Life Cycle Sustainability Assessment: some reflections on the state of the art and research challenges, with focus on technologies

Position Paper

Sustainability Assessment of Technologies

The term Sustainability Assessment of Technologies (SAT) is used to define a comprehensive approach aimed at evaluating the sustainability (environmental, economic and social aspects) of future and existing technologies. Over the past decades many different approaches and methods have been developed for assessing the different aspects of sustainability: tools for environmental assessments, tools for economic modelling and assessments, approaches for sociological analysis, approaches for integrated assessments, methods and tools for futures studies, and participatory approaches. Each of these models and tools has its own strengths and weaknesses; nevertheless, none of them is able to cover all the complexities of the problem. An interdisciplinary and multidimensional approach is required to deal with multiple effects in different domains, forecasting of system behaviour and technology evolution, normative choices, uncertainties and risks, etc.

The complexity of SAT is showed also by the definition itself, which refers to two big issues: *Technologies* and *Sustainability*, and in principle each of these elements would require a very complex treatment of its foundations and characteristics.

Technologies are characterised by very high variability (different types, development levels, effects and impacts on sectors, territories, markets, etc). The most recent and updated development theories consider the technology completely “endogenous” to the economy and the society. The relation with sustainability is twofold: technology can be considered both a cause of many environmental problems and a key to solve them. Today the technology is considered the main agent of the present industrial, economical and social evolution and the main cause of the high speed of the present changes. As the Lisbon strategy said, the development of knowledge and of technological innovation is one of the main objectives of the European policies. Many theories and models have been developed in order to analyse, describe and support the penetration and diffusion of the technologies, considering barriers, drivers, agents, epidemiological effects, different backgrounds and effects on interested sectors, territories, etc.

The concepts of ***sustainability*** and sustainable development are very controversial and disputed at scientific and social level. Indeed, the sustainable development cannot be simply considered a goal, rather a social process where shared sustainability principles are considered as starting point for assessing decisions through an interactive learning process.

A third element can be added, the ***decisions*** based on the results of a sustainability assessment. They have different nature and are assumed on the basis of different metrics, methods and processes, depending on the subjects and stakeholders involved and their culture, the purposes, the related time and space, etc. Their multifaceted aspects need to be considered in the process together with the more scientific ones: all together define the multidimensional aspect of SAT, highlighting the need to adopt a multidisciplinary approach able to deal with complex interrelationship and feedbacks among the different variables.

Why do we speak about SAT? The European framework

The need for methods and tools to deal with present and future potential environmental, economic, and social impacts in a life-cycle perspective, has been expressed by several public and industrial stakeholders, including EU Technology Platforms. Its real implementation has become a priority in political agendas. From the European political and strategic perspective, the reference framework is represented by the EU Lisbon strategy, which identifies economic, social and environmental aspects as key elements to foster growth in Europe. The availability of environmental technologies in this context can be relevant, because they can support the development of new products, processes and services with a lower environmental impact than the existing alternatives. Within this framework, in 2004 the Commission adopted the Environmental Technologies Action plan (ETAP), aimed to further environmental technologies as to improve the environment and European competitiveness. Environmental technologies are technologies designed to prevent or reduce the environmental impacts, at any stage of the life cycle of products and activities: "[…], are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substitutes."
ETAP is considered a bridge between the EU Sustainable Development (SD) strategy and the Lisbon agenda. A full implementation of the SD strategy, and thus the shift from environmental to sustainable technologies, implies the availability of methods and models to evaluate the environmental, economic and social aspects, an aspect that represents a real challenge for the scientific community. For this reason, the Directorate Environment of DG Research – Environmental Technologies and Pollution Prevention Unit organised a Workshop on SAT in Brussels on 24-25 April and 14 June 2007. The necessity and feasibility of a SAT method in a life cycle perspective was discussed, also considering the willingness of the EC to launch a dedicated call in the 7FP. During the workshop, it has also been stressed by the EC that "a fundamental step to achieve ETAP objectives might consist in the definition of a harmonised method for the Sustainability Assessment of Technologies. […] To avoid potential shift of burdens, Life Cycle Thinking has to become the standard methodological framework for all Sustainable Development discussions and Life Cycle Assessment could represent a useful operative tool in several cases" (EC, 2007). It is apparent that the life cycle approach plays a fundamental role in the definition of a SAT methodology: the challenge is to develop a method comprehensive enough to allow the evaluation of such an integrating concept, which cuts across different domains, environmental, economical and social and across time and space.

