Identifying environmental improvement opportunities for newsprint production using life cycle assessment (LCA)

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Abstract: LCA is used for the assessment of opportunities to improve the environmental performance of newsprint production. A cradle-to-gate LCA baseline model for the production of 1 admt newsprint from TMP and DIP was developed, and used to examine the impact from increased DIP production capacity and co-generation. It was found that a 20-40% reduction in Global Warming Potential could be achieved, and the fuel mix for power generation was found to be a critical factor.

LIFE CYCLE ASSESSMENT (LCA) is a method which can be used to assess the potential environmental impacts associated with a product, process, or service along its entire life from resource extraction to ultimate disposal (i.e., cradle-to-grave). The LCA methodology was recently standardized by the International Organization for Standardization (ISO) 14040 series, and consists of the following phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA), and interpretation. Figure 1 shows the relationship between these four phases and general LCA applications, as per ISO 14040 [1]. The double arrows illustrate the iterative nature of the methodology.

The study goal defines the purpose of the LCA as well as its intended application, while the study scope defines its extent and contains a description of the system. In the inventory phase, data on the environmental interventions or stressors (e.g., emissions, resource usage) related to each process included in the scope of the study are collected and expressed per functional unit (e.g., kg SO2 per ton of product). Data for the LCA can be obtained directly from the production site and suppliers (called primary data), or from LCA databases for standard inputs such as those related to purchased chemicals and fossil fuels (called secondary data). The inventory calculation is not always straightforward because in practice, most industrial process chains result in more than one product (e.g., softwood lumber), and intermediate or final products are recycled as raw materials (e.g., woodwaste). Decisions must be made in the LCA about how to allocate environmental burdens to each of these outputs. The purpose of the impact assessment phase is to determine the relative importance of each environmental intervention (calculated in the inventory phase) by aggregating them into a set of environmental impact categories. Finally, the interpretation step serves to evaluate the study results from each step in order to draw conclusions, explain limitations, and give recommendations. The results of this last phase may lead to an adjustment of the goal and scope, or to further investigations of the inventory and associated impacts [2].

The LCIA phase is fundamentally an analysis of inputs and outputs associated with the process chain, rather than an analysis of the actual environmental consequences or effects from a system. Impact assessment modeling in LCA involves, in some cases, highly simplified assumptions about complex environmental processes (e.g., ecotoxicity) and there are also assumptions for dealing with spatial, temporal, and dose-response issues. This is why some authors recommend complementing LCA results with other analysis techniques (e.g., risk assessment [3]). Other limitations of the methodology include the uncertainty of the results due to data gaps, data uncertainties, methodological choices, and values. However, this is also the case with many other environmental tools [4].

In a recent survey of LCA applications in the pulp and paper industry, Gaudreault et al [5] showed that LCA applications have evolved from traditional product comparison (e.g., paper vs. plastic bags) to process analysis (e.g., emissions assessment along the paper chain), comparison of technological options (e.g., wastepaper management options), and to a lesser extent, strategic evaluation (e.g., supply chain structuring). Another important finding of this survey was that most of the published case studies employed incomplete LCA methodologies. About half of reported LCA studies were limited to the inventory analysis phase, and most of them did not present interpretation checks. Nonetheless, an improvement in the completeness of the studies was identified in more recent publications, probably as a consequence of the methodology standardization by ISO.

STUDY OBJECTIVES

“Life cycle thinking” is being increasingly employed by the pulp and paper industry. This concept implies that the impacts of all product life cycle stages are systematically considered using LCA when making key decisions, such as those on changes in mill configuration, company policies, and overall management strategies. The most effective strategy for applying life cycle thinking concepts is by using LCA for the assessment of mill process variants.

The objectives of this study were to illustrate life cycle thinking by completing a systematic
LCA for newsprint production, including the following:

- To show how LCA can be used to examine the newsprint production chain in order to assess its potential overall environmental impacts,
- To show the critical mill process and non-process parameters which have a significant influence on the environmental impacts from the product chain,
- To use LCA to assess relevant process variants, by comparing the base case mill model with modified mill process configurations (i.e., process variants).

This LCA baseline model for newsprint production was used for the following applications in other ongoing work:
- The demonstration of continuous environmental improvement in the context of environmental management systems,
- Improved assessment of major process modifications in the context of environmental impact studies,
- For the investigation of the minimum impact mill configuration in the context of mill strategic planning.

**OVERALL LCA METHODOLOGY EMPLOYED**

The most important methodological choices and the assumptions and simplifications made during the baseline model development, as well as the procedure followed for the interpretation of the baseline model results, are presented in Salazar et al [6].

