



Innovating for Sustainability: Cleaner Production, ESG, and LCA in the Wood Industry

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ABSTRACT:

The wood sector is vital to both worldwide economic expansion and environmental preservation, yet there is growing pressure on it to embrace sustainable practices. To address environmental issues and assure sustainability, this case study examines how the wood sector has adopted cleaner production methods, Environmental, Social, and Governance (ESG) frameworks, and Life Cycle Assessments (LCA). In addition to highlighting the major environmental effects of the wood industry—such as deforestation, biodiversity loss, and carbon emissions—the study looks at the industry's attempts to lessen these effects through resource management. Businesses that integrate sustainability into their business operations, such as IKEA, set the standard for the sector. One of the biggest furniture producers in the world, IKEA, derives 98% of its wood from recycled or Forest Stewardship Council (FSC)-certified sources. By encouraging product recycling and refurbishing, the company extends the life cycles of its products and reduces waste, so promoting a circular economy. By minimizing the overall environmental impact, its life cycle assessment (LCA) approach helps assess the environmental footprint at every stage of a product's lifecycle, from sourcing raw materials to end-of-life disposal. Cleaner production technologies (CPT) have become indispensable instruments in the industry's efforts to curtail waste, energy usage, and emissions. Every stage of operations is guaranteed to incorporate sustainability through the application of CPTs and ESG criteria. This report presents best practices that strike a balance between profitability and ecological and social responsibility, giving readers a thorough understanding of the wood industry's transition to greener manufacturing. Through an analysis of the interrelationships among cleaner production, ESG, and LCA, this study provides valuable insights that help steer the sector in the direction of a resilient and sustainable future.

Key words: Sustainability, Cleaner Production Technologies (CPT), Environmental, Social, and Governance (ESG), Life Cycle Assessment (LCA), Wood Industry, Carbon Footprint, Waste Reduction, Waste Management

1.Introduction:

Global economic development proportionately increases living standards in the developed industrialized world, resulting in growing global consumption of energy resources. It is estimated that by 2030, the global energy demand will increase by 50 percent, and fossil fuels will represent 80 percent of reserves. This trend is further exacerbated by the inability to reduce the loss of biodiversity, with serious consequences for long-term economic sustainability. The assessment carried out in furniture industries in Australia on wood waste and the respective discharge costs concluded that, in the period of 1 year, 7–50% of wood Raw Materials (RM) was wasted, with 65–85% resulting from sawdust and chips of wood, 15–35% from mass timber and pieces of wood panels. The costs of these production losses represented 2–8% of the business carried out. Cleaner production methods are becoming vital instruments to lessen environmental effects, improve resource efficiency, and promote social responsibility, together with frameworks like Environmental, Social, and Governance (ESG) requirements. Additionally, criteria for sustainability like Life Cycle Assessment (LCA) provide priceless information about the environmental impact of wood products, from the extraction of raw materials to their disposal at the end of their useful lives. The goal of this paper is to present a thorough overview of the main tactics guiding the wood industry's transition toward sustainability. To guarantee that environmental, social, and governance considerations are incorporated into corporate decision-making, it looks at the adoption of greener production technologies that reduce waste and emissions in addition to incorporating ESG criteria. This assessment will also look at how LCA approaches, and environmental audits might help the industry evaluate and enhance its sustainability performance. By evaluating the synergies between cleaner production, ESG, and LCA, this paper seeks to illuminate best practices that can guide the wood industry toward a greener, more responsible future. The insights gathered will not only highlight the current state of sustainable practices but also offer recommendations for further improvements that can help balance profitability with environmental and social well-being.

The Comprehensive Journey of the Wood Industry :

The wood industry includes several stages are forestry, Logging, Sawmilling, Wood Product Manufacturing, Distribution & Retail. The first phase of the wood industry is forestry, which focuses on growing and maintaining forests to provide a steady supply of lumber. This includes choosing the right species, planting, and caring for trees, as well as making sure they develop healthily. To preserve the health of the forest, effective forest management

