Beyond Life-Cycle Thinking: the SOVAMAT initiative and the SAM seminars

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ABSTRACT

Life Cycle Thinking (LCT) is a popular concept in the EU. Derived from LCA methodology, it is being used as a tool to regulate business and consumption from Brussels. It has done much to enforce a transverse approach that cuts across business boundaries and unifies the players of the value chain of products and services. LCT shows signs of breathlessness, though, and is faced with inadequacies and difficulties, which strain the rationale on which it is based and calls for a re-construction of the concept along wider and broader lines: time needs to be better taken on board, the time of prospective and consequential LCA for example, the functional unit should probably try to imitate the closed systems familiar to physicists who carry out energy and mass balances, while a more macro-economic description of human activities, such as that performed by MFA for example, should complement the micro-level description of conventional LCA. Moreover, societal issues should be addressed more directly than social LCA is attempting to do. This is an agenda for a radical re-construction of a "New Metrics" which would extend further the conceptual revolution that LCA had brought about. This innovative approach is embedded in an initiative called SOVAMAT (SOcial VAlue of MATerials), which plans to develop this New Metrics initially in the context of materials. The initiative is structured around several research activities and an annual meeting in a series of seminars called Society and Materials (SAM).

SUSTAINABILITY AND SUSTAINABLE DEVELOPMENT

There is probably no simple answer to the question of what came first, theory or practice? Except for mathematics and perhaps also technology, the answer is almost always practice. This is particularly true of Sustainability, a concept that was theorized in 1987 in the Brundtland report, but which captures an age-old relationship between mankind and nature: reread Genesis, for example, where are set the rules for the Garden of Eden, a metaphor of our planet Earth.

Like many strong political concepts, the Brundtland vision, which was strongly anchored in what is now called intergenerational equity, has been adopted by numerous stakeholders and, in the process, each of them has added to the complexity of the analysis that now defines sustainability[1]. This is enough to write books about this and their content will depend on the philosophical, political or epistemological flavor that the author will favor.

Economists have struggled with the issue of internalizing the environment in their analysis, which had been considered as an externality by the neoclassicists [1]. Business has published annual environmental reports and now moved on to social responsibility reporting. From their regal perspective, Regulators have used the concept to protect the environment, which they see as threatened by human activities. NGOs have done the same, but from a different standpoint, acting as spokesmen for the planet or for the future of mankind.

Various tools have been developed to provide a quantitative vision of sustainability. Then new disciplines have emerged around the use of some of these tools. Life Cycle Analysis (LCA), Substance Flow Analysis (SFA), Materials Flow Analysis (MFA) have thus grown as disciplines out of popular tools, i.e. of applied methodologies. They have developed within groups of scientist who call themselves a community. These communities are populated by scientists of various origins: each of them has specific players and a specific audience.

The MFA Community, for example, is close to Industrial Ecology, Geography and Geopolitics: it looks at broad, macro subjects and systems, stretching over space and time. The LCA Community is populated by Engineers and Technologists, as it is interested in consumer

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[1] e.g.: the Rio Summit, Global Compact, the Earth Charter, Agenda 21, the Human Development Index (HDI) of UNDP, the Environmental Sustainability Index (ESI), the Environmental Performance Index (EPI) reported under the World Economic Forum(WEF), the Genuine Progress Index (GPI)), regional organizations' indices (e.g. EU Sustainable Development Strategy (SDS))

products and in manufacturing. Bridges between the two approaches are few. Economists do not mingle too much with either of them, although they may feel closer to the MFA Community and contribute to their toolbox with methods such as Leontiev matrices. Ecodesign, a discipline which tries to extend Design beyond utilitarianism and pure business economy, feels closer to the LCA Community, although it goes along its own routes. NGOs do no embrace any specific methodology but use each as they see fit.

It is interesting to notice that Regulators, especially in Europe, had been looking for tools that could help them frame their environmental policies and support them. Since they regulate industry and consumers, LCA has stood out as the most useful tool for them. Indeed, it provides the language and the numbers to police both industry and consumers. LCA has thus branched off from being a tool used to measure some aspects of sustainability into becoming a more generic methodology that has been supported by the European Commission.

