Dynamic LCA and LCC with ECOFACT

Emilia Ingemarsdotter[1],
Sahil Singhania[1] and Georgios Pallas[1]

[1] PRé Sustainability, Stationsplein 121, 3818 LE Amersfoort, Netherlands

Abstract

This paper introduces the work on dynamic life cycle assessment (LCA) and life cycle costing (LCC) carried out within the EU Horizon 2020 project ECOFACT. The goal of the ECOFACT project is to develop a digital platform for manufacturing companies to optimize their production systems for energy, costs, resources and life cycle impacts. The platform will include a manufacturing decision-support-system based on dynamic LCA and LCC and it will be demonstrated in four factories that are members of the project consortium. Dynamic and automated LCA and LCC provides opportunities for new insights compared to conventional, static assessments. For example, temporal variations in the environmental impact can be made available on an hourly, daily, monthly and yearly basis. Moreover, once set up, LCA and LCC results can automatically be updated with the latest data, reducing efforts and costs related to data collection and reporting. In this paper, we briefly explain the ECOFACT approach to dynamic LCA and LCC and discuss preliminary learnings as well as future opportunities.

Keywords: Life Cycle Assessment, Smart Manufacturing, Life Cycle Costing, Industry 4.0, Sustainability

1 Introduction

Life Cycle Assessment (LCA) is a science-based and standardized method for assessing the environmental impacts of products and services used by companies as well as policy makers (LCANZ 2022; Nygren & Antikainen, 2010). Life Cycle Costing (LCC) is a method to compile all the costs associated with a product throughout its life-cycle (ISO 15686-5:2017). The combination of LCA with LCC can support decision making based on both environmental and economic factors (Stewart, et al. 2018).

The increasing focus on sustainability in business and policy drives a strong demand automated and large-scale solutions to LCA. The current practice of doing LCA often relies on static calculations based on average input data from a limited temporal scope (Sohn, et al. 2020). The effort of updating the results for another time period can be considerable. Therefore, one way to accommodate the scale-up of LCA is to automate the data collection process. This can reduce the time needed, increase the reliability of the data, and ensure that comparable data is used every time. Moreover, automatic data collection allows for dynamic assessments, i.e. that the results can be updated frequently with new input data. Such a dynamic approach can help identify environmental impact patterns based on short-term variations in input data. Similarly, dynamic input data to LCC calculations allow for cost impact results that vary over time, including for example fluctuations in material costs.

This paper presents work carried out as part of the EU Horizon 2020 'ECO-innovative Energy FACTory Management' (ECOFACT) project (ECOFACT 2021). The goal of the ECOFACT project is to develop a digital platform for manufacturing companies, which can use it to optimize their production systems in terms of energy, costs, resources, and life cycle impacts. A high-level visualization of the proposed platform is presented in **Fig. 1**. The project includes four manufacturing companies serving as demonstration cases. The demonstration cases cover the following types of production processes: beer brewing, cookies/biscuits baking, washing machine production, and car painting.

The work presented in this paper relates to work package 4 (WP4), focusing on developing a dynamic LCA/LCC module. The ECOFACT platform allows data from the factories to be sent to the LCA/LCC module. For example, dynamic data can be collected about the energy consumption of factory processes, amounts of incoming materials used in the factory, and amounts of waste sent to waste treatment. The LCA/LCC module can then continuously and automatically generate updated environmental and cost impact results. The scope for the LCA is cradle to gate, i.e. including the production of upstream materials and components as well as the manufacturing process itself. For the LCC, costs borne by the manufacturing company are included (e.g., raw material costs, energy costs maintenance costs, waste management costs). In the LCA, the production of upstream materials and components are generally included using secondary datasets. However, a "supply chain collaboration service" is used in one of the demo cases to demonstrate how dynamic data from a supplier can be transferred and used.

