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LIFE CYCLE ASSESSMENT OF KITCHEN CABINET:

The case of Finfine Furniture Factory (3F)

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Abstract

A life cycle assessment (LCA) is conducted for kitchen cabinet manufacturing in Finfine Furniture Factory (3F). The LCA methodology is used to assess the environmental impacts and explore ways alleviating environmental burdens at the kitchen cabinet production stages. The assessment covered the cradle-to-gate production of major inputs to 3F including their transportation to the factory gate. Primary data were collected on materials and resources used as inputs to, and on the product outputs from the factory. Data for the production of upstream inputs and supplements were taken from the USLCI and ELCD databases. The collected data were imported in, and analyzed with the Open LCA software. Emissions from transportation of raw materials were quantified based on emission factors from various studies and guidelines. Thereafter, the resulting life cycle inventory (LCI) table was evaluated with the CML 2001 baseline characterization method to quantify the contribution of the kitchen cabinet manufacturing chain in nine environmental impact categories. The study result indicated that there is an intensive use of particleboard, medium density fiberboard, lumber, and polyvinyl chloride. There is also large environmental impact contribution from the production and use of these materials. The production of particleboard generates significant potentials of Acidification, Terrestrial Eco Toxicity, and Eutrophication with magnitudes of 1.7 kg SO_2-eq, 0.04 kg -1,4-DCB-eq, 0.3 kg PO_4-eq, respectively. The emissions from the production of MDF cause Human Toxicity and Stratospheric Ozone Depletion with magnitudes of 213.1 kg-1,4-DCB-eq and $3.7x10^{-6}$ kg CFC-11 eq, respectively. There is visible contribution from the harvesting stage to Freshwater Aquatic Eco-toxicity and Global Warming with magnitudes of 10.2 kg-1,4-DCB eq and 45.2 kg CO_2 eq. The kitchen cabinet production stage is also another important contributor to Photochemical Ozone Creation, Abiotic Depletion and Terrestrial Eco Toxicity with magnitudes of 0.1 kg ethylene eq, 0.52 kg 1,4-DCB eq and 0.04 kg 1,4-DCB eq, respectively. The results of this study clearly indicated that non renewable energy use and emissions from formaldehyde use are the major issues to be prioritized for environmental optimization of the kitchen cabinet manufacturing chain in the factory. Therefore, making energy conservation, using biomass as source of energy and substituting toxic resin (UF) by less toxic resins can minimize the environmental burdens caused by the manufacturing of kitchen cabinet at 3F.

Keywords: *Life cycle inventory, kitchen cabinet, medium density fiberboard, particle board, impact assessment, urea formaldehyde*

List of Abbreviations

ADP - Abiotic Resources Depletion Potential

AP- Acidification Potential

Bhd. - Berhad

CFC- Chlorinated fluorocarbon

CML- Center of Environmental science of Leiden University

CNC- Computer Numerical Control

CORRIM- Consortium for Research on Renewable Industrial Materials

DCB- Dichlorobenzene

EDIP- Environmental Design of Industrial Products

EFB – Empty Fruit Bunch

EHR - Evergreen Hevea Resource Sdn. Bhd.

ELCD- European Reference Life Cycle Database

EP- Eutrophication Potential

EPA –Environmental Protection Authority/ Agency

EPS- Environmental Priority Strategy

ESA- Environmental System Analysis

EUSES- European Union System for the Evaluation of Substances

EVA – Ethyl Vinyl Acetate

FAETP100a - Freshwater Aquatic Eco-Toxicity Potential at 100 years horizon

FU- Functional Unit

GWP100a - Global Warming Potential at 100 years horizon

HAPs- Hazardous Air Pollutants

HHV- Higher Heating Value

HTP 100a - Human Toxicity Potential at 100 years horizon

INW- Inland Northwest

ISO- International Organization for Standardization

JB – Johor Bahru

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LCIA – Life Cycle Impact Assessment

LHV- Lower Heating Value

MC- Moisture Content

MDF - Medium Density Fiberboard

NC- North Central of America

NE- North East of America

NMVOCs – None Methane Volatile Organic compounds

NO_x - Nitrogen Oxides

ODP 10a - stratospheric Ozone Depletion Potential at 10 years horizon

OPT – Oil Palm Trunks

PEC- Predicted effect concentration

PM- Particulate Matter

PNEC- Predicted no effect concentration

POCP - Photochemical Oxidation Creation Potential

RCO- Regenerative Catalytic Oxidizers

RNA- Regional North America

RTO- Regenerative Thermal Oxidizers

Sb- Antimony

SO_x - Sulfur Oxides

TETP 100a - Terrestrial Eco-Toxicity Potential at 100 years horizon

TRACI- Tool for the Reduction and Assessment of Chemical and other environmental Impacts

