Review on PhD Thesis by Luca De Benedetto

Title: Integrated Life Cycle Analysis Approaches to Strategic Decision Making in Waste to Energy

Supervisor: Prof. Dr. Jiří Klemeš, DSc.

The whole document containing 117 pages includes all appropriate features of a good thesis like introduction, very broad search retrieval, research purpose and questions, research presentation itself, future study proposals and conclusions.

The work has been already published and I have been rather impressed by the number of fast growing citations already recorded.

The language of the dissertation is acceptable, the typos have been corrected and idioms improved to a sufficient level.

The *first chapter* gives very nice and clear introduction to Life Cycle Assessment (LCA). It mentions its history, standards, related challenges and drawbacks, LCA framework, methodology and fundamentals of impact assessment. The author's contribution has been now better specified and it is possible to accept it as it is.

The author stated that work environment (human) factor is still not included enough in a standard LCA as well as a solid applicability on Waste-to-Energy field needs new analytical tools to be integrated. At the end of the chapter there are fundamental questions for this thesis and the purpose of the research is explained.

The *second chapter* already introduces the author's research. The border between already proven and newly proposed techniques has been now specified. He combines existing environmental assessment categories of "footprints family" (which is also widely described there) and extends it to a useful framework. The author combines all carbon, water, energy, emission and work environment footprints and relates them with cost to create so called Environmental Performance Strategy Map (EPSM). A result graphically calculated from EPSM is a single number (Sustainable Environmental Performance Indicator, SEPI), is therefore easily comparable value and should be the desired easy-to-use tool for the decision makers. This is one of the major contributions of his research, it has received a wide interest from the scientific community and as I already stated, the number of citations has been very high.

The approach is explained clearly and supported by a case study. At the very end of 2nd chapter there are proposals for future studies in this area.

In the *third chapter* two additional innovative analytical tools are presented. They generally decompose a life cycle into single items (materials) and processes (technology) which contribute to environmental burden. It is considered necessary, because raw the EPSM gives only a much aggregated result. Material decomposition is named an Environmental Bill of Materials (ENV-BOM)

and technology decomposition stands as Technology Routing. The use of these tools is illustrated in a case study with results interpretation. Results obtained can be readily used in the Environmental Performance Strategy Map to calculate Sustainable Environmental Performance Indicators (SEPI) to express the overall contribution.

The *fourth chapter* presents a solution to uncertainty issues in LCA and EPSM. Fuzzy logic is declared as suitable approach for uncertainty calculation. A case study is presented there but it is on a level which is not always easy to follow. A proper conclusions have been not delivered.

In *chapter five* all previous concepts introduced earlier in this thesis are combined in one package called E^3-methodology (Environmental End-to-End Methodology). The author now stated in the introduction of this chapter that it stands for a combination of previous models.

After a short introduction, necessary steps and algorithm of the concept is proposed, the figures used are simple and explicit. An explanation why two different steps distributions are used is needed has been provided.

E^3-Methodology, being one of the main finding of the thesis, is then applied on a complex case study. The case is a comparison of building materials in rural region of the Philippines. Materials investigated are coconut husk (coir) board and bamboo mat board. Following scope definition and technology descriptions are rather broad, but considering a large number of used data, it is utterly appropriate. The required improvements have been completed.

After the Environmental Footprints are calculated and normalized (the Environmental Map is created), SEPI detailed calculation follows. Results are finally compared as well as the importance of financial impact inclusion is proven.

Chapter six summarizes all the accomplishments. The author emphasizes the necessity of LCA results to be easily grasped and to include costs so that it can be more powerful tool for the decision makers. He was able to answer all the questions stated before the research and based on developing three main novel research results:

1. The Environmental Performance Strategy Map (EPSM) and Strategic Environmental Performance Indicator (SEPI) to support strategic decision making process,
2. The Environmental Bill of Materials (ENV-BOM) and Technology Routing to understand the single contributions,
3. The E^3-methodology to account also for uncertainty issue, to integrate all elements into one framework and provide with software tools to be used in Waste-to-Energy field.

In my opinion, the whole work is well structured in content and it is rather advantageous to introduce research concepts gradually (as it is), since they build on each other.

Questions to be answered during the defence:

- The topic of this PhD has been very fast developing research area and every month new important results are presented. Could you provide an overview of the most recent research results in your topic ?
- Who has been main authors cited your work and in which sense? What was they relation to your research? Would you present five main cases?
- Could you explain the main conclusions related to chapter four?

Typographical typos have been properly corrected and the points, which I raised covered in the presented new version.

The PhD Thesis is well written and represents an up to date approach to solve problems connected with energy and environmental problems. I recommend it to the final defence and suggest Summa cum laude outcome.

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