Life Cycle Assessment (LCA) and its importance for the agricultural sector

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1. Introduction

Sustainability and as a specific aspect of it sustainable energy supply from renewable resources will be one of the top issues of society and of environmental policies in the future. Agriculture is a key driving force for renewable energy, because it is the sector which not only consumes, but also has the future potential to produce large amounts of renewable energy [1]. The call to sustain our welfare is neither new, nor an invention by the economic system. The word “sustainable” is used very often and actually is a term which deeply is anchored in the human history. The term originates from the 18th century, describing the problems of the coeval silviculture and the use of wood in the Saxonian silver mines. Hans Carl von Carlowitz, superintendent of the mines, declares formerly that only as much wood ought to be removed from the forest as grows again. He even recognized the economic and social implications of this decision. [2]

The awareness of limited resources availability, environmental problems and pollution, the increasing demand for goods, energy and materials in the already developed and in the new developing countries, as well as the increase of costs of scarce resources, are calling for a new paradigm of life, overcoming the obsolete consumerist model of modern societies [3]. In current literature, sustainability denotes a development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs [5]. It identifies three dimensions – economic, environmental and social issues – which, in regard to the characteristic of the model of sustainability, are considered equally important and standing side by side [3].

Whether a new product is to be designed or an existing one is to be improved, the process of creating distinctly more sustainable product needs to be monitored and managed. In order to address a global engineering design process, appropriate methods and tools are required. An internationally standardized tool to serve the ecological dimension of sustainability does already exist - Life Cycle Assessment (LCA) [6].

Moving on to the sector of agricultural machines the high importance for LCA is easily recognizable. Similar to passenger cars sector, where the political and technical requirements are already very high, the sector of mobile working machines is now in change [7]. The scarcity of fossil resources and raw materials, together with the rising energy costs in the last years, has brought the industry to a massive rethinking. The reduction of energy consumption and the successive use of renewable energy are one of the most important innovation topics in this industry branch. In order to fulfill the high energy requirements in the near future, extensive concepts, new structures and innovative technical approaches for increasing the total energy efficiency of the machines, as well as concepts for application of alternative, environmentally friendlier fuels, are

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needed [1]. Considering the Life Cycle of an agricultural machine LCA helps to identify environmental key factor and cost driver within the use phase, where CO_2 emissions, resulting from fuel consumption, are still very high.

2. Life Cycle Assessment (LCA)

Product related life cycle assessment with focus on energy, resource and waste was started back in the 1970s – the time of the famous report ´The Limits to Growth` addressed to the Club of Rome and the first worldwide oil crisis. As a result the finiteness of oil and respectively the vulnerability of the global economic system were realized for the first time. In the 90s Life Cycle Assessment was developed by the United Nations Environmental Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) in the Life Cycle Initiative and standardized by the International Organization for Standardization (ISO). Later on, in 2006, the standards have been slightly revised to their current version of ISO 14040 and 14044. [8]

Basic principles of any Life Cycle Assessment are the "cradle to grave" analysis and the use of a functional unit, to which all mass and energy flows, resource and land use, and even the potential impacts and probable interventions, are set in relation as a quantitative measures in order to evaluate the environmental aspect of a product system. LCA can assist decision-makers in industry by identifying opportunities for improving the environmental performance of a product and can also help government and non-government organizations by the implementation of eco-labeling and environmental product declarations.

2.1. Environmental Performance

National and International legislation is used as main driver for environmental protection. Political pressures alone will not be able to establish sustainable development. The business has to realize, that ecological responsibility should be integrated the enterprise's vision, practically meaning evaluating their environmental performance with main objective to reduce ecological impacts. The environmental profile of a product is thereby determined in dependence on five categories [9]:

- Energy use
- Material use
- Emissions in air, water and soil
- Toxic potential of used and released substances
- Compliance to environmental laws and regulations

Life Cycle Assessment (LCA) is a method to analyze environmental parameters out of these categories and across the life cycle of a product. It can systematically identify key areas to improve environmental performance and can be applied to agricultural systems.