UF- Urea Formaldehyde

UN-ECE- United Nations Economic Commission for Europe

USLCI- United State Life Cycle Inventory Database

VOC- Volatile Organic Compounds

WPB- Wood Particleboard

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1. Introduction

Over the past decades there has been a growing recognition that consumption of manufactured products affects both resources and the environment [1]. Society faces a wide range of challenges related to the degradation of the Earth’s natural resource, including major impacts on climate and biodiversity. Rate of biodiversity loss, interference of nutrient cycle and climate change are the most challenges caused by mainly anthropogenic activities.

Production of industrial products has impacts on the environment, beginning with the extraction of raw materials, through processing, and subsequent manufacturing including the associated transportation. Several factors contribute to existing trends in consumption of materials and waste generation which include economic activity, demographic changes, technological innovations, life style and patterns of production and consumption. Hence these factors also have to be taken into consideration in order to achieve a successful and sustainable management of materials consumption and waste generation. The generation of waste reflects loss of materials and energy thus imposing both economic and environmental costs to society for its collection, treatment and safe disposal. How waste impacts the environment is largely dependent on its quantity, nature and the waste management option available for its treatment. The quantity of waste is an indicator of material efficiency of a society, since excess amounts of waste imply an enormous loss of resources in the form of material and energy. High quantities of waste can result from inefficient production processes, poor durability of goods and unsustainable consumption patterns.

Interest in environmental issues is constantly increasing and at the same time, environmental issues have gradually been expanded with concepts such as sustainable development which includes economic and social as well as ecological responsibilities.

Worldwide, there is a growing interest in using wood products due to the environmental and economic concerns. Urbanization in Ethiopia is being highly accompanied by scarcity of living space and expansion of high rise communal residential buildings. The rapid economic and urban population growth will add to the cost and scarcity of the living space. Big furniture companies like 3F are establishing plants which are dedicated to only kitchen and built-in cabinets. Hence, space saving units like built-in storage and kitchen cabinets will continue to be in increasing high demand. The kitchen cabinet manufacturing process is composed of several stages associated with the consumption of large amounts of woods as well as the generation of liquid, solid and gas wastes.

Finfine Furniture Factory (3F) is one of the biggest furniture factories in Ethiopia. It manufactures kitchen cabinets and office furniture using skilled manpower and state- of- the -art technology. All of its kitchen products are consumed in the domestic market. Generally, the demand for wooden kitchen cabinet is increasing in the domestic market as well as in the international market due to its traditional appeal and durability [2]. In order to be competitive in global market the company has been improving the quality of its products by considering the environmental impacts that arise due to its production processes. Global climate change has captured media headlines for some time now and environmental consciousness is driving consumers towards more resource-minded products to support the joint effort of reducing greenhouse gas emissions worldwide. Ethiopia has started the path of green economic development which includes promoting the design, production, marketing and use of products and services with reduced environmental impacts. Therefore, such issues become important and force companies to produce eco-friendly products.

A useful tool to evaluate the environmental burdens associated with a product, process or activity is Life Cycle Assessment (LCA). It is a comprehensive environmental accounting tool with well-established procedures and methods that are governed by specific rules and standards, most notably those developed by the International Organization for Standardization (ISO). Its use continues to increase and there are now many experienced LCA practitioners world-wide who have successfully applied LCA across a broad range of industry sectors [3]. According to the ISO guide on life cycle assessment principles, LCA means compilation and evaluation of the inputs, outputs and potential environmental impacts of a product throughout its life cycle. The general categories of environmental impacts needing consideration include resource use, human health and ecological consequences. LCA is compiled from several interrelated components; goal and scope definition, inventory analysis, impact assessment and improvement assessment [4].

For this thesis the LCA approach is based on ISO-14040 standard and focuses on cradle to gate approach due to the available limited time, finance and lack of representative data on use, reuse and disposal. An important driver for this study is the prospect to increase use of the renewable wood kitchen cabinet products in society in place of non-wood alternatives, and thereby mitigate potential environmental impacts. To do so all the identification and quantification of the inputs and output flows of the process, energy and materials used and wastes released into the environment were dealt.

