LCA calculations in LTDH systems

1 Life Cycle Thinking

Life cycle of a product or system (a.k.a. "cradle to grave") begins with primary resource extraction, moving towards raw materials production and extends to manufacture, use, transport, and finally waste management (eventually including recycling and/or reusing).

The Life Cycle Thinking approach is specifically addresses the sustainability challenges that are highlighted in the Sustainable Development Goals (SDGs) and in the Paris Agreement. In the strategic views described within these framework is put an emphasis on the sustainable consumption and production (SCP) system from a holistic perspective, which is actually the core a life cycle thinking.

SCP focuses on more efficient (and thus sustainable) production, processing, and consumption systems meantime ensuring a natural resource efficiency with the environmental impact reduction towards the whole life cycle of product.

The SCP gives an opportunity to meet the sustainable goals (i.e. producing more well-being with less material consumption) to meet present and future human needs ensuring the preservation of ecological systems capacity. Such approach can trigger the competitiveness of enterprises.

Within this background the Life cycle thinking provides a frame for a quantitative and holistic approach to evaluate the overall sustainability acknowledging the complex connectivity of our societies, economies and the natural environment. This includes also the social dimension thus understanding system behaviours and their feedbacks on the analysed system). Some of the benefits of Life Cycle Thinking (LCT) are:

- Aid Policy makers and entrepreneurs for better choice making in terms of sustainability and resource efficiency;
- Understand complex systems to enable actions for a more sustainable sound system;
- Burden allocation on several actors (i.e. holistic and multidisciplinary approach);
- Identification and strengthening of cleaner production process;
- Use of the LCT towards the application of Eco-design perspectives;
- Guide consumers and rise awareness towards sustainable development.

2 Life Cycle Assessment

Life Cycle Assessment (LCA) is a methodology to identify, measure, and characterize different potential environmental impacts associated to each of the stages of a product's life cycle. A product can be a good or a service. LCA considers the following stages in the life cycle of a product: Extraction and processing of Raw materials, Manufacturing, Transportation and Distribution, Use, Reuse

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and Maintenance, Recycling, and Final disposal (a.k.a.crade-to-grave) – see fig. 1.

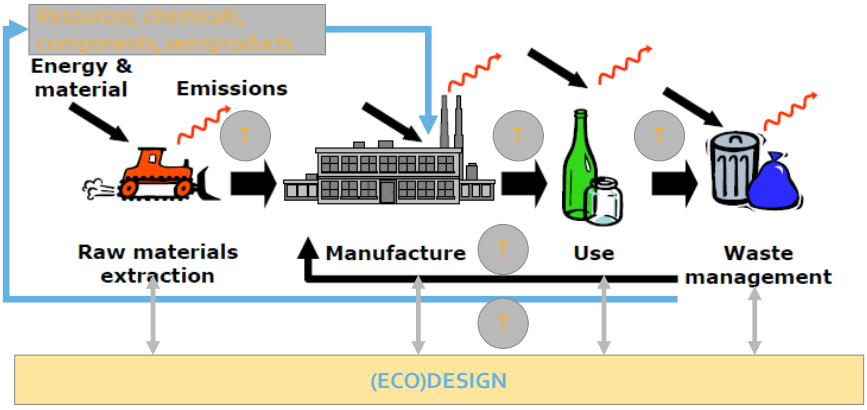

Fig. 1. "Cradle-to-grave" approa ch in the LCA [1].

LCA also helps to promote situation-based decisions, it is a good comparative tool for sustainability and environmental performance assessment and uses holistic approach avoiding burden shifting.