2.2. Standardized Method

A main characteristic of the current ISO standards 14040 and 14044 is the clear framework which consists in the four components: "Goal and Scope Definition", "Inventory analysis", "Impact Assessment" and "Interpretation" [6] [10].

Goal and the Scope Definition

The definition of the goal and the scope of any LCA is crucial, since this is the phase of essential determinations. According to the aims and the insight interest, the survey framework is defined and the demands on the further phases are determined. This may concern the intensity of the survey, the necessary quality of the data, the selection of the effect parameters with regard to the impact assessment, and the interpretive possibilities within the framework of the evaluation. [8]

Inventory Analysis

In the inventory analysis, the material and energy flows are grasped and listed during their entire life. In a first step, process structures are modeled in order to have a basis for assembling data. The material and energy flows are determined as input-/output-sizes for every partial process with regard to the system boundary. By connecting all partial processes, the relations between the modules and the environment are represented, and the mass/energy balance is drawn up as the inventory of the total system. All material and energy streams which pass the system borders are listed as quantities in physical units. The data refer to the functional unit. [8]

Impact Assessment

The task of the impact assessment is the evaluation of the material and energy flows raised in the inventory analysis according to certain environmental effects. Thus, the impact assessment serves the recognition, summarization, and quantification of the potential environmental effects of the examined systems and delivers essential information for the evaluation. The following impact categories are usually included into a LCA:

- Global warming Potential (GWP)
- (Stratospheric) ozone depletion (ODP)
- (Tropospheric) photochemical ozone creation (POCP)
- Acidification (AP)
- Eutrophication (NP)
- Human toxicity (HTP)
- Ecotoxicity (ETP)
- Land use

The impact categories describe potential effects on human and environment. Among other things, they differ according to their spatial references (global, regional and local effects). In principle, every environmental effect can be included into the survey, as long as the necessary data and a suitable model for the description and parameterization of the effect are available. [8]

Interpretation

The task of the interpretation step is the analysis of the results as well as the explanation of the meaningfulness and the restrictions. The essential facts, based on the results of the inventory analysis and the impact assessment, are to be determined and checked with regard to their completeness, sensitivity, and consistency of the results. The assumptions made in the phase of the goal and scope definition have to be considered. Based on this, conclusions have to be drawn and recommendations are to be made. [8]

2.3. Example: Life Cycle Assessment of a Tire

In a Life Cycle Assessment the effects of a product on the environment is captured and evaluated under ecological point of view. In this example [11] the whole life cycle of an automobile tire is investigated, starting from the extraction of mineral and fossil natural resources, throughout the production of raw materials for the tire, the production of the tire itself and its use phase, until the utilization of the old tires as a raw material or an energy source. The assessment is performed conformable to the ISO 14040 standard.

Among the goals of the original study one is particularly interesting for this article, namely finding out the phase or phases of the tire’s life with biggest environmental impact. Due to the many parameters taken into account within the LCA one could not expect that a general domination of a phase will be present in regard to all parameters. For example biggest environmental pollution of the atmosphere in caused within the use phase, and of the waste water within the raw material extraction phase. Despite that a summary comparison can be accomplished taking the accumulated energy demand and the different environmental potentials as a basis.

As shown in **Figure** 1, the use phase dominates in all categories with highest impact on the environment, followed, with a big difference, by the raw material extraction phase. Therefore the largest potentials for reduction of the environmental pollutions are located within the use phase of the tire.

Likewise, the biggest amount of the Global Warming Potential (GWP) of many products, including any mobile working machine, is generated during use phase, while the total GWP is defined mainly during the design phase of the product.

3. Example for reducing the Global Warming Potential (GWP) of Ag Machinery

The GWP of mobile working machines is mainly generated during its use phase, while the GWP the product is defined mainly during the design phase has been driving agricultural and construction machinery industry to design solutions with special focus on environmental efficiency. With these solutions the "agricultural and construction machinery users are key contributors to the achievement of a globally competitive sustainable business sector. Fuel is one of the highest input costs the sector faces and therefore there is constant pressure on machinery manufacturers to achieve efficiency improvements which result in a reduction in fuel consumption and consequent reduction in CO_2 emissions" [12]. Accordingly, there will stay a strong pressure from society and policy makers onto agricultural manufacturing industry to further reduction of environmental (and social) impact of machinery.