In the process, LCA has grown in ambition and become *Life Cycle Thinking,* which is now presented as a universal tool to quantify the burden set by economic activities on the environment. In parallel, Sustainability has moved from being a quality, which applies to a whole economy, to one that each activity in this economy, be it small or big, ought to demonstrate: products and services should be sustainable, but also technologies, intermediary goods, such as materials and the handling of public goods such as air, water, soil, etc: from holistic, the concept has become focused and rather narrow. This has also put the lid on the social or societal dimension of sustainability and pushed its economic dimension into a corner.

MERITS AND DEMERITS OF LIFE CYCLE THINKING

The merits of the life cycle approach are twofold:

• the method cuts across business boundaries and follows a product or a service as it moves from material production, to manufacturing, to the use phase by a consumer and then is discarded at the end of life. The focus on this so-called functional unit (FU) has made this possible, because this FU travels in turn through these various realms.

• the methodology takes time into account at least the linear time of a life-cycle, from cradle to grave, or from well to wheel, or whatever applies to the particular FU being investigated.

This has amounted to exploding organizational and time boundaries. It has been a shift of paradigm as far as sustainability analysis is concerned as well as a positive disruption in the way that economic players had interacted and dealt with each other in the value chain of producing a product.

On the other hand, LCA has limitations and blind spots, which can lead to rebound effects, and sometimes to perverse ones. Here are some criticisms of the method:

• the FU is similar to the close systems that are used in thermodynamics or chemical engineering to calculate energy and mass balances, but some special features such as system extension, burden allocation and the cut off method bring it into the world of scenario simulations, where mass and energy is no longer conserved. It makes it easy to compare various strategies and solution paths, which is very positive, but the loss of the physical connection to conservation laws can lead to strange or paradoxical conclusions [2]. The mixed status of LCA, standing in-between physics and management science, has led the method to being governed by a standard, the famous ISO 1440 series, rather than by a theory that would have been acknowledged for its logical and scientific consistency.

• time is only taken on board in LCA to a limited extent. Of course the time of the life-time is there, but time has more than this one dimension:

- there is the *cycle time of recycling,* which can happen once or several times, again and again. Taking recycling into account is possible in the present status of LCA (i.e. recycling is ISO-compliant), but using it or not is left to the discretion of the LCA practioners: they can leave it aside, which means that their analysis does not have to comply with a reality principle, as physics does. This also can lead to broadly different estimates of impacts, differing sometimes by a factor 2 or more! [3]

- there is *historical time,* past or future time, the time of history or the time of prospective, which will change the impacts. The same historical time will change the context in which the analysis is carried out: technologies change; breakthroughs are introduced; materials, chemical and fuel change because they become scarce or too expensive or are replaced by more alluring ones such as biofuels or hydrogen; society changes and its demand evolves. Threats and challenges arise and come to dominate the political and societal scenes, such as climate change in recent years. These changes may not take place during the life of a simple consumer product, but when recycling becomes an issue, when long-life products are under discussion, then the materials of which they are made go down the timeline and are witnesses to such historical and prospective changes.

- some of this is taken into account in *consequential LCA*, but not all of it, as a *prospective LCA* would have to be further developed.

• LCAs are complex and based on very large amounts of data, the quality of which is often debatable. It is common place to find studies carried out on the same products, which lead to opposite conclusions because the databases used are not identical [4].

- conventional LCA is fully focused on environmental issues and on analyzing human activities as casting a shadow on the environment, of causing negative impacts. When the LCA tool is used exclusively, then societal issues are not given their true weight. The positive side of things is overlooked.

TOWARDS A NEW GENERATION OF SUSTAINABILITY TOOLS

Our experience with LCA at ArcelorMittal has led us to lead an initiative to work on overcoming these difficulties and to move on to a new generation of sustainability tools, which we have called the New Sustainability Metrics.

The initiative is called SOVAMAT, an acronym standing for SOcial VAlue of MATerials, and it brings together players from the materials industry (ferrous and non-ferrous metals, glass, paper and cardboard, wood, cement, plastics), academia and research institutes from Europe, Asia and America [5]. The initiative is trying to obtain financial support to carry out its research agenda from regional and national research programs, such as the 7th Framework RTD pro-gram in the EU but is also progressing on its own momentum [6].

The SOVAMAT Community meets once a year in regular seminars called Society and Materials, where experts from the fields of Sociology, History of Sciences and Technology, Economics, Foresight Studies, Materials Sciences, LCA, LCIA, Toxicology, Eco-toxicology, MFA and Ecodesign confront their approaches and look for synergies: 5 such seminars have been organized and 3 of them have been formalized [7,8,9]. The proceedings are available on the SOVAMAT website.

