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Article

Natural Resources Management: Life Cycle Assessment and Forest Certification and Sustainability Issues

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Abstract: Forest sustainability and forest certification are important natural resource management and environmental issues. Forest certification addresses the social and environmental issues in the acquisition of raw materials (e.g., lumber to be used in the building process). Life cycle assessment is a common technique used in the evaluation of forest sustainability issues and forest certification programs. Life cycle assessment is a tool to evaluate multiple issue environmental and some social impacts attributed to a product or process (e.g., wood as a building material). Inputs (like raw material extraction) and outputs (like pollution) are measured over the entire life process, with a goal to minimize negative environmental impacts over the life cycle of a product or process. The relationship between forest certification schemes and life cycle assessment is examined and assessed.

Keywords: life cycle assessment; forest sustainability; forestry; forest industry; forest certification

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1. Introduction

Forest sustainability and certification emerged as crucial global issues following the Earth Summit in 1992, with an original focus on tropical forests that quickly broadened to temperate and boreal forests [1]. Today, several leading certification groups have a huge impact on millions of hectares of forestlands [2]. Forest sustainability will be a fundamental issue impacting world forests over the next few decades, creating many related problems that will need to be addressed [3].

As human population increases, so does the demand for food, fuel, lumber, and other forest products. Increased food supply usually comes from clearing forestland for crop production and grazing. These harvested forests are often not reforested and forest depletion occurs. This happened in ancient Greece and the Roman Empire, throughout Europe during the mid- to late-Middle Ages, in Central Asia and China during the early centuries of the Common Era, and in the United States in the mid- to late-nineteenth century as timber was cut from region to region across the country [4]. Forest depletion seems to follow the development of civilization. Today it is still a global problem, especially in the tropical rain forest regions and even some boreal forests [5].

Forest depletion causes both ecological and economic problems. The vanishing forests provided timber and other forest products that serve as a foundation of many economies, habitat that supported biological diversity, and functioned as regulators of global climate change [6]. Deforestation leads to soil erosion problems and changes in the hydrologic cycle (ground water). Soil erosion can impact vegetation and the rate of evaporation from a watershed; it can also lead to siltation and shallower river channels. Trees serve as a storehouse for carbon and the loss of forest can result in greenhouse gas emissions. Deforestation can even lead to animal and plant species extinction. Illegal logging and loss of forest cover even in countries with a strong forest industry economic sector can easily impact quality of life standards [7].

Forestry has a central underpinning of sustained yield [8], developed in eighteenth century Europe to ensure a steady supply of wood, fuel, game, and other forest products [9]. The owner of a castle might require his forest to generate annual revenue to support the estate, or a town might require a local forest to provide a steady supply of firewood. A timber famine could lead to social and economic disruptions, and forest regulation was developed to ensure growth, mortality, and harvest levels produced a steady flow from the forest.

Sustained yield has been a hallmark of industrial and investment forest land management, guaranteeing a maximum even flow of timber and producing products that supported economic interests [10]. Over the past quarter century the concept of forest sustainability has evolved to consider non-economic interests and the forest as a naturally functioning ecosystem; ecosystem productivity maintenance depends on all of its components and natural processes [11]. The concept came to be called ecosystem management. Today, forest sustainability has a broad multifaceted context that embraces more than the functioning of an ecosystem; ecological, economic and social values are integrated to form the basis of sustainability [12].

Forest sustainability in the management of forest resources is supported by forest certification schemes that attest that specific standards are met. Forest certification is performance-based and is primarily concerned with current forest management practices and their immediate impact on the environment. It does track the forest products through the commercial chain, from the harvesting site to the final users (chain of custody), but does not explicitly measure the impact of a particular forest product on the environment over its lifetime. Life cycle assessment (LCA) is used to assess a product's environmental impact over an entire life cycle, from resource procurement to final disposition. One ensures forest sustainability standards are being met and the other measures environmental impact of specific forest products over a life cycle. The interaction of forest certification schemes and LCA in contributing to improved natural resource management and enhanced environmental protection is the focus of this article.

2. Forest Sustainability

Forest sustainability is recognized today as a global problem. The United Nations Conference on Environment and Development held in Rio de Janeiro (also called the Rio Conference or the Earth Summit) in 1992 produced a Statement of Forest Principles, significant as the first global agreement on sustainable forest management [13]. In 2000, the United Nations Forum on Forests was established to promote "the management, conservation, and sustainable development of all types of forests" [6]. In 2007 the United Nations General Assembly adopted the "Forest Instrument" as a global agreement on the framework for national action and international cooperation to advance sustainable forest management. A year after the Rio Conference, an International Seminar of Experts on Sustainable Development of Boreal and Temperate Forests was held in Montréal and led to the development of the Montréal Process that identifies criteria and indicators for sustainable forest management [14].

The Montréal Process provided seven key criteria and seven similar thematic areas are now considered fundamental to sustainable forestry on a regional or national basis. They form a structure for systems that certify forest sustainability and are now generally accepted as an implicit definition of sustainable forest management [14]. These seven thematic areas are extent of forest resources, biological diversity, forest health and vitality, productive functions of forest resources, protective functions of forest resources, social and economic functions, and legal, policy, and institutional framework.

Sustainable forest management is one of two approaches for sustainable development of forest resources [13]. The second is the ecosystem approach developed by the Convention on Biological Diversity. The Convention defined it as "a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way". There are three objectives: conservation, sustainable use, and equitable sharing of benefits. Maintenance of fully-functioning ecosystems leads to sustainable development. The crux of the approach is to manage the range of demands placed on the forest. Adaptive management, a system to optimize decision making, is a requirement, as ecosystems are not fully understood. A second requirement is that the forest ecosystem's intrinsic values and tangible benefits should be shared in fair and equitable manner. The approaches promote practices that are environmentally, socially, and economically consistent.