The functional unit in the LCA was defined as the production of 1 admt of newsprint. The system boundaries include the production chain from wood extraction to newsprint distribution (cradle-to-gate). Figure 2 summarizes the system boundaries.

For the inventory analysis, primary data for the processes with major contributions was used (i.e., data for the integrated mill and electricity production), while secondary data was used for the background systems having less contribution (i.e., data for fuel and chemicals production, industrial landfill). A previous environmental profile data sheet (EPDS) developed by the mill was the starting point for modeling the life cycle inventory. The system was modeled using the LCA software SIMAPRO 5.1, and selected the impact categories relevant to the study based on SETAC guidelines, using the characterization factors developed by the USEPA (i.e., TRACI impact assessment method) in order to characterize the emissions from the system. Table I presents the selected impact categories, indicators, and models used in this study. Finally, based on the interpretation results, mill alternatives to improve the life cycle environmental performance were identified.

**DEFINITION OF NEWSPRINT SYSTEM ADDRESSED BY LCA**

Standard newsprint production from an integrated TMP/DIP mill is the system under study. The main production chain elements (i.e., woodlands, sawmill, and newsprint mill) are located in Northern Ontario and managed by a single company. Furnish includes 75% spruce and 25% aspen. During winter, spruce logs are transported to the mill by truck, while aspen is sold as plywood and therefore not included as part of the system. Lumber is produced at the on-site sawmill and is sold for the construction industry, and this product is thus also excluded from the system. The on-site sawmill provides approximately 70% of the chip furnish to TMP, and about 55% of the woodwaste burned to pollution control.
in the boiler house. Additional chips and woodwaste required for the mill needs are purchased from local area sawmills and transported by truck.

The TMP yield is around 95%. 70% of the total electricity at the mill is used in TMP refining, of which a part is recovered as steam, which constitutes 20% of the total amount of steam produced at the mill. The secondary fiber furnished to the DIP process includes old newspaper (ONP) and coated groundwood specialties (CGS), which are purchased mainly in Ontario and the USA, and transported to the mill by truck or rail. The DIP process yield is around 85%. TMP and DIP pulps are furnished to four paper machines at a ratio of approximately 4:1 to produce standard newsprint. This newsprint is distributed to Ontario, Quebec, and several US cities by truck and rail.

Steam for the process is produced on-site from hog fuel (44%), natural gas (48%), and sludge (8%). Approximately 70% of the process steam is consumed by the paper machines. The mill wastewater is treated in a primary clarifier and an activated sludge treatment plant, and the wastewater treatment plant sludges are combined with those from DIP for dewatering. Of the dewatered sludge, 50% is burned in the boiler house and the rest is landfilled on-site. Almost all the electricity consumed at the mill (around 98%) is purchased from the grid, for which the average power mix is 33% fossil fuel (coal), 39% nuclear, and 28% hydro.

**LCA BASELINE MODEL FOR NEWSPRINT**

*Life Cycle Inventory (LCI)*

Figures 3, 4 and 5 present, respectively, the product chain inventory results for greenhouse gas emissions (GHG), other emitted gases, and particulate emissions.

Figure 3 shows that CO\(_2\) is emitted in much higher amounts than methane or N\(_2\)O. Most of the CO\(_2\) (79%) is emitted from electricity production, however it should be noted that data for GHG emissions from electricity production were collected in terms of CO\(_2\)eq. For methane and N\(_2\)O, the direct mill emissions present more important contributions: 88% of the methane is emitted from the industrial landfill, and 55% of N\(_2\)O from biomass combustion at the boiler house.

Figure 4 shows that SO\(_2\) is the largest gaseous emission, mainly from electricity production (57%) and fuel production (38%). CO and NOx are emitted almost in equal amounts; their main contributors are biomass combustion (43% of CO) and electricity production (45% of NOx). VOCs are emitted in the lowest amount of these gases, mainly from fuel production (69%). The contribution of VOCs from thermomechanical pulping is very small in comparison.

Figure 5 shows the inventory results for particulate emissions. The contribution of electricity production is the most important for TSP (60%) and PM10 (52%). However, for PM2.5, which is of some concern due to their inhalability, the contribution from transportation becomes more important (45%) than that from electricity production (32%). The combustion of biomass at the boiler house is the third most important contributor, with around 10% of TSP and PM10, and 16% of PM2.5.

Figures 6, 7, 8, and 9 show water-based emissions, respectively, for solids, organic load, nutrients, and metals.