We would like to explain here some of the directions in which we are working to meet the overall objectives of the SOVAMAT initiative.

We will discuss three areas specifically: the various dimensions of time, which help explain why the MFA and LCA Communities sometimes seem to describe a different reality; an agenda and an example for developing a dynamic LCA, which ends up being probably also a dynamics MFA; and directions in which to look for the "New Metrics".

VARIOUS TIME DIMENSIONS

The idea that there are several dimensions to time is rather common in social sciences but may seem paradoxical to physicists, unless they are working on String Theory [10]! Duby and Foucault have thus spoken of the time of the Church or that of the merchants in famous books [11,12]. Physics is familiar with introducing time in its analysis of the physical world and the exercise is usually called dynamics as opposed to statics.

In the case of sustainability analysis, the role of time is more difficult to analyze in all of its complexity. Figure 1 and Figure 2 make an attempt at grasping the viewpoints that are relevant in sustainability analysis.

Calendar time is the physical time that is obvious to every one.

MFA or SFA make synchronic cuts of reality at a constant time, typically one calendar year, and describe the flow of a material or a substance during this localized time frame: the MFA of iron and steel in 2007, for example.

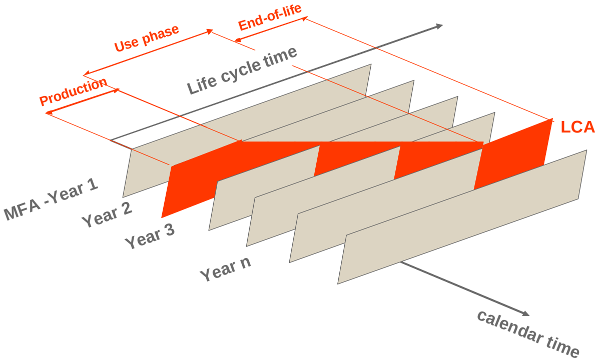


Fig. 1 calendar time and life cycle time

An LCA will be interested in the whole life cycle of a product and cut diachronically across calendar time, with a production phase and a end-of-life phase, which are well pinpointed in time and a use phase that can stretch for short or long periods depending on the kind of product that is the subject of the analysis: a steel can will be used within one year, an auto-mobile for 10 to 12 years and a building for 60 years, for example.

Note also that cars will be built every year, for several years for a given model, that new technologies will be introduced including, most probably, breakthrough technologies in the longer terms, such a electric of fuel cell cars. There is a *fleet effect*, which is typically a dynamical effect [13]; the change in society's expectation towards the car environmental footprint as well as the likely future

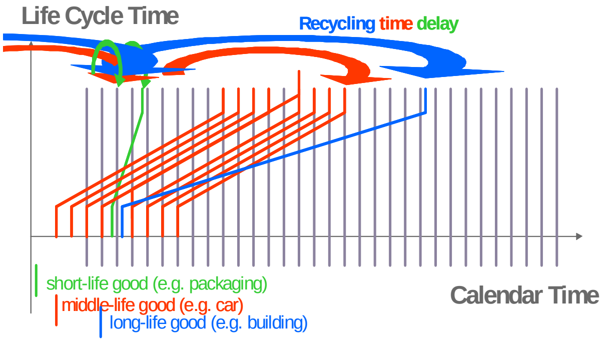


Fig. 2 calendar time, life cycle time and recycling time + fleet effect (the representation is similar to that of the previous figure, except that calendar and life cycle times are now shown as an orthogonal system; grey vertical lines are annual sections; LCA trajectories are shown for short lived (green), middle lived (red) and long-lived (blue) systems; the large arrows at the top show recycling streams).

changes in transportation technologies are other, more subtly different time effects.

The time of MFA and that of LCA are thus quite different. This is a non issue in the case of cans, but a serious one when a long-lived building is concerned and it raises many methodological questions: the building will probably be refurbished several times over 60 years; its uses will change and its energy performance will also change with changing attitudes towards energy conservation and GHG emissions.