techniques like thinning, insect control, and fire management are used. Furthermore, harvest planning is essential for deciding when and how best to harvest trees to balance ecological sustainability and economic feasibility. Logging is the process of chopping down trees and moving them to facilities for processing. Key tasks include felling, which is the process of cutting down trees with chainsaws or feller bunchers; limbing and bucking, which is the process of cutting the trunk into manageable lengths and removing branches; skidding, which is the process of moving logs with skidders or forwarders from the felling site to a landing area; and loading and hauling, which is the process of loading logs onto trucks and delivering them to sawmills or processing facilities [6]. The raw materials needed to feed the wood industry must go through this procedure. Logs are turned into lumber in sawmills by several processes, including debarking (removing the bark), sawing (cutting the logs into boards), trimming and edging (standardizing sizes), drying (lowering moisture content), and grading (sorting the lumber according to size and quality). This makes the lumber suitable for a range of applications. In the process of making wood products, timber is made into many different things. This covers furnishings like tables, chairs, and cabinets; wood pulp paper goods; building supplies like beams and panels; and additional things like flooring, doors, and window frames. This phase makes use of wood's adaptability to produce necessary items for construction and daily use. Finished wood products are supplied to businesses and customers during the distribution and retail phase. This includes retail sales, which serve customers directly through hardware stores, furniture stores, or internet platforms, and wholesale distribution, which involves selling big amounts to merchants or construction businesses. To guarantee that goods are delivered on schedule and in acceptable shape, effective logistics are essential for handling storage and transportation. [11]

Uses of wood:

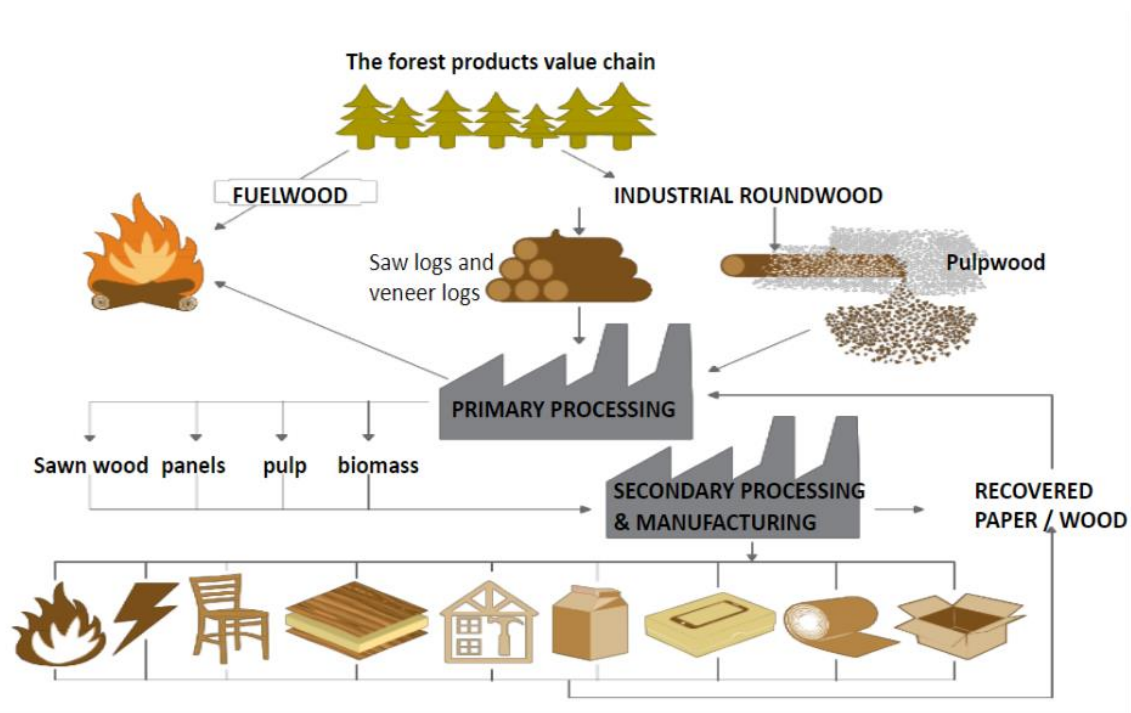


Fig 1: - Uses of wood source: forest and wood products (2012)

Leading Entities in the Wood Industry :

Important figures from a variety of industries propel the wood sector. To guarantee a steady supply of lumber, forestry businesses maintain forests and supervise harvesting activities. Manufacturers of wood products, like West Fraser Timber, Georgia-Pacific, and IKEA, control several market niches and produce everything from paper goods to building supplies. Globally recognized furniture manufacturers such as Herman Miller and Ashley Furniture are well-known for their extensive selection of wooden furniture, which meets a variety of client demands. Together, these businesses make sure that raw wood is efficiently transformed into finished goods for a range of applications.[24][25]