3. Forest Sustainability Certification Programs

During the 1980's and 1990's forest sustainability came to the forefront as a global problem. In particular, massive deforestation of tropical rainforests and the rapid loss of biodiversity caught the public's attention. In 1988, several environmental groups urged the International Tropical Timber Organization to develop a labeling program to identify tropical timber produced under sustainable forestry principles. The demand for "eco-labeling" of wood increased. Eco-labeling is a "claim" (tag) attached to a product that indicates its environmental characteristics [2]. Consumers can then identify environmentally-friendly products and can direct their purchasing power to firms producing those products. Likewise, forest certification is an eco-labeling process that identifies forest products that originated from sustainably-managed forests and is an attempt to use the market place, rather than government regulation, to ensure forest products are harvested using sustainability criteria [15].

Europe, the United States, and Canada have substantial environmental regulations that cover both private and public forest lands. But not all consumers, especially those associated with environmental organizations, were confident that government regulation was effective. This provided an opportunity for environmental groups and forest industry trade associations, among others, to develop programs that certify forest products meeting specified forest sustainability requirements. Forest certification assures customers that the timber that went into their products was managed correctly.

Some of the certification pressure is indirect. The U.S. Green Building Council has introduced Leadership in Energy and Environmental Design (LEED) to improve the environmental performance and economic return in buildings [16]. The architectural design requirements recommend the use of recycled or local materials and forest products that have been certified to have been produced using sustainability criteria. LEED requirements are often in the bid requirements for public buildings. Even loggings organizations have set up certification programs to ensure that harvesting systems support sustainability objectives.

Forest certification must involve all the stakeholders to be effective, including consumers, retailers, producers, mills, environmental organizations, trade groups, professional societies, and certification systems [17]. It involves standards that are the basis of an assessment, a certification process that regulates the use of the "label", and an organization to manage the system. This is usually best handled by a third party or independent organization. Forestry can involve many emotional issues and vested interests; identifying organizations to perform truly independent third party audits can sometimes be challenging.

The integrity of the assessment and the assurance quality of product origin (chain of custody) determine certification program credibility. The consumer evaluates credibility by asking questions like: How well does the program assesses the quality of sustainable forest management? How much assurance does the program offer that chain of custody has not been broken (is the product in the store actually the one that originated from a certified forest)? Does a conflict of interest exist? Do all stakeholders feel the process fairly measures sustainability and effectively meets program objectives?

In the wake of the Rio Conference a number of environmental groups met to develop an independent global organization to certify forest products that were grown on a sustainable basis. The certification schemes took two forms: process-based and performance-based. Process-based systems focus on a systematic approach to management and performance-based systems specify performance standards that must be met. Elements of both can exist in a system. Environmental groups tend to favor performance-based systems as they include specific environmental protection standards [18].

The Forest Stewardship Council (FSC) is performance-based and was formed in 1993 [19]. FSC does not certify forests themselves, but it accredits other organizations to do the actual on-the-ground certifications (called certification bodies). FSC certification covers over 100 million ha of forest land in over 82 countries. FSC certification standards are based on ten primary principles and it has strong chain of custody procedures. FSC International voting members are composed of three chambers representing economic or commercial interests (like wood products retailers), socially beneficial forest management interests, and environmentally friendly forest stewardship interests. Thus, they operate through multiple stakeholder negotiation [20,21].

In the United States, the American Tree Farm System (ATFS) dates back to 1941 and originally had a wood supply orientation, but has always promoted sustainable forestry and is one of oldest certifiers. The ATFS has always considered resources beyond timber, like wildlife and watersheds, but obviously its definition of sustainable forestry has changed since 1941 to more closely reflect current definitions. It's performance-based and certification is based on a set of standards and guidelines, and it offers a group certification for tracts under the same management [22]. Most of the certified forest land is owned by family forest owners, and currently about 10 million ha are covered by the program.

In 1994 the American Forest and Paper Association, an industry trade organization, established the Sustainable Forestry Initiative (SFI) to provide sustainable forestry standards for forest industry land [23]. Since then SFI has become an independent organization and about 70 million ha of North American forest land are now certified to these standards. Participants are mainly forest industry firms or timber investment management organizations. SFI uses a hybrid of process-based and performance-based standards and is certified by independent third parties [20].

In 1999 the Program for the Endorsement of Forest Certification schemes (PEFC) was established as a independent non-governmental third-party umbrella organization that recognizes local forest certification schemes. Originally it was developed by European forest industry as an alternative to FSC [20]. While programs are developed locally, they must meet internationally-recognized sustainable forestry management requirements [20]. Initially it had a European focus, but now is global and covers 200 million ha of forest land. A fundamental difference between FSC and PEFC is the stakeholders. While FSC was founded mainly by environmental groups, PEFC had strong forest industry and trade groups among its founders. This is one reason FSC is not a member of PEFC. Both the ATFS and SFI are recognized by PEFC as acceptable standards.

