SUSTAINABLE SUPPLY CHAIN IN PULP AND PAPER INDUSTRY: A REVIEW

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ABSTRACT

Pulp and paper products are used on regular basis by human, which made its industry prominent in this world. The pulp and paper industry turns wood into more useful products. The pulp and paper manufacturing process comprise preparation of raw materials, pulping process, chemical recovery, bleaching, stock preparation and paper making. This industry is not only giving good economical impacts, but also negative impacts such as high energy consumption, improper waste management, bad planting methods. Sustainability assessment is required to provide a more sustainable option during decision making by enterprises. The aim of research is to review sustainability assessment research in pulp and paper industry and to identify gap in research for further analysis. Broader indicators will accommodate a more comprehensive review of sustainability industrialization in this sector.

KEYWORDS: *Pulp, Paper, Sustainable Supply Chain.*

1. INTRODUCTION

The industry of pulp and paper produces enormously than another cellulose based fibre products. Annual total global consumption of cellulose-based products exceeds 360 million tonnes.[1] According to Food and Agriculture Organization of the United Nations, the pulp and paper industry contributed half of the total gross value-added in the global forestry sector, which roughly amounted USD 300 billions in 2000. [2] A few examples of products regularly used in our everyday life are various types of papers, tissue, bottle labels, and coffee filters. A lot of involved activities in the chain consisted of planting the trees, until the product is used by consumer, and disposed of or recycled afterwards.[1] Maximizing energy costs and talent deficiency, more sustainably resource maintaining is becoming a new challenge for all sectors in anticipation of raw materials scarcity. Pulp and paper enterprise nowadays are required to perform sustainably and to adopt strategies of waste reduction in order to create a minimum impact mill towards larger issues and challenges included resource and emissions

minimization, reducing cross-media effects, considering working environments and economic perspectives. [3]

One of complex appraisal methodologies is sustainability assessment (SA). Sustainability assessment is used to support decision making and development of policies in a wide aspects, which are economic, environmental and social. Sustainability assessment is commonly used in appraisals of policy, product, and institutional. [4]

Prior to pulp and paper manufacturing, supply chain in this industry starts from plantation. Eucalyptus consists of 800 species, belongs to the family Myrtaceae, subfamily Myrotideae. Eucalyptus is evergreen, which means it retains green leaves throughout the year. The planting of Eucalyptus has resulted in high economic profitability. It was introduced in Ethiopia a century ago for multipurpose use and rescues the remaining indigenous forests from being destroyed, for replacing indigenous species for fuel-wood, for controlling soil erosion. [5]

Pulp and paper manufacturing process consists of five steps, which are plantation, raw material preparation, pulping, stock preparation and papermaking, and finally, post use treatment. Usually forest products removal from the oldest stand counterbalances the growth of another stands. Hence there is no change in biomass yearly. The forest will continue to be a reservoir once established, but will not be either a C sink or C source. A net C sink will be formed from normal forest establishment, that contains little C in the vegetation. Before the first harvest, this phase will make one rotation with the greatest sequestration.

It is a common growth habit of trees to persist for a long period in the mature form, but with very little volume growth. The criteria of natural normal forest would contain many stands with a low proportion of stands and a high standing volume in the vast growth phase. To replace it with a managed forest, clearing a natural forest will make a large capacity reservoir with a smaller one. Hence a well managed plantation is important. [6]

During the pulping step, fibres from the cellulose raw material must be processed for paper product. [7] The fibres from harvested wood are separated from the lignin, which is unusable. Pulping process can be done either mechanically or chemically. The pulp is bleached before further process, depending on the characteristic of paper product. Drying and pressing the pulp is necessary to produce paper sheets. After being used, paper and paper products is recycled. Nonrecycled paper is either incinerated or landfilled. [3] Emissions obtained by eucalyptus forestry subsystem activities that include diesel use in harvesting and timber transportations to pulp mills and the use of fertilizer in tree plantation. [8] The carbon dioxide are from several sources in kraft mill lime kilns. These are released CO_2 from $CaCO_3$ during calcining process, and CO_2 from burned fossil fuel.

