP and REACH.

- other tools are meant *for big and unique events*. They include all the *Impact Assessment* tools which administrations require to use prior to formally authorizing some new activity or the building of some large structure (licence to operate, for

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example), which will affect the social context and the environment in a broad sense. They usually address all important issues, positive and negative ones, and use whatever method is necessary to do so: quantitative and qualitative approaches exist side by side. There is also no aggregation of the impact assessment studies. Last, although they are public, they are not usually published in the scientific community and thus are known by local stakeholders rather than by global ones.
- *global tools* are available to describe aggregated data, the best-known one being MFA and derived tools. They describe economic goods, often commodities, which are used to make consumption or investment goods but are not necessarily easily visible to the naked eye. Steel, for example, is ubiquitous in final goods, but usually hidden inside the good (as a structural material) or below its surface (which is coated or painted or somehow covered); steel is also the core component of the machines that are used to produce almost everything else. In addition to being hidden, these intermediary goods are usually recycled and thus constitute complex streams woven in space and time, sometimes for very long times.

Energy has the same "qualities" from this methodological standpoint as materials. MFA can in principle address energy issues as in *E-MFA*, for example, or methods based on more conventional physics such as Exergy Analysis. One of the classical difficulties is the issue of adding up different kind of energies, especially when the distinction between primary and secondary energy is made: arbitrary yield factors have to be used, a common feature with LCA approaches, which does not always clarify things: why would wind energy have a yield of 1, while nuclear and coal power plants have roughly 0.3? Similarly, is the distinction between renewables and non-renewables always relevant, beyond a strong stakeholder's political standpoint? Shouldn't the concept of carbon-lean energy be used more commonly instead?

- tools that use *complex enough concepts of time* are rare, except for future studies/prospective, where dealing with this methodological issue is clearly their core business. *dLCA* is presently in the making but no accepted methodology exists in this area yet [32–34]: as already pointed out, it can actually be argued that some propositions stray away from conventional LCA. See also *consequential LCA and prospective LCA.*
- *Social tools* are even fewer, mainly because sustainability issues have been developing as part of political science rather than social sciences. A strong input in this area will be necessary in the future and it is indeed an important part of the SOVAMAT Initiative, although the way to go is still widely open.
- at a more abstract level, although still in the political/regulatory area, sits the *Sustainability Assessment of Technologies.* We see it as an attempt to make sure that new technology does not contradict the goals of sustainable development, a *weaker vision* probably than the European Commission's. Its downside is that it could be viewed narrowly as a pass/non-pass criterion for a new technology, with only pure sustainable technologies meeting it - whatever this may mean: this would instrumentalize the conservative, *strong* view of the *precautionary principle.* It might also be the prelude to future ambitious regulation extending to new technologies similar to the approaches already implemented for products, i.e. in IPP and REACH. Beware of rebound effects!

A few last but very important remarks:

- some kind of sustainability analysis (SA) should be performed early, when new technologies are being introduced, in order to avoid unsubstantiated hype about anti-physical concepts, like the "CO_2 engines" that seem to have replaced water engines in the news, nowadays! But a subtle, reasonable, critical, complex enough and modest SA.
- on the other hand, product comparisons, where only small differences are exhibited, lying most of the time within the range of uncertainty due to the quality of

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the data, are mostly a waste of time, producing more debatable and commercial arguments than scientific facts.

8 Towards a New Metrics?

In our SOVAMAT approach, with ambitions to be both critical and pro-active, it would be paradoxical to propose a *New Metrics* that would replace LCA or MFA or anything else! This would negate our goal of accepting the complexity of the issues we raise.

Therefore, we do not think of proposing one single *New Metrics,* but rather a more complex, polymorphic approach that would extend the existing tools and adapt the answer to the question raised.

We will give some examples of how this ambition can be achieved, although the necessary research is still mostly under way.

8.1 Towards a new LCA

Let us take the example of a consumer product, like an automobile (cf. Sect. 3), and a functional unit made of 1 kg of steel used initially in that automobile and then further recycled, indefinitely, until it becomes dissipated in the environment. Of course, this FU, although formally compliant with ISO14040, is somewhat different from the spirit of the standard. Then, the assumption of indefinite recycling means that we shall introduce a time that is incommensurate with the life cycle time in that it extends linearly far into the future, maybe 120 years (10 times 12 years). During this long time, almost everything will change, for example technologies: driven by the need to control GHG emissions, they will achieve a mitigation target of 75% by 2050 and 100% by 2100 – clearly a scenario for the future, but one which is coherent with present international policy trends for the post-Kyoto period and beyond. This will apply to cars, into which steel is re-embodied in its metempsychosis due to recycling, to steel production, to energy generation, etc. The results have been worked out in a rough first attempt at developing a version of dynamic LCA or dLCA [32].