1.1. Statement of the problem

In the past natural resources had been assumed to be abundantly available. But, through time people have recognized the sudden scarcity of these resources along with the increment of pollutants and environmental problems. Hence, industries have started to use these resources sustainably and rationally to solve the problem of scarcity and environmental damages.

Ethiopia ranks in the last row of the global competitiveness index. The global industrial competitiveness indirectly implies environmental performance of the Ethiopian manufacturing sector, though there are no data to support whether the assertion holds true for the wood industry. Wood-based products in general tend to have favorable environmental performance compared to non-wood alternatives. However, the use of wood as industrial raw material is not a guarantee for the end products to be fully environmental friendly. Hence, kitchen cabinet manufacturing, like any industrial activity, involves consumption of raw materials and energy which are inherently accompanied by generation of wastes and emissions. Furthermore, these products are often treated with various chemicals such as formaldehyde to enhance properties like durability and appearance which in turn become causes for emissions of carbon and other toxic substances to the environment. Therefore, there is a need to analyze the environmental performance of kitchen cabinet manufacturing stages in order to know the corresponding environmental impacts and, at the same time, to enhance the current ambition of Ethiopia’s green growth strategy by increasing efficiency and green competitiveness of its manufacturing sector.

1.2. Objective

1.2.1. General objective

The main objective of the study is to assess the environmental impacts of kitchen cabinets at 3F using LCA and to explore ways of alleviating environmental burdens of their manufacturing.

1.2.2. Specific objectives

- ✓ To carry out life cycle inventory of kitchen cabinets in 3F during manufacture based on input-output of raw materials and energy
- ✓ To characterize environmental impacts of kitchen cabinets of 3F during manufacture.
- ✓ To interpret life cycle inventory and life cycle impact assessment results
- ✓ To identify methods that reduces emissions

1.3. Significance of the study

Information on life cycle assessment of kitchen cabinet is expected to result from this research. Subsequent analysis of collected data as well as their interpretations will be used;

- ➢ To improve the kitchen cabinet and its production process to be competitive in regional, national and international markets
- ➢ To support and improve environmental performance and management
- ➢ To mitigate climate change by contributing measures reducing emissions

Therefore it could be beneficiary for the following individuals;

- ➢ To decision makers in environmental protection and management
- ➢ To those who involve in the area of furniture production factories
- ➢ To economic and development policy makers
- ➢ To LCA practitioners and scientific communities

2. Literature Review

2.1. Classification of Kitchen Cabinets

A kitchen is a room or part of a room used for cooking and food preparation. A modern residential kitchen is typically equipped with a stove, a sink with hot and cold running water, a refrigerator and kitchen cabinets arranged according to a modular design. Its main function is cooking or preparing food but it also be used for dining, food storage, entertaining, dish washing and laundry. A cabinet is a box-shaped piece of furniture with doors and/or drawers for storing miscellaneous items and it is typically made up of wood, plastic and metals. Some cabinets stand alone while others are built into a wall or are attached to it. They usually have one or more doors on the front, which are mounted with door hardware, and occasionally a lock. Many cabinets have doors and drawers or only drawers. Short cabinets often have a finished surface on top that can be used for display, or as a working surface, such as the countertops found in kitchens.

Kitchen cabinets are one of the fore front furniture which helps modern households simplify food preparation by providing systematic storage, access to cooking ingredients and minimizing human movement during cooking. Many of the advantages of wood kitchen cabinets can be seen with just one glance: they are usually quite attractive, and the appearance can vary depending on the type of wood used for construction. These types of cabinets also tend to be fairly durable, again depending on the type of wood used. Wood tends to be a fairly easy material to work with, so construction of wood kitchen cabinets often allows for customization, more elaborate patterns or shapes. An experienced woodworker or cabinet maker will be able to create attractive and functional cabinets at a lower cost in many cases if wood is used, whereas metal cabinets may be more expensive and environmental unfriendly because construction is more energy and labor-intensive. The different grades of wood allow a homeowner to choose a material that fits his or her aesthetic needs and budget; lower-grade woods tend to be fairly inexpensive, but they will still often be durable and reasonably attractive [7]. Even lower-end woods tend to be fairly attractive, and if they are not, they can be painted or stained to improve the visual appeal. High-end hardwoods can be stained to showcase the wood's grain, or they can sometimes be left bare and simply protected with a sealant. Most woods will fit in aesthetically with the current kitchen decor, and wood kitchen cabinets are unlikely to go out of style, even after many years or decades.