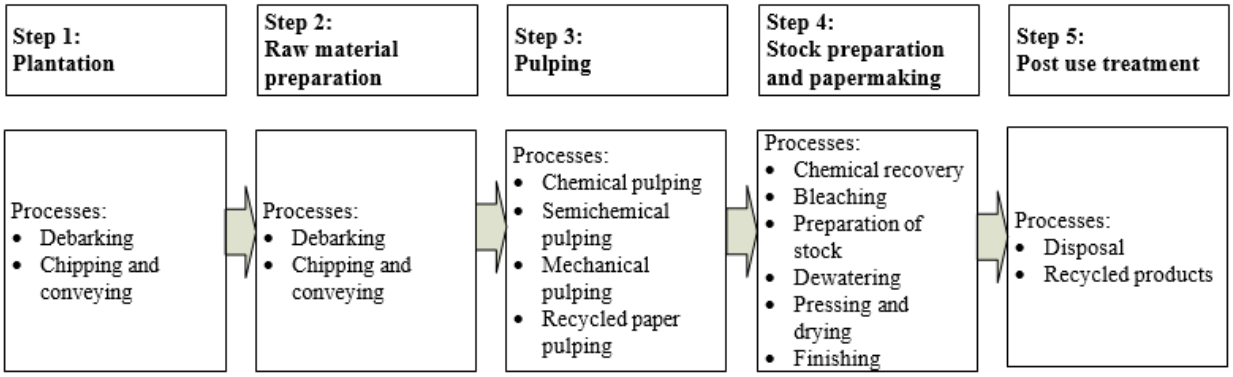

Figure 1. Steps in the manufacturing of pulp and paper

2. RESEARCH METHOD

The aim of research is to review sustainability assessment research in pulp and paper industry and to identify gap in research for further analysis. Literature review is selected as research method to achieve those research purposes.

The research method comprises three steps. First step is searching for matching journal papers. The keywords used to conduct the search were "sustainability assessment" and "the pulp and paper industry". Second step is categorizing the papers based on the focus in the pulp and paper industry, which are objects of assessment, tools and indicators used in the assessment and presentation of assessment results.

First focus is object of assessment in the literature, which shows process being assessed. Second focus is tools and indicators for assessment that shows methods, models or tools, and criteria used during assessment process. Third focus is presentation of assessment result, which is which decisions are provided by the results and how the results of assessment are presented.

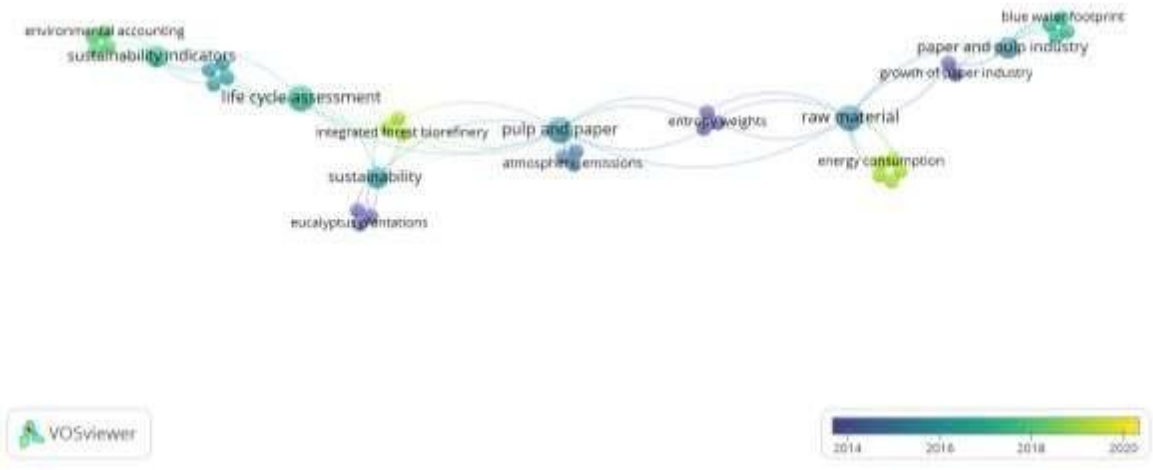

Figure 2. Annual Publication Main Topics

This paper reviews 34 papers from different journals which were published in 2013 to 2020. It was found that most pulp and paper topic articles were published in 2017, while most recent article publication are related to energy consumption topics and integrated forest

biorefinery.

