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# Opportunities and Limits In The Application Of The Life Cycle Assessment (LCA) Method Adopted To Pulp Demanded By the German Paper Production Industry

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**ABSTRACT**

The Life Cycle Assessment (LCA) approach is the most important tool in the evaluation of environmental (sustainability) impacts of products and processes. We used the method to conduct an impact analysis with regard to raw material inputs (pulp) for the German paper production industry. In our analysis, we compare the environmental effects of primary sulphate pulp, scrap paper pulp and grass-based pulp and estimate their impacts in the impact categories "greenhouse gas emissions", "eutrophication" as well as "energy and water consumption". Furthermore, we discuss the opportunities of the methodical approach and some general problems and limits of the application of a LCA. In conclusion, we found environmental advantages for the use of grass as an alternative resource in the German paper production industry, especially in the fields of transport and water consumption.

*Keywords: Life Cycle Assessment (LCA); grass-based pulp; German paper production industry; sustainable development; environmental impact analysis; methodical limits of LCA*

**Introduction**

Currently, we observe a broad discussion in academia and business regarding the possibilities of application of alternative resources and raw materials. One of the objectives is the efficient use of non-renewable resources or their (partial) substitution or supplement with regenerative resources. In our study, we examined the ecological impact of raw materials throughout the international value chains regarding pulp as input for the German paper production industry. We used the Life Cycle Assessment (LCA) approach and its sub-methods, to evaluate the environmental impacts of our subjected raw materials, since LCA methods are the most important and appropriate tools in the evaluation of environmental (sustainability) impacts of products and processes.

According to data of the German Paper Industry Association (VDP), the German paper production industry produced about 22.6 million tons of paper products in 2016, what made the processing of around 4.5 million tons of raw material (pulp) necessary. The produced amount equals a moderate increase compared to 2015 of 0.1% and was used for the production of paper and paperboard (50.3%), graphic paper (36.9%), tissue paper (6.7%) and for technical and special use (6.1%). In 2016, 76% of the pulp was imported caused by the high demand of short-fibred pulp from, for instance, eucalyptus. In contrast to previous studies in the field of the ecological evaluation of grass as input for paper production, we consider a far broader range of countries of origin



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(i.e. Brazil, Finland, Sweden, Portugal, Chile, Uruguay and Spain) in our investigation of the value chains. The necessity for short-fibred pulp from these countries results in long transport routes for raw material and therefore affects their ecological balance. Besides primary pulp, 16.9 million tons of scrap paper pulp was used in Germany in 2016. Unlike primary sulphate pulp, these raw materials are mainly recovered from German sources (94%) or the sources of direct neighbors (e.g. The Netherlands, Poland or France). Moreover, the grass-based pulp investigated in our study was extracted from compensation areas within a 50 km range of the respective paper production facility. This had strong implications for the respective value chain and economic and ecologic transport costs.

A valid application of the LCA method requires available, adequate and tailored data, which have to be collected through different channels. Based on this insight, our study does not only show an application to a practical environmental issue within the pulp production and German paper production industries, but shades light on the data quality necessary for an analysis and on the informative value of the method in general. Finally, our goal was to examine the ecological impacts of primary sulphate pulp, scrap paper pulp and grass-based pulp and to compare them in different environmental impact categories. In the frame of the LCA, we define the functional unit as one ton of paper manufactured in Germany. This meant, that for the production of one ton of paper, 2.2 tons of wood (primary sulphate pulp), 1.25 tons of scrap paper pulp (plus 5% of primary sulphate pulp) and 1.07 tons of grass-based pulp were used.

**Assessment**

We adopted the method of LCA to compare the most essential parts of the value chains for the three different and aforementioned inputs, which are vital for paper production: primary sulphate pulp, scrap paper pulp and pulp based on grass. After initial definitions of purpose, functional unit and system boundaries of the analysis according to ISO 14040 (Life Cycle Assessment – principles and framework) and ISO 14044 (Life Cycle Assessment – requirements and guidelines), a breakdown and deep understanding of the operating modes of the German paper production industry and the associated global value chains was crucial. For modelling the value chains, every step between the exploitation of raw materials and the transport to the production facility ("Cradle-to-Gate") was taken into consideration. This includes processing, wood treatment, drying, (chemical) bleaching, different phases of transport, power generation, storage, wastewater treatment, refinement and deinking. Upstream processes like planting and growing or the manufacturing of primary or intermediate products as well as infrastructure (e.g. road construction, shipbuilding) were not part of the analysis.