4. Supply Chain Analysis :

The supply chain for the wood sector is heavily reliant on natural resources and is extremely vulnerable to shifts in the environment, in legal frameworks, and in international trade laws. It is separated into three primary sectors: upstream, midstream, and downstream. To provide a consistent and environmentally responsible supply of timber, upstream activities include logging, sustainable harvesting techniques, and forest management. The milling and processing of raw wood into useful products like lumber and wood pulp are considered downstream activities. Lastly, downstream operations concentrate on producing final goods like building materials, furniture, and paper and delivering them to consumers via a variety of channels. [17]

CP is related to Green Supply Chain Management (GSCM), used to improve operational and financial performance, as well as to improve and reduce environmental waste. According to the literature, CP strategies represent 58% of the practices for GSCM, followed by ecodesign and reverse logistics

practices (55%), and green procurement (53%). In turn, studies on Green Furniture Manufacturing (GFM) emphasize the development of ecological products and manufacturing processes, besides an optimization of the industrial structure. [15]

Current market trends in the wood industry:

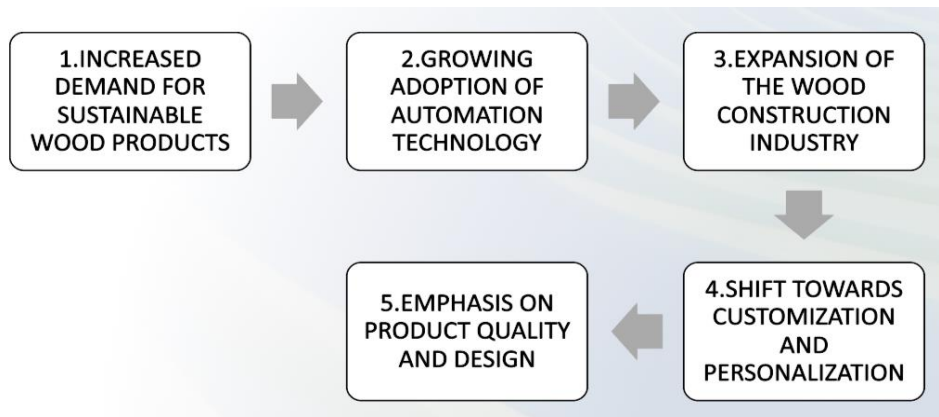


Fig 2: - Current market trends Source: (Opportunities and Challenges in the Wood Manufacturing Industry, 2023) [16]

The wood industry encounters several significant challenges

Numerous major obstacles affect the timber industry's efficiency and sustainability. Deforestation, biodiversity loss, and carbon emissions are important environmental concerns. Unregulated logging poses a serious threat to ecosystems and contributes to climate change. The stability of the sector is further complicated by supply chain disruptions brought on by trade rules, natural disasters, and geopolitical conflicts. Furthermore, consumers and authorities are placing more and more pressure on businesses to be sustainable, which makes waste reduction and renewable forest management techniques necessary. While integrating cutting-edge technologies like automation, artificial intelligence, and sophisticated machinery is crucial for increasing production, it can still be expensive for smaller businesses. In addition, the business faces a labor shortage due to the difficulty in attracting skilled personnel due to competitive wages and hazardous working conditions in other industries. [16]

Challenges Facing the Wood Manufacturing Industry:

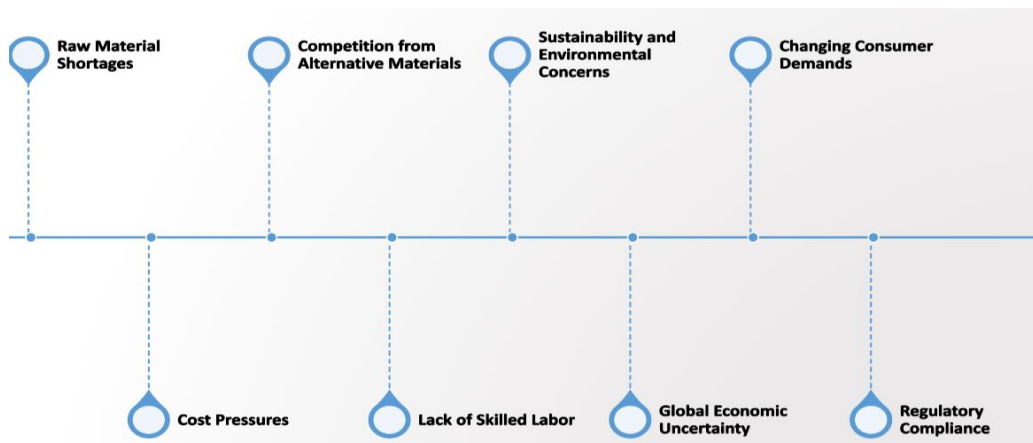


Fig 3:- Challenges Facing by the Wood Manufacturing Industry

Source: (Opportunities and Challenges in the Wood Manufacturing Industry, 2023) [16]

Sustainability Initiatives

Because the wood sector depends so heavily on natural resources, sustainability is essential. Numerous important projects and practices that are backed by a lot of data are part of the efforts to improve sustainability. A global certification program called Forest Stewardship Council (FSC) Certification encourages ethical forest management. Globally, about 160 million hectares of forests are FSC-certified as of 2024. With this certification, you may be sure that woods are managed to protect biodiversity, strengthen relationships to the community, and maintain the economy. Sequestering carbon is yet another essential endeavor. Carbon dioxide (CO₂) is largely removed from the atmosphere by forests. Every year, forests around the world absorb over 4 billion Tonnes of CO₂. This organic process lowers the atmospheric concentration of greenhouse gases, which helps to moderate climate change. Initiatives for afforestation and reforestation are crucial to increasing the capacity of this carbon sink. Reducing the environmental impact of the industry

requires more and more recycling of wood waste. Repurposing wood waste for the production of bioenergy reduces dependency on fossil fuels. Millions of tons of wood are kept out of landfills and used for energy recovery thanks to the recycling of wood waste, which has increased energy production in the United States alone. To keep forest ecosystems healthy and productive, sustainable forestry techniques are essential. These methods include planting new trees to maintain a forest cover, utilizing ecologically friendly pesticides to lower pollution, and selective logging, which minimizes damage to the forest. Over the past 50 years, the amount of hardwood forest land in the United States has increased by 18% thanks to sustainable forest management. Technology is also advancing in the wood business to help sustainability. To increase productivity and cut waste, automation and smart forestry technologies are being implemented. For example, automated techniques are currently used in 50% of sawmills worldwide, improving accuracy and lowering resource waste. Together, these initiatives help create a more sustainable wood sector by striking a balance between social responsibility, environmental preservation, and commercial demands.

In Spain, the Act of 20 May 2021 on “Climate Change and Energy Transition” includes as one objective the minimum national targets for greenhouse gas emission reductions, renewable energies, and energy efficiency for the years 2030 and 2050. By the year 2030, these emissions should be reduced by at least 23% (compared to 1990) and Climate neutrality must be achieved by 2050 at the latest. To achieve these objectives, public procurement should include criteria to promote the use of sustainable building materials, considering their lifespan, while the use of materials with the smallest possible carbon footprint is clearly encouraged. In this respect, wood is the only building material named in the Act. Hence, the use of wood, and its sustainable origin, will be included in future public procurement and contract award procedures, and companies wishing to participate in public procurement will have to adapt to its use.[13]

According to Pandey et. al, 900,000 cubic meters of timber and 1.2 million m³ of fuelwood could be sustainably produced annually and generate employment for about 4.8 million people [19]. Wood-Based Activated Carbon and Carbon Nanostructures the earliest known use of wood-based carbon materials is 3750 BC when the ancient Egyptians and Sumerians used wood chars for the reduction of copper, zinc, and tin ores in the manufacture of bronze and as domestic smokeless fuel.³² Since then, many other forms of wood-based carbon materials have been developed, including activated carbons and carbon nanostructures. [12]