Figure 3. Network Publication Topics

This network publication topics graph shows that reviewed papers consisted of seven clusters. Cluster 1 (Red) contained keywords such as paper and pulp industry with blue, grey and green water footprints, different processes, and the growth of industry. Cluster 2 (green) is related to raw material, which contained eucalyptus plantation, harvest scheduling, multi objective modeling, goal programming, integrated forest biorefinery, and sustainability. Cluster 3 (Dark blue) consisted mostly of consumption, related to energy and paper consumption, paper products, paper recycling, and raw material. Cluster 4 (Yellow) consisted mostly of end products sustainability assessment, with keywrods consumer product, life cycle assessment, life cycle impacts assessment, paper towel, and sustainability metrics. Cluster 5 (Violet) consisted of ecosystem services, emergy, environmental accounting, papermaking, sustainability indicators. Cluster 6 (Light blue) consisted mostly of sustainability issues caused by pulp and paper industry, with keywords such as atmospheric emissions, community, concerns, effluents, pulp and paper, regulatory. Cluster 7 (Orange) consisted of phological analysis and topsis, which are decision support system methods for selecting sustainable supplier for pulp processing.

3. RESULT AND DISCUSSION

Previous reviews about sustainability assessment in pulp and paper industry were identified. [10] evaluated the water footprint and its impact to sustainability at different processes from the source to the end-product. [11] reviewed application to a integrated forest biorefinery by using multi-objective optimization model and integrating environmental life cycle assessment (LCA) in Canadian pulp and paper mills. [12] reviewed sustainable consumption of paper and paper products and its production in Nigeria. Assessment done by [13] discussed eco-efficiency of pulp and paper industry to support China sustainable industrialization. A Canadian case study done by [14] assessed environmental compliance of facilities used at pulp and paper industry. Each review papers focused only on a specific step of pulp and paper industry activities, which are energy usage for production in general [10],[11], [12], consumption[12], emission[13], and facility compliance to environment[14]. This paper provides review sustainability assessment of all process related to pulp and paper industry.

3.1. Sustainability Assessment at Plantation

Sustainability assessment at plantation, specifically eucalyptus trees which are processed to pulp and paper manufacturing process later.

3.1.1. Object of Assessment at Plantation

Object of assessment at plantation in reviewed papers are eucalyptus trees. [15][16] [17] While [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] used Eucalyptus plantations as object of research, mainly for its impact towards environment and climate change.