Table 1 gives an estimation for energy reduction potentials in agriculture: Column II gives the values for energy input or energy equivalence of fertilizer, plant protection chemicals (PPC) and seeds for a 100 ha farm in South West Germany (rounded for crop rotation Rapeseed, Wheat, Sugar beet and Maize; ploughless). Column III shows measures to achieve a reduction of energy usage and column IV gives a rough estimate for potential energy savings. It is obvious that the biggest saving potentials for energy consumption are achievable by renewable energies sources replacing fossile fuels (drive train) and by more accurate handling of mineral fertilizers (high-lighted yellow fields). As looking dor PPC shows it is further obvious that energy consumption and related CO_2 emissions is not exclusively relevant but at least one important factor of sustainability.

In general, wind, sun, and biomass are renewable energy sources that will power the agriculture of tomorrow. Very high efficiency as well as a very high reduction of CO_2 emissions can be realized by a closed cycle of energy production and its consumption in combination with the exclusive use of renewable sources. Pure vegetable oil is a highly promising renewable fuel source, especially in agricultural applications [12] [14] [15]. Besides the obviously broad ecological benefits due to the carbon footprint, pure vegetable oil offers an enormous potential for agricultural farms in the field of energy production within the lifecycle view of LCA. This is especially true in decentralized supply chains [12] [15], where a self supply with this biofuel can be realized without difficulty. As an enabler for self supply of fuel on farms, pure plant oil is promising a significant customer value. To enable the use of such cold pressed vegetable oil fuels, modern engines have to be adapted and the fuel itself has to fulfill some strict quality requirements in order to ensure a reliable long term operation of the engines [15].

The environmental effect is quite large. The decentralized production of vegetable oil fuel implies the reduction of approximately 60% of greenhouse gas emissions (GHGE) compared to fossil diesel fuels [16].The self supply with vegetable oil fuel will require only about 10% (or even less) of a farmer's acreage. This is a similar ratio as was used in pre-industrial times for the production of feed for draft animals. Knowing that Europe is importing 80% of its required plant proteins, the vegetable oil production can be seen the other way round. When pressing the oil seeds, only one third of it will be retrieved as oil. Two thirds of the seeds will be the press cake, which is a protein feed that can replace protein imports, for example soya from the American continent. Thus the oil can be seen as a by-product of the more and more relevant protein production, see Fig. 2. Here, one could even consider the social aspect of sustainability, which due its abstract nature is not yet to be evaluated by a particular method, and make the assumption, that it will not be compromised trough excessive use of land territories for production of fuel instead of food.

Thus, the usage of Vegetable Oil Fuel improves the environmental performance within the use phase. A holistic approach for an environmental optimization has to start in the early lifecycle phases, when the physical product does not yet exist. The availability of options for improvement, which promise much greater effect, is much higher within the product development phase compared to the others life cycle phases. A holistic approach within a full LCA could also deliver reliable information on economical and social impact of solutions like vegetable oil fuels and many other such as seen and developed by the agricultural and construction machinery industry [12].

4. Beyond Life Cycle Assessment

One of the guiding principles for engineering design is to develop products that are conforming to environmental protection and to promote the sustainability paradigm. Already in the early phases of the product lifecycle, the engineer defines key properties of a product, implicitly including the definition of the resulting lifecycle costs as well as environmental and social effects. Industry and research are challenged to provide tools to handle the already enormous complexity in the process of product development and consider other aspects such as environmental influences. Product Lifecycle Management (PLM) [17] is gratefully assisting the engineering and is proposed to be one key concept for the establishment of sustainable engineering design processes.

4.1. Product Lifecycle Management

In order to manage an engineering design process and handle the product complexity the engineer has to administrate all kinds of data and information about the product. This would not be possible without using modern IT tools. The use of IT tools for support of the integration and federation of distributed product data and their related processes, as well as the administration of a high number of product variants have already been recognized as driving factors for success, survival and competitiveness. Product Lifecycle Management is the administrative and managing backbone for all these tasks in product engineering [17]. It offers a solution to systematize the various operational tasks in design and production so that processes are rationalized and optimized. The concept is concerned with both: the product and the engineering processes [17]. The aim consists in supporting product data generating and manipulating processes in a multidisciplinary, federated and integrated way, as it is shown in F**igure 3**.