This we can call *a New Metrics approach to LCA,* related to all the steel components in a car. It retains the consumer product emphasis and the life cycle approach that are the key features of LCA, but projects a radically different picture of what a standard LCA does (i.e. 18 t_{CO_2}/t_{Steel} over the total life cycle vs. 32). Not least is the fact that the GWP, for example, is no longer one single figure, but a time series, the sum of which adds up to much less than the classical one.

A further step would consist of aggregating dLCA analyses in order to obtain a global image of the impact of a family of cars or of the whole automotive sector. The work on this subject remains mostly to be done, with some complexity due to the fact that there are different ways of doing it, depending on whether one looks at it in a diachronous (following the flow of cars in time) or a synchronous manner (describing all the cars that are used at a given time), the equivalent for the time coordinate of Bernoulli or Euler space coordinates in CFD [2,51].

Prior or in parallel to engaging in the development of dLCA, improvements are needed in LCA methodology as explained in Table 2.

8.2 Towards a new MFA

MFA also needs to progress further in the future, mostly in 4 directions:

- homogenize the practice of MFA, possibly by going through a standardization procedure like the one LCA went through very early in its history, when ISO 14040 was created;
- accumulate layers of annual MFAs – and probably complexify slightly the content of the data collection (see below, IO table), in order to make it possible and easy to calculate data related to recycling, such as recycling rates of materials and collection rates from the scrap stock. Many regulations have been issued, particularly at a European level[7], which require a specified level of recycling to be achieved, while there is no simple, accurate and unambiguous method for estimating these figures. MFA is the best available technology for doing this but does not do it

[7] WEEE Directive, and directives on waste from packaging and automobiles.

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Table 2. Guidelines for methodology improvements in LCA.

☑ simplify LCA methodology. . .	➨ streamlined LCA
☑ but introduce the required level of complexity	➨ e.g. water, country-specific inventories, second-tier impacts, etc.
☑ introduce time in a more complex way	➨ dLCA (dynamic LCA)
☑ show uncertainties of input & output data	➨ systematic uncertainty analysis
☑ systematically carry out parameterized studies	➨ parameterized LCA, sensitivity analysis
☑ introduce time dimension beyond cycle time	➨ dynamic LCA
☑ principle of reality model what really	➨ happens (e.g. avoid cut-off method)
☑ recycling, reuse	➨ introduce 3R practice into the modeling
☑ use physical system that verifies conservation laws	➨ physical FU, rather than system expansion
☑ introduce a scenario vision of the future	➨ consequential LCA, prospective LCA
☑ introduce positive indicators	➨ social LCA
☑ regionalize relevant impacts on the proper scale	➨ regionalized LCA

yet completely satisfactorily, because of a lack of MFA stock and flow map time series. Filling this gap is part of the creation of a *dynamic MFA*;

– extend MFA methodology beyond materials, e.g. towards energy, consumer goods, in fact any category that needs to be addressed from a global, geographical standpoint.

What we actually need from a materials standpoint beyond simple MFA is a matrix showing how materials are used in each economic sector, i.e. a material/product IO table. Creating time series, including foresight projections, would actually make it possible to answer most global questions relating to materials and the market and thus establish a link between a macro-level and a lower level, not quite at a micro-level but probably at a meso-level. The information could then be used in relation to the product focus of New Metrics LCA and of other methodological entries into the New Metrics approach.

8.3 Future studies and prospective visions

It would not be realistic to expect prospective studies to be conducted systematically as part of any New Metrics (NM) study: the expertise involved would be out of reach of NM practitioners. On the other hand, some reference work needs to be conducted that would provide the necessary background for this foresight vision: there are actually quite a few around already, for example for steel [35], the major structural materials [36] and for energy [37]. The IPCC work on Climate Change is another such example on a grander scale [38].

These long-term, macro-scale visions should be organized around some of the Grand Challenges that are facing mankind (demography, poverty, climate change, depletion of natural resources, etc.) and the major global issues, related to energy, materials, water, biodiversity, etc. At a modest level, the simple sketch of a dLCA methodology presented before was based on such a long-term vision of the Climate Change constraint.