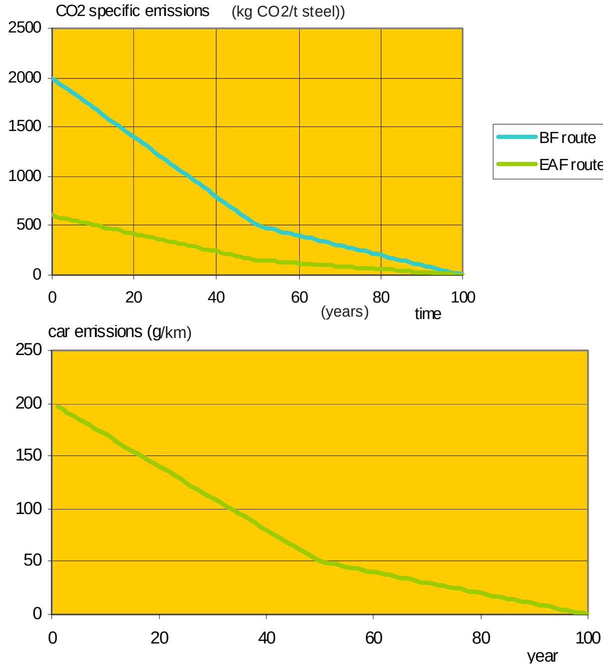


Fig. 3 for the evolution of Climate Change technologies (steel and automobiles). BF: Blast Furnace; EAF: Electric Arc Furnace)

Material stakeholders are also interested in recycling. Recycling does not exactly belong to MFA or LCA time. Figure 2 tries to give a hint to what recycling represents in terms of time: the material that is recycled comes back to the material market, as steel scrap for example, after the product has outlived its use phase, which can be short or long (*p* years) as already pointed out. Recycling reshuffled the time cards in bringing back at time *n* materials that were actually produced at time *n-p*. The definition of the recycling rate has to take this complexity into a account and to compare the streams of materials made available at time n to that produced at time n-p; simple as this may sound, it requires models to calculate the recycling rate and much confusion exists in the literature between recycling rate, collecting rate, recycled content, etc. which are all different concepts and consequently have different values [14].

MFA, if it extends far enough along the timeline, collects the data necessary to calculate a proper collecting rate – which however does not come naturally with the method. LCA can also take recycling on board, but this is optional!

There are more subtleties to the dimensions of time that sustainability has to encompass, but they will be better analyzed in developing and example of dynamic LCA or dLCA. We use the expression dynamic LCA to mean a time-dependant LCA, with time exhibiting all the flavors already outlined in the previous discussion.

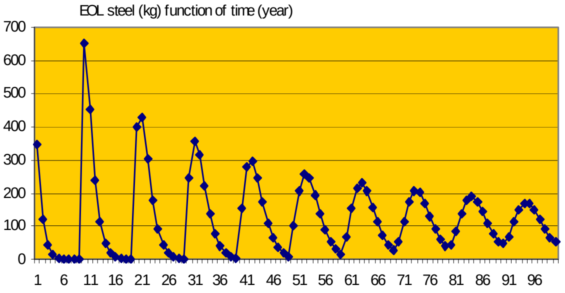


Fig. 4 time evolution of the generation of scrap (PC collecting rate: 0.95)

dLCA: A ROADMAP?

Let us start from the metaphor of a river. The flow of water can be described by fluid dynamics. The river has a geographical extension as well as a time extension: during droughts the flow is low and it is high at times of floods, which are related to seasonal cycles; the river was also already flowing in the Middle Age and was then quite different from today's, as it will be different in the future if climate change gets worse. Etc. One can look at the river from the perspective of a city through which it flows (Eulerian description) or from a boat that is carried downstream by the current (Lagrangian description). This is an analogy of what a dLCA ought to be.

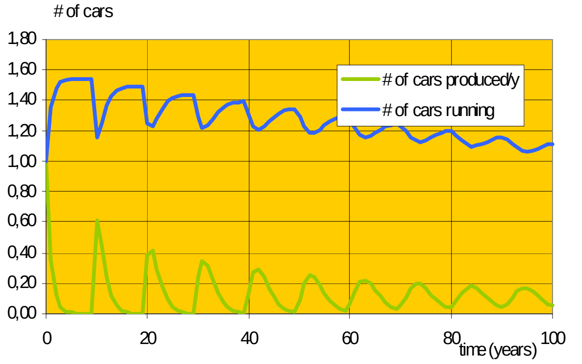


Fig. 5 evolution of the introduction of new cars on the market from the initial 1 t of steel

A simple example has been worked out. It describes the LCI of one t of steel used initially to make an automobile and recycled over and over again to make more cars until the material is fully dissipated in the environment. Only one impact is shown, the Greenhouse Warming Potential (GWP). The viewpoint is Lagrangian and the fleet effect is not taken into account: the initial ton of steel is produced today and not re-initialized every year for several years.