In recent years, because of the resource of forest have been lessened and the environmental protection dominating, the furniture manufacturers in general and kitchen cabinet factories in particular use more laminated wood composite panels (such as plywood, particle board, and medium density fiberboard, MDF) instead of solid wood. The panels have different specification for every processing demand, which through surface laminating, cutting, edge banding, and boring become different kinds of knock down panel furniture. Modern style kitchen cabinets become more popular to the modern family which is equipped with decorative surface kitchen door and top, the cabinet inside could be equipped with gas burner, ventilator, refrigerator, microwave, garbage disposer and etc. [8]. Kitchen cabinets can be categorized based on the following classification.

2.1.1. Kitchen cabinet classification based on their designs

There are many styles of kitchen cabinet layouts including L-shape, U- shape and galley [9]. However, there are five basic kitchen cabinet design layouts. These are;

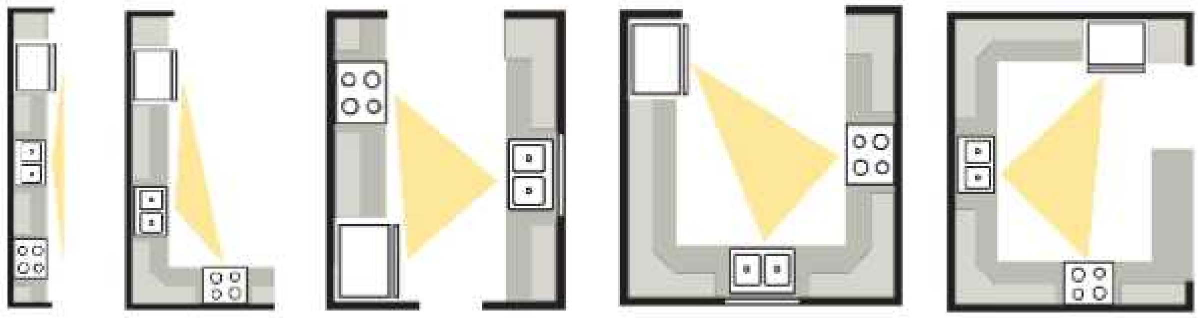
Straight run: a kitchen that is found along a single wall in a straight run is referred to as a straight run, or Pullman-style layout. This layout generally includes a small number of cabinets efficiently used within a small space, such as studio or apartment.

L-shape: it is found along two joined walls in an L-shaped layout. Typically, this layout has a point of the triangle on each wall and may or may not include an island. This layout is very common in homes with large open floor plans.

Galley: it is a shape used when two walls are parallel to each other with cabinets on both sides. Perhaps the most efficient kitchen design, as the distance to each point of the work triangle is relatively short. However, this layout is difficult for more than one cook to be working in the kitchen at any given time.

U-shape: it is a kitchen design shaped just like a letter U. This layout typically has a point of the work triangle on each of the three walls.

G-shape: it is similar to a U-shaped kitchen design, except it includes a peninsula or detached run of cabinets from the wall, commonly functioning as a breakfast bar area.



Straight run L-shaped Galley U-shaped G-shaped

Fig.2.1: Kitchen cabinet design layouts; Source; [10]

2.1.2. Kitchen cabinet classification based on their constructions

Despite the tremendous variety of kitchen cabinets, they all come down to two basic types: face frame and frame less box type. Each has characteristics that greatly affect how the heart of the modern home will appear and function. For the designer, cabinet maker, and installer, they all determine how the cabinets will be created. Framed cabinets incorporate a wood 'frame' around the front outer edge of the cabinet box. The face frame is made up of several pieces of wood that are fastened to the forward edge of the cabinet, framing the cabinet box. The outside edges of the frame are flush with the outside surfaces of the cabinet box whereas the inside portion of the frame extends to the inside edges of the box slightly. The face frame provides some rigidity to the cabinet box, helping it to remain square and sturdy. They are generally considered more traditional looking and offer some style variety based on the amount of door overlay. Door overlay just means the extent to which the door covers or "lays-over" the face frame. Frameless cabinetry was started in Europe after World War II. It addressed some of the challenges of the times, such as the shortage of lumber and the need to rebuild housing rapidly. The simplicity of the frameless kitchen cabinet greatly reduced material, needs, and production time. Doors would align tightly together, creating a clean, flowing line of casework. This reflected a modernist view of a changed world where time was short and production and efficiency reigned supreme. This construction method yielded other benefits. Drawers could be wider and deeper because they didn't need to clear face frame. And storage and removal of items along with cleaning the cabinet interior became easier and more efficient [11].