3 LCA methodology

Although there are several approaches to undertake an LCA, the ISO Standard is the commonly accepted and most used within the academic field and industry. The main four steps included in the LCA methodology (see fig. 2) are:

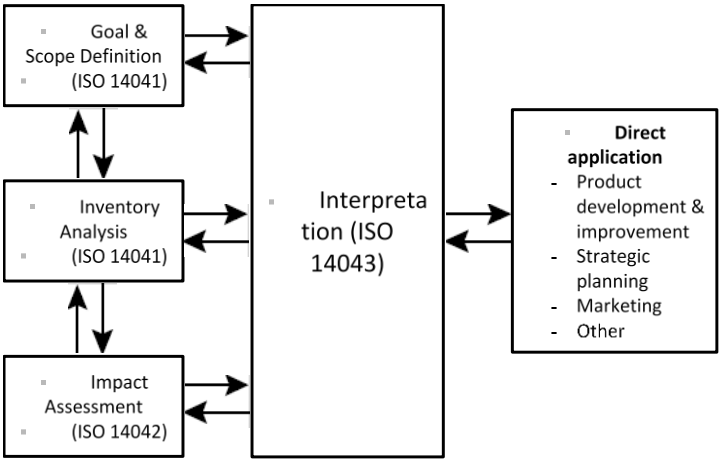

Fig. 2. ISO Standard 14040-44 [2].

- goal and scope,
- life cycle inventory,
- life cycle impact assessment, and,
- life cycle interpretation.

The four main steps are described in the ISO 14040 where the LCA principles for conducting an LCA and framework is set along with the product system definition. In the ISO 14044 the LCA methodology is described in detail with requirements and guidelines.

3.1 Goal & Scope

The goal and scope must define the intended application, the product system, functional unit (FU), system boundaries, LCIA methodology, assumptions and limitations, and some other data requirements.

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3.2 Life Cycle Inventory

The aim is to identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, wastewater discharges).

3.3 Life Cycle Impact Assessment

Includes the collection of indicator results for the different impact categories, which together represent the LCIA profile for the product system. Such results are categorized in impact categories. It is at this point, where sensitivity analysis can be performed to determine how changes in data and methodological choices may affect the results.

3.4 Life Cycle Interpretation

In this LCA phase the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

4 LCA in Low Temperature District Heating systems

LCA has been used for assessing the environmental impact of Low Temperature District Heating systems (LTDH) using the ISO standard 14040-44 methodology as it delivers several benefits to different stakeholders as energy planners, DH operators, engineers, public officials and policy makers. Some of the most mentioned benefits are: allows benchmarking, identification of process affecting the overall environmental performance of the infrastructure, and evaluation of eco-design perspectives for municipal energy strategies.

4.1 How to build an LCA for DH system

The LCA product tailored for the DH sector system can be divided in three parts, the supply with energy production and distribution systems, and the demand side. In the supply sides, the raw material extraction, energy use, construction activities, operation of boiler house, and distribution network infrastructure are included, hence, all the inputs related to these activities can be grouped depending on the scope of the study. On the demand one, the building system is included, in terms of heat consumption and losses, and all inputs related to activities required to settle the preparedness of the DH users to receive the service. Usually these types of studies are normalized either to 1 year of operation or a determined lifespan of the project.

The goal and scope of the study defines the boundaries of the study, and specific aspect should be clarified, for example: is the renovation of buildings accounted for? Are demolition or any other activity in the end-of-life stage to be considered within the boundaries?

Within the goal and scope the geographic and time boundaries are defined, which are highly important for energy sources to use, heat demand calculations, and normalization purposes respectively.

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For the Inventory analysis, a flow chart where boundaries are clearly defined is drawn, and processes identified accompanied by their respective data inventory for material and energy inflows as well as emissions. Fig. 1. "Cradle-to-grave" approach in the LCA.