8.4 Towards a Social Value formulation

The social value of materials (or of any major economic or social activity) also requires specific studies that would similarly feed smaller-scale studies.

In the case of steel, for example, one can imagine the following developments, presented here in a very rough and oversimplified manner:

– in terms of direct impact on employment, the steel industry accounts today for 422 000 jobs in the EU, while it indirectly supports 23 million jobs in related activities in its value chain [39,41]. The leverage is 1 to 55! One could add a 3rd level of job creation in public and other services (education, administrations, health services, cultural services, etc.), a rough estimate of which is 190 million people.

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– similarly, in terms of GDP, the total turnover of the EU steel industry is 187 G€ to be compared with a total GDP of the EU in PPP of 12 260 G€, i.e. 1.5%. With the strong but not untrue assumption that most of the GDG is related to steel[8] (cf. Fig. 1, a GDP per capita gap of 25 000 $ between a pre-steel country and Europe), i.e. 8440 G€. The leverage then becomes 45, somewhat similar to that on employment.
– Second-order effects, such as those meant by *inclusive business*, might also be evaluated quantitatively but can certainly be exposed qualitatively, as a storyline.

8.5 Ecosystems?

The ultimate theoretical framework in which the New Metrics would strive is a kind of general model of ecological systems – and, ultimately, of society as a whole in an even more utopian vision. The model would be scientific, broad, far-ranging and dynamic.

The knowledge base that would be needed to address such an agenda and which would encompass no less than the fields of physics and biology in systems where both interplay through the biosphere and the technosphere is still not here of course. But local models focusing on some well-identified particular problem are not out of reach and, in truth, impact indicators used in LCA have been modeled in this manner. An excellent example applied to the water issue was thus presented by M. Margni during the 3rd Society & Materials seminar [40].

The point we are making here is that this approach goes beyond the scope of traditional LCA, as the complexity of ecosystems goes beyond simple indicators. A good example of a re-examination of a metrics is given by the work carried out for the IPCC to develop new metrics for describing Climate Change [23]. Note though that the outcome of this work is meant for climatologists and that the LCA community will need to do its own shopping among the materials produced on this occasion.

8.6 New Metrics summary

What we have been calling New Metrics is a multipoint entry methodology that would bring together existing approaches, develop them further and be able to answer various questions relative to the sustainability of a material, a product, an activity, with a long view.

If an analogy is drawn with economics, what is advocated with SOVAMAT is a macroscopic approach to complement the microscopic one of LCA with a better integration of time, both multidimensional and long. MFA goes part of this way and future studies/prospective/foresight do as well. The New Metrics should organize these various approaches and lead them toward a clear and practical tool, or, rather, a set of complementary tools.

A scheme of the approach is shown in Figure 2.

9 Conclusions

The SOVAMAT Initiative was initially imagined as a large program that would be included as a whole in the EU's 7th FP program.

It is supported by several European Technology Platforms (ETP), including the Steel Platform, ESTEP [41], the Forest-based Sector Technology Platform [42], EUMAT [43], SusChem [44] and by about 80 partners from academia and business. Basic research in the fields of economics, sociology, LCA, MFA and ecodesign is represented in the group of people who framed the agenda of the Initiative, with participants from Europe, the US, Canada and Japan. In the business community, many materials are on board, mainly structural materials: steel,

[8] The connection is not one of causality, of course: steel itself cannot be claimed as being directly responsible for this large part of GDP. Taking all materials on board would be closer to the truth but would still remain short of it. It would therefore be clearer to speak of *anti-causality*, to mean that without steel, then, very probably, this increase in GDP would simply not have taken place. This is admittedly a fairly strong statement, one that almost belongs to *uchroniae*, stories similar to *utopiae* but that draw pictures of what the world would be if some key event of our world had been absent.