For quantification purposes, we use databases of the German Paper Industry Association (VDP), the World Trade Organization (WTO), the Statistical Office of the European Union (Eurostat), different national statistical offices and industry associations as well as ecoinvent v3.3 and data of the German Federal Environmental Agency (ProBas). From these sources and own calculations, we were able to define an average tree used in our examination, that is 2.2 tons heavy, has a volume of 3.3 cubic meters and consists of raw material from South America (49%), Northern (45%) and Southern Europe (6%) as well small proportions from other regions. The estimation of local circumstances are based on information from for instance German pulp mills, German Federal and State Ministries, the Asociacion Tecnica de la Celulosa y el Papel (Chile), Department for Research and Economic Studies (Brazil), Stora Enso (Finland), the Swedish Forest Industries Federation (Sweden) and the American Forest & Paper Association or Wood Resources International (US).

In the following, we present our analysis for grass-based pulp in detail as an exemplary presentation of our methodical approach. In our case, the raw material grass was extracted from non-used agricultural compensation areas at the Swabian Mountains in Germany. We assumed an annual harvest yield of five tons dry mass per hectares from unfertilized meadows, which is an average for comparable areas in Germany. The grass is mowed two times a year, turned, collected and balled for transport to the respective paper production facility within a 50 km range. Vehicles with an overall capacity of about 20 tons carry out the transport, whereas the total route of 100 km includes deviations and empty journeys. For instance, the transport route of pulp in form



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of either logs, wood chips or processed pulp by ship, train and truck is 14,000 ton kilometers on average. In our model, we include all transport efforts from cradle to gate. At the gate, the pellet machine, which is located on site at the paper production facility, is responsible for bringing the grass resource into a suitable form for processing. At the very last transport step, a forklift is used for moving the pellets from the pellet machine to the actual paper production facility (see Fig. 1).

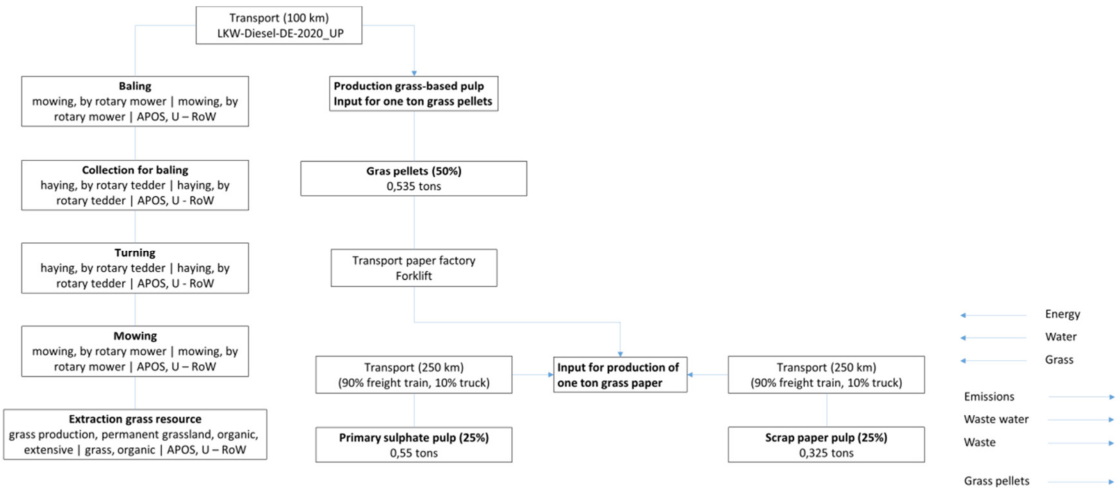


*Figure 1: Product system for grass-based pulp (own illustration).*

The pellet machine needs the energy of 134 kWh and two liter of water for the production of one ton of grass pellets. As outlined in Fig. 1, we assumed that the final paper product consists of 50% grass pellets, 25% primary sulphate pulp and 25% scrap paper pulp, whereas an input of 1.07 tons of grass pellets is necessary for the production of one ton of paper.