Four kinds of time are introduced in the model:

- the time of the car life-cycle: 10 years, 150,000 km
- the time of indefinite recycling: the recycling rate is 100% for pre-consumer (pC) scrap and 95% for post-consumer (PC) scrap
- the time of historical change: an F4 (factor 4) scenario is supposed to be achieved by 2050 and a zero emission scenario by 2100
- the time of the environmental impact: 100 years GWP (cf. Figure 3)

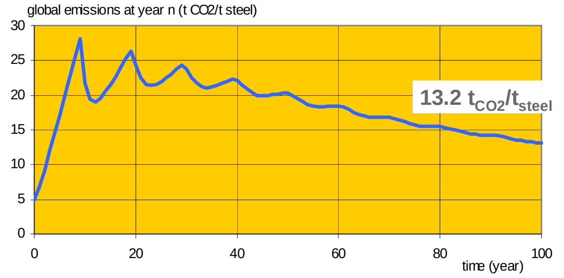


Fig. 6 evolution of the introduction of new cars on the market from the initial 1 t of steel

The dLCA model first calculates the amount of scrap recycled each year (Figure 4): at year 1, pre-consumer scrap is generated, while it takes 10 years till the end of life to generate the post-consumer scrap. "Fractional" cars are produced from this scrap according to these same rules and thus generate the cyclic but decaying curves shown on the figure. The number of cars is shown in the next figure: it decreases on an annual basis, but the number of car still running decays much more slowly, because of the high – but realistic - recycling rate chosen in this example (95% collecting rate of PC scrap).

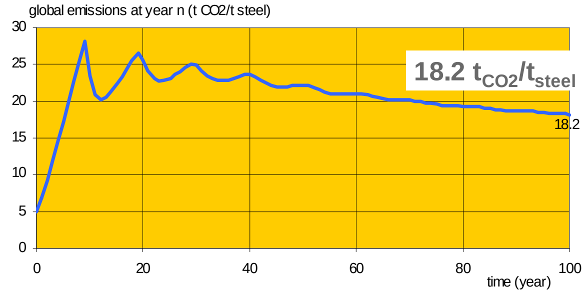


Fig. 7 cumulated specific CO_2 emissions per initial ton of steel (PC scrap collecting rate: 0.80)

The global cumulated CO_2 emissions are shown in Figure 6 for this same collecting rate.

One may notice that a new and maybe unusual feature: the emissions are time-dependant and they reach a maximum and then decay and tend to a value of 13.2 t/t of steel – to be compared to 32 t/t of steel which would be the standard result in a classical static LCA (sLCA).

The dLCA value if less than half of the sLCA, which results from the dynamic nature of the simulation and is actually due to the various time dimensions introduced in the model, as all of them concur in lowering the traditional value.

Figure 7 introduces a different value of the recycling rate in order to test the sensitivity of the model to this parameter. As expected, the overall asymptotic emissions are higher than in the previous case and the decay takes place more quickly.

This rather simple simulation of what a dynamic LCA might turn out to be shows both that the method introduces new layers of complexity in Life Cycle methodology, but also at the same time that the figures from conventional LCA should be handled with even more care than previously realized.

Moreover, the results should be analyzed further to weigh the individual effect due to the various time dimensions and to estimate how they would vary if a fleet effect was introduced or an Eulerian description – which would become closer to an MFA than an LCA description.

Last and not least, our simple model that states that steel from a car is recycled into steel in a new car is not showing the true nature of steel recycling: scrap is a true secondary raw material, with no predetermination of how it will be reused and, in the real world, a car can become a can and a can a high speed train, as an Arcelor advertising campaign used to claim humorously! This requires re-examining the definition of the functional unit and dropping the reference to the car: we are then in the rationale of an MFA and no longer of an LCA.