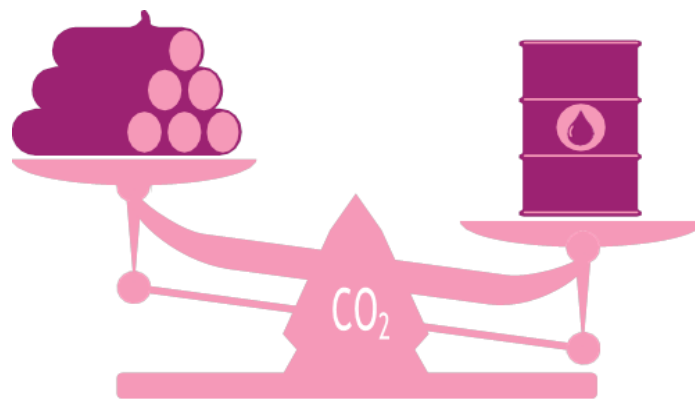


Fig 4:- Forms of wood-based carbon materials

Moreover, climate change and resource depletion seriously threaten the planet and human civilization. Buildings consume 35% of all produced energy and generate 40% of direct and indirect CO₂ emissions [21]. They also use 12% of our water and produce more than 30% of greenhouse gas emissions. The construction industry can contribute to the better management of limited resources and to a reduction in greenhouse gases (particularly CO₂) more than transport or any other industry. [22]

Economic impact (The wood industry boosts GDP, jobs, and global trade significantly)

The wood industry plays a pivotal role in the global economy, significantly contributing to GDP, employment, and trade. For instance, the global forest sector added over \$663 billion to the world GDP in 2015, with countries like Canada, Brazil, and Russia heavily relying on forestry for economic growth. In the United States, the forest products industry accounts for about 5% of the manufacturing GDP. Employment-wise, the industry provides jobs to millions, particularly in rural areas, contributing to 1.2% of global employment opportunities in 2014. However, the rise of mechanization and automation, with 50% of sawmills globally using automated processes, is impacting employment levels. On the trade front, wood products are heavily traded, with major exporters like Canada, the USA, and Russia, and significant importers such as China and the European Union. In 2022, global wood exports were valued at \$188 billion, underscoring the robust production capabilities and economic importance of this sector. [1]

1. **Contribution to GDP:** The global forest sector contributed more than \$ 663 billion to world GDP in 2015 (FAO).
2. **Export Value:** Global wood exports valued at \$188 billion in 2022 (OEC).
3. **Import Value:** Global wood import value was \$257.7 million in 2023 (Trade Map).[2]

Technological Trends

Significant technical breakthroughs are changing the timber sector and its operations. Automation is leading the way, with sawmills and logging equipment of today using robotics and artificial intelligence (AI) more and more to increase productivity and reduce human error. The usage of wood-based materials in 3D printing is another new trend that has the potential to drastically cut waste and transform production methods. Additionally, as

businesses use digital technologies to trace their supply chains and ensure greater sustainability and transparency, digital supply chain management is growing in popularity. Industry is moving toward more sustainable and effective processes due to these technological advancements.[7]

Recycling technologies:



Fig 5: - Wood Recycling Technologies

Source: Garcia et al., 2024

Cleaner Production Technologies (CPT) in wood Manufacturing:

Cleaner Production (CP) was defined in 1990 by the United Nations Environmental Program (UNEP) as an integrated environmental prevention strategy applied to production processes, products and services with the objective of continuously improving the efficiency of systems while also reducing the risks for human beings and the environment. In the 1990s, UNEP and the United Nations Industrial Development Organization (UNIDO) started the industry support program, promoting the provision of CP services, and Resource Efficient and Cleaner Production (RECP) to support Small and Medium-sized Enterprises (SMEs) to preserve and minimize the use of natural resources, optimizing the economic performance of these resources and improving employability, safety and the well-being of workers and local communities. CP identifies opportunities for continuous improvement in environmental performance, avoiding higher costs and considering a systemic view that allows the interaction of all elements [15].

The implementation of CP programs presents multiple advantages:

It requires commitment from management, staff and operational levels, focused on a continuous, improvement approach , It includes a defined methodology for the implementation , It can produce economic benefits such as reducing operating costs of materials and processes ,It can improve the image of the company , It can be implemented from low-cost levels (self-sourced) to high-cost levels (financial assessment),depending on the cases and the scope of the program[15].

2.Case Example: IKEA's Wood industry

Company Overview:

IKEA, a global home furnishings retailer founded in Sweden in 1943, is known for its affordable, stylish, and functional products. As one of the world's largest furniture retailers, IKEA's innovative flat-pack furniture allows customers to assemble products themselves, enhancing transportation and storage efficiency. The company aims to become climate-positive by 2030, focusing on sustainable sourcing, with 98% of its wood being FSC-certified or recycled. IKEA also promotes circular economy practices by encouraging customers to return or refurbish furniture, extending product life cycles and minimizing waste. Additionally, their flat-pack design reduces transportation costs and carbon emissions by fitting more products into fewer shipments.