2.1.3. Kitchen cabinet classification based on their raw materials used

2.1.3.1. Wooden kitchen cabinets

The raw materials used for producing wooden kitchen cabinets in 3F are medium density fiberboard (MDF), particle board, glue, vinyl foil, lumber, and marble as countertop. The MDF and particle board are made from rubber wood and oil palm trunks.

Rubber Tree and Oil Palm Plantation and Management: Forestry is the cradle of kitchen cabinet factories; the raw materials basically originate from the forest in general and from timber production byproducts in particular. But, as environmental regulations has been becoming stricter and the cost of forest logs simultaneously been increasing. Wood industries such as Evergreen Fibreboard Berhad S.C., have shifted towards cheaper inputs such as the use of rubber wood logs and oil palm trunks which were used to be considered as manufacturing waste after harvesting the latex and fresh fruit bunches respectively [43]. Rubber wood emerged as an alternative source of timber for the wood industry, when restriction in logging activities was implemented by the Malaysian government. The commercial production of rubber wood in the wood based industry, particularly sawn timber, furniture and wood based panel began in the 1980s. In fact, the vast potential of rubber wood in sawn timber and other wood products application has been evaluated since 1950s [43]. Tapping of rubber trees starts in the fifth to seventh year after planting and continues for 25 to 30 years. The classical method for tapping is the removal at each tapping of only a thin layer of bark from the cut end, thus permitting a smooth flow of latex and allowing the bark to regenerate. After 25 years, a decline in latex production renders further tapping of the trees uneconomical, although smallholders may continue for many years. The trees are then removed and replaced with new seedlings.

The production of rubber wood logs showed a downward trend through time [44]. The matter that should be of concern is if the supply of rubber wood logs can meet the high demand from the wood based industries particularly for industries that have been utilizing rubber wood as the main raw material. Further, the numbers of mills consuming rubber wood have been increasing every year.

On the other hand, oil palm trees are the most important plantation crop in Malaysia. The plantations cover an area of roughly 4.7 million hectares in the country with about 100-130 trees per hectare. It bears fruit at the age of approximately two to three years, has an economic life of approximately 25-30 years, upon which the tree is felled for replanting and several million trees are felled every year for the foreseeable future. Therefore, large quantities of biomass wastes are generated in Malaysia [45]. Six types of oil palm biomass are produced as by-products of the palm oil industry: oil palm fronds, oil palm trunks (OPT), empty fruit bunch, palm kernel shells, mesocarp fibre and palm oil mill effluent [46]. OPT biomass residue has greater potential for commercial exploitation than other types of oil palm biomass residue [47]. Oil palm trunks become available at the end of a plantation's life cycle every 25–30 years. After that the production of oil seeds declined and the OPT are cleared for next re-plantation. Therefore, the MDF and WPB factories of that company have started to use a combination of 80% rubber wood logs with 20% oil palm trunks [48].

Rubber tree and palm oil plantation operations include growing seedlings, site preparation, planting, thinning, fertilization, spraying pesticide, latex harvesting and oil seed harvesting throughout their economic life span. But, the interventions from seed production have been regarded as insignificant due to the life time of palm oil and rubber tree is more than 25 years [49]. Therefore, inputs to the plantation resources management LCI includes fertilizer and pesticide used during nursery, immature plantation and mature plantations, and the fuel and lubricants needed to power and maintain equipment for thinning, and harvesting operations. But, since this stage produce multiple outputs it needs allocation.

Allocation: In LCA methodologies, it is common to allocate the overall environmental impacts associated with the production of the main products (fresh fruit bunches and latex), between the main product and the by-products. Various allocation methods exist, including [50].

1. Allocation by market prices, i.e. allocation of the emissions proportional to the market prices of the main product and the by-products.

2. Allocation by energy content, i.e. allocation of the emissions proportional to the total energy content of the main product and the by-products.

3. System expansion. The by-products are included in the project boundary. For each by-product, the baseline production processes are identified. Respectively, the emissions associated with the production of the by-products in the absence of the activity are included in the baseline emissions.

4. Attributing all emissions to the main product. As a conservative approach, all emissions from production process are accounted as project emissions where the main product is produced.

