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Target-Driven Life Cycle Engineering: Staying within the Planetary Boundaries

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Abstract

The definition of Life Cycle Engineering has evolved from a bottom up - to an integrated approach in order to steer the LCE activities towards achieving the goals of sustainability in absolute terms. The Lyngby Framework [9] was recently proposed in order to position Life Cycle Engineering in an absolute sustainability context and bring together the top-down and bottom-up approaches so that the technological solutions developed at the product and company level become target driven as determined by the planetary boundaries. Building further on the Lyngby Framework, this paper analyses means of operationalising the concept of absolute boundaries for environmental sustainability within a company's LCE activities and discusses a number of new tools and techniques for the LCE practitioner.

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Keywords: Life Cycle Engineering; Absolute sustainability, Planetary boundaries, Eco-effectiveness

1. Life Cycle Engineering and absolute sustainability

A sustainable society meets the needs of its people without compromising the life support functions of the planet ("meeting the needs of present generations without compromising the ability of future generations to meet their own needs", Brundtland Commission report, [1]). This means that our impacts on the environment must not reach a level that exceeds its resilience and impairs the function of the exposed ecosystems. The report also introduced the point that a sustainable development at the same time must consider the environmental dimension as well as the social and economic dimensions. This inspired the concept of the triple bottom line to the corporate world, challenging companies to consider all three dimensions of sustainability and at the same time optimise the use of the economic capital, the human capital and the environmental capital [2].

The IPAT equation, based on work by Ehrlich and Holdren as well as Commoner supports an analysis of the challenge that central driving forces pose to the development of the production and consumption patterns in a future sustainable society. This equation presents the total environmental impact (I) as a function of the central drivers represented by the human population (P), the human affluence (A), representing the average material standard of living per capita, and the technology factor (T), representing the environmental impact caused by our technology per created value [3, 4]. The equation highlights the relationship between environmental impact and technology development and the challenge to engineering that lies in adequately addressing these challenges. Building from this, a number of top-down and

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bottom-up concepts have been introduced to address these grand challenges. Life Cycle Engineering (LCE) was introduced as one of the bottom-up engineering approaches in the early 1980s and a formal understanding of the LCE in the 1990s is expressed by its definition as "a systematic "cradle to grave" approach and that it "provides the most complete environmental profile of goods and services" [5, 6, 7]. Although, this original definition clearly puts environment as a priority, subsequent definitions expanded from the original focus on environmental impacts to include the economic dimension with the advent of the triple-bottom line concept, which has led to trading off the economic dimension at the expense of the environmental and social dimensions. This has introduced the concept of eco-efficiency in developing products and services (defined as the value or functionality of the product or service divided by its life cycle environmental impacts), the focus on which has enabled significant increases of eco-efficiency of many products. However, taking into account the coupling of technology (T), affluence (A) and the population growth (P), efficiency gains made during this period may well have been wiped out due to the population growth as well as the affluence increase, resulting in an increase of total environmental impact during the same period. Gutowski et al. for example show, that due to forecasted population growth and an increase in industrial emission per person, the accumulated technology- and industry-based emissions resulting in peak warming of 2°C will have been surpassed by 2020 [8]. In the meantime, it has become increasingly clear that the earth's carrying capacity is not infinite and there are limits and planetary boundaries to the earth's eco-capacity, which will be discussed further in the next section.

These developments in the understanding of the strain that our societies have put on the natural environment and the consequences that the resulting changes may have on its life support functions now and in the future are pushing stronger sustainability definitions where the social and economic dimensions are nested inside the environment rather than considered as equal dimensions to be traded off. As a result, a new LCE framework (the Lyngby Framework) has been proposed in order to position Life Cycle Engineering with respect to other concepts and approaches in the field [9]. One of the aims of the proposed framework was to bring together the top-down and bottom-up approaches so that the technological solutions developed at the product and company level become target driven as determined by the planetary boundaries (see Fig. 1).

Fig. 1 makes an explicit attempt to bridge the gap between life cycle engineering of product technologies, based on life cycle assessment, and the total impact associated with the use of these technologies in the context of an increase in affluence (consumption) and population. Thus, new product technologies need to be life cycle engineered, not only for the single product and product life cycle (technology effect), but also for the anticipated volume growth as a result of consumption and population increase (volume effect) so that the associated total environmental impact can be taken into account and addressed during the product development stage. In order to stay within the boundaries for environmental sustainability (e.g. the planetary boundaries) and achieve sustainability in absolute terms, the total environmental impact of the new product generation as the result of the combined change in eco-efficiency and market volume must not exceed the space that is available for the activity. Considering the need to reduce the overall burden for many types of impact, this often means that it has to be less than the total environmental impact of the previous generation. If this is not attainable with the current product technologies, then the eco-efficiency limits are exhausted and a new eco-effective technology solution has to be sought, meaning that the path towards sustainability may require more fundamental function and system innovation. In line with this understanding, a Life Cycle Engineering is defined as "sustainability-oriented product development activities within the scope of one to several product life cycles. The methods and tools used in life cycle engineering must support reducing the total environmental impact associated with technology change and volume increase from one product generation to another, in order to ensure that new product technologies stay within their environmental space as derived from the planetary boundaries" [9]. This definition explicitly acknowledges for the first time the necessity that LCE activities become target driven in accordance with the restrictions imposed by environmental sustainability as defined by e.g. the Planetary Boundaries. It is the aim of this paper to build further on the Hauschild et al. [9] paper and propose means of operationalising the concept of absolute boundaries for environmental sustainability within a company's LCE activities.

2. Setting targets for absolute sustainability

The Brundtland Commission's definition of a sustainable development represents an anthropocentric view on the environment – we must protect it to ensure that we will be able to meet human needs now and in the future (with a growing population and changes in consumption patterns). Central in the determination of the levels of impact that will still allow protecting the environment is the understanding of which functions are to be protected.

2.1. Determination of sustainability targets

Planetary boundaries have been proposed for the impacts from man-made activities with a suspected influence on the stability of environmental regulation systems, which have kept the global climate in an unprecedented stability since the last glaciation [10, 11].

Nine environmental processes are identified as relevant for the climate regulation and for each of them, a control variable and a threshold is identified to describe the development in the pressure and the current level of impact relative to the threshold. Considering the uncertainty accompanying the determination of the threshold, the Planetary Boundary is defined at the lower end of the uncertainty interval surrounding the threshold (See Fig. 2a and 2b).