Types of wood-based material used in IKEA products

Composites account for 61% of the material composition of IKEA's wood-based items, making them the predominant material type. These composite materials, including fiberboard and particleboard, are prized for their sustainability and effective use of wood fibers. The remaining 39% is made of solid wood, which has a durable and organic appearance. IKEA can satisfy a broad range of design preferences and practical needs while balancing cost-effectiveness, environmental concerns, and product quality thanks to this combination of materials.

Table 1: - Wood-based materials

wood-based material	Percentage
Composite	61%
solid wood	39%

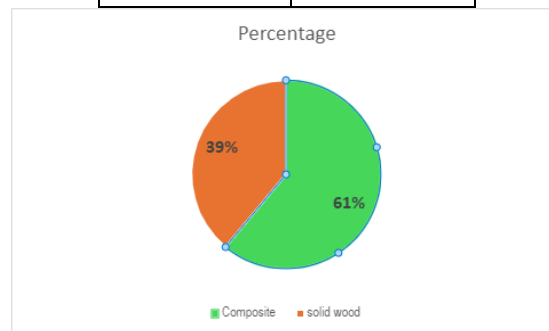


Fig 6: - Pie chart depicting composite and solid wood

Which market supplies the most virgin wood for IKEA products

Wood-based materials for IKEA's market are supplied by a number of nations, with Poland being the biggest source at 32%. Sweden and Lithuania each make 10%, demonstrating the significance of these European nations in IKEA's supply chain. China contributes 9%, Germany contributes 6%, and Romania and the Czech Republic provide 4% apiece. 3% comes from Latvia, 3% from Slovakia, and 3% from Vietnam. In order to maintain a diverse and internationally dispersed supply chain that supports IKEA's manufacturing and sustainability objectives, the remaining 16% originates from other locations.

Table 2: - Market supplies

Market supplies	Percentage
Poland	32%
Lithuania	10%
Sweden	10%
China	9%
Germany	6%
Romania	4%
Czech Republic	4%
Vietnam	3%
Slovakia	3%
Latvia	3%
other	16%

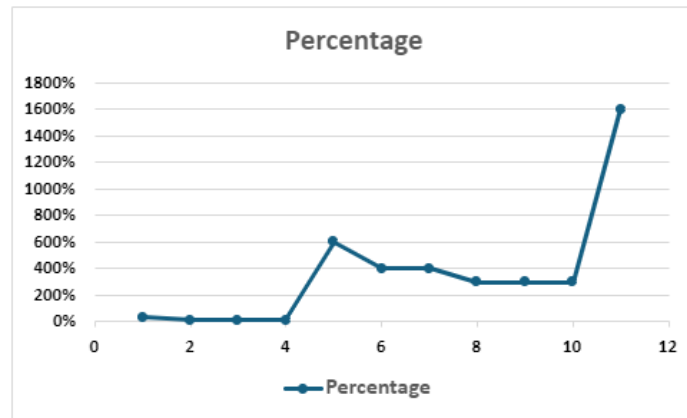


Fig 7: - Graph depicting market supplies

84% of its supply comes from Europe, IKEA sources its wood from a variety of places throughout the world. Asia makes up 13%, demonstrating the region's importance in IKEA's wood sourcing strategy. The lesser but significant contributions from North America and South America are reflected in their respective contributions of 0.4% and 2%. Africa makes up the least percentage of IKEA's wood supply (0.002%), with Oceania accounting for 1%. In addition to promoting ethical forest management techniques globally, this global sourcing strategy guarantees a varied and sustainable supply of wood for IKEA's production needs. [23] IKEA has 473 locations in 63 markets worldwide, demonstrating its wide-ranging global reach. IKEA's global expansion began in 1958 when its first store opened in Älmhult, Sweden. Cali, Colombia, is the newest member of the IKEA family, demonstrating the company's ongoing expansion into new areas. The country having the most IKEA stores globally is Germany. In the meantime, Pasay City, Philippines is home to the biggest IKEA store, which serves a wide variety of consumer demands by providing a vast array of goods in a spacious retail area.