Figure 6 shows that the major sources for suspended solids are the newsprint mill (65%) and, to a lesser extent, electricity production (33%). Fuel production contributes significantly to the dissolved solids result (93%). Figure 7 shows the results for two organic load indicators: BOD\(_5\) and COD. Around 99% of the organic load (for both indicators) is discharged from the newsprint mill. Indirect emissions are shown separately, and among the indirect emitters, fuel production has the highest contribution. Figure 8 shows the nutrient load expressed using two indicators, N-t and P-t. As in the case of the organic load, the major contribution comes from newsprint production (99% of N-t and 93% of P-t). The second major contributor of P-t emissions is electricity production (7%). Figure 9 shows the most significant metals in terms of mass (>1 g/admt). Newsprint production represents the highest contribution (around 98%) for the natural wood constituents Zn and Mn, while for the rest of the metals, the major contributor is chemicals production.
Life Cycle Impact Assessment (LCIA)

Table II shows the impact assessment from the inventory results for the 9 impact categories presented in Table I. Note that it is not appropriate to make comparisons between impact results without using valuation elements. The systematic and careful interpretation of LCIA results is critical for the use of LCA in decision making.

Key Parameters and Sensitivity Analysis

During the interpretation phase, a sensitivity analysis was completed in order to identify the model parameters for which the category indicator results are most sensitive. The model parameters over which the mill has direct control (called foreground parameters) or indirect control (called background parameters) were analyzed. The details of the interpretation methodology are presented in Salazar et al [6], and incorporate a sensitivity index (SI) defined as:

$$SI = \frac{D_{\text{max}} - D_{\text{min}}}{D_{\text{max}}}$$

(1)

where $D_{\text{max}}$ and $D_{\text{max}}$ represent the minimum and maximum output values resulting from varying the input over its uncertainty range [7]. Figure 10 shows that the main opportunity for improving the life cycle environmental performance of newsprint production is with the reduction of energy use, especially through electricity and natural gas use. Potential eutrophication could also be significantly reduced by decreasing N-t emissions due to the newsprint mill effluent.

SCENARIO ANALYSES

Energy Management Scenarios

The energy-oriented scenarios developed for analysis focus on reducing purchased electricity and natural gas consumption, following the sensitivity analysis results. The following strategies were considered:

- Reducing the consumption of electricity by increasing DIP production and lowering TMP production,
- Reducing the amount of energy purchased from the grid by co-generating steam and electricity, preferentially from biomass,
- Implementing a combination of these two strategies.

Based on these strategies, three alternative mill configurations were developed, presented in Table III.

The increase in DIP production (100% DIP) results in a consumption of around one half of the electricity required in the base case mill. At the same time, there is a 35% increase in steam production requirement by the boiler house to replace the steam previously recovered from the TMP process. The main assumptions for the inventory analysis of this configuration are:

- The additional ONP/CGS is transported from the same locations as the base case mill. A credit for recycling this amount of wastepaper was included, which otherwise would be landfilled.
- The dewatered DIP sludge can be burned in the boiler, producing increased ash compared to the base case.
- The additional energy required in the boiler house to produce steam is supplied by natural gas.

As a consequence of the last assumption, Table III shows that natural gas consumption increases by approximately 40%, and the amount of sludge used as an energy source is twice as high as in the baseline model.

In the 100% CE configuration, all the electricity consumed by the mill is co-generated on site. The required amount of boiler steam for this configuration is around twice as much as for the baseline model, and therefore the total amount of energy required at the mill also increases, Table III. It was assumed that hog fuel consumption was doubled (limited by availability), and the balance of the fuel requirements was covered using natural gas. As a result, natural gas consumption for this configuration is around 4 times that for the baseline model. The last configuration shown in Table III is a combination of the first two models.

Figure 11 shows a comparison of the...
different models and the GWP of the entire system (i.e., per 1 admt) was re-calculated. The results are shown in Fig. 13. The mill location dramatically influences the category indicator results.

Effluent Reduction Scenarios
Three scenarios were developed whose goal was to reduce nutrient emissions from the newsprint mill, as follows:
- Tertiary treatment of the current quantity of effluent by alum-polymer coagulation/flocculation,
- Implementation of water conservation programs in order to reduce the volume of effluent by in-mill process modifications, and tertiary treatment of the reduced amount of effluent by coagulation/flocculation, and
- Implementation of a membrane filtration technology after secondary treatment in order to reuse the effluent as fresh water in the process.

The two first scenarios are based on data from a tertiary treatment plant in a TMDP-DIP newsprint mill in Sweden utilizing dissolved air flotation aided by chemical coagulation and flocculation with alum and polymer, in order to reduce COD and phosphorus discharges [8]. This process produces a quantity of sludge that is difficult to dewater and must be landfilled [9]. Table V presents the main characteristics of the two first scenarios in terms of quantity and quality of the discharged effluents.

