Doctoral Dissertation

Doctoral Program in Environmental and Civil Engineering (31th Cycle)

Lifetime extension of products as Circular Economy strategy.

Applications in key sectors for the EU

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Abstract

The lifetime of products can be extended through different strategies, e.g. repair, reuse, second-use, which contribute to a more Circular Economy. Accordingly, resource efficiency is maximized and wastage is minimized supporting a more sustainable development. In Europe, reuse of products is attracting the interest of industries in specific sectors and new strategies to extend the lifetime of products are under development.

The extension of lifetime brings potential benefits from environmental, economic and social perspectives, even though such potential benefits have to be verified quantitatively in order to support decision-making and to define what strategies should be incentivized (e.g. design for reuse). A methodological framework to assess the environmental performances of products in a circular economy framework is still work in progress. Currently available indicators for the monitoring of circularity are not able to fully capture the potential environmental benefits of extending lifetime of products. Moreover, potential benefits of reuse strictly depend on the characteristics of the assessed product groups; therefore, the assessment should capture the characteristics of products groups under analysis.

This work contributes to the development of a methodological framework and its implementation to quantify the environmental consequences (benefits or burdens) of extending the lifetime of products in a circular economy context. To capture the complexity of assessing the extension of products lifetime through different strategies, different assessment tools are part of the developed framework and they can be combined in order to provide a wider understanding of the environmental effects of extending products' lifetime. With this aim, the knowledge of the related processes, the knowledge of technical feasibility and sector-specific data are needed. However, due to the novelty of reusing products for certain sectors and also to the existing issues on confidentiality of industrial information/practices, stakeholders should be pro-actively involved in the development of the framework. Therefore, modelling should be coupled with a structured and extensive data collection and a better understanding of the value-chain of products.

In the proposed framework, *Life Cycle Assessment* (LCA) and *Resource Efficiency Assessment of Products* (REAPro) methods are combined to assess the environmental performances of reusing products. According to the developed work, economic and social aspects importantly affect the possibility of extending the lifetime of different products; therefore, the *Environmental and Economic Assessment of Durability of Product* ("Pro-EnDurAncE") was extended to also include economic aspects.
LCA is used to provide the necessary background information of the product/service under analysis, and this is particularly relevant in case of complex systems. The development of modular LCAs and the adoption of parameters make the life-cycle model flexible to update according to available input data and to speed-up the LCAs of different products. The adoption of the same approach allow quick and consistent comparisons between environmental performances of different products/systems. Additionally, due to the fast development of the technology

especially in specific sectors, the modularity of the LCA model allows to enlarge it adding e.g. new materials and/or components.
Finally, *Material Flow Analysis* (MFA) is used to complement the assessment to also capture the potential effects of reusing products in terms of stocks and flows of products and materials. Overall, according to the assessed product sector, one or more methodological components can be combined in order to have a more complete overview of the effects of reusing products in a specific system.

The proposed metrics and framework are applied to two sectors, which are relevant for the EU both economically and environmentally: house appliances and vehicles. The most suitable assessment tools are selected and properly adapted to the sector specificities. For the assessed case-studies, modular LCAs and the adoption of parameters are used to create flexible and customizable models.
For the house appliances sector, the "Pro-EnDurAncE" method is applied to an Energy-related Product, i.e. vacuum cleaner (VC). Lack of data were addressed through the dismantling of a case-study VC and obtained primary data were used for the assessment.
Concerning vehicles, a parametrized and modular LCA model was developed in collaboration with a car manufacturer to estimate the environmental impact of vehicles, to ease the comparison between different vehicles' models and to allow the potential updatability according to the fast development of the mobility. The increasing penetration rate of electric vehicles in Europe is shifting the impacts of vehicles from the use phase to the manufacturing phase, mainly due to the electric powertrain (i.e. electric motor and traction battery); an adapted-LCA and an *ad hoc* energy modelling were used to assess the potential impacts of extending the lifetime of traction batteries in second-use applications.
To track the stocks/flows of batteries in Europe in the next decades and estimate the potential effects of extending the lifetime of batteries, a dynamic MFA model was developed according to the information gathered by the interviewed stakeholders. Parameters allow to assess different scenarios and also different aspects related to batteries, e.g. stocks and flows of storage capacity and embedded materials (in this case Co and Li).
Results of the all the performed analyses pointed out the environmental benefits of extending the lifetime of products entails some environmental benefits under certain conditions and the proposed methodological framework should be adapted to the characteristics of assessed products.

Overall, the developed methodological framework contributes to the field of resource efficiency and offers a framework to assess the environmental effects of extending the lifetime of products. Different stakeholders of the products' value-chain can adopt it to better understand the potential environmental benefits of extending the lifetime of products. The adoption of parameters in all the methodological components allow to update the analysis based on the availability of data. Multiple criteria are used to provide a more complete overview of the impacts (positive and/or negative) of complex systems. The methodological framework can be further extended to include multiple aspects and, if possible, to update models and data through a stricter collaboration with industrial stakeholders.

Keywords:

Lifetime extension; reuse; second-use; Life Cycle Assessment; resource efficiency; Material Flow Analysis; Circular Economy