3.1.2. Tools and Indicators of Assessment at Plantation

Tools used by [15] is appropriate MCDM framework based on goal programming to promote sustainable management of Eucalyptus plantations in northwestern Spain. Indicators used are different rankings of management alternatives derived from different measures of sustainability. While [16] used evaluating the economic feasibility of the introduction of eucalyptus (Eucalyptus spp.) as energy crop for farmers of Southern Italy, by comparing it with traditional crop rotations. Indicators used are comparing the annual cash flows of the two cropping systems, applying the method of discounted cash flow. This methodology is also used by [17] to quantify relevant environmental impacts of proposed bioenergy systems from eucalyptus processes, from plantation activities which uses energy and transportation services in Europe. [18] evaluated sustainability of plantation from economic perspective. Tools and indicators used are modeling profitability potential of candidate short rotation woody species which includes Eucalyptus by Internal Rate of Return, extending to research such as the potential environmental effects, and validating such models. While [19] evaluated how key stakeholders relate certification to sustainability, and its effects for forest management of Eucalyptus spp. plantations in Spain. [20] evaluated Eucalyptus evapotranspiration was through joining evaporation model and micro-lysimetric measurements in Eucalyptus plantations' age sequence, that used the shorter rotation duration (i.e. < 6 years) as indicators of reducing the negative effects of soil water sustainability. [21] used carbon and nutrient concentration in tree biomass components of forestry involving Eucalyptus plantations as the indicator, and used descriptive statistics as the method to compare with other species in the forestry. [22] used line transect survey method to compare Eucalyptus plantation and natural forest, which also involved soil seed bank sampling, soil sampling, soil data analysis and statistical analysis. [23] used methods consisting of Multiple linear regression (MLR), random forest (RF), support vector machine (SVM), and artificial neural network (ANN). Those methods were used for basal area and volume estimation. [24] evaluated environmental degradation through understory vegetation and soil quality as indicators, while methods used to assess influence of different sourced soil and varied water supply on the germination rate of five types of seed were assessed using a three-factor analysis of variance (ANOVA). [25] used experimental design to assess rarefaction curves, species richness and diversity indices, overstory, canopy and soil characteristics, correlation and multiple regression analysis, and canonical discriminant analysis. Experimental design is also used by [26] to assess effects of eucalyptus plantations on stream functioning in seven regions, litter decomposition and its effects to plantations depended on decomposer communities and region, and inhibition of decomposition which affected macroinvertebrates. [27] used indicators comprising whole crown sampling, detailed crown measurements, and individual branch sampling, with methods to analyse are mathematical model of volume and test for treatment effects, using a linear model with treatments as factors. [28] conducted the experiment using analysis of variances (ANOVA), with effects are amount of carbon stored in eucalyptus trees (TC), the understory

vegetation (UC) and forest floor litter (FFC), Soil organic carbon (SOC) stocks, and total ecosystem carbon.

3.1.3. Presentation of Assessment Result at Plantation

Assessment tools and indicators gave different assessment result. [15] presented assessment results by displaying weight attributes to assess sustainability using MCDM methods. [16] presented comparison of economic indicators in graph, and calculated sensitivity analysis to study the impact of the independent variables of a model in which uncertainty may affect the results. [17] presented an alternative of bioenergy systems to support processes in eucalyptus production in Europe. [18] presented value for return on investment, and proposed Eucalyptus species as the highest modeled productivity for short rotation woody species. [19] shows that it should not be presumed that certified plantations has guarantee of sustainability. However it is concluded that FSC (Forest Stewardship Council) was perceived as being the plantations' certification system with the best guarantee of sustainability. To minimize rising temperatures, droughts and more negative impact towards climate, [20] proposed the idea that policy makers should implement a rational distribution for Eucalyptus plantations. [21] presented nutrient amounts using box plot graph that is classified according to age of trees. [22] presented the final result of comparison between Eucalyptus plantations and natural forest using table and bar charts after going through independent T-tests. [23] provided a framework for integrating field and multispectral data, highlighting methods that greatly improve spatial prediction of basal area and volume estimation in Eucalyptus stands. While [24] used table and box plot graph to show average water content of soils based on vegetation type, and finally concluded that retaining native vegatation is more preferable in dry areas, although conservation of soil characteristics seems to be effective for encouraging growth of understory vegetation. [25] presented species accumulation curves for each species, mean and standard error of the mean for species richness and Shannon index in plantations, and finally ANOVA table is established. Leaf area index is also used in presenting the results. [26] provided response of litter decomposition of eucalyptus plantations according to mesh size and region. [27] showed results of experiments using scatter diagram that shows relationships between each effects. [28] presented the idea to use a sound silvicultural strategy to achieve the best combination of high wood yield and carbon stock potential.

3.2. Sustainability Assessment at Raw Material Preparation Process

Processes involved during this step are debarking, chipping and conveying. Logs are usually debarked during the first process step in pulp and paper mills.