“Integrated” means that IT solutions have to handle the whole product lifecycle beginning with the first idea up to the recycling. The “federated” component calls for an engineering collaboration in distributed enterprises as well as within suppliers, customers or even the whole supply chain. “Multidisciplinary” refers to the cooperation of different disciplines or specialized divisions which are involved in the product development. [17]

Product Lifecycle Management represents a concept rather than a monolithic IT-System. Its core components are Product Data Management to describe the product structure and Workflow Management which is respectively responsible to describe the product related information throughout the lifecycle and for modeling the deployment of enterprise business processes. One benefit of computer aided engineering design is that it facilitates the development of sustainable products by a better availability of relevant information. Even as early as today, a computer aided lifecycle assessment with an automatic calculation and monitoring of energy and material flows caused by the processes of the product and the linkage with conventional lifecycle databases could be customized. Therefore, the product structure - available in a Product Data Management (PDM) system - has to be extended with lifecycle processes like production, transport, use and end-of-life processes. Product Lifecycle Management solutions offer first answers to these problems by linkage to tools for Life Cycle Assessment (LCA) [2]. A first step towards an integrated sustainability assessment provides the link between economic and ecological issues and is represented in the new international standard ISO 14045 - Eco-efficiency assessment of product systems: principles, requirements and guidelines, adopted in 2012 [18]. A holistic Product Lifecycle Management approach has to take into account such an integrated view of an environmentally friendly, economically viable and socially acceptable sustainable product.

4.2. Sustainability

The standard model to quantify sustainability used by industry is the interpretation with three pillars. It is also called "The Triple Bottom Line Model" founded by Elkington [19]. Economic, environmental and social aspects are the three classes for the differentiation. In an assessment of sustainability, all of the dimensions have to be checked against each other. But this interpretation of sustainability appears to be problematic and it is animadverted in sciences.

The engineering mechanics would call the system of three pillars over-determined. Apparent from the drawing (a), one pillar could be removed without influencing the structural stability. The structure shows that a model with single, segregate and parallel pillars is not capable to show the complex interactions between the dimensions of the 21st century paradigm dimensions [20]. In (b) the pillars are moved in space. Now each pillar is necessary for the structural stability of the construct. In an equilateral triangle, with the corners ecology, economy and society, all of the target-dimensions are on an equal footing in a discussion [20]. According to the guiding principle, a sustainable monitoring has to consider aspects of all dimensions in the same manner [3] [4].

The Integrated Sustainability Triangle, originally introduced as a promising new possibility of quantification and monitoring the Sustainable Development of a national economy, is also an appropriate instrument for systemization of the sustainability performance of a company and currently for monitoring the product development process regarding sustainability management [2]. It is above all a graphical representation of actions and achievements, based on the three dimensions of sustainability: economy, ecology and society [3] [4]. The segments of the Integrated Sustainability Triangle are shown in the following **Figure 5**.

After some years of intensive discussions at an international level, several indicator catalogs are now available, even for the development of a sustainable product [20]. Many of these catalogs are arranged in the three dimensions of Sustainable Development as well as being differentiated according to both mandatory and optional, perhaps company specific indicators. Hence, there is no generally valid set of indicators. However, a foundation of important indicators does exist that enjoys wide acceptance today. Thus, in the field of ecological sustainability LCA is one adopted method to quantify the performance.

5. Conclusion

Within the life cycle more than 2/3 of the Global Warming Potential (GWP) of any mobile working machine is generated during the use phase. However, the total GWP of any machine is mainly determined in the design phase. Therefore, equipment developers can deduct appropriate measures or improvement fields within the product development to reduce CO_2 emissions later on.