The plantation of rubber and palm oil trees produces rubber latex and fresh fruit bunches as main products. In addition, they produce by-products such as rubber wood logs, fronds and oil palm trunks. Their rotation is 25 years, as after this age the latex and FFB production becomes uneconomical then the trees are cleared. These were considered as waste and left in the field and burnt away and produce environmental pollutants but, now a day they are consumed as raw materials for wood industry. Hence, environmental impacts from the processes stages such as plantation management, fertilization and production of fertilizers and chemicals are attributed for only the production of rubber latex and FFB without allocating overall environmental impacts between main product and by-products as in method 4 above. Therefore, environmental impacts due to plantation management is not included in this paper because the impact due to these by products is insignificant compared to the main products.

Log Harvesting: Log harvesting methods have changed dramatically over years. Prior to the end of 20th century, log was harvested using mostly manual labor methods: felling trees and skidding to roadside landings for processing into around 4-metre logs; or cut-and-buck operations with 4-metre logs brought roadside using forwarders. Using skidders is not environmental friendly because of the amount of soil disturbance. Harvesting systems started to change, partially due to unacceptable negative effects on the environment, but also to help meet the Mill's demand for a more even distribution of fresh wood throughout the year [51].

At this stage, the uneconomical aged rubber and palm trees are felled and transported as inputs for the MDF and WPB plants. The harvesting process is mainly necessary for the MDF and WPB production. Hence, the harvesting process should be attributed to these plants rather than palm oil and rubber industries. Harvesting system includes felling, bucking, sorting, stocking, loading, transportation, and unloading [52]. Evergreen Hevea Resource (EHR, the company which supply wood logs for all EFB's sister factories) uses clear cut harvesting method. It uses a chainsaw to fell and buck the trunks. All bucked trunks are transported to road side by forwarder. Then it is transported from 100km and 80km radius to the MDF and Particle board plants respectively by truck. Finally, the load is unloaded by a loader. Generally, 25% of the wood demand of EFB is supplied from its own plantation and the rest is from estate and smallholder farmers. Therefore, logs are then collected by different collection methods ranging from simple manual collection with a wheelbarrow, to collection with a buffalo cart or motorized cart, to advanced mechanization. The choice of collection method for a specific plantation depends on the terrain (elevation), labor constraints and economies of scale [46].

Harvesting systems are chosen for a specific operation area based on stand and terrain conditions and other site-specific concerns. The system used in Evergreen Hevea resource (EHR) is a conventional method where, Rubber trees and OPT are felled, de-limbed, topped and cut into 4-metre lengths with a chainsaw. The wood is then picked up and transported to roadside by a forwarder.

Forwarders which are used in logs harvesting vary in size and wheel configuration. EHR currently uses the conventional method with 6 wheel forwarders with a carrying capacity of 12 tones. These trunks are then transported by a truck which consists of two trailers, one at roadside being loaded directly by a forwarder, and the second in transit to the plants mill. The logs are then unloaded by large-wheeled loaders and fed directly to the mill in-feed conveyors, or stockpiled for later use.

A. Particleboard: it is made from small chips of wood glued together and compressed in a high-temperature press. Different glues are used to bond the fibers, such as melamine formaldehyde and urea formaldehyde combined for 'moisture resistant' particleboard used in kitchens, bathrooms and laundries and phenol formaldehyde for high strength sheet flooring. 3F uses two sides' melamine laminated particle boards. Various additives are included in particular grades, depending on the properties the board needs to have. For example, paraffin wax is used to increase the board's resistance to water and to reduce the swelling that occurs if it is exposed to moisture. Fire retardants, insecticides and fungicides are also used to improve the board's durability and in-service performance. The board is actually built up in layers. The most common structure is three-layer particleboard, which has fine particles and more adhesive in the two outer layers and a coarse layer in the middle. Melamine-faced moisture-resistant particleboard is particularly suitable for cabinet carcasses and shelves [14, 16].

Particle Board Manufacturing: The major types of particles used to manufacture particleboard include wood shavings, flakes, wafers, chips, sawdust, strands, slivers, and wood wool [63]. None wood plants such as oil palm trunks, bamboo and kenaf mixed with rubber wood are currently used as raw materials of particle board manufacturing in response to the depletion of wood resources [64]. Evergreen is a leading worldwide producer of engineered wood-based products consisting of Medium Density Fiberboard (MDF) and Particleboard with an annual production exceeding 1.3 million cubic meters. The process flow diagram of particle board production line is given in figure 2.2.