The work is thus still very much in progress…

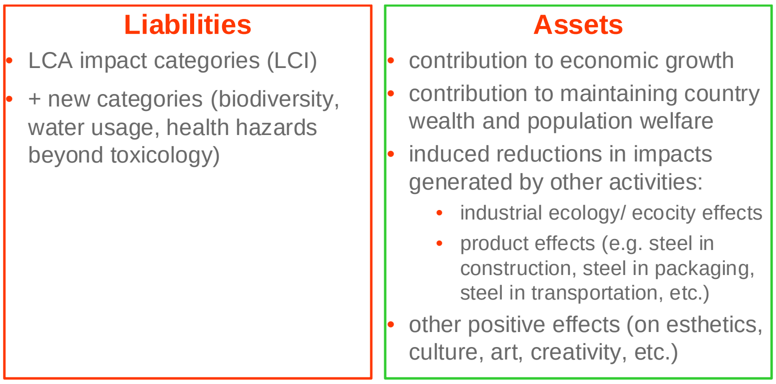
TOWARDS A "NEW METRICS"…

This is even truer of the Sustainability "New Metrics".

The idea of the New Metrics is to move away from the monolithic description of human activities provided by one single method, LCA for example, and to introduce the necessary level of complexity that gives credit to a principle of reality: decision making, at the policy making level of governments or at the strategic level of a firm, has to pragmatically balance pros and cons, synchronic and diachronic approaches, micro and macro levels of analysis, qualitative and quantitative descriptions, etc. This cannot be achieved satisfactorily by introducing global integrated indicators, such as practiced in LCIA, as they over-simplify things.

LCT is based on a black and white vision of the world: it lists the environmental burdens that human activities generate. Add a level of management or political science, and burdens become liabilities, clearly on the "bad guy" side of things. Action, in this kind of analysis, brings burdens and liabilities: should this mean that inaction is best!?

Economic growth - and the better life it brings about - tells the story differently: for example, transportation generates CO_2 and uses energy resources but it also bring people and goods and raw materials together, makes education, industry, the whole economy possible! There is an asset side to human activities! This is rather obvious, although the weight given to LCT something seems to indicate otherwise.



Liabilities

- LCA impact categories (LCI)
- + new categories (biodiversity, water usage, health hazards beyond toxicology)

Assets

- contribution to economic growth
- contribution to maintaining country wealth and population welfare
- induced reductions in impacts generated by other activities:
  - industrial ecology/ ecocity effects
  - product effects (e.g. steel in construction, steel in packaging, steel in transportation, etc.)
- other positive effects (on esthetics, culture, art, creativity, etc.)

Fig. 8 BSA sustainability New Metrics showing the assets and liabilities of steel

As a way to giving an example of how to manage this complexity, use the best of the existing methods and weave them into a new, more powerful and balanced one we propose here what we call a Balance Sheet Approach (BSA) to this New Metrics. This is not necessarily what it will end up being when the development has been carried out to its conclusion, just food for thought.

The analogy is to a balance sheet, with its assets and liabilities (cf. Figure 8). The liabilities are the classical impact categories, as proposed by LCA, but they should also be extended beyond the present status of that methodology, i.e. incorporate more sophisticated models than simple indicators. The assets are the positive aspects of the activity: its contribution to economic growth, to a country's wealth and to its people's welfare, to the conservation and creation of jobs, to synergetic effects with other activities (sometimes called industrial ecology), etc.

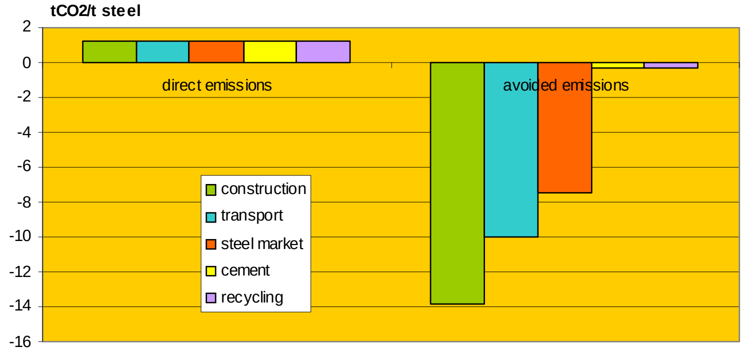


Fig. 9 BSA sustainability New Metrics BSA sustainability New Metrics example, where direct emissions due to the production phase are compared to the avoided emissions in the use phase, to the use of by-products (BF slag) In other industries (cement) and to recycling.