3.2.1. Object of Assessment at Raw Material Preparation Process

Assessment object in reviewed papers comprised debarking, chipping and conveying. To separate the bark from wood, debarking is required. After debarking the logs, chipping is conducted to produce chips and reduce logs size. Screening of the produced chips is required to separate long size chips that are not properly chipped; and to remove sawdust. Chips produced can now be processed to pulping.[3] Energy, water and materials are consumed, making several impacts such as exhaustion of resources and emission obtained. The main issue of this process is optimizing unused waste and reducing non-renewable energy usage, which led to environmental sustainability issues during raw material preparation process.

3.2.2. Tools and Indicators of Assessment at Raw Material Preparation Process

Mechanised harvesting of eucalyptus pulp logs may badly affect recovery of fibre as opposed to logs which are manually debarked, caused little or no log surface damage and developed the research into analyzing impact of log surface damage that may affect chip size that influences pulp quality.[29], [30] Meanwhile, [31] gave a systematic review and analysis of the effectiveness of existing technologies for debarking waste processing.

Using life cycle assessment tools, [32] highlighted that wood waste from debarking and chipping are allocated to biomass fuel for pulp processing. However, the raw material preparation process itself used the fossil fuel and electricity which led to non-renewable energy depletion. Emergy accounting method (EMA) is a top down approach used to evaluate effectiveness, efficiency, and sustainability of the paper making process under different perspectives. Eucalyptus woodchips production in Brazil used diesel fuels for agricultural, harvesting, debarking, chipping, transport activities which emergy flow amounted 3.69E+14 sej, ranked fourth largest among all resources. This indicates diesel fuels offer larger potentiality for sustainability. [33] Meanwhile [34] focused on suitable eucalyptus species selection for pulping and papermaking using TOPSIS Multi Criteria Decision Making (MCDM) approach, weighing morphological and chemical characteristics of raw materials as the main attributes. Sustainable supplier selection on pulp and paper industry done by [35] using differential evolution algorithm, with CO2 emission and service quality as the focus.

3.2.3. Presentation of Assessment Result at Raw Material Preparation Process

Assessment tools and indicators gave different assessment result. The presentation varied from providing decision making results and offering solution to minimize non-renewable energy [32], and reduce water soluble consumption for processing raw materials that may cause lower pulp yield [34], showcasing efficiency comparison in each resources involved using unit emergy value[33], to proposing selected optimal sustainable suppliers [35].

3.3. Sustainability Assessment at Pulping Process

There are three types of pulping process, which are chemical pulping, semichemical pulping, mechanical pulping, and recycled paper pulping.

3.3.1. Object of Assessment at Pulping Process

The main issue of this step is mainly sludge generated by pulping process, either during chemical pulping [36] or any types of pulping[37].

3.3.2. Tools and Indicators of Assessment at Pulping Process

Tools used by [36] to assess sustainability are quantifying water footprint accounted and doing multi criteria analysis to find optimal solution of supply mix which minimizes cost of chemical pulp and water footprint accounting. Indicators used are local forestry climatic conditions and specific wood yield used for pulping. While [37] reviewed technoeconomic assessment with indicators such as payback period (PP), total capital investment (TCI), and Internal Rate of Return (IRR).

3.3.3. Presentation of Assessment Result at Pulping Process

Assessment results are presented differently, [36] demonstrated which criteria worked as representatives of aspects reviewed. Nevertheless it provided no further research on how the pulp supply mix affect to productivity of the paper mill. [37] through review provided conclusion that paper sludge is suitable to reduce landfilled waste and as a renewable source of chemicals and biofuels.

3.4. Sustainability Assessment at Stock Preparation and Papermaking Process

Processes involved in chemical recovery process include evaporation, recovery boiler, recausticizing, calcining. Processes involved in bleaching process include mechanical pulp bleaching and chemical pulp bleaching. Processes involved in stock preparation and papermaking process are stock preparation, dewatering, drying, pressing, finishing.