The objectives, standards, and criteria used by the various certification groups tend to be similar. However, structural differences in the programs result in significant differences in terms of what is permitted on the ground. Rules may vary due to differences in regional or national laws or standards [21]. Differences tend to result from the focus of the founding groups; environmental groups established standards somewhat different than those established by forest industry groups. FSC, for example, founded by environmental groups, stressed basic goals like minimizing forest conversion, respect of international workers rights, respect of human rights with particular attention to indigenous peoples, limited use of hazardous chemical, no corruption, and special protection for special cultural areas [18]. FSC's ten principles illustrate the types of rules and policies that form forest certification systems: compliance with all applicable law and international treaties, demonstrated and uncontested land tenure and use rights, respect of indigenous peoples' rights, maintenance and enhancement of forest workers and local community well-being, equitable use and sharing of forest benefits, minimization of the environmental impact of logging and maintenance of ecological functions, an appropriate and continuously updated management plan, appropriate monitoring and assessment activities on forest conditions and impacts, maintenance of high conservation value forests that are significant or critical, and reduction of pressure on and promotion, restoration, and conservation of natural forests. FSC standards may be more appropriate in less developed nations where land use systems and ownership rights may not be well established.

Sustainable forest management and forest certification have gained wide acceptance over the last twenty years and around ten percent of the world's forest area is now under some forest certification [24]. The acres managed under certified sustainable forestry have grown steadily and the concept has found strong support from environmental groups, non-governmental organizations, and even forest industry/timber investment groups [1]. The original impetus for increased forest sustainability and certification was tropical deforestation, but the majority of growth in forest certification has been in North America and Europe. Strong environmental pressure to gain forest certification in tropical forests should be expected; at the same time substantial social and economic pressures will continue to fuel deforestation in the tropical regions.

Environmental groups have taken their efforts to impact environmental performance on both public and private forest lands directly to the marketplace. They have applied pressure on retailers that sell forest products to limit their procurement to certified products. Many major corporate chains agreed to the limitation. One of the major means of strengthening forest certification will be *via* the marketplace [2]. Consumers have not yet sent strong market signals to suppliers that they demand certified forest products (willingness to pay a premium for certified wood). Most of the market pressure for certification has been on "buyer groups", like home improvement chains. This consumer pressure is fundamental to the long-term success of these environmental groups.

All certification systems have costs. Forest management activities and plans must be changed, special inventories might be required, and tracking systems will be needed. Production costs can sometimes increase by up to 25 percent. Especially in developing countries these costs can be prohibitive [17]. Major net importers of forest products, like East Asia, would be most affected and could suffer. The cost of certification will continue to be a factor in its growth at least as long as there is not a full accounting of the societal costs of uncertified forest products.

To date, most of the certified forests have been industrial and investment ownerships. A significant portion of the world's forest are in small private holdings. These ownerships will need to be addressed as certification grows [25]. Measures to assist these owners may be necessary. The ATFS, for example, allows independently managed groups of small private landowners to obtain a group certification.

4. Life-Cycle Assessment

Interest in forest certification and eco-labeling began in the mid-1990's; corporations and individuals are becoming more environmentally aware and now ask questions on how particular products impact natural resources depletion or degrade the environment. Consumers want to know how products are manufactured, used, and recycled. There seems to be a slowly-developing market advantage for "greener" products produced by "greener" processes. The interest goes beyond the forest certification schemes.

Thus it becomes critical for firms to develop means to determine environmental performance of their products and processes. It is not enough to meet minimum pollution and environmental standards; many consumers expect active improvement of environmental performance by the companies producing the goods they buy and they want to see this performance measured. Life cycle assessment (LCA) is one of these performance measures. LCA is an analysis method that measures the environmental impact of a product, service, process, or system over its total lifespan [26].

LCA is often a "cradle-to-grave" approach that includes the entire life span of the product or process. All stages or phases of the life span are evaluated as interdependent operations, meaning one operation will lead to the next operation. The methodology is well-defined in the literature and will only be briefly described here [27]. LCA is concerned with impacts on resources and the environment that occur at all stages of a product or process life: raw materials acquisition, manufacturing, transportation and distribution, use/reuse and maintenance, and recycling, waste management, and final disposal [28]. LCA is a method to assess the impact of products, services, systems, or processes on the environment by compiling an inventory of raw material and energy inputs and environmental releases, evaluating the environmental impact of those inputs and releases, and using the results in decision-making [29]. Environmental impacts center on resource use, human health, and ecological effects. These impacts may be direct or indirect. For example, the use of electricity for an energy source produces no direct greenhouse gas emissions; however, there are indirect greenhouse gas emissions from generating the electricity in the first place.

LCA does not always use the full cradle-to-grave life span. Cradle-to-gate is common and runs from creation to the factory gate (where the product is ready for shipment to the consumer). Cradle-to-cradle is used when, instead of disposal, recycling efforts lead to a new identical product. Gate-to-gate is used at a single processing facility where it represents value-added in production (that is, time within just one factory). Finally, wheel-to-wheel is used to evaluate road transportation systems.

LCA involves a systematic process that operates in phases with a focus on physical flows of energy and materials. The production chain or technological system is separated from the surrounding environment by a system boundary. Inputs to the system are raw materials and energy and outputs from the system are emissions and waste. First, is goal definition and scoping. The product, service, process, or system to be assessed must be defined, as well as the context in which the assessment will be made. System boundaries and the functional units (such as a ton of newsprint or 1,000 cups) of the system must be established and the environmental impacts under consideration must be identified [30]. Second, an inventory of energy, water, raw material usage, and environmental releases is established, plus the quantitative measures to evaluate them must be identified. These flows are connected to environmental impacts and involve raw materials, air emissions, soil and water, and final disposal [31]. This list of environmental impacts and outputs is called the Life Cycle Inventory (LCI). Third, the Life Cycle Impact Assessment is performed; this is where the LCI data are converted and allocated among environmental impact indicators, resulting in an environmental profile [30]. Last, the results are interpreted and used to make a decision [29].

