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Publication date:
2015

Document Version
Early version, also known as pre-print

Citation for published version (APA):
Pizzol, M. (2015). *Does resilient mean eco-inefficient?*. Abstract from SETAC Europe 25th Annual Meeting, Barcelona, Spain.

Does resilient mean eco-inefficient?

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1. Introduction

Resilience is a property of systems that is deemed essential for their sustainability. The term “resilience” has become a buzzword in the last few years: it is used and abused in science, business, and policy. There is no clear agreement on what resilience is. According to previous studies [1], the term is used with two main meanings: ”*the amount of disturbance that an ecosystem can withstand without changing self-organized processes and structures”,* and “*the return time to a stable state following a perturbation”.* The literature agrees that resilience depends on the structure and architecture of a system. It increases with system complexity, because the redundant connections between elements of a system make it less efficient but also more flexible and adaptable and allow to perform a function even if some connections are interrupted or missing. Balancing between resilience and efficiency seems to be the key for sustainability intended as long-term perfomance. Resilience is not explicitly taken into account within life cycle assessment (LCA). LCA determines the eco-efficiency of product systems, i.e. the ratio between the function provided by the product and its impact on the environment. Therefore, it is unclear whether a product system which structure is improved or designed to be more resilient will not only be more inefficient, but also eco-inefficient, when studied by means of LCA.

2. Materials and methods

Since LCA is based on the assumption of partial equilibrium and steady state, it can’t analyze the dynamic behavior of a system and thus can not address the second definition of resilience provided above. The first definition focuses instead on the structure-disturbance relationship, and can be addressed within a static and linear framework. In this case, a two steps approach is proposed to study resilience of product systems: 1) assessment of disturbance conditions and their inclusion within the scope of the study; 2), system expansion, i.e. changing the structure of the system by including additional disturbance-preventing processes and disturbance-dependent ones. This approach is basically an application of sistem expansion according to consequential LCA modelling.

Disturbance is defined as any change in the conditions under which the system performs its function that can potentially jeopardize the entire system’s performance. The ability to respond to disturbance (i.e. the option of performance under disturbance) should explicitly be included in the functional unit, as it is part of the function provided by the system. In case of disturbance a system can not perform its function and must use some distrubance-dependent processes, thus shifting from an initial configuration A to a disturbed configuration B. The corresponding resilient system, instead, would employ some redundant and disturbance-preventing processes and keep a structure C no matter if the disturbance is occurring or not. Assuming that both disturbance and resilience are quantifiable, and combining the two states of disturbance and not disturbance, a virtual system given by $A*(1-d) + B*d$ can be imagined that is determined as a function of the probability of disturbance d. This virtual system should be compared with the resilient structure $C= f(r)$ that is determined as a function of the variable r.

This theorethical situation can be modelled with LCA, the approach has been tested on two fictional case studies using data from literature.

3. Results and discussion

The first example is the case of a remote island where waste should be shipped to mainland for treatment. A likely disturbance is a storm that impedes the transport of waste between the island and the mainland where it is incinerated. The disturbance-dependent process is the undesirable disposal to landfill in the island. The redundant disturbance-preventing process is storage of goods or waste in a transfer station. Inspiration for this model was taken from previous waste management studies [2, 3] and the system was modelled with secondary data from ecoinvent v. 3 database. Figure 1.A. shows the conditions under which the impact of the resilient system is lower than the impact of the vulnerable system.

The second example compares two biofuel refineries using one optimal feedstock, or multiple ones with lower feedstock-ethanol conversion efficiency and consequently lower eco-efficiency. The disturbance is extreme weather events reducing the provision of optimal feedstock. In that case, diesel produced via petroleum refinery (disturbance dependent-process) should be used instead of ethanol to compensate partly or fully for the missing ethanol production. The multiple-feedstock system would still be able to fully perform its function (providing ethanol) without changing structure by relying on the additional feedstock (disturbance-preventing process). This system has been modelled using data from literature [4]. Figure 1.B. shows the carbon footprint of the two systems per increasing probability of extreme weather, and the conditions under which the impact of the resilient system is lower than the impact of the vulnerable system.

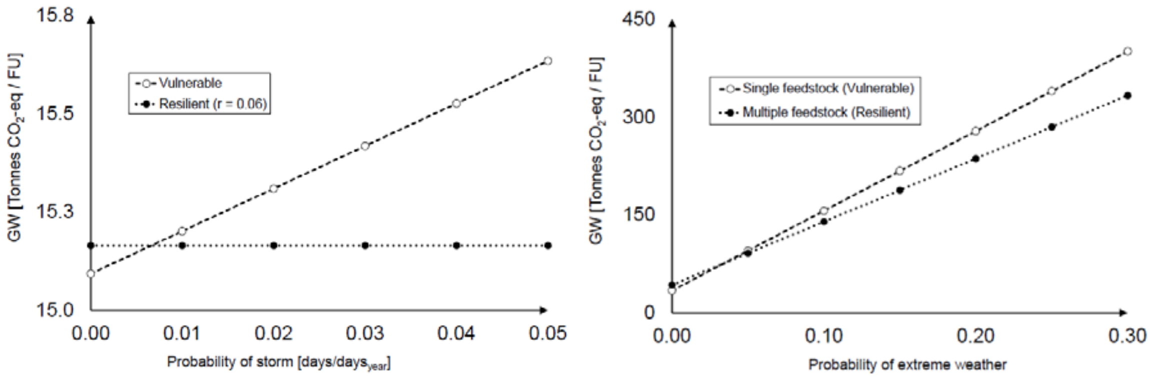

Figure 1: Carbon footprint of A) two different waste management systems of a remote island; B) two different biofuel systems: single- and multiple-feedstock.

These two simplified case studies have primarily an illustrative purpose. They show that increasing the complexity of the system to achieve higher resilience does not necessarily correspond to an increase in the overall impact of the system. This depends on the ration between the impacts of the additional disturbance-preventing process and the impacts of the disturbance-dependent process, on the probability *d* of occurrence of the disturbance, and of the resilience capacity *r* of the system.

4. Conclusions

Although LCA is probably not the best tool to study resilience, because of many intrinsic limitations and a static approach, the study showed how its modelling frametowk can be applied to study a resilient product systems. If proper LCA modelling is applied, resilient product systems are not necessarily less eco-efficient than their vulnerable counterparts and instead can allow for eco-efficiency gains. This goes against the intuitive idea that optimizing a system for efficiency only will necessarily allow achieving eco-efficiency as well, and suggests that design for resilience may be a valuable idea towards sustainability. It was outside the scope of this study to say how the variables *d* and *r* shuold be determined. A probabilistic approach has been applied but other metrics may be employed. However, a quantification of these variables seems a minimum requirement to operationalize the vague concept of resilience. Imaginary case studies have been analyzed, but more experimental work is clearly needed on the subject, that would allow drawing more robust and generalizable conclusions.

5. References

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