Fig 8: - Number of stores

IKEA promotes sustainable practices in its supply chain through several key initiatives.

The IWAY code of conduct sets strict standards for environmental, social, and working conditions, ensuring responsible sourcing and ethical practices among all suppliers and service providers. IKEA ensures that 98% of the wood it uses is either FSC-certified or recycled, protecting forests and promoting responsible forestry practices. The company encourages a circular economy by promoting the return and refurbishment of furniture, extending product life cycles and reducing waste. IKEA also uses tools like the "e-wheel" to assess the environmental impact of its products at various stages of the supply chain, identifying areas for improvement and implementing more sustainable practices. Additionally, IKEA works with suppliers to increase water efficiency and the use of renewable energy, aiming to replace fossil fuels in transportation with alternative energy sources. These initiatives collectively help IKEA minimize its environmental footprint and promote sustainability across its entire supply chain.[23]

Key strategies:

IKEA's sustainability strategy focuses on three key areas: Healthy & Sustainable Living, Circular & Climate Positive, and Fair & Equal. The company aims to inspire over a billion people to live more sustainably and healthily. By 2030, IKEA plans to become a circular and climate-positive business, reducing its greenhouse gas emissions by at least 50% compared to 2016 levels. This involves transforming its business model to regenerate resources, protect ecosystems, and enhance biodiversity. Additionally, IKEA is committed to creating a positive social impact by providing decent work, promoting equality, and fostering inclusivity across its value chain. These efforts align with the UN Sustainable Development Goals and demonstrate IKEA's dedication to tackling climate change, unsustainable consumption, and inequality [23].

Identifying effective strategic alternatives

The third step of the hierarchical analysis process was to identify cleaner production strategic alternatives. First, the effective parameters were identified through library studies and interviews with industry experts. The Delphi method was employed to divide the cleaner production alternatives into five general groups[10], namely

- Alternative 1: Reducing energy consumption
- Alternative 2: Reducing water consumption
- Alternative 3: Reducing waste generation
- Alternative 4: Reducing emissions and environmental pollution
- Alternative 5: Increasing health and safety at work

3. Methodology:

In the technical visit for diagnosing the process flows of the company in study, based on the methodology used in industrial layout projects , we obtained the qualitative input data (raw materials, products, production routes) and output data (products, waste, residue, by-products), as well as the areas, arrangement of machinery, equipment, and sectors, information regarding the relationship between the different activities, the flow of materials, people, and information for product handling, measurements of the physical space, and the location of residues and by-products in the layout. presents the design requirements included in the questionnaire and checklist carried out[14].

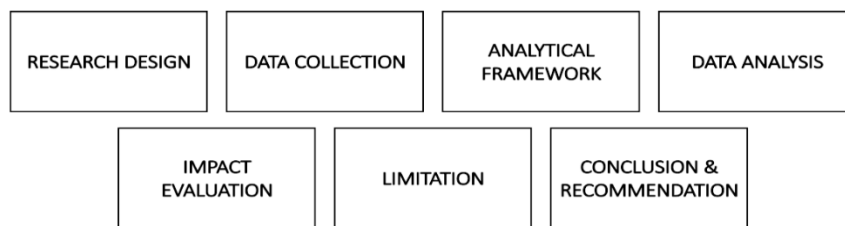


Fig 9: - EIA Methodology

Life Cycle Assessment (LCA)



Fig 10:- Life cycle Assessment

IKEA strives to use renewable energy sources across its operations. Many of its factories and stores are powered by solar and wind energy, significantly lowering carbon emissions. KEA uses life cycle assessments to assess how their products affect the environment. This guarantees that choices are made to reduce the environmental impact at every stage of the product lifetime, from procuring raw materials to disposing of them after use[23].