Life cycle approaches have distinct advantages. LCA promotes an awareness that utilization decisions influence a larger system. If a consumer was aware of how building a wall of wood compared with building a wall with steel and concrete, he or she might opt for a different construction of their home. LCA focuses on the long-term impacts of utilization decisions and considers the entire life of a product. This avoids shifting environmental problems between life stages, or geographic regions, or parts of the environment. LCA allows for informed decision-making that avoids unintended consequences or related environmental damage [32].

4.1. Brief History of Life-Cycle Assessment

The beginnings of LCA were in the 1960's and were based on concerns over supplies of raw materials and energy resources. Various studies attempted to model long-term energy and raw materials demand and production levels. An internal study of the raw material and energy requirements of beverage containers at the Coca Cola Company in 1969 was the foundation for LCA in the United States. During the 1970's its popularity increased in the United States and Europe. It was called Resource and Environmental Profile Analysis in the United States and Ecobalance in Europe [28]. The Society of Environmental Toxicology and Chemistry (SETAC) sponsored two LCA workshops in 1992 and a year later SETAC LCA advisory groups produced the "Bible" of LCA principles and procedures (Guidelines for Life-Cycle Assessment: A "Code of Practice") [28]. Since then numerous governmental agencies, mostly in Europe and the United States, have developed their own guidelines [33]. In the mid 1990's an international set of standards was published by the International Standards Organization (ISO) [34] and today are the most recognized [33]:

- ISO 14040 Environmental management, LCA, Principles and framework.
- ISO 14041 Environmental management, LCA, Goal definition and inventory analysis.
- ISO 14042 Environmental management, LCA, Life-cycle impact assessment.
- ISO 14043 Environmental management, LCA, Life-cycle interpretation.
- ISO 14044 Environmental management, LCA, Requirements and guidelines.

Life-cycle assessment is an environmentally-based analytical tool and many early applications were related to wood and paper products sustainability issues. LCA will not capture and measure many of the variables that are important in forest certification standards, so actual forest management sustainability life cycle assessments are not very common. Forest products are well-covered in the literature and were some of the first to be analyzed *via* LCA. Wood [35,36] and wood products, like wood building supplies [37], softwood lumber [38], plywood [39], oriented strandboard [40], I-joists [41], glue-laminated timber [42], and laminated veneer lumber [43] have fully-developed LCAs in the literature and a review of LCA and the environmental impact of buildings has been published in this journal [30]. Pulp and many types of paper have been analyzed by LCA [36,44-46].

Forest products tend to be the focus of consumer involvement in terms of actual purchasing decisions that might favor products with lesser environmental impacts. Few consumers interact with the forest, while most all consumers interact with forest products on a regular basis. LCA was used in the mid-1970's to evaluate competitive building materials. The earliest life cycle inventory on wood products was conducted by the National Research Council, Committee on Renewable Resources for Industrial Materials (CORRIM). The CORRIM report contrasted energy requirements to produce various building construction materials. For example, compared to a wood stud wall, steel studs would require nine times more energy to produce and concrete blocks would require three times more energy [47]. Wood in use was not the only LCA focus; declines in Pacific Northwest timber harvests resulted in use of nonrenewable resources for construction purposes and significant carbon dioxide being added to the atmosphere. Wood was shown to use less energy in the manufacturing process and to produce less carbon dioxide emissions than steel or concrete [48]. LCA has generally been restricted to life cycle inventories for the wood and paper industries; a full LCA would be very complex and would have to start with timber growing, harvesting, cutting, barking and chipping in the woods and follow through manufacturing, processing, use, and disposal. The manufacturing process has thus been the focus of LCA in these industries [49].

4.2. Life-Cycle Assessment and Forest Sustainability

Sustainable forestry certification systems have been developed in over 150 countries, often by intergovernmental, national, or local organizations. Methods and tools have been developed to evaluate these systems: criteria and indicators, cost-benefit analysis, knowledge-based systems, environmental impact assessment, and life cycle assessment [50]. While criteria and indictors are the popular method to assess forest sustainability, LCA is also a tool for this purpose, but it is product-focused and evaluates the whole product system.

One of the major strengths of LCA is that it is transparent. Many consumers are demanding a means to compare products in terms of impact on the environment and LCA allows for development of quantitative indexes that allow for this comparison [51]. Another strength is that the process is input/output based. LCA evaluates a closed system and measures inflow and outflow, allowing for measurements of changes in key elements. Forest sustainability measures tend to concentrate on traditional environmental values like timber, soil and water. LCA can measure use of those variables, but it is ideal to measure more complicated variables (such as greenhouse gases) in terms of input and output.

Greenhouse gases (GHG) are a good example and one reason LCA is currently a very popular tool for evaluating forest-based products and services. Forests are an important means to control GHG because carbon is stored in forest products and remains out of the atmosphere during this storage. Incrementally, about 100 million t of carbon is sequestered annually U.S. forests [52]. The net impact of forest products on carbon in the atmosphere is complex. Forest products tend to have superior thermal properties, require less energy to produce than other building products, and produce fewer carbon dioxide emissions.

One reason for this is that much of the energy used to produce forest products come from biomass, and biomass is somewhat carbon-neutral (fossil fuels introduce “new” carbon to the atmosphere, while biomass recycles carbon in the atmosphere) [53]. Time frame impacts carbon neutrality of biomass. As long as there is no net temporal change in forest land or productivity, a specific timber harvest management regime should equilibrate to some level of carbon stock on the forest landscape, plus a carbon yield from harvest. However, any change in a harvest management regime (defined at the landscape level) will cause a change in overall levels of carbon stocks on the landscape (positive or negative depending on whether harvest rates increase or decrease), and this will produce a transient net flux to or from the atmosphere.