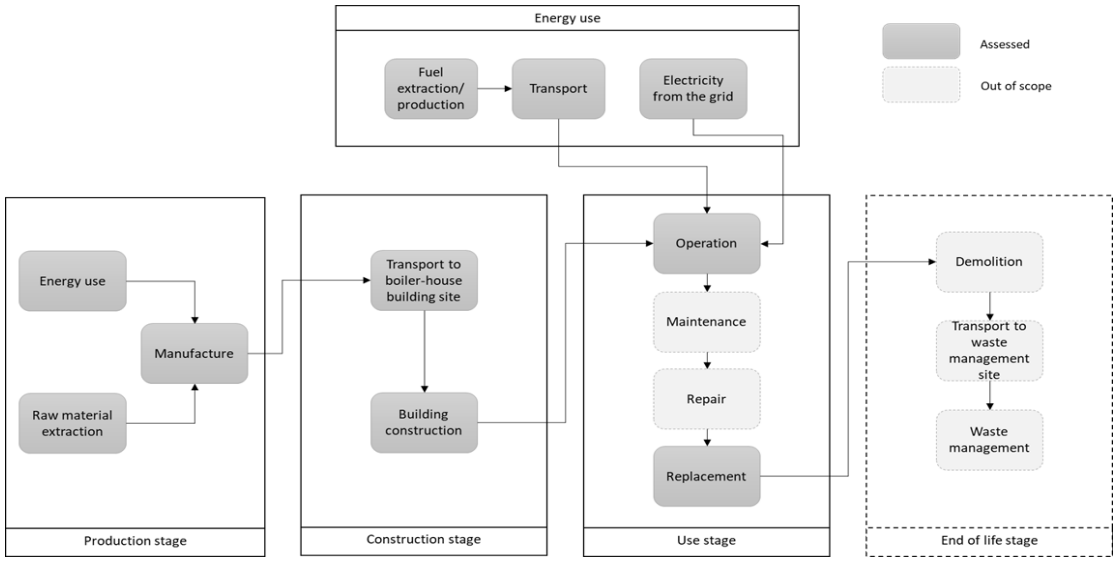

Fig. 3. Example of the boundaries defined within the "goal & scope" see the LCA performed within the project LowTEMP (www.lowtemp.eu) for a more complete overview.

Material/Assemblies	Amount	Unit
Solar Plant	18.2	p
Old District heating Pipelines	10.6	p
New District heating Pipelines	1.39	p
Old Boilerhouse - No furnace	1	p
DH nodes	10.6	p
Boiler's pumps, taps, heat m., exch. & flow device	2	p
Node's pumps and taps	10.6	p
Pipeline's pumps, taps, heat meters, exch., flow d	10.6	p
Op. Phase	25	p
Processes	Amount	Unit
Furnace, wood chips, average storage area, 1000kW	4.5	p
Furnace, wood chips, with silo, 5000kW	1	p
Hot water tank, 600l	4.16	p

Fig. 4. Example of a simplified "Life Cycle Inventory", see the LCA performed within the project LowTEMP (www.lowtemp.eu) for a more complete overview.

Finally, the Impact Assessment after normalization, grouping and weighting is presented as ecoprofile into impact categories (see figure 5). Normalization, grouping and weighting are not mandatory and depend from the LCA impact assessment method selected.

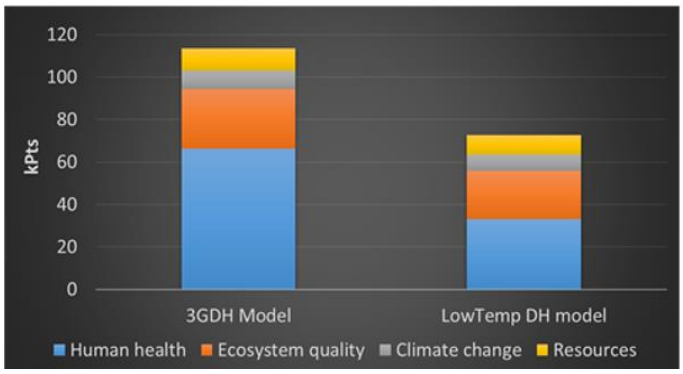

Fig. 5. Example of a final environmental impact assessment comparing a renovated LTDH system with a former 3rd generation. See the LCA performed within the project LowTEMP (www.lowtemp.eu) for a more complete overview [3].