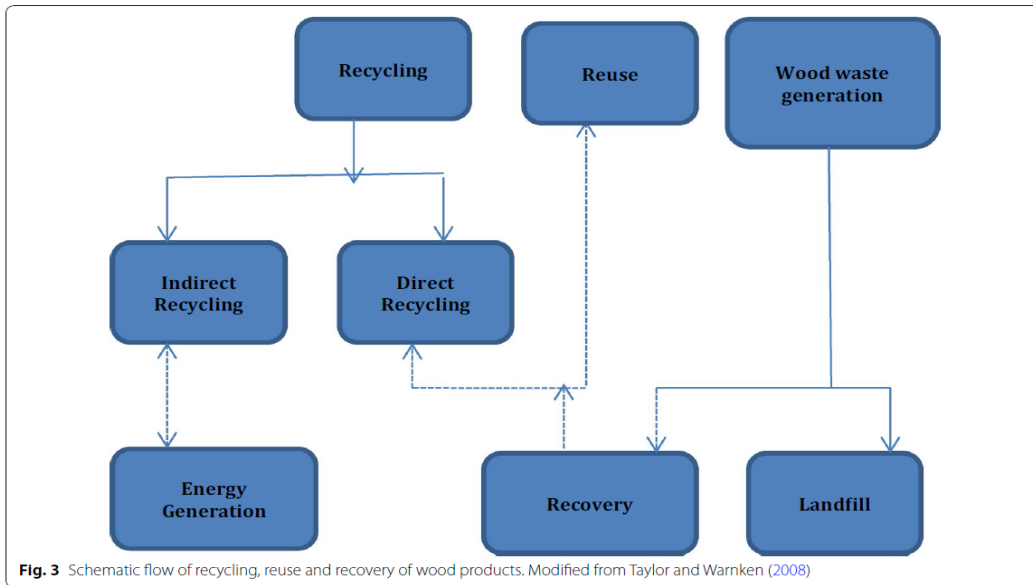


Fig 11: - Flow chart of recycling, reuse, and recovery of wood products

Source: (Adhikari & Ozarska, 2018)

Life cycle inventory included first-hand data collected at the host enterprise during the CP program implemented; secondary data adapted from previous studies related to eucalyptus plantations in Salvador Bahia, Brazil and complementary data adapted from other specialized literature[18].

ISO 14040/14044 Framework:

The ISO 14040 and ISO 14044 standards provide guidelines for conducting LCA. This framework involves four key stages:

- **Goal and Scope Definition:** Establishing the purpose, system boundaries, and functional unit (e.g., 1 cubic meter of engineered wood or one piece of furniture).
- **Life Cycle Inventory (LCI):** Gathering data on resource inputs (energy, water, materials) and outputs (waste, emissions) across the product's life cycle.
- **Life Cycle Impact Assessment (LCIA):** Assessing the environmental impacts of inputs and outputs, such as global warming potential, resource depletion, water use, and pollution.
- **Interpretation:** Analyzing results to identify improvement areas and assess the overall environmental performance of products.

Benefits obtained from the reduction of wood waste generation,

Table 3: - Benefits obtained from the reduction of wood waste generation

Material specifications	Amount consumed (kg/year)	Waste specifications	Amount generated(kg/year)	
Wooden boards with old dimensions	1,856,059	Non-reusable rigid plastic tape (board packaging) Non-reusable wood beams (board packaging) Wood waste	362 6594	Before CP
Wooden boards with new dimensions	1,555,968	Reusable rigid plastic tape (board packaging) Reusable wood beams (board packaging) Wood waste	395 10,370	After CP
Wooden boards with old dimensions	300,091	(board packaging) Reusable wood beams (board packaging) Wood waste	395	Benefits obtained

			10,370	
			286,792	

Source: Carlos Henrique Ribeiro Massote et al. (2012) Implementation of a cleaner production program in a Brazilian wooden furniture factory. <http://dx.doi.org/10.1016/j.jclepro.2012.09.004> [4]

4. Conclusion:

Significant environmental and economic obstacles, such as deforestation, biodiversity loss, and tighter laws, confront the wood business. The sector is moving toward sustainability through the integration of Life Cycle Assessments (LCA), Environmental, Social, and Governance (ESG) frameworks, and Cleaner Production Technologies (CPT). By embracing circular economy ideas, sustainable sourcing practices, and carbon footprint reduction, businesses such as IKEA set the standard. This case study shows how these tactics might be used to strike a balance between social and environmental responsibility and profitability. ESG guarantees ethical decision-making, LCA offers instruments to minimize environmental effects over the course of product lifecycles, and CPT aids in the reduction of waste and emissions. When combined, these strategies help the wood sector reduce harm to the environment, increase resource efficiency, and aid in the worldwide effort to combat climate change. In conclusion, the wood industry's resilience and long-term profitability in a market that is becoming more environmentally sensitive depend on its capacity to innovate and embrace sustainable methods. Sustainability is a moral and strategic requirement.

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