Biomass use is carbon-neutral in the long run as long as vegetation is allowed to grow back and the ecosystem retains as much carbon as before. For example, cutting an old-growth forest on the American West Coast that is 1,000 years old and contains a huge amount of biomass will not be carbon-neutral because the same amount of biomass may never be allowed to grow back. Also, in some cases, a forest is harvested and the soil is disturbed to increase productivity, which releases carbon that was locked in the soil. So, although the forest might regrow quickly, it is important to determine how much carbon stored in the soil was released and how much is going back. Carbon neutrality is a tough question, but it is certainly better, for example, to burn biomass from the forest that does not require as much fossil fuel energy to produce as agricultural biomass. Also, harvesting forest biomass requires some external energy and this means the entire system is not balanced in terms of carbon neutrality.

Plus, when viewed from a global level, GHG emissions from forest industry are mostly offset by carbon sequestration in forests and forest products [54]. These trends can be impacted by recycling, materials in landfills, methane emissions from landfills, fiber supply changes, changes in energy policies, and the amount of sustainable forest management [55]. This complexity is ideally measured by some sort of input/output analysis and life cycle assessment is the environmental measurement tool that best serves this function.

Carbon stocks on forest industry-owned timberlands, generally managed under sustainable forestry principles, produce a negligible net increase in carbon dioxide emissions. When other private lands impacted by forest industry and its requirements that timber purchased be produced under forest sustainability systems are considered, the net flux of carbon dioxide from forest industry is close to zero [56]. Much of the carbon removed from forests ends up in products that become carbon stocks, producing a net removal of carbon from the atmosphere. The industry does have direct emissions from manufacturing and indirect emissions from purchased electricity and production of raw materials. However, this industry is noted for producing much of it own energy from biomass. There are also emissions from transportation at several points in the production and distribution systems. At the end of life, some forest products end up in landfills and some material is recycled [57]. These kinds of carbon sequestration issues even impact international trade, and the accounting can be quite challenging [58]. The complexity quickly becomes an accounting nightmare unless some sort of analytical system is used to calculate the net amount of carbon sequestration. Life cycle assessment is that accounting system.

4.3. Life-Cycle Assessment and Forest Certification

The International Organization for Standardization's (ISO) 14000 Environmental Management System Standard series is the basis of several forest certification systems and it also provides guidance to forest products companies in term of environmental practices at the mill and forest levels. It provides for three types of environmental eco-labeling claims: Type I is a voluntary, multiple criteria, third party verification system and life cycle assessment is used to define the environmental characteristics of the product or process (environmental labeling program). Type II involves an environmental performance statement that is made by the evaluated entity without third party verification (self declaration). Type III presents independently verified and quantifiable environmental performance data (environmental declaration). Forest certification systems do not match perfectly with any of these three claim types. Some eco-labeling aspects are very compatible with forest certification systems, like voluntary, multiple criteria, and independent verification. But forest certification systems typically do not make any claims on life cycle assessment type impacts of forest products or forest practices. Instead, forest certification systems attest to the quality of the forest management practiced. What is being certified is the production process that went into the final product, rather than the end product itself [59]. Some forest certification standards go beyond forest management quality and include chain-of-custody audits that track wood from the forest to the point of sale, but none include life cycle assessment types of analyses to determine the least overall impact on the environment [60].

Forest certification does offer consumers proof that forest products with the certification logo come from well-managed forests and that ethical and environmental standards were met in their production. In that sense they are systems of identification [61]. The logo of the forest certification scheme confirms to the consumer that the products are certified and have met environmental and social standards in their production. But, forest certification, while it does involve labeling, is not Type III eco-labeling. Forest certification is a single-issue label and it only certifies relative to the quality of one issue, forest management [60]. Type I eco-labeling is applied to product groups and involves the entire life cycle of the product or process, from raw materials acquisition to end disposal. Eco-labeling does look at the issue of forest management, but it is only one of the many issues considered [61].