In figure 5 is reported an example of a final environmental impact assessment comparing a renovated LTDH system with a former 3rd generation. Results are presented as overall environmental profile in terms of Ecological Point (Pt) with reference to the functional unit of the system. The environmental profile is accounted for 4 main damage categories (also called End Point Impact Categories) with reference to a specific type of impacted assessment method selected for such study (i.e. IMPACT 2002+), namely: Human Health, Ecosystem quality, Climate Change and Use of Resources (both biotic and abiotic).

In the last phase, the Life Cycle Interpretation, results are analyzed versus the goal of the study, to see if the intended one was reached. Also, hotspots are identified and sensitivity analysis can be conducted for a better understanding of the model and to detect new improvement opportunities.

Figure 5 is the result from the implementation of a LCA study proposed within the LowTEMP project for the pilot measure developed in Beļava Parish in Gulbene Municipality. The pilot measure includes the full reconversion of a former 3rd generation type DH distribution network to a novel Low Temperature DH system. In the old system, the boiler house was operating with wood logs fired boiler and the distribution network is not renovated. The new LTDH concept includes a 0.2 MW new pellet boiler house, the full change of the distribution grid's pipes (for a length of 150 m) and the installation of a remote data reader system to provide continuous monitoring of the system.

The realized LCA study includes the assessment of the implemented LTDH scenario taking into account a supply temperature of 60 °C and a return temperatures of 35 °C, its potential future improvement including renewable energy solution and the comparison with the ex-ante situation.

From the results of the LCA models processed with an LCA commercial software, is possible to notice a major improvement in the overall environmental performance with a decrease, respect the ex-ante situation, of approximately 50%. The results (already included in a scientific publication) show that the highest contribution to environmental impact in all scenarios is mainly allocated to the energy flows during the operational phase of DH.

Overall the specific study shows the marginal impact of the construction and maintenance phase compared to the operational phase of DH. The heat production and ash treatment represent an environmental "hot-spots". This is a proof that more work should be made, from an environmental point of view, for a reduction of the fuel consumption of boiler houses.

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For a more detailed information on the application of the LCA framework for LTDH system is recommended to see the LCA studies proposed within the LowTEMP projects (www.lowtemp.eu).

In the context of the project implementation, the expected findings from LCA studies should be relevant to:

- definition of a specific inventory data of the LTDH pilot measures implemented in the LowTEMP project for all investigated subsystems;
- answer which sub systems or components of a district heating grid are the main contributors to the overall environmental impact of the infrastructural transition;
- provide environmentally sound strategies for eco-designed and resilient infrastructures based on the analysis of selected LCA impact categories;
- compare the results obtained from the implementation of a novel LTDH concept with an ex-ante scenario in the same urban or rural context.

Recommended supporting material

1. Michael Z. Hauschild, Stig Irving Olsen, Ralph K. Rosenbaum. Life Cycle Assessment. Theory and Practice. Springer International Publishing AG, 2018.
2. ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance. European Commission - Joint Research Centre - Institute for Environment and Sustainability, https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf
3. EUROPEAN PLATFORM ON LIFE CYCLE ASSESSMENT, https://eplca.jrc.ec.europa.eu/

References

[1]. Ecodesign and LCA course - Riga Technical University, Institute of Energy Systems and Environment

[2]. ISO, "ISO 14044:2006," Environ. Manag. - Life cycle assessement - Requir. Guidel. ISO 14044, Int. Organ. Stand., 2006.

[3]. LCA study of the Pilot Energy Strategy for low temperature district heating system implementation in Gulbene municipality [Online]. Available at http://www.lowtemp.eu/wp-content/uploads/2020/12/LCA-report-pilot-measure-Belava.pdf

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