As result, a paradigm change occurred but a holistic approach is to be claimed. Life Cycle Assessment (LCA) is a powerful tool to support product development and lifecycle engineering, which is to become a part of Product Lifecycle Management (PLM). [3] With the increasing importance of Design for Environment due to the scarcity of resources and stricter requirements on products a close collaboration between design and environmental engineers is needed. Therefore LCA tools will become fully integrated in the PLM solution, meaning that relevant product data will be shared across all modules of the PLM and authoring systems infrastructure and limitation on data availability will come only from user related permission restrictions. Product Lifecycle Management does not provide innovative products, but with linkage to LCA it is a concept that can support the administrative level by connecting knowledge. Thus it seeks to provide the right information at the right time in the right context for developing future sustainable products.

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Figure 1 - Relative comparison of energy consumption and different impact potentials in the phases of the tire's life [11]

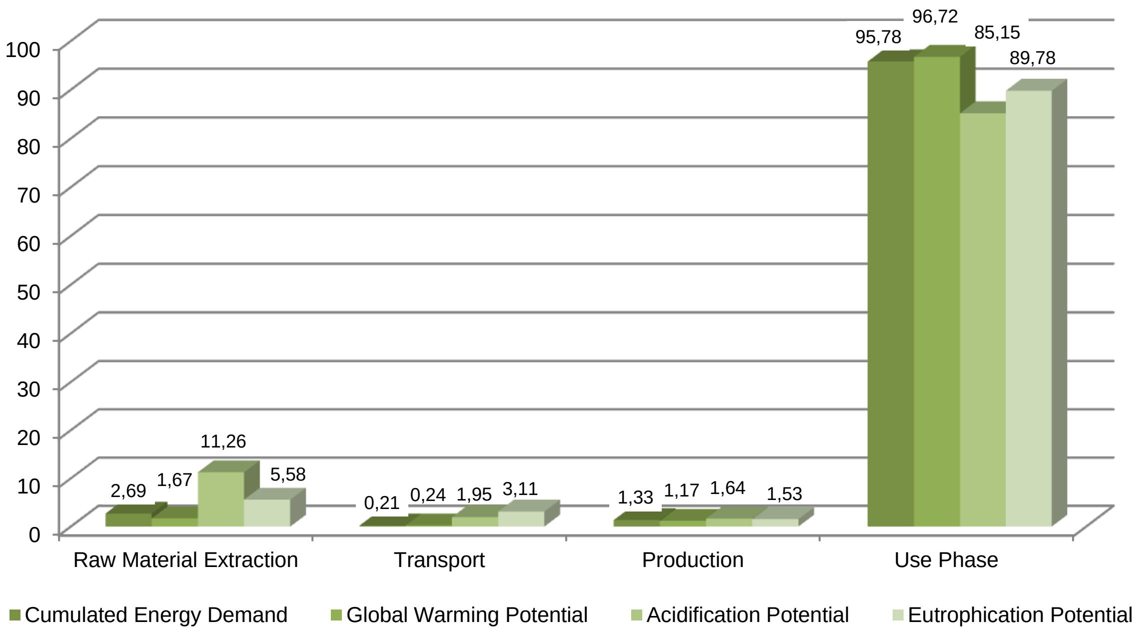

Figure 2 - Usage of the whole seed for food and fuel

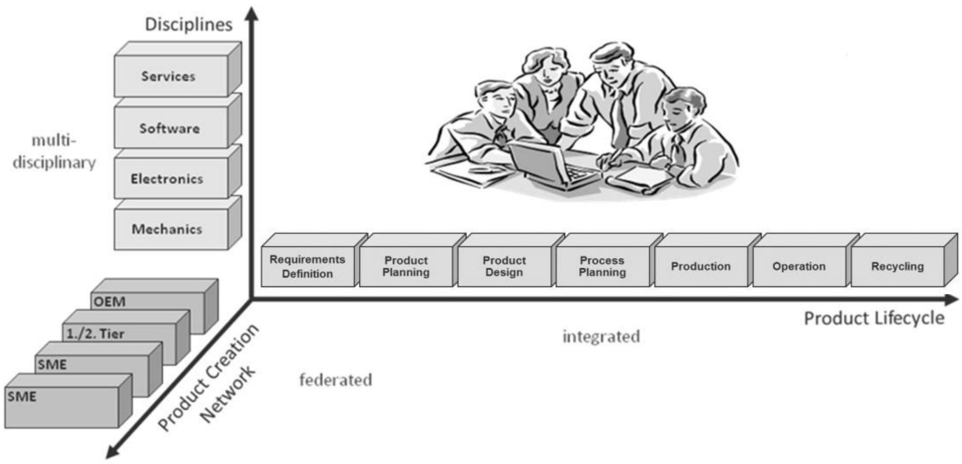

Figure 3 - Dimensions influencing enterprises in product development processes today. [17].