For achieving the zero effluent treatment scenario, an approach based on membrane technology was assumed. Depending on the applicable membrane cut-off size and the filtering pressure, it has been assumed that essentially 100% of the colloidal and suspended organic materials are removed with ultrafiltration, producing a filtrate with sufficient quality to replace most of the fresh water used in the process. The generated sludge can be sent to biological treatment or may require further concentration into a solid fuel for disposal by incineration [9]. Figure 14 shows the comparative results for the eutrophication impact category, which is most sensitive to the nutrient emissions from the newsprint mill.

The contribution from the newsprint mill effluent represents around 80% of the eutrophication potential in the baseline model. With the implementation of tertiary treatment, the eutrophication potential can decrease by 50 to 60%, compared to 80% for implementation of zero effluent operation.

Additional Scenario Regarding Waste Paper Management Options
An additional analysis was completed in order to analyze the alternatives of a) recycling wastepaper to the mill for DIP production, versus b) incinerating it in a city cogeneration plant to recover electricity. There has been a concern with this question, due to the impact from wastepaper transportation. In order to assess this question, the baseline model system was expanded to include the wastepaper transportation from curbside to material recovery facilities. The results show that the contribution due to this activity in all impact categories is negligible (<1%) for the base case mill. The scenarios described in Table VI were compared.

For the 55% electricity from wastepaper (EW) scenario, the additional amount of wastepaper that was recycled in the 100% DIP scenario was incinerated in the urban center, generating electricity for the grid. The amount of electricity produced in this way constituted 55% of the total electricity consumption at the mill. Since these alternatives are oriented
towards reducing the impacts caused by energy consumption, the model was also run for the three power mixes which were presented in Table IV. Figures 15, 16, and 17 present the profiles normalized against the baseline model results. Scores lower than 1 represent a decrease in the category indicator results, and therefore an improvement in the environmental performance.

The results show that when fossil fuel sources have a high contribution in the electricity mix (e.g., Ontario and Alberta), there are greater environmental benefits. The 55% EW scenario has benefits mainly for global impact categories as well as for eco-toxicity and human toxicity, presenting a range of improvement from 7% to 30%. For the power mixes where both alternatives have environmental benefits, the difference in environmental performance improvement between options is less than 10% for most of the impact categories, except for regional impacts, for which 100% DIP represents a better alternative (since the 55% EW scenario produces a higher quantity of combustion gases, which contribute to regional impacts), and for ozone depletion for which 55% EW is a better alternative (since the chemical consumption is higher for the 100% DIP scenario).

CONCLUSIONS
A cradle-to-gate LCA study for the production of 1 admt of newsprint was completed following ISO 14040 standards, and employed to address some important energy and effluent management questions. The following general conclusions were drawn from this study:
• A sensitivity analysis of the baseline model results showed that energy consumption, mainly in the form of electricity and natural gas to produce steam, and effluent emissions are the process parameters that show significant sensitivity (>10%).
• The electricity mix, which varied with 3 mill locations, is a non-process parameter that dramatically affects baseline model results and the potential benefits resulting from the energy management scenarios.
• The developed alternative mill configurations involving increased production of DIP and/or co-generation systems have potentially important environmental benefits for the system studied (e.g., 20-40% reduction in global warming potential), except for the impact categories that are more sensitive to natural gas consumption (i.e., acidification, photochemical smog, and human health particles).
• The contribution from the newsprint mill effluent represents around 80% of the eutrophication potential in the baseline model. With the implementation of tertiary treatment, the eutrophication potential can decrease by 50 to 60%,
pared to 80% for implementation of zero effluent operation.

• When fossil fuel sources have a high contribution in the electricity mix, recycling wastepaper for DIP production, or incinerating it in a city cogeneration plant to recover electricity, have similar environmental benefits.

This work comprises the first results of an overall program themed “Life Cycle Thinking in the Pulp and Paper Industry”, which is oriented towards developing the LCA application as an engineering tool in the assessment of process variants.

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LITERATURE

5. GAUDREAULT, C., SAMSON, R., STUART, P.R., Survey of LCA applications and methodologies in the pulp and paper industry, paper submitted to TAPPI Journal (2006).

Résumé: L’analyse du cycle de vie (LCA) est utilisée pour évaluer la possibilité d’améliorer la performance environnementale de la production de papier journal. Un modèle de base du début à la fin du LCA pour la production de 1 tonne métrique sèche à l’air à partir de pâte thermomécanique et de pâte désencrées a été élaboré, et employé pour examiner l’effet de l’accroissement de la capacité de production de la pâte désencrée et de la cogénération. Nous avons trouvé qu’il serait possible de réduire le potentiel d’effet de serre de 20 à 40 %, et que le mélange de combustible pour la production d’énergie était un facteur critique.


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