Approaches to SAT: lessons from the past

SAT has its roots in the framework of Technology Assessment (TA), whose first experience is dated in 1972 when in the USA the Office of Technology Assessment – OTA has been established. This was an office of the United States Congress with the purpose to provide Congressional members and committees with "objective and authoritative analysis of complex scientific and technical issues". OTA was active for 24 years, during which delivered about 750 studies on a wide range of topics. Nevertheless, it was abolished by the Congress in 1995, with the motivation that the reports delivered were not effective for the decisional process, as they analysed the present status of a technology without forecasting possible alternative future scenarios.
After that, several other countries tried to follow the American experience in a more effective way. With reference to the environmental aspects, the Environmental Technology Assessment (EnTA) was defined. It is a methodology aimed to support stakeholders, at the scoping stage, in making

informed choices about technologies that are compatible with sustainable development goals. Nevertheless, this approach addresses only environmental aspects, neglecting the relevance of economic social ones.
Besides the short story of TA, several approaches can be identified in the scientific literature. As already mentioned, there is a large amount of methods and tools, but in essence there is no method, framework or approach that encompasses, in a combined and consistent way, all the various aspects needed for a sustainability assessment of technologies:

- how to consistently combine methods to assess economic, environmental and social aspects, in relation to material and energy flows associated with the technology and with each other in a life-cycle perspective;
- how to estimate the market opportunities for the technology in the future;
- how to address the volume and physical constraints aspects, i.e. how the material and energy flows and the associated impacts will change when the technology is implemented on large scale and what physical constraints exist for e.g. natural resources;
- how to account for future changing structures of the economy, changes introduced by the technology itself or by developments outside the technology scope;
- how to involve stakeholders in the necessary consultation and learning processes, to understand the drivers and barriers to technological and societal change, to gain acceptance and legitimacy for new technologies.

An answer to all these questions will require several efforts to the scientific community: presently, the most encompassing solution is represented by the life cycle approach. In the last years, there was an increased awareness of the importance of the life cycle approach (and the standardised method Life Cycle Assessment – LCA) as a way to face the challenges posed by sustainability questions. Indeed, its system approach, which avoids the environmental burdens-shifting, makes it suitable for evaluations in which it is important to look at the whole picture of the problem. This awareness is turning into a real striking effect at EU-policies level: LCA is a central theme of the recent Sustainable Consumption and Production Action Plan, as it was in the Eco-Design (EuP) Directive, the Waste Framework Directive, and the Environmental Technologies Action Plan (ETAP). Besides, in the Integrated Product Policy Communication, the Commission stated that currently LCA provides the best available framework for assessing the potential environmental impacts of products.

Present state of the art: Life Cycle Sustainability Assessment

Staying in the realm of LCA, Kloepffer (2008) proposed a well known scheme for Life Cycle Sustainability Assessment (LCSA):

$$LCSA = LCA + LCC + SLCA$$

where LCA is the SETAC/ISO environmental Life Cycle Assessment, LCC is an LCA-type (environmental) Life Cycle Costing assessment and S-LCA stands for social Life Cycle Assessment.
The three methods show different degree of development. LCA is a mature method, standardised by the ISO 14040 series. It maps the environmental performance of products along their whole life cycle, covering all the activities technically required for delivering their functions, from cradle to grave (from raw material acquisition, via production and use phases, to waste management) or from

cradle to cradle. The basic modelling assumption is that for most economic activities performance in the past is indicative of performance in the future.

(Environmental) Life Cycle Costing (LCC) is a technique that “considers […] all cost associated with the life cycle of a product that are directly covered by one or more actors in that life cycle […]”. Externalities that are expected to be internalized in the decision-relevant future comprise real money flows as well, and they must also be included. One of the main features of LCC is that it shares the same LCA structure, i.e. they have equivalent system boundaries and functional units, because they are built upon the same product system providing the same function, and have a steady-state nature.

The term of reference in this field is represented by the work of Hunkeler et al. (2008), which provides a detailed description of the methodology, and can be considered a precursor to a code of practice leading to a potential standardization, in analogy to ISO 14040 series.

A social Life Cycle Assessment (S-LCA) is a social (potential) impact assessment technique aimed to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle. It differs from other social impacts assessment techniques by its objects (products and services), and its scope (the entire life cycle). Social and socio-economic aspects assessed in S-LCA are those that may directly affect stakeholders positively or negatively during the life cycle of a product. They may be linked to the behaviours of enterprises, to socio-economic processes, or to impacts on social capital. S-LCA does not have the goal nor pretends to provide information on the question of whether a product should be produced or not. Still in its infancy, the recent Guidelines published by Benoît and Mazijn (2009) within the UNEP/SETAC Life Cycle Initiative represent a step forward but we are still far from a proper systematisation of the approach.

Beyond the present state of the art

The present approach to LCSA, even if represents a good attempt to analyse the sustainability problem according to different perspective, fails to not account for interrelations and feedback within the system. Indeed, the three methods are presently applied separately, according to a life cycle model which inevitably shows limitations.