**Limits**

Any LCA is strongly reliant on adequate data. For some cases, like transport routes, information and environmental impacts could be estimated "by hand". However, for most of the processes internationally recognized databases have to be chosen. The information, inputs and outputs of processes are stored from individual or organizational research and underlying several assumptions, which literally cannot be proven always and in any detail in the process of the LCA preparation. Furthermore, database information often do not fit into the desired period or geography and therefore have to be modified. Any LCA is foremost delimited by the assumptions of value chains and the quality of the data used to represent them. For instance, the selection of equivalent emissions (e.g. equivalent to carbon dioxide) and conversion factors strongly affects the environmental impact analysis. For instance, we used a conversion factor of 25 from methane to carbon dioxide equivalent. To adapt available LCA databases, which provide basic information, we used additional country-specific, transport, trade- and material-flows, technology, forestry and land use data. Such "tailored data" allows for a more precise LCA, since we add explanatory content, but we face the risk of adding both additional (unknown) assumptions and (unobservable) errors to our model. In conclusion, a strong and clear model of value chains is essential to minimize biases.

**Results**

The LCA gave us the possibility to value the environmental impact of the objects of investigation. Subsequent to our analysis (see Fig. 1) of paper and pulp production processes, the global supply and value chains and the impact assessment phase (greenhouse gas emissions, eutrophication, energy and water consumption), we could detect environmental advantages with the usage of grass pellets. Compared to primary sulphate pulp and scrap paper pulp, the main advantages of grass-based pulp lie in the fields of transport (i.e. much shorter transport routes) as well as superior water and energy balances and consumption figures. For instance, grass-based pulp causes only 26% of $CO_2$ emissions, requires 16.000 times less water and its eutrophication potential



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is 18 times smaller than during exploitation, transport and the production process of primary sulphate pulp. The detailed results for the impact categories are plotted below (Fig. 2-4). The calculation of the anthropogenic greenhouse effect, the additional temperature increase beyond the natural greenhouse effect caused by human activity, and the respective carbon emissions consists of the greenhouse gases carbon dioxide ($CO_2$), methane (25x $CO_2$-equiv.) and nitrous oxide (300x $CO_2$-equiv.). For instance, we observed carbon emissions of 351.78 kg/ton for primary sulphate pulp and respective raw material, 119.98 kg/ton for scrap paper and 74.23 kg/ton for grass. By far the highest emissions of carbon and sulphur dioxide as well as energy consumption occurred throughout the course of transport of primary sulphate pulp and respective raw material.

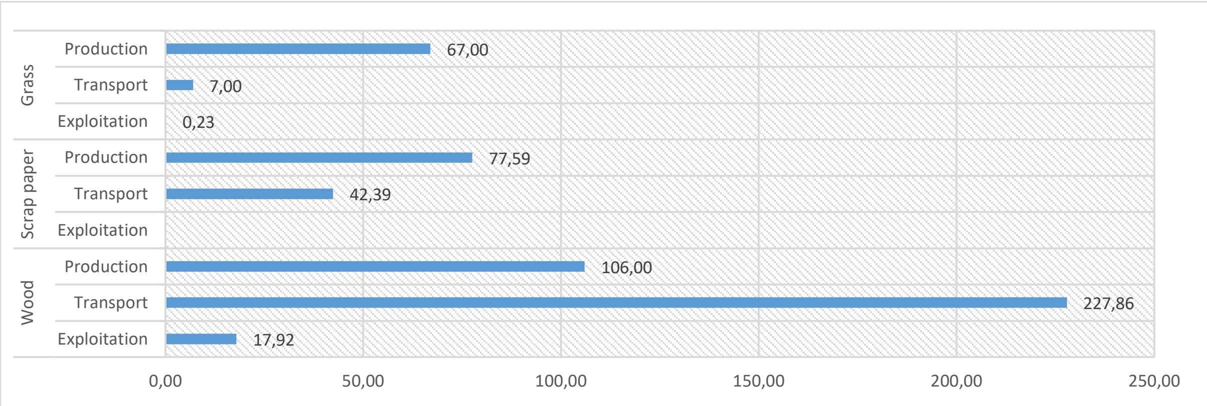


*Figure 2: Carbon emissions (kg/ton) for wood, scrap paper and grass (own illustration).*

The energy consumption during the processing comprises of the usage of machinery, heat generation and other electrical devices. Moreover, we include the generation of on-site power.