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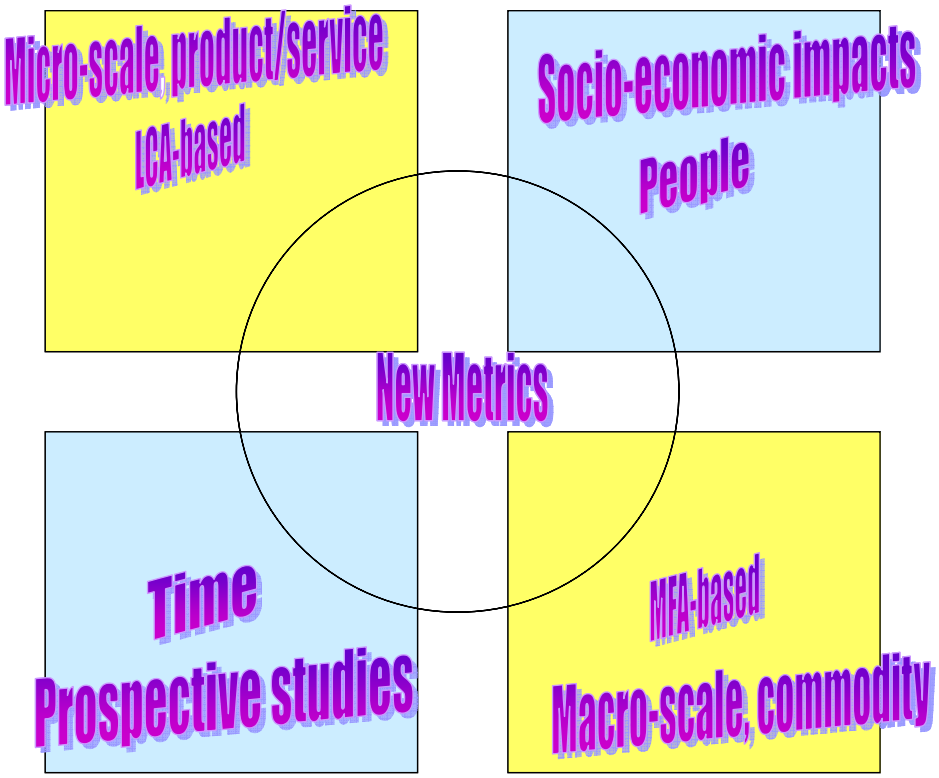


Fig. 2. Scheme of the New Metrics construction.

non-ferrous metals, especially aluminum, cement, glass, paper and cardboard, wood and fiber composites.

After 6 large meetings bringing together all the partners mentioned above and dedicated to framing up an ambitious proposal, it became clear that the European Commission was not prepared to issue a Call for proposals broad and transversal enough to allow such a bottom-up program to be at the core of a proposal, even though it was strongly supported both by industry and academia.

Rather than giving up, a strategy to keep moving forward was reformulated on the basis of smaller, more local projects and of regular seminars which would bring partners together to share their advances independently of financing opportunities.

The core of this new organization is structured around the Society and Materials Seminars (SAM), which have already met 5 times annually in Seville [45], Nantes [46], Freiberg [4,15], Nancy [47] and Metz [48] invited by research organizations and universities (IPTS-JRC, Ecole des Mines de Nantes, Technische Universität Freibergs) and sponsored by businesses and ETPs (ArcelorMittal, ESTEP, Corus, ThyssenKrupp Stahl, Worldsteel). Programs and, eventually, all the proceedings, are or will be posted on the SOVAMAT website [3]. The list of SOVAMAT partners can also be consulted there, as they are, more or less, identical to the participants in the seminars. Note that existing programs/groups such as the UNEP LC Initiative, CALCAS [49] and CIRAIG [50] report regularly in these meetings.

A 6th SAM seminar (SAM-6) is scheduled for 30–31 May 2012, in Leuven.

The SOVAMAT Initiative is therefore very much alive!

The present status of the Initiative consists mostly of work focused on improving existing methodologies, where much effort is still needed. The convergence of the various methodologies towards a *New Metrics* is also taking shape and a direction for doing this has been proposed in the present paper and in former ones [2,51]. Other proposals are also on the bench (M-LCA, [52]).

A weakness of our Initiative, today, is the limited participation of social scientists,

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which mirrors a difficulty also met by LCA methodologists in attracting these disciplines in the development of SLCA. Input is needed from sociologists, anthropologists, cultural anthropologists, ethnographers, geographers, historians, historians of science and historians of technology, economists, eco-critics [53], etc.

A major challenge to our Initiative, but also to already existing methodologies, is the need for very large amounts of statistical data, which are not necessarily available anywhere because they simply are not collected! Some may be inferred from existing information by data reconciliation, estimated through modeling or collected through specific surveys. More can be obtained thanks to new technologies, such as RFDI, and through the pressure of new laws and regulations. But, finally, some may be completely out of reach, a limitation due in last resort to the level of complexity involved, which may eventually force us collectively to trim down some of the ambitions of our and others' initiatives.

Last and very importantly, data depositories should be created in a way that makes them widely available and transparent. As a kind of public service, for example.

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