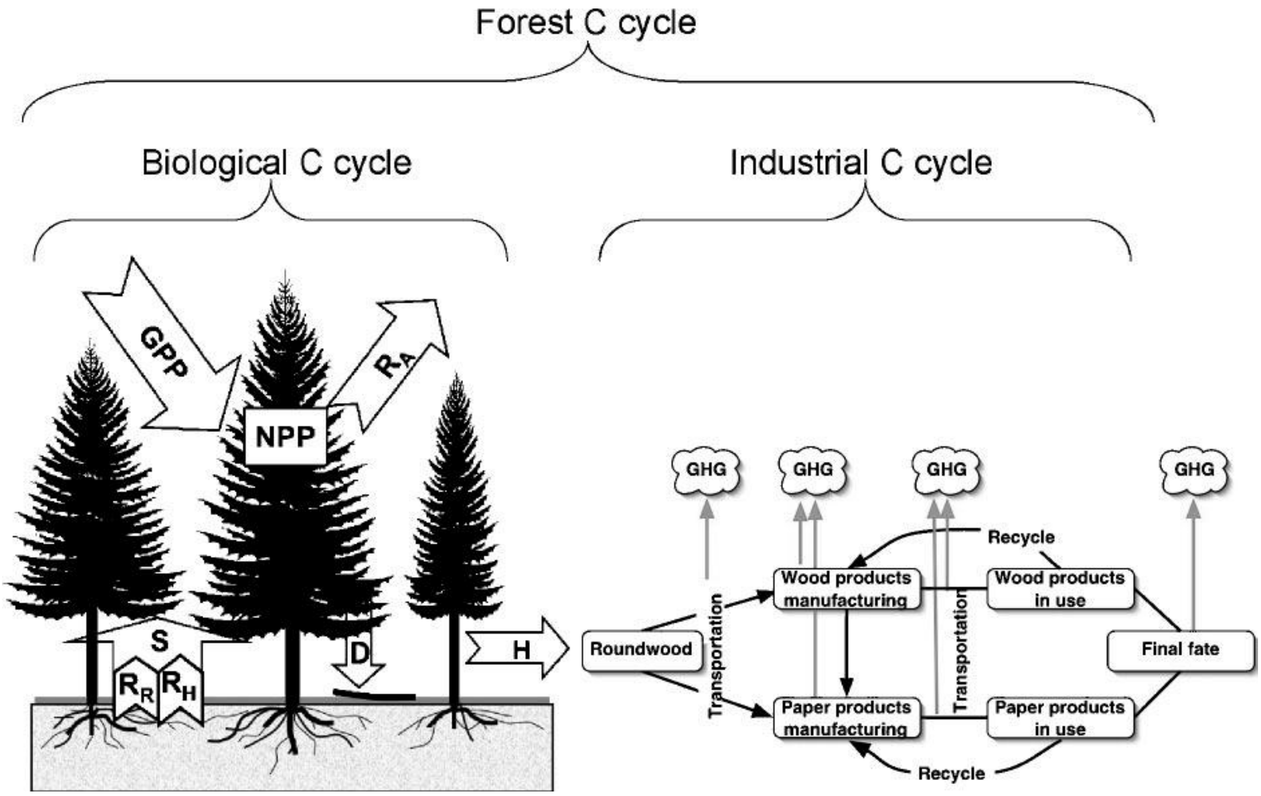
Both forest certification and eco-labeling are voluntary. While eco-labeling schemes are not common in the forest products industry, they do exist [62]. Eco-labeling systems require vast information on the life cycle of a product and this information is difficult and expensive to obtain. So these systems tend to be publicly funded and administered and the focus is, thus, usually on national concerns or national industries [62]. Forest certification systems tend to be private sector and non-governmental organization based. Both forest certification and eco-labeling systems are relatively young and their relative impact on forest management is difficult to judge [61].

5. Case Study of Life-Cycle Assessment and Forest Products

There are many life cycle assessments that deal with forest management, forest products, or related products or processes [63,64]. While forest management is always the focus of forest certification systems, it is usually just one of many issues addressed by life cycle assessments [65-67]. This case study is a detailed greenhouse gas (GHG) life cycle assessment (LCA) for two forest product chains: pulp and paper for the production of magazine grade paper and the production of dimensional lumber [68]. It involved North American wood and product flows. The LCA included all major direct and indirect carbon and GHG emissions involving all processes from harvesting and transportation of wood to the mill to disposal of waste and recycling [68].

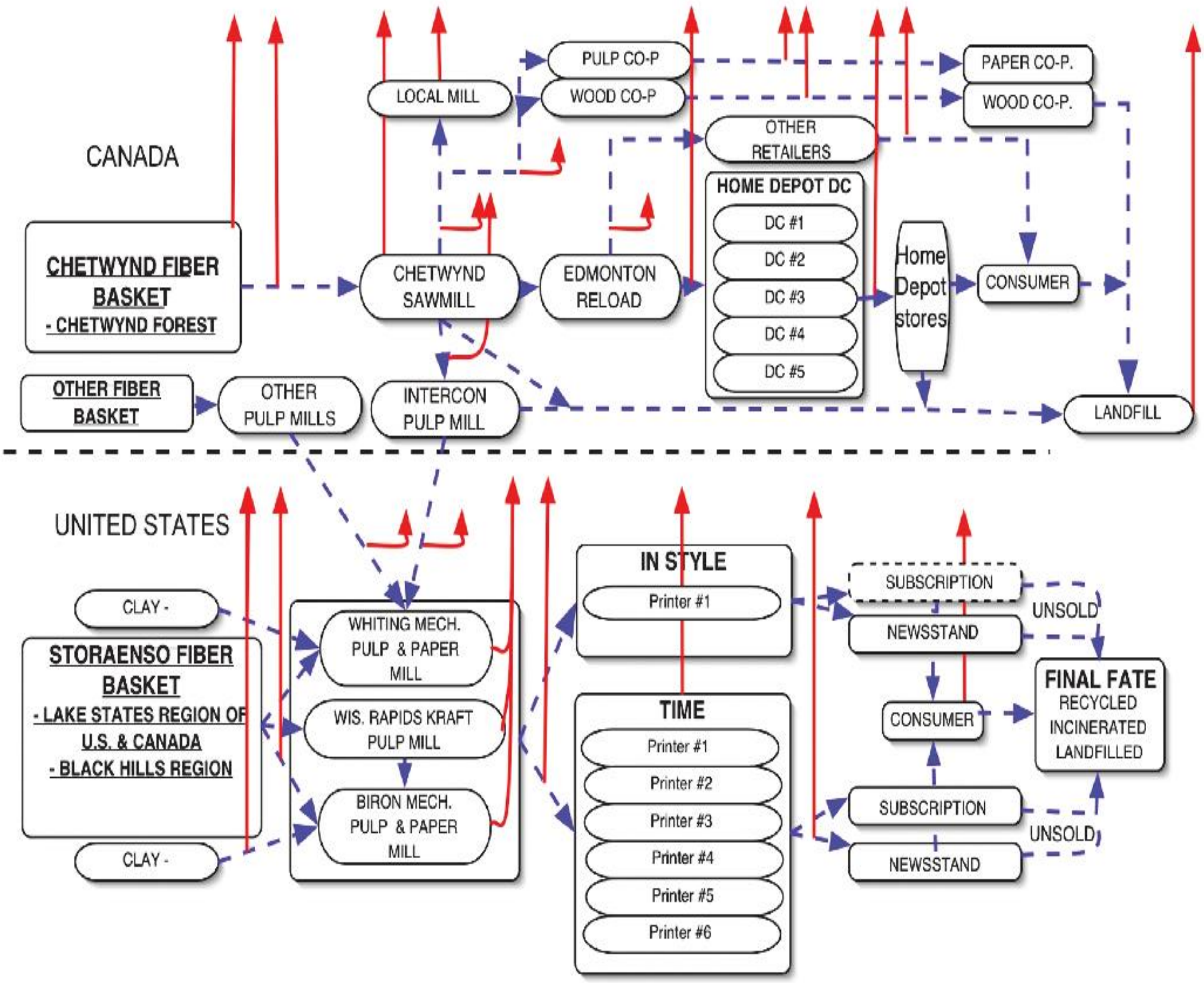
Dealing with a forest's carbon cycle makes the normally complex LCA even more complex. Figure 1 illustrates a forest carbon cycle that is comprised of a biological carbon cycle (forest ecosystem) and an industrial cycle (forest manufacturing) [69]. The temporal and spatial boundaries for a problem like this are not easy to define, especially because there are multiple sources of both raw materials and energy to produce the final product, varying life spans for the products, by-products, and disposed material in the cycle [70]. It is important to understand that primary biological productivity is the product of photosynthesis in which carbon dioxide and water combine using the energy of the sun to produce the elemental carbon input to the tree. At the other end of the process respiration releases oxygen to the atmosphere. The study boundaries were defined to include the wood flow from two major wood procurement regions, transportation of the wood to the mills, all manufacturing stages of both primary products (magazines and dimensional lumber) and by-products, transportation of the products to the consumer, and the final disposition of those products. This life cycle is shown in Figure 2 [68].