There are examples in previous literature of dynamic LCA and LCC applications based on variable manufacturing data (e.g., Cerdas et al. 2017, Andersson 2013, Rödger et al. 2020). However, most papers are based on simulations rather than real-time monitoring, and to the best of the authors' knowledge, there are no reports of previous projects in which an automated solution for dynamic LCA is implemented and tested at large-scale, fully-operational manufacturing sites. The goal of this paper is thus to introduce the ECOFACT approach to dynamic LCA and LCC and to extract preliminary learnings from the project so far. In order to present general learnings that are not tied to the use of specific software or service providers, we focus on the key steps of the approach rather than the detailed technical solution.

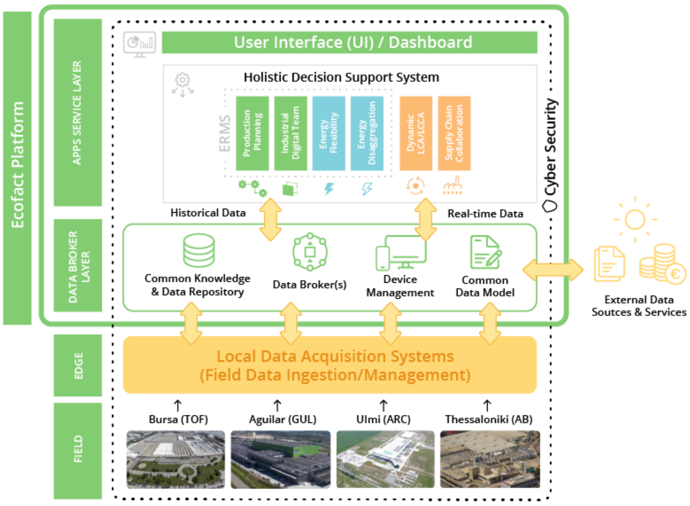

Fig. 1. High-level visualization of the ECOFACT platform and its different components

2 The ECOFACT approach to dynamic LCA and LCC

The LCA/LCC module is one part of the ECOFACT platform (**Fig. 1**), which will receive up-to-date data from the factory. The ECOFACT project also demonstrates the integration of dynamic data from suppliers via a supply chain collaboration service. This means that dynamic energy and water data for the production of one component from one supplier is collected and introduced to the ECOFACT platform.

The flowchart in **Fig. 2** shows how the dynamic LCA/LCC results are generated from the collected data. The ECOFACT platform integrates the data and sends an Application Programming Interface (API) request to the LCA/LCC module. The model is updated with the new values coming from the field, an LCA/LCC calculation is triggered, and the updated results are sent back to the ECOFACT platform. The platform visualizes the results and provides decision support to the user.

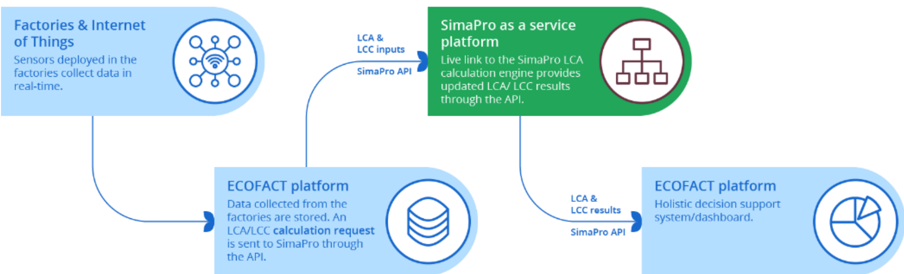

Fig. 2. Flow chart for dynamic LCA and LCC model (Pallas, 2021). Visualization by Catinca Popescu.

In **Fig. 3**, and in the text below, we detail five key steps in the ECOFACT approach to dynamic LCA and LCC. The steps are elaborated from the four steps described in the ISO standard for LCA (ISO 14040:2006) and which are also applicable in LCC: A) goal and scope definition, B) inventory analysis, C) impact assessment, and D) interpretation. We argue that a fifth step is relevant to add, namely E) application. This is the step where the learnings from study are put in practice.

