Potentials and Limitations of Combined Life Cycle Approaches and Multi-dimensional Assessment

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Abstract  The use of life cycle approaches—purely or in combination with non-life cycle methods—to assess product systems from a multi-dimensional perspective arises as a current need in the path towards actual sustainability. While pure life cycle approaches involve mainly life cycle sustainability assessment, a wide range of novel approaches are currently under study in order to overcome the limitations typically linked to multi-dimensional assessment and multi-criteria decision analysis. This is done through the synergistic combination of life cycle (mainly, life cycle assessment) and non-life cycle (techno-economic assessment, data envelopment analysis, energy systems modelling, agent-based modelling, land change and ecosystem services modelling, urban metabolism analysis, interdisciplinary policy assessment, material flow analysis, etc.) methods. The main potentials, fields of application and pending issues associated with these tools are summarised herein.

1 Introduction

While life cycle methodologies such as life cycle assessment (LCA), carbon footprinting (CFP) and emergy analysis focus on the evaluation of the environmental realm of systems, other approaches such as life cycle costing (LCC), social life cycle assessment (SLCA) and life cycle sustainability assessment (LCSA) attempt to extend life cycle thinking to other spheres of sustainable development [1]. Though valuable and useful, the life cycle-based approaches proposed to date have not yet succeeded in providing a well-accepted and sound evaluation of sustainability issues. In this respect, it is acknowledged that the combined use of life

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cycle and other system-based or non-life cycle methodologies might offer interesting potentials towards a robust and practical assessment with a multi-dimensional perspective [2]. Nevertheless, scarce and scattered information is available on this type of integrative approaches.

LCA and other system-based approaches (e.g., technological innovation systems analysis, policy and market analysis, and design and analysis of user needs) provide clues about the environmental, economic and social nature of current and future industrial systems. Material flow analysis, cost-benefit analysis, energy systems modelling and multi-criteria decision analysis (MCDA) tools such as data envelopment analysis (DEA) are also among the methodologies that have already been used in combination with life cycle approaches [3]. However, because each of the methods separately is likely to provide different observations and conclusions, the development of harmonised approaches and guidance for technical innovation is required. Within this context, further discussion on both potentials and limitations concerning the use of hybrid approaches is needed.

2 Current Activities in Life Cycle-Based Multi-dimensional Assessment

During the LCM2017 conference held in Luxembourg, a number of multi-dimensional approaches including a life cycle perspective were addressed. The main methodological frameworks are summarised below:

- Life cycle sustainability assessment (LCSA) to comprehensively assess the relation and trade-offs between environmental, social and economic impacts under circular economy and industrial ecology principles. Current advances include the use of open space workshops and the combination with agent-based modelling.
- Environmental techno-economic assessment through the integration of LCA and techno-economic assessment. For instance, this could be applied to thoroughly assess a technology from the first stages of development until its industrial commercialisation.
- Development of new LCA tools for environmental optimisation and implementation in biddings, thereby integrating environmental impact budgeting into decision-making processes.
- Combination of life cycle approaches with DEA for sustainability benchmarking of multiple similar entities. The so-called LC + DEA concept benefits from the availability of different life cycle approaches (LCA, CFP, emergy analysis, etc.) and numerous DEA models. In this respect, the novel use of the SBM-Max model combined with LCA has recently been proposed for the gradual operational and environmental benchmarking in terms of continuous improvement.
Highly trans-disciplinary frameworks examining the system from multiple perspectives. For instance, this can involve technical (e.g., laboratory cultivation and mechanical testing), social (e.g., actor analysis, policy analysis, market analysis and social acceptance), resource (e.g., material flow analysis) and environmental (e.g., LCA) evaluations.

Other relevant methodological frameworks referred to the integration of land change modelling and ecosystem services modelling into LCA, the use of urban metabolism analysis, interdisciplinary policy assessment, and environmental, health and safety screening.

Finally, regarding the field of application of these hybrid methods, a wide range of case studies were presented during the LCM2017 conference. An increasing interest in bioeconomy-related case studies is observed, involving e.g. algae-based biorefineries, bio-based high-density polyethylene, microbial production of succinic acid from mixed food waste, and other biomass value chains. Nevertheless, many other sectors and topics could be highlighted, such as road planning, food industry, fishing sector, nanomaterials, and residential buildings.

3 Lessons Learned

It is seen that the development and application of methodological frameworks involving different approaches, scopes and methods leads to a useful holistic perspective in the evaluation of product systems. In this sense, this type of nuanced evaluation can offer a more robust foundation for decision-making processes than one perspective or method in isolation. Nevertheless, with the aim of guaranteeing the provision of consistent and sound results, a robust methodological harmonisation is of paramount importance, but often underdeveloped in many cases, e.g. when defining benchmarks in MCDA studies. This arises as a key issue to be addressed when developing and applying combined methods for multi-dimensional assessment.

A key strength of the proposed frameworks is the enriched interpretation and communication of the results, often providing easy-to-report results in line with the demands of the industry and other relevant stakeholders (policy-makers, society, etc.). Trans-disciplinary approaches can inform an arena of research and industrial partners with different perspectives to facilitate discussion and more well-informed decisions. Furthermore, combined methodological frameworks can even shorten the time-to-market for new technologies. However, achieving an extended use of multi-dimensional approaches is still a pending issue. In addition to research efforts in the field of systems analysis, a higher level of stakeholder involvement (e.g., through open space workshops) could help in this direction.
4 Conclusions and Perspectives

The combination of life cycle approaches such as LCA with other life cycle (e.g., LCC and SLCA) or non-life cycle (e.g., techno-economic assessment, DEA, interdisciplinary policy assessment, etc.) approaches offers singular advantages for the multi-dimensional assessment of product systems. The enrichment of decision-making processes and the enhancement of the discussion, interpretation and communication of the results arise as key strengths of these hybrid methods. Nevertheless, further efforts are still required in order to guarantee the consistency of the results through methodological harmonisation, as well as to involve stakeholders and achieve an extended use of these approaches.

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