Figure 1. A conceptual diagram of the forest carbon cycle, from the biological cycle to the industrial forest products cycle (GPP = gross primary production, R_A = autotrophic respiration, NPP = net primary production, R_H = heterotrophic respiration, R_R = root respiration, D = detritus, and H = harvest removal) [68,69].



The complexity can be shown by just the classifications and types of GHG that were included in the system. Direct carbon dioxide emissions included emissions from forest harvesting activities, pulp and paper manufacture, lumber production, and printing. Indirect carbon dioxide emissions were from transportation (of wood to the mill, finished products to the printing houses and outlets, printed magazines to newsstands and subscribers, and recycling, recovery, and disposal). The study used a carbon soil dynamics assumption that harvesting did not change soil carbon content during the rotation of a forest stand. However, this variable can be dependent upon forest type, harvest method, and utilization rate [71]. Site preparation and planting, as opposed to natural regeneration, are also sources of GHG emissions and are part of the life cycle [68]. Harvested wood and skidding harvested wood to collection points result in GHG emissions. The final fate of the forest products (type of disposal, recovery, or recycling) is also going to have a GHG impact.

Figure 2. Illustration of the complexity of magazine and dimensional lumber chains [68].



The LCA of the dimension lumber chain showed that 0.22 tons of carbon were emitted per ton of lumber produced. The relative GHG contribution of the various processes were: forest management, including harvesting, contributed less than 1%, transportation of wood to the sawmill contributed 2%, sawmill production contributed 2%, transportation and distribution of the lumber to the consumer contributed 94%, and emissions from by-products and final fate contributed 2%. Ninety-eight percent of all GHG emissions were indirect [68].

The LCA of the magazines averaged about 0.31 tons of carbon per ton of magazine produced. The relative GHG contribution of the various processes on average were about: forest management, including harvesting, contributed 2%, transportation of wood to the mill contributed 5%, pulp and paper mill emissions contributed 69%, transportation of paper to the printers contributed 1%, magazine printing contributed 3%, transportation and distribution of the magazines contributed 7%, and final fate of the magazines contributed 13%. About 13% of GHG emission were indirect for the magazine chains [68].

Potential opportunities for reducing GHG emissions included: more efficient energy use, increased mill efficiency, replacing fossil fuels with renewable fuels, and utilizing combined heat and power production. Several opportunities also existed within the transportation chains [68].

6. Conclusion

LCA is product- or process-based and, in terms of forestry most end products (e.g., lumber, paper, or plywood), include forest management as just part of a life cycle. Forest sustainability has a biological foundation with inputs and outputs that can be incorporated into LCA. For example, the biological carbon cycle illustrated in Figure 1 is just one of the many biological systems that make up a forest. Forest sustainability must be part of any LCA that evaluates a forest product and it has the potential to be a very complex portion of an already complex LCA.

