Review of existing LCA studies on the recycling and disposal of paper and cardboard - DTU Orbit (29/11/2018)

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The present study has been prepared by the ETC/WMF for the European Commission as an input to the process of elaborating the Thematic Strategy on the Prevention and Recycling of Waste. During the debate on the Thematic Strategy, a need has been identified for clarifying the relevance of the results from various sometimes conflicting LCA-based and CBA-based studies that have been published on recycling of paper and comparison of recycling with other recovery or disposal-based processes. The objective of the present study has been to identify and subsequently to make a critical review of existing LCA studies covering alternative disposal/recovery options for paper and cardboard. It has also been the aim of the study to identify and assess the system parameters and boundary assumptions that have been most decisive for the conclusions obtained in the LCA studies analysed, since there are many methodological issues involved in carrying out such a study. Variations in the outcome of an LCA can be due to methodological issues (e.g. LCA goal and scope definition, definition of the system boundaries, weighting, impact categories selected) or determined by the geographical characteristics/constraints of the region covered by the LCA. A total of nine LCA case studies containing altogether 73 scenarios have been selected from a thorough literature search. The selected studies are primarily comparative LCAs including different management options for waste paper. The nine studies have been selected on the basis of a combination of selection criteria, including e.g. compliance with international LCA methodology standards, the perspective adopted by the study (company/society), the time frame (long term/short term), the year of the study, and the type of paper/cardboard. The life cycle of paper is characterised by a number of system parameters and boundary assumptions, which not all LCAs include. These parameters and assumptions should cover all essential activities/processes in the technosphere affected by the choice, including secondary services such as generation of energy from wood residues and paper incineration, forestry services, and parallel services provided by the existing waste management systems.

