Synergies in sustainability assessment: Combining Life Cycle Assessment and System Dynamics for better insights

Level: Master

Start: Year round

Project form: Literature thesis

Duration: 4-5 weeks (6 EC) or 8-9 weeks (12 EC)

Supervision: Sara Gonella and Steef Hanssen

Contact: sara.gonella@ru.nl

Background

Life Cycle Assessment (LCA) is a methodology for assessing the impacts of a product throughout its life cycle, ideally from cradle to grave. It focuses mainly on environmental impacts, but can also include costs and social impacts in the analysis, through Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA), respectively (Guineé, 2016; McCabe & Halog, 2018). LCA is increasingly used not only to assess existing products, but also to evaluate new technologies at an early stage of development (Prospective LCA) (Buyle et al., 2019; Cooper & Gutowski, 2020; Thonemann et al., 2020; van der Hulst et al., 2020).

System Dynamics, on the other hand, is a method for analysing complex problems that looks at the structure that drives problematic behaviour over time. The structure of the systems studied takes the form of feedback loops, delays and nonlinearities. SD was originally developed as a quantitative modelling approach to simulate industrial supply chain problems (Forrester, 2007). The methodology has subsequently been further developed and applied in many different fields such as urbanisation, growth dynamics, environmental studies, economics, socio-technical transitions (de Gooyert et al., 2016; Gonella, 2021; Hayden, 2006). Depending on the type of research and available data, an SD model can be based on qualitative or quantitative relationships (Coyle, 2000; de Gooyert et al., 2016, 2019; Forrester, 1994; Janipour et al., 2021; Kim & Andersen, 2012; Wolstenholme, 1985). When based on qualitative data, it is sometimes referred to as Systems Thinking (Forrester, 1994). The data can be drawn from the literature or from various forms of empirical research, such as interviews and workshops (i.e. Group Model Building (Vennix, 1996)).

LCA is a well-established methodology in environmental studies. While it allows for complex studies of detail and can provide a deep understanding of a specific supply chain, it does not consider the broader dynamics of the interdependent subsystems of the product and is therefore less suited to multi-disciplinarity than SD. System Dynamics can provide a broader understanding of the interaction of a product/supply chain in a wider system by considering different aspects beyond the environmental (e.g. social and economic aspects), their mutual influence (feedback mechanisms) and the evolution of a system over time. The different strengths and weaknesses of LCA and SD could make it interesting to combine the two methods.

Aim and research questions

To date, there are few examples of the combination of LCA and SD methodologies. The aim of this project is to conduct a systematic literature review to see what attempts have been made to combine LCA and SD. These examples will be carefully analyzed and compared in order to answer the following questions:

- How have LCA and SD been combined?[1]

- What are the benefits of using a combination of LCA and SD rather than just one of the two?

References

Buyle, M., Audenaert, A., Billen, P., Boonen, K., & van Passel, S. (2019). The future of ex-ante LCA? Lessons learned and practical recommendations. In Sustainability (Switzerland) (Vol. 11, Issue 19). MDPI. https://doi.org/10.3390/su11195456

Cooper, D. R., & Gutowski, T. G. (2020). Prospective Environmental Analyses of Emerging Technology: A Critique, a Proposed Methodology, and a Case Study on Incremental Sheet Forming. Journal of Industrial Ecology, 24(1), 38–51. https://doi.org/10.1111/jiec.12748

Coyle, G. (2000). Qualitative and quantitative modelling in system dynamics: Some research questions. System Dynamics Review, 16(3), 225–244. https://doi.org/10.1002/1099-1727(200023)16:3<225::AID-SDR195>3.0.CO;2-D

de Gooyert, V., Rouwette, E., van Kranenburg, H., Freeman, E., & van Breen, H. (2016). Sus-tainability transition dynamics; Towards overcoming policy resistance. http://hdl.han-dle.net/2066/160112

de Gooyert, V., Bleijenbergh, I., Korzilius, H., Fokkinga, B., Lansu, M., Raaijmakers, S., Rouwette, E., & Van Der Wal, M. (2019). Why we do not always simulate.

Forrester, J. W. (1994). System dynamics, systems thinking, and soft OR. System Dynamics Re-view, 10(2–3), 245–256. https://doi.org/10.1002/sdr.4260100211

Forrester, J. W. (2007). System Dynamics - The Next Fifty Years. System Dynamics Review, 23(3), 359–370. https://doi.org/10.1002/sdr

Gonella, S. (2021). Pursuing a Just Transition in the power sectors of Poland and South Africa: Identifying barriers and drivers using System Dynamics. Eindhoven University of Technology

Guineé, J. (2016). Life Cycle Sustainability Assessment: What Is It and What Are Its Chal-lenges? In Taking Stock of Industrial Ecology. https://doi.org/10.1007/978-3-319-20571-7

Hayden, F. G. (2006). The inadequacy of Forrester System Dynamics computer programs for institutional principles of hierarchy, feedback, and openness. Journal of Economic Issues, 40(2), 527–535. https://doi.org/10.1080/00213624.2006.11506932

Laurenti, R., Lazarevic, D., Poulikidou, S., Montrucchio, V., Bistagnino, L., & Frostell, B. (2014). Group Model-Building to identify potential sources of environmental impacts outside the scope of LCA studies. Journal of Cleaner Production, 72, 96–109. https://doi.org/10.1016/j.jclepro.2014.03.001

Matsumoto, H. (1999). System Dynamics Model for Life Cycle Assessment (LCA) of residential buildings.

