Product lifetime in life cycle assessment of circular strategies

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1. Introduction

Extending the lifetime of a product with, e.g., repair or reuse, is promoted as one of the key strategies of circular economy. Longer product use can reduce society's environmental impact by delaying products' replacement and thus the need for new product production. But life cycle assessments (LCA) show that lifetime extension does not systematically lead to lower environmental impacts and the extent of the benefits vary greatly with assumptions on the product lifetime. For instance, a minimum additional lifetime (i.e., the lifetime after the repair) is necessary for the repair of energy-using products to be beneficial [1]. Besides, the results can depend on how product lifetime is defined. Definitions of several types of lifetime have been developed [2]: 1) the technical lifetime when a product has the physical capacity to function and ending when the product breaks or wears out, 2) the service lifetime from the start to the end of use, and 3) the use time as the total periods during which the product is in use. Thus, product lifetime is not trivial and at the same time important for LCA results of lifetime extension. However, no guidance exists for LCA practitioners on how to express product lifetime to calculate environmental impacts, hereafter referred to as "lifetime modelling". First, there is no overview of available lifetime modelling approaches. Second, the advantages and limitations of different lifetime modelling approaches have not been compared. This study aims to fill these gaps with a review and analysis of LCAs of lifetime extension and a comparison of identified lifetime modelling options on the case of lifetime extension of a mattress by remanufacturing.

2. Materials and Methods

2.1. Overview of lifetime modelling approaches

To identify available lifetime modelling options, LCAs of lifetime extension reported in scientific literature were selected with a literature review. The search string was developed to include LCAs of lifetime extension strategies (with keywords in title, abstract and keywords such as "repair*", "reus*", "remanufactur*" or "circular*") having a focus on product lifetime ("lifetime", "lifespan", "durability", etc.). After screening the resulting 534 entries, 50 studies containing 66 cases were selected for analysis. All cases are comparing a base case to an alternative with lifetime extension. Information on the cases (i.e., the product and lifetime extension strategy under study) and on the approach used to model product lifetime in the LCA was reported. Categories of different types of approaches were then identified.

2.2. Comparison of lifetime modelling approaches

The identified lifetime modelling approaches were compared in an LCA study where remanufacturing spring mattresses by the reuse of steel springs is compared to directly recycle the mattress. The mattress represents a durable consumer product with a wide distribution of its service lifetime, ranging from users replacing the mattress only after a few years for aesthetic reasons or changed requirements (e.g., size or firmness) to users keeping the mattress over several decades. The goal of the LCA is to compare different lifetime modelling approaches, using cradle-to-grave attributional LCAs with a cut-off allocation method. Data on the product system were retrieved from academic literature [3], [4] and data on mattresses' service lifetime from a user survey from the International Sleep Products Association [5]. It was assumed that a remanufactured mattress could be used as long as a new mattress.

3. Results and Discussion

3.1. Identified lifetime modelling approaches

Modelling approaches were identified as differing over three steps: lifetime definition, modelling of the lifetime and sensitivity analysis. The identified approaches are summarised in Figure 1. The most common approach is to partition the lifetime (i.e., distinguish between initial and additional lifetime), to focus on the service lifetime of the product, expressed in years, and to model it as a single value estimated from various sources (e.g., literature, expert judgement). For the additional lifetime, modelling with no fixed value (i.e., a parameter) is also

often used as an approach requiring little data and is often complemented by a break-even analysis. A third modelling approach with a distribution over a given population sample was observed in one case.