In particular LCA has been developed and standardized for evaluating the environmental potential impacts of goods and services by applying a steady-state and linear model, based on the concept of functional unit, and in which spatial differentiation is mainly lacking. Moreover, no social and economic effects are considered. ISO-LCA typically takes into account only technological and environmental relations, respectively in the life cycle inventory (LCI) and in the characterisation step of the impact assessment phase (LCIA). This narrow focus, together with its inherent limitations, was mainly due to the useful intentions to keep LCA operational, to limit its complexity and uncertainty by focussing on the main and direct effects along the life cycle.

Nevertheless, when we move from environmental to sustainability questions, and - even staying in the realm of environmental evaluation - when systems with high impacts on the economy and society are the object of the study, these main features of LCA become constraints, because ISO-LCA is not able to adequately consider many possible relevant effects. Discussions on biofuels have shown that “simple” LCA-type models can hardly answer the question if large scale biofuel is attractive from a sustainability point of view, while the use of different models would be more appropriate (Guinée et al. 2009). A nice treatment of this subject is provided in Huppes and Ishikawa (2009).

Indeed, in these circumstances, we should take into account the complex system of relations and casual-effects originated by our choice. These causal-effect relations, or mechanisms, range from the micro to the meso/macro level, and includes technological relations, environmental mechanisms, physical relations, economic mechanism, social, cultural and political relations and normative analysis as to sustainability (Huppes and Ishikawa 2009).

For this reason in the last years many researchers and LCA practitioners in their applications have proposed a very large number of new approaches and have provided guidance on how to implement some methodological issues not fully addressed by the standards. This period has been defined as the decade of elaboration (2000-2010) (Guinée et al 2010), in which many subjects have been discussed but often in an inconsistent way. As ISO never aimed to standardize LCA methods in detail and as there is no common agreement on how to interpret some of the ISO requirements, diverging methods have been developed with respect to system boundaries and allocation methods, dynamic LCA, spatially differentiated LCA, risk-based LCA, and input-output (IO) based and hybrid LCA.

Despite new LCA handbooks were published, there is a further need for structuring this varying field of LCA approaches while taking into account more types of externalities (economic and social costs) and more mechanisms (rebound, behaviour, price effects), handling time ((quasi-)dynamic, steady-state) and space differently and/or meeting specific user needs such as in simplified LCA.

Thus, now a new decade is opening, in which important methodological developments are needed to support life cycle sustainability evaluations. These developments can be grouped in the following (Zamagni et al 2009):

- deepening the scope of mechanisms and/or a particular mechanism. Deepening can be achieved by going beyond the focus on technological and environmental mechanisms and including also physical, social, economic, cultural, institutional and political ones (Heijungs et al. 2010)[1]. On the other side, deepening means also further sophisticating the modelling, for example adopting spatially differentiated models.
- broadening the scope of indicators and/or the object of the analysis. Broadening can be achieved by extending the number of environmental indicators or by going beyond the focus on environmental aspects and including also the economic and social ones. Another example of broadening is the shift of the analysis from individual product systems to sectors, baskets of commodities, markets or whole economies (from micro to meso and macro levels).

In conclusion, LCA is rapidly evolving and in this process the influence of other disciplines can play an increasing role. Nevertheless, even if traditionally LCA marks itself out for providing a framework in which other disciplines and related models can find a place (as actually occurs in the life cycle impact assessment phase), many authors question to what extent the integration and/or combination with other methods and models, especially for the modelling phase, would be desirable and necessary. One could argue that LCA, as conceived now, has been developed for certain types

[1] An example of economic mechanisms is the following. “If we start producing bioethanol, we add a new energy product to the market, with price changes induced and volume changes following. These market mechanisms in principle are linked. More corn for bioethanol squeezes out corn for food and also land use for wheat production. Both prices will increase, with still other products being squeezed out and rising in price in turn. These market mechanisms are interrelated.”(Heijungs et al 2010)

of applications and that the expansion of the methodology towards a broader and deeper method could violate its inherent principles. Indeed, this concern could be justified by the fact that LCA was very criticized in the past, and only with standardization it gained again a reputation. Therefore, any major change of LCA could endanger again its credibility. On the other hand, others could assert that the LCA framework has been conceived flexible enough to allow the combination and/or integration with other models, and thus it is part of its character to grow and to further expand. Thus some questions arise: Would these “contaminations” with other disciplines be desirable? Would this expansion make available a method able to provide more reliable information with acceptable uncertainty? These are indeed open questions which would be interesting to debate on, a debate in which the contributions from other disciplines are warmly encouraged. The scientific community will be called to reflect about these questions, carrying out its principal task of continuously investigating new lines of developments, testing their scientific soundness, selecting the most promising approaches and preparing the next steps of development.

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