3.4.1. Object of Assessment at Stock Preparation and Papermaking Process

The main issue of this step is to build a more sustainable chemical recovery process. [38] used pulp and paper mill case, specifically in recovery boiler to develop a green integrated biorefinery and aimed for fossil free fuel. [39] focused on emergy efficiency technology used during chemical recovery in pulp and paper industry. Objects of assessment during bleaching varied. [40] used sludge composition as the main focus. focused on emergy efficiency technology used during pulp bleaching in pulp and paper industry. [41] used reviewed paper additive as the focus of research. [42] used folding box board and *kraftliner* paper.

3.4.2. Tools and Indicators of Assessment at Stock Preparation and Papermaking Process

Tools in chemical recovery process used by [38] is progressive implementation strategy of sustainable green integrated biorefinery (GIFBR) model, with dissolving pulp mill as the indicator. While [39] used literature review as the tools which focused on evaluate technology used in pulp and paper industry. Indicators used are status of potential benefits such as energy saving and CO2 reduction, also commercial status comprised research, development, demo, pilot, semi-commercial, and various stages. Recovery boiler technology is already in demo status, which means that an industrial-scale pilot plant has the technology being tested. Causticizing is in various stages. Meanwhile recycled paper fractination, steam cycle washing and spray deinking of surfactant are still in demo status.

Tools in bleaching process used by [40] are sensitivity analysis assuming variation of feedstock composition, with indicators used are effect of the bleaching extent and the addition of carbonate. [41] evaluated papermaking process by using paper additives from more sustainable cellulose nano fibers (CNF), and assessed the influence of pretreatment for papermaking process. Life cycle assessment is used by [42] for cellulose packaging materials production with energy, water, wood consumption and emission as indicators,

3.4.3. Presentation of Assessment Result at Stock Preparation and Papermaking Process

Different assessment results at chemical recovery process are presented, [38] provides economical feasibility and energy usage reduction, which affected by integrated biorefinery model scenarios. [39] presented structured review of emergy-efficiency technologies of pulp and paper industry, specifically in chemical recovery and suggest development to achieve industry energy saving strategies.

Assessment in bleaching process are presented differently. [40] evaluated that the pulp

and paper sludge usage for producing bioethanol allows for the waste to reduce its amount and its valorisation, which are presented in graphs that shows comparison between three scenarios. [41] presented the review result that bleaching can replace certain pretreatment over environmental impact and lower cost in CNF production from agro-wastes studies. The presentation of [42] proved improvements of environmental impacts which reduced energy consumption of papermaking process.

3.5. Sustainability Assessment at Post Use Treatment

Processes involved in this step are treatment of post-used paper products, such as disposal and recycled products.

3.5.1. Object of Assessment at Post Use Treatment

Object of assessment in this step are papermaking material to produce end-products of pulp and paper industry. [40] used papermaking sludge, [43] used recycled paper as the focus of research.

3.5.2. Tools and Indicators of Assessment at Post Use Treatment

Life cycle assessment approach was used by [40] evaluated environmental performance from pulp and paper sludge using optimisation scenarios, [43] assessed solid waste management of the industry.

3.5.3. Presentation of Assessment Result at Post Use Treatment

Different assessment results depends on tools and indicators used. [43] presented graph that shows comparison between products from virgin and recovered fiber, which works as decision support system. While [40] proposed the feasibility of advanced bioethanol production as treatment of sludge that is usually landfilled.

4. CONCLUSION

The pulp and paper industry is one of the largest industrial sector in the world. We conclude that various tools and indicators are used to assess sustainability in the industry of pulp and paper, due to different types of processing. This review shows that Life Cycle Assessment approach is mostly applied in research papers related to this industry, with main focus on energy consumption and waste treatment among all other indicators.

Future works regarding sustainability assessment of the pulp and paper industry specifically in every supply chain activities can be useful. More indicators used will accommodate a more comprehensive review of sustainability industrialization in this sector.

5. ACKNOWLEDGEMENTS

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