Comparative LCAs should, as far as possible, include such services in order to describe correctly the environmental consequences occurring when choosing one alternative over the other. These parameters and assumptions are needed to ensure that the two or more systems to be compared are actually fully comparable. The present project has included a systematic exploration of the key system boundary criteria that can have an influence on the result of a comparative paper LCA. This exploration has resulted in the identification of 15 key assumptions, covering the three paper cycle system areas of raw materials and forestry, paper production, and disposal/recovery: 1Is the alternative use of land/wood included? 2Is the saved wood used for energy production? 3Is wood considered a scarce resource, and what is then the wood marginal? 4Which is the marginal energy source for the electricity used in virgin paper production? 5Which is the marginal energy source for the heat (steam) used in virgin paper production? 6Which is the marginal energy source for the electricity used in recycled paper production? 7Which is the marginal energy source for the heat (steam) used in recycled paper production? 8Is the energy export from virgin paper production included? 9Which is the main alternative to recycling: incineration or landfilling? 10Are the emissions from paper landfilling included? 11Does the thermal energy produced from incineration substitute other sources? 12Does the electricity produced from incineration substitute electricity from the grid? 13Are the alternative uses of incineration & landfilling capacity included? 14In which ratio does recycled paper substitute virgin paper? 15Is the handling of rejects and de-inking waste from paper recovery included? The results of the 73 scenarios have been classified and presented as a function of the 15 key assumptions identified. The overall results of the LCA studies indicate that recycling of waste paper has a lower environmental impact than the alternatives of landfilling or incineration. The result is very clear in the comparison of recycling vs. landfilling, and less pronounced but also clear in the comparison of recycling vs. incineration. The results obtained refute one of the hypotheses motivating the present study, namely that the results of existing paper LCA studies were very different. The LCA studies analysed, selected from existing literature on the basis of a set of quality criteria, to a wide extent arrive at similar results. Some differences are observed, however. These differences are not found to be due to actual differences in the environmental impacts from the paper systems studied, but rather to differences in the applied LCA methodology and especially the definition of the paper system and its boundaries. The differences observed in some of the studies, therefore, are not believed to be the result of conscious methodological choices, but rather to unawareness about the need to include and justify certain assumptions in a comparative LCA. The outcome of comparative LCAs on paper production depends on the choices made in some of the 15 key assumptions identified. The most important of these assumptions are: 2The assumption of the energy and material marginals for wood, and the alternative uses of wood and forest land. If an alternative use of wood other than the use for paper production is included in an LCA, or if wood is considered to have a fossil fuel marginal, all LCA studies analysed show preference to paper recycling no matter what other assumptions were made. 3The assumption of the electricity marginal for virgin paper production. If the electricity used for virgin paper production is assumed V as in almost all cases it should be V to be based on fossil fuel and not hydropower, the vast majority of the analysed LCA studies show that paper recycling is more favourable than both landfilling and incineration. 4The assumption of substitution of electricity from incineration of paper. If it is assumed that no electricity is produced at waste incineration plants and accordingly electricity does not substitute electricity from the grid, paper incineration almost never turns out to be favourable. 5The assumption of alternative use of incineration capacity. If it is assumed that an increase of paper recycling releases some incineration capacity, and it is assumed that this capacity is used to incinerate waste that would otherwise have been landfilld, then in almost all cases assessed this implies that the results of the LCA are in favour of paper recycling. LCAs on paper depend also on a series of data that are linked to the geographical conditions of the region analysed. It is estimated that most geographical boundary conditions that can potentially influence the result of an LCA, are included in one or more of the 15 assumptions mentioned. The most essential geographical conditions are: 1Geographical differences in the sources of energy for electricity and heat production and the energy marginal. 2Geographical differences in the waste management structure of two given regions. Specific examples of these are: incineration/landfill capacity energy (heat, electricity) use from waste incineration collection of landfill gas and energy generation.
Nevertheless, an important conclusion from the present study is that the results from the nine studies, produced in different geographical areas, and including to different degrees the key assumptions mentioned, indicate that recycling has a better environmental profile than both landfilling and incineration. The impact categories for the environmental assessment of paper systems used in this study, representing the scope of categories contained in the analysed LCAs, are: XEnergy use (or generation), XResource consumption, XEnergy related impacts, XToxicity (of emissions), XWaste generation, XWastewater. The environmental impact categories which are most clearly in favour of recycling are 'Energy Use', 'Energy related impacts' and 'Wastewater'. Other impact categories where the picture is still favourable to recycling, however not as markedly, are 'Use of resources', 'Waste generation' and 'Toxicity'. It is also interesting to observe that the results in certain environmental impact categories are more robust than in others with respect to the choice made in the key assumptions. 'Energy use', 'Energy related impacts' and 'Wastewater' results are more robust than 'Resource consumption' and 'Waste generation' results. The robustness of 'Energy use' is explained by the fact that energy data are mainly dependent on the type of technology used, and not on the key assumptions of system definition and boundary conditions. 'Resource consumption' and 'Waste generation' are categories whose results are very dependent on the fuel mix used for producing the energy that is used in the virgin paper and recycling systems. The results in these categories can be slightly favourable to incineration if wood is used as fuel for virgin paper production and simultaneously coal is used as the only fuel for recycled paper production. Additionally, obtaining reliable data about waste and resource use can in some cases be difficult. The impact category 'Toxicity' is only included in very few scenarios. Therefore, the information about this category has not the same statistical value as the results from the other impact categories where information from most scenarios exists. Additional difficulties for a comparison can be of non-technical nature, e.g. legislative: the residues from coal combustion (gypsum, slag and ashes) are currently characterised and registered as waste in the EU countries, whereas they are by-products in others outside the EU. Such differences make the comparison of environmental profiles in these categories more difficult. Paper fibres become shorter and shorter every time they are recycled, and after a maximum of six to seven times of recycling, fibres eventually become too short for further recycling. The results from the present study do not provide information that can be used to recommend an optimal ratio of recycling. A general screening of some non-LCA studies, including several CBAs, has also been carried out. The studies included in the screening have different objectives, starting points, and very different methodologies. Compared to the conclusions observed in the LCAs, the results from these non-LCA studies are more spread than the LCAs. Some studies seem to be in favour of recycling, some in favour of incineration. The authors of these studies often find no absolute justification for recommending any particular management option, when taking into account also financial variables of waste management and incorporating environmental costs and benefits in their analyses. Few studies make categorical conclusions about the issue, and most of them arrive at soft conclusions, very dependent on the set of assumptions taken. The methodological difficulties are reflected in the fact that a majority of the studies acknowledge the limitations of the economic tools used as a basis for decision support, and focus on a description of the uncertainties and the boundary conditions rather than on the result. It is suggested as a challenging future activity to complete the literature list of non-LCAs of the present study, and investigate in detail the results and methodological implications of these non-LCAs, similarly to the activities carried out with the LCAs.

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