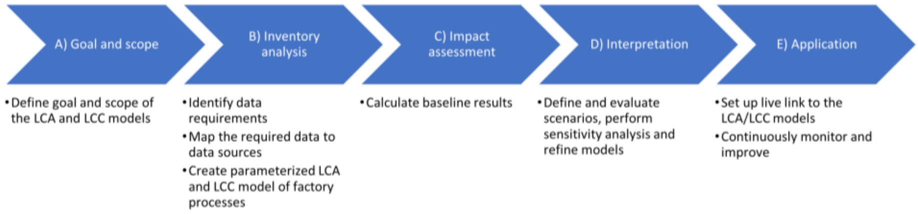

Fig. 3. Steps of an LCA/LCC detailed in the context of automated, dynamic LCA/LCC based on manufacturing data.

A. Goal and scope definition

- *Define the goal and scope of LCA and LCC models*

This step includes describing the system boundaries and defining the environmental and cost KPIs to be calculated. This step is the same as for a conventional static LCA. In the ECOFACT demonstration cases, the goal for the LCA and LCC models is to continuously monitor the environmental impact and costs of the factory as a whole and in relation to a unit of the produced product (e.g., one washing machine or one hectoliter of beer). The scope of the LCAs is from cradle to gate and the scope of the LCC is costs borne by the manufacturing company. The environmental KPIs to be calculated include a selection of the impact categories from the EF3.0 impact assessment method (Zampori and Pant 2019) as well as total energy consumption and total resource consumption. Cost KPIs include, for example, energy costs, maintenance costs, and waste management costs.

B. Inventory analysis

- *Identify data requirements*

Based on the goal and scope, the next step is to list the data requirements for performing the desired analysis. This step is the same as for a conventional static LCA. Important data points include, for example, the bill of materials of the product, energy consumption of different process steps, water use, material inputs, and waste amounts. Identifying the data requirements in dynamic LCA and LCC also includes specifying which data points will be dynamic, i.e. updated continuously, and which can be considered static. For instance, electricity consumption can updated continuously while the bill of materials of the supplied components can be static.

- *Map the required data to data sources*

For the dynamic data points, it is necessary to make a detailed map of the data sources from which the data will be collected. The data sources can be sensors, meters, management systems, but also manual input from users. Apart from using data sources from the manufacturing company itself, the ECOFACT project also demonstrates the integration of dynamic data from a supplier. If this mapping step reveals that additional components for automated data collection are desirable, such installations should be detailed and planned.

- *Create parameterized LCA and LCC models of the factory processes*

The next step is to build the model that will use the data. The models need to be parameterized, meaning that inputs are defined as parameters that are updated when new data becomes available. This way, we get a dynamic model that continuously calculates updated impact results. The first version of the model can use input values based on historical data from the factory. In ECOFACT, the models are built in SimaPro Flow (SimaPro-Flow 2022), which is a cloud-based online software. A calculations request with updated parameter values can be sent to the models via the SimaPro API (SimaPro-API 2022).

C. Impact assessment

- *Calculate baseline results*

When a model is in place, a baseline result is obtained based on historical data. The baseline results give initial insights into environmental and cost hotspots. At this stage, the models or data requirements can also be modified. For instance, if a certain process has an insignificant effect on the total results, data from that process might not have to be measured dynamically, thereby reducing unnecessary data transfer and processing.

D. Interpretation

- *Define and evaluate scenarios, perform sensitivity analysis and refine models*

Sensitivity analysis of the results can give important insights into the type of actions that would be effective for the company to pursue. Depending on the user’s needs, it is possible to create scenarios to be evaluated. Based on this interpretation step, it might, again, be decided to modify the model or the data requirements.