Figure 4 - The three pillars of sustainability in a not long lasting conception on the left (a) and in a long lasting conception on the right (b) (adapted from [20]).

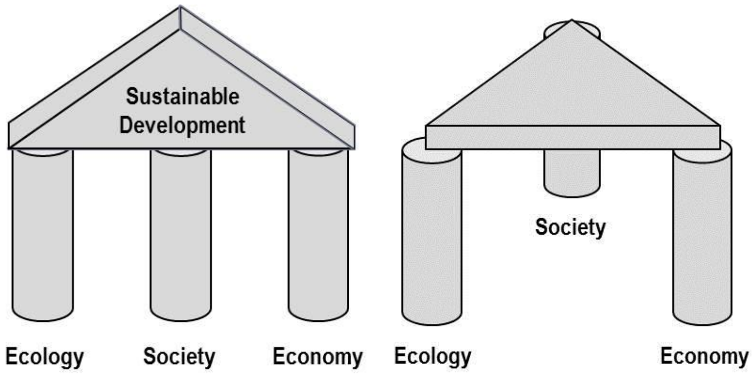

Figure 5 - Subdividing the fields of economical, ecological and social relevancies in the Integrated Sustainability Triangle (adapted from [4] first [20]).

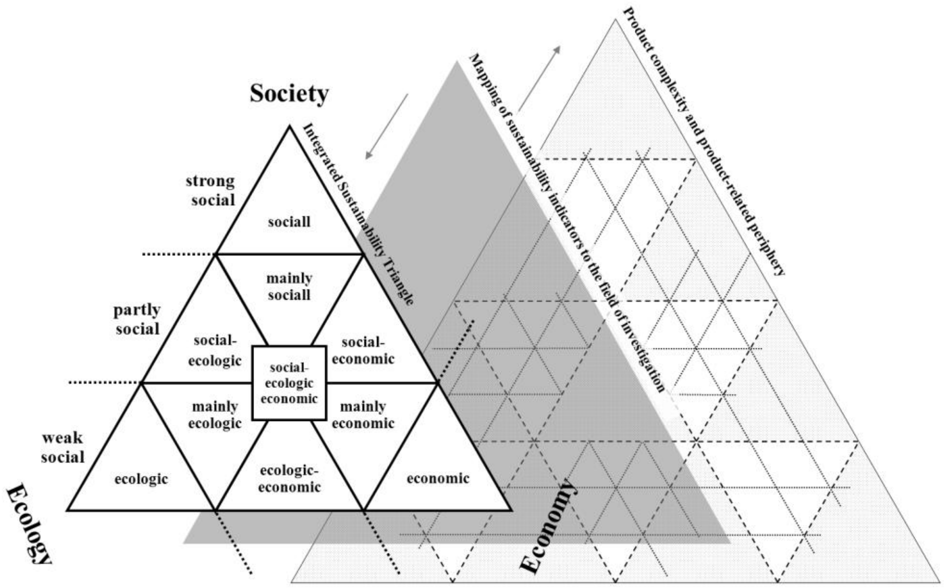

Table 1 - Estimated CO_2 reduction potentials in Agriculture (*) data in Col. II from [13] based on KTBL

	II Energetic inp. (MJ/ha/a) (*)	**III** Savings by	**IV** Estimated potential CO_2 reduction
Drive train	3000	Higher efficiency	35 % (on long term)
		Renewable energy	≥60 %
Fertilizer (N, P, K, S)	10000	Automation, Precision	20 %
PPC, seeds	400	Automation, Precision	