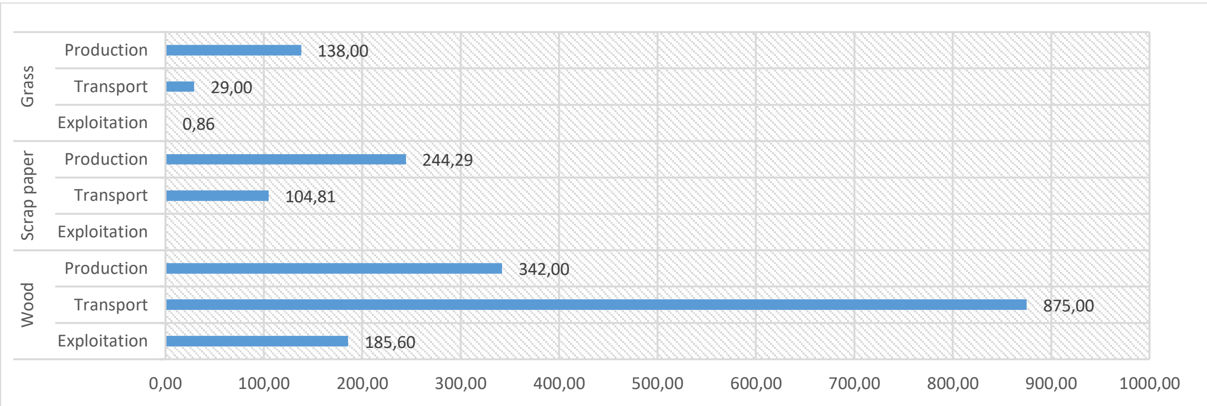


*Figure 3: Energy consumption (kWh/ton) for wood, scrap paper and grass (own illustration).*

Eutrophication means the decrease of the pH-value in soil and water bodies, mainly caused by air pollution through combustion and (undesired) nutrient inputs, for instance due to agricultural activity and fertilization. Besides sulphur dioxide ($SO_2$), we reviewed nitrogen oxide (0.7x $SO_2$-equiv.) and ammonium (1.88x $SO_2$-equiv.) and used them within our calculation.



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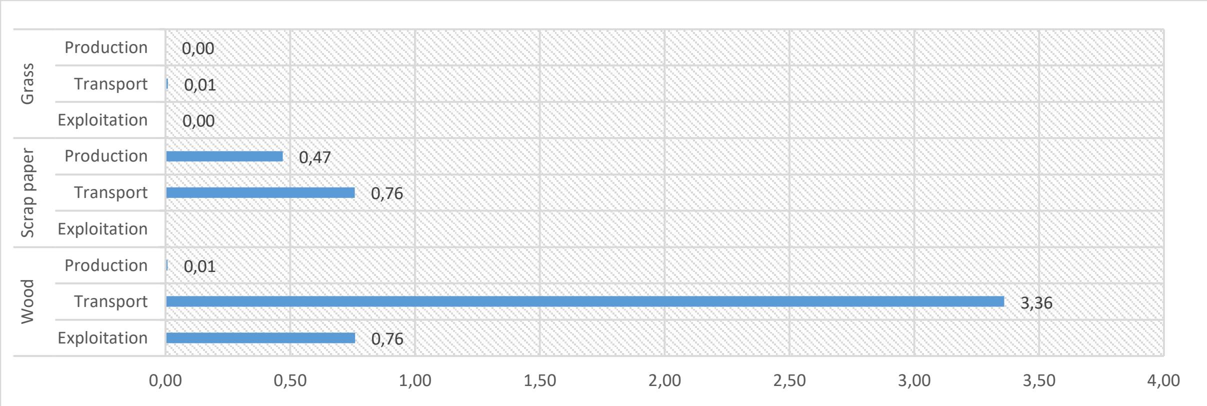


*Figure 4: Eutrophication (sulphur dioxide equivalent) for wood, scrap paper and grass (own illustration).*

**Conclusion**

The method of Life Cycle Assessment worked well with complex environmental issues in product value chains, but the underlying data needed to be modified during the analysis. Although information taken from official statistical offices, industry associations, industry databases and science provide first indications, we adjust a substantial part of them for our purposes. As long as the process of modification is transparent and comprehensible, there is absolutely no problem for the explanatory power of the LCA in doing so. Quite the contrary, without adjustments we would not be able to meet the requirements of our analysis with regard to the input resources, the global value chains and the characteristics of the German paper production industry. Having this in mind, our model provided us with the findings already outlined above. We found, that the usage of grass as a natural and regional input for paper production is a reasonable way to improve the ecological balance of the final product and reduces the environmental impacts (regarding greenhouse gas emissions and eutrophication) during the course of the value chain and final consumption, especially of energy and water.

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