This type of comparison will require indicators, quantitative models and also simple storylines woven together in a kind of text. The balance between the two sides will not necessarily be a perfect equilibrium: some activities will have a positive and others a negative overall effect so that the balance sheet analogy stops there.

We have worked out an example, clearly oversimplified, of how to proceed. It is proposing the balance sheet of steel and focusing for the sake of simplicity on CO_2 emission: producing steel generates GHG but using it in investment or consumer goods reduces them compared to a "no steel" scenario. Slags are sold to the cement industry as clinker substitute and thus help cut overall emissions further. New steels with advanced properties & new steel solutions replace more ordinary steels in selected but major markets.

Figure 9 shows an example of how this can be presented: n the left hand side, the liabilities due to steel production; on the right hand side the assets, i.e. the amount of avoided CO_2 compared to a “no steel” scenario. The bottom line of that story is that a material such as steel solves more problems than it creates, as seen through this particular lens. Of course the problems are not suppressed and still have to be solved. In even simpler terms, it means that the use phase of a product carries a heavier burden than the production phase.

From the “New metrics” point of view, this is only a simple example. The choice of showing avoided CO_2 may not be the best: these emissions do not add up with the ones on the liability side and the conservation laws are not satisfied here.

The example has been worked out further in Figure 10. We have tried there to show together quantitative indicators along with qualitative ones (i.e. in this case showing only two values). The spider web presentation also helps to avoid coming up with a single overall indicator that adds positive and negative contributions, but it has forced us to normalize the various indicators to some arbitrary index. This also is too simplistic yet.

CONCLUSIONS

The world definitely needs a better set of tools to evaluate human activities, especially for the benefit of regulators, who are strongly focused on environmental issues but need to integrate the rest of the picture into their approach.

Life Cycle Thinking has been

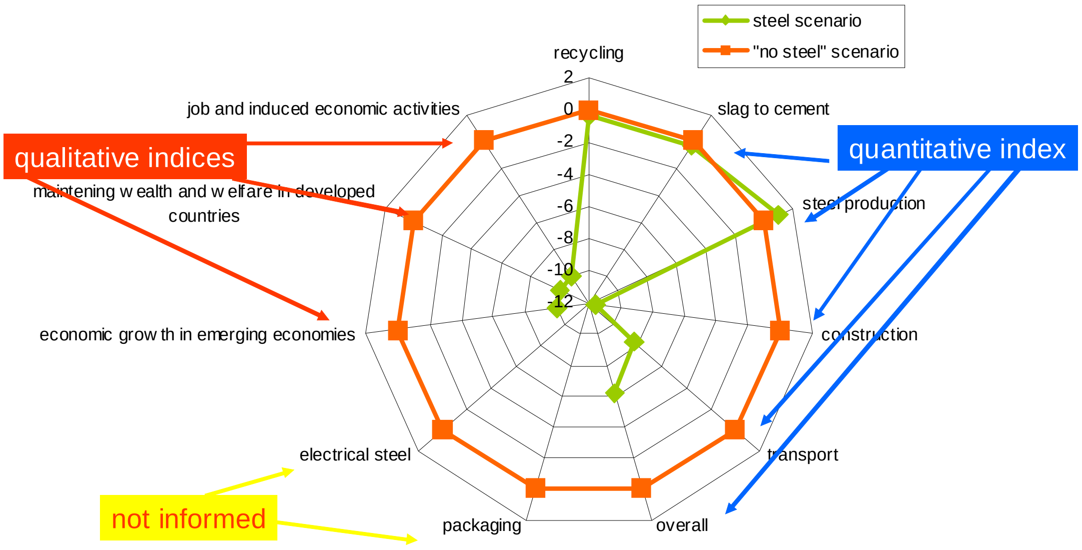


Fig. 10 BSA sustainability New Metrics example: quantitative and qualitative indicators are shown in a spider web diagram. A normalized index is shown along the radius.

a useful tool in broadening the area of analysis, but, somehow, has stopped half-way in carrying out its agenda of re-evaluating the conceptual construct at the disposal of government agencies.

The solution is most probably a more open, probably somewhat more complex and changing tool that takes on board the assets and not only the liabilities of human activities, what we called their Social Value in the SOVAMAT initiative.

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