E. Application

- *Set up live link to feed data to the LCA/LCC models*

The measurement devices in the factories will continuously monitor the important parameters in the production processes and send the data to the ECOFACT platform in specific time intervals. Via the so called Data Broker, which manages data flows between platform modules, a calculation request is sent to the LCA/LCC models, containing updated parameter values. The LCA/LCC models calculate a new results and send it back to the Data Broker. For this to work, there needs to be a way to exchange data between the Data Broker and the LCA/LCC module. In the ECOFACT project, the models are built in the online software SimaPro Flow (SimaPro, 2022). When the Data Broker receives new data from the factory, or at certain pre-defined time intervals, a calculation request is triggered using the custom-built SimaPro API (SimaPro-API 2022).

- *Continuously monitor and improve*

The ECOFACT platform will provide continuously updated environmental impact results to the factories. It will allow them to monitor their environmental footprint and cost impact over time. The insights derived from this can provide opportunities for targeted actions that can optimize the production and costs associated with energy, resource use and life cycle impact.

3 Discussion

3.1 Dynamic vs. static LCA/LCC

Traditional static LCA/LCC is useful for identifying environmental and cost impacts, opportunities and trade-offs and it allows for scenario analyses and product comparisons. The life cycle impact is typically assessed as an average impact of a product over a period of time. Automated, dynamic LCA/LCC based on real-time manufacturing data can go beyond what traditional static LCA offers by unlocking new temporal insights. Below we list some examples of such potentially new insights:

- Seasonal variations in performance can be observed. For instance, a factory might have a lower environmental impact during the summer months due to lower heating needs or the use of more renewable energy.
- The effect of changing settings or operational parameters of the production machineries can be observed in the life cycle impact on daily, or even hourly basis.
- If a quality issue results in higher scrap levels for a certain time period, a temporary increase in environmental impact can be observed.
- The effect of maintenance can be observed. For example, the maintenance of a machine might reduce its energy consumption and thereby the environmental impact.

These new insights could be translated into targeted actions to improve the factory's environmental performance, such as:

- Through production planning, it might be possible to shift production to specific days of the week or even specific hours during the day when the impact is low.
- Particularly energy-intensive production processes can be moved to days with favorable weather forecasts to derive maximum potential from renewable energy sources.
- Operational parameters can be adjusted for optimal performance.
- The maintenance frequency could be adjusted for optimal performance.

3.2 Future work

The ECOFACT project will demonstrate the use of dynamic LCA and LCC in four factories. In these demonstration cases, the scope of the LCAs are cradle to gate, which means that we do not include impacts that take place in the life cycle stages after manufacturing. Future projects could include the use phase and the end of life of the products produced in the factory. To include these stages dynamically, data would have to be shared between different actors along the life cycle. As mentioned earlier, the ECOFACT project integrates dynamic data from an upstream supplier of one factory, but this could in theory be extended to include downstream data from the product use or recycling.

Another interesting avenue for future research and innovation is to make the model more dynamic in itself by coupling the LCA software to other systems containing information about, for example, the factory layout or the bill of materials of the products. The model could then be updated automatically if the factory layout or product design changes. Dynamic aspects can also be introduced in impact assessment methods (e.g. Lueddeckens, et al. 2020) and even in the scope (Sohn, et al. 2020).

Finally, the continuous monitoring of environmental and cost impacts would potentially lead to new (research) questions, opening up the road to new developments and added value to the stakeholders involved. For instance, machine learning models could be applied to the large input data gathered from the factories and their associated LCA/LCC results that will be generated over time. Applying analytics can allow the identification of patterns, parameter correlation with impacts or other insights. Machine learning could be used to predict impacts of specific actions, further optimize product manufacturing, and reduce costs and environmental risks of new product developments.

4 Conclusion

The goal of this paper was to introduce the ECOFACT approach to dynamic LCA and LCC and to extract preliminary learnings from the project so far. In order to present general learnings that are not tied to the use of specific software or service providers, we focus on the key steps of the approach rather than the detailed technical solution. We described our approach based on the standardized steps of an LCA/LCC and discussed opportunities and future work. As the ECOFACT project is an ongoing innovation project, the paper presents preliminary findings. Interested readers should refer to the to-be-published ECOFACT project deliverables for more detailed reports on the setup and approach.

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