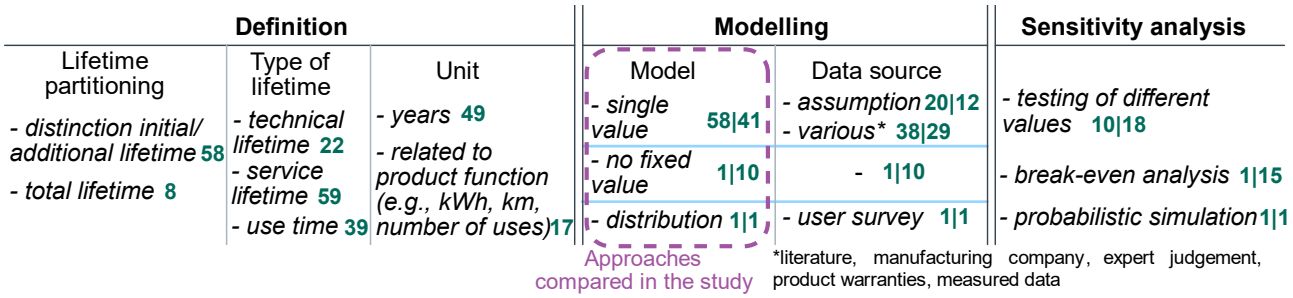

Figure 1: Summary of lifetime modelling approaches identified in the review. In green: number of cases out of 66 using this approach, eventually distinguished for the initial | additional lifetime. In purple: approaches tested in the next section.

3.2. Comparison of lifetime modelling approaches

Figure 2 presents the LCA results for global warming of a mattress with and without remanufacturing with the three identified modelling approaches in Figure 1. Each modelling approach generates different types of results from which different types of conclusions can be drawn. With the single value approach, the contribution of different life cycle stages or processes can be clearly identified for different combinations of initial and additional lifetime. With the non-fixed value approach, the evolution of the environmental performance as a function of the lifetime is shown. A range of validity and a threshold value of the necessary additional lifetime for the remanufacturing to be beneficial can also be provided with a break-even analysis. With the distribution approach, information on the average and spread of environmental impact is provided. This makes it possible to identify user groups for which lifetime extension is environmentally arguable or not.

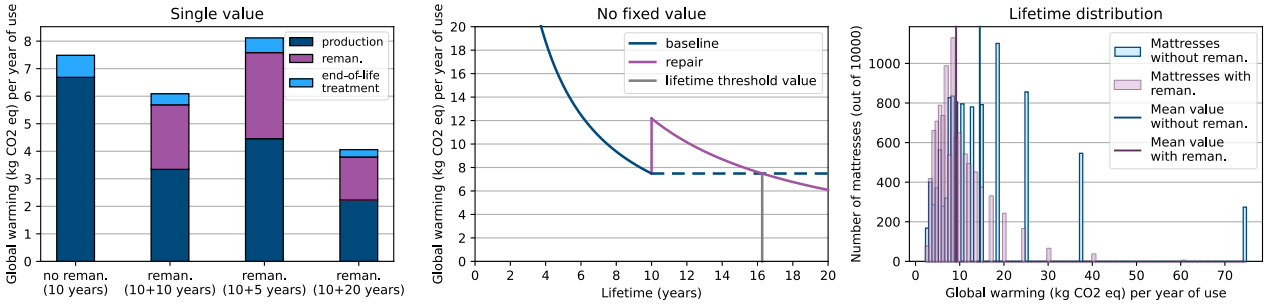

Figure 2: LCA results of a mattress with and without remanufacturing with different lifetime modelling approaches.

4. Conclusions

Product lifetime modelling for LCA of lifetime extension differs in terms of lifetime definition, modelling and type of sensitivity analysis as shown in Figure 1. The LCA results with the three identified approaches (single value, non-fixed value or distribution) provide different information on the benefits and limitations of lifetime extension, highlighting the need to adapt lifetime modelling to the goal of LCAs of lifetime extension. This study is a stepping stone in providing methodological guidance to LCA practitioners for meaningful and methodologically robust assessments of lifetime extension.

5. References

[1] A. Jerome, M. Ljunggren, and M. Janssen. 2023. Is repair of energy using products environmentally beneficial? The case of high voltage electric motors. Resour. Conserv. Recycl. 196:107038.

[2] T. Cooper. 2010. The Significance of Product Longevity. In: Longer Lasting Products, Routledge.

[3] T. Lanoë, C. L. Simões, and R. Simoes. 2013. Improving the environmental performance of bedding products by using life cycle assessment at the design stage. J. Clean. Prod. 52:155–164.

[4] D. Glew, L. C. Stringer, A. A. Acquaye, and S. McQueen-Mason. 2012. How do end of life scenarios influence the environmental impact of product supply chains? Comparing biomaterial and petrochemical products. J. Clean. Prod. 29–30:122–131.

[5] D. Perry. 2024. Mattress Replacement Cycle Drops to 8.3 Years. https://bedtimesmagazine.com/2023/02/mattress-replacement-cycle-drops-to-8-3-years/ Accessed: 30 April 2024.