McCabe, A., & Halog, A. (2018). Exploring the potential of participatory systems thinking tech-niques in progressing SLCA. The International Journal of Life Cycle Assessment, 23(3), 739–750. https://doi.org/10.1007/s11367-016-1143-4

Onat, N. C., Kucukvar, M., Halog, A., & Cloutier, S. (2017). Systems Thinking for Life Cycle Sus-tainability Assessment: A review of recent developments, applications, and future perspec-tives. In Sustainability (Switzerland) (Vol. 9, Issue 5). MDPI. https://doi.org/10.3390/su9050706

[1] For example, one possible approach is to take the inventory or impact assessment results from an LCA model and link them to stocks and flows in an SD model (e.g. (Yao et al., 2018)). Alternatively, SD can be used to perform a sensitivity analysis on the different parameters or system boundaries used in the LCA (e.g. (Matsumoto, 1999)). Another possible approach is to use the results of an SD model to determine the stock levels in the LCA model (e.g. (Peng et al., 2019)). There have also been some attempts (although fewer in number) to combine qualitative SD models with LCA. For example, Laurenti et al. (2014) used Group Model Building (GMB) to identify variables that are not typically considered in LCA studies, but which may have a significant impact on environmental impacts through cause-effect relationships and feedback loops in product systems, in this case washing machines and passenger cars. The (new) variables identified during the group interviews are mainly soft variables, depending for example on user behaviour, market demand and government policies and taxes. GMB could be a valuable tool to delineate system boundaries during the goal and scope definition in LCA and to identify variables/areas that could be included in sensitivity and scenario analyses (Laurenti et al., 2014). Qualitative System Dynamics can support the development of the Social LCA framework as a decision support tool and basis for effective policy making. This methodology is less developed than traditional LCA, so it could benefit from integration with SD, especially participatory modelling techniques (McCabe & Halog, 2018; Onat et al., 2016, 2017).

Onat, N. C., Kucukvar, M., Tatari, O., & Egilmez, G. (2016). Integration of system dynamics ap-proach toward deepening and broadening the life cycle sustainability assessment frame-work: a case for electric vehicles. International Journal of Life Cycle Assessment, 21(7), 1009–1034. https://doi.org/10.1007/s11367-016-1070-4

Peng, S., Li, T., Wang, Y., Liu, Z., Tan, G. Z., & Zhang, H. (2019). Prospective Life Cycle Assessment Based on System Dynamics Approach: A Case Study on the Large-Scale Cen-trifugal Compressor. Journal of Manufacturing Science and Engineering, 141(2). https://doi.org/10.1115/1.4041950

Janipour, Z., Swennenhuis, F., de Gooyert, V., & de Coninck, H. (2021). Understanding con-trasting narratives on carbon dioxide capture and storage for Dutch industry using system dynamics. International Journal of Greenhouse Gas Control, 105, 103235. https://doi.org/10.1016/j.ijggc.2020.103235

Kim, H., & Andersen, D. F. (2012). Building confidence in causal maps generated from purposive text data: mapping transcripts of the Federal Reserve. System Dynamics Review, 28(4), 311–328. https://doi.org/10.1002/sdr.1480

Thonemann, N., Schulte, A., & Maga, D. (2020). How to conduct prospective life cycle assess-ment for emerging technologies? A systematic review and methodological guidance. In Sustainability (Switzerland) (Vol. 12, Issue 3). MDPI. https://doi.org/10.3390/su12031192

van der Hulst, M. K., Huijbregts, M. A. J., van Loon, N., Theelen, M., Kootstra, L., Bergesen, J. D., & Hauck, M. (2020). A systematic approach to assess the environmental impact of emerging technologies: A case study for the GHG footprint of CIGS solar photovoltaic lami-nate. Journal of Industrial Ecology, 24(6), 1234–1249. https://doi.org/10.1111/jiec.13027

Vennix, J. A. M. (1996). Group Model Building. Facilitating Team Learning Using System Dynam-ics. John Wiley & Sons.

Wolstenholme, E. (1985). A Methodology for Qualitative System Dynamics. https://www.re-searchgate.net/publication/244958745

Yao, L., Liu, T., Chen, X., Mahdi, M., & Ni, J. (2018). An integrated method of life-cycle assess-ment and system dynamics for waste mobile phone management and recycling in China. Journal of Cleaner Production, 187, 852–862. https://doi.org/10.1016/j.jclepro.2018.03.195