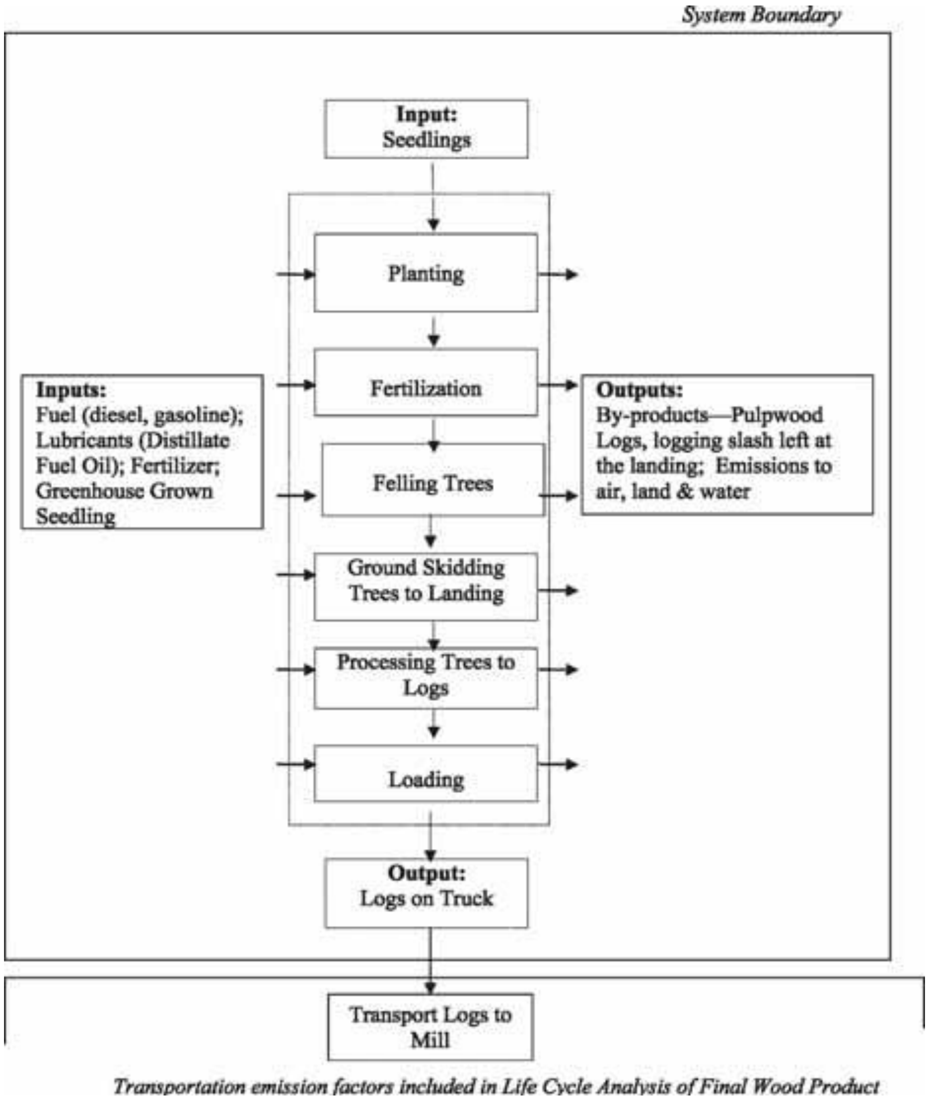
Even though forest certification systems are single-issue based (quality of forest management), that does not mean they cannot be part of a multiple-issue eco-labeling system. If the eco-labeling system is addressing forest products, then forest certification may be required to be an issue. Thus, forest certification can be part of the eco-labeling process. This usually means a life cycle approach to accomplish the eco-labeling goals; so forest certification systems, that evaluate an extremely important part of the environmental impacts of a forest product, do become crucial additions to an LCA for that forest product. Forest sustainability systems themselves may lend themselves well as complements to LCA, but any forest product undergoing LCA will need to address forest sustainability as a component or adjunct of the analysis.

LCA is being expanded beyond environmental and technical aspects of the life cycle. Social LCA addresses many of the issues that impact the social side of forestry (like land ownership, loggers, and property transfer). Social LCA of products can address workers (human rights), the local community (working conditions), society (health and safety), consumers (cultural heritage), and value chain actions (governance and socio-economic repercussions) [72].

LCA does have weaknesses relative to forest sustainability issues. Descriptive data are not readily available to quantify forest ecosystems using the approach. Biological diversity, for example, is a fairly qualitative concept and the social and economic factors associated with forest sustainability can be just as hard to quantify. LCA is especially well-adapted to comparing a renewable resource like forests with nonrenewable resources [73], especially if the accounting system separates fossil from non-fossil carbon. Even though forest certification is a single issue system, the forest is a very complex system itself and can be difficult to quantify as a component of an LCA. Figure 3 shows the complexity of an LCA forest harvesting scheme [74].

Prior to and since the Earth Summit, questions concerning the environmental impact of products have been important. LCA has been used to answer questions about the environmental impact of a product [75]. This resulted in numerous LCA studies such as those comparing paper *versus* plastic bags [76] and paper *versus* cloth diapers [77]. While these LCAs provided answers to some generic questions about environmental impacts of a product, they did not address the sustainability of a specific forest that provided the wood for an individual package of diapers or paper bag. Forest certification systems, through their chain of custody programs, can accomplish this. Forest certification systems, when combined with LCA, provide more information about the environmental impact of a product and the sustainability of the forests from which the fiber was produced.

Figure 3. System boundaries and process flows for transportation fuels used in forest stand establishment and harvesting [74].



The combination of a product LCA and a forest certification label should provide more assurance to the consumer that the product is not harming forest sustainability and its life cycle is more environmentally preferable. LCA's are expensive and are usually performed only for a single product. This generalizes the sources of inputs into the system. It would not account for any specific differences among forests, mines, agricultural fields, rangelands, oil wells, waters, *etc.* Forest certification, through chain-of-custody methods, does account for the differences among forests.

Nevertheless, LCA is an important environmental impact analysis tool and it does have a place in evaluating forest sustainability issues [78,79]. The acquisition, manufacture, and use of forest products produce some of the most environmentally-sensitive consumer sentiments. Forest sustainability is important as a single issue, but it must be evaluated in a multiple-issue framework to capture its true environmental impact [80]. LCA is one of most effective tools to capture this total impact and LCA should continue to develop as a tool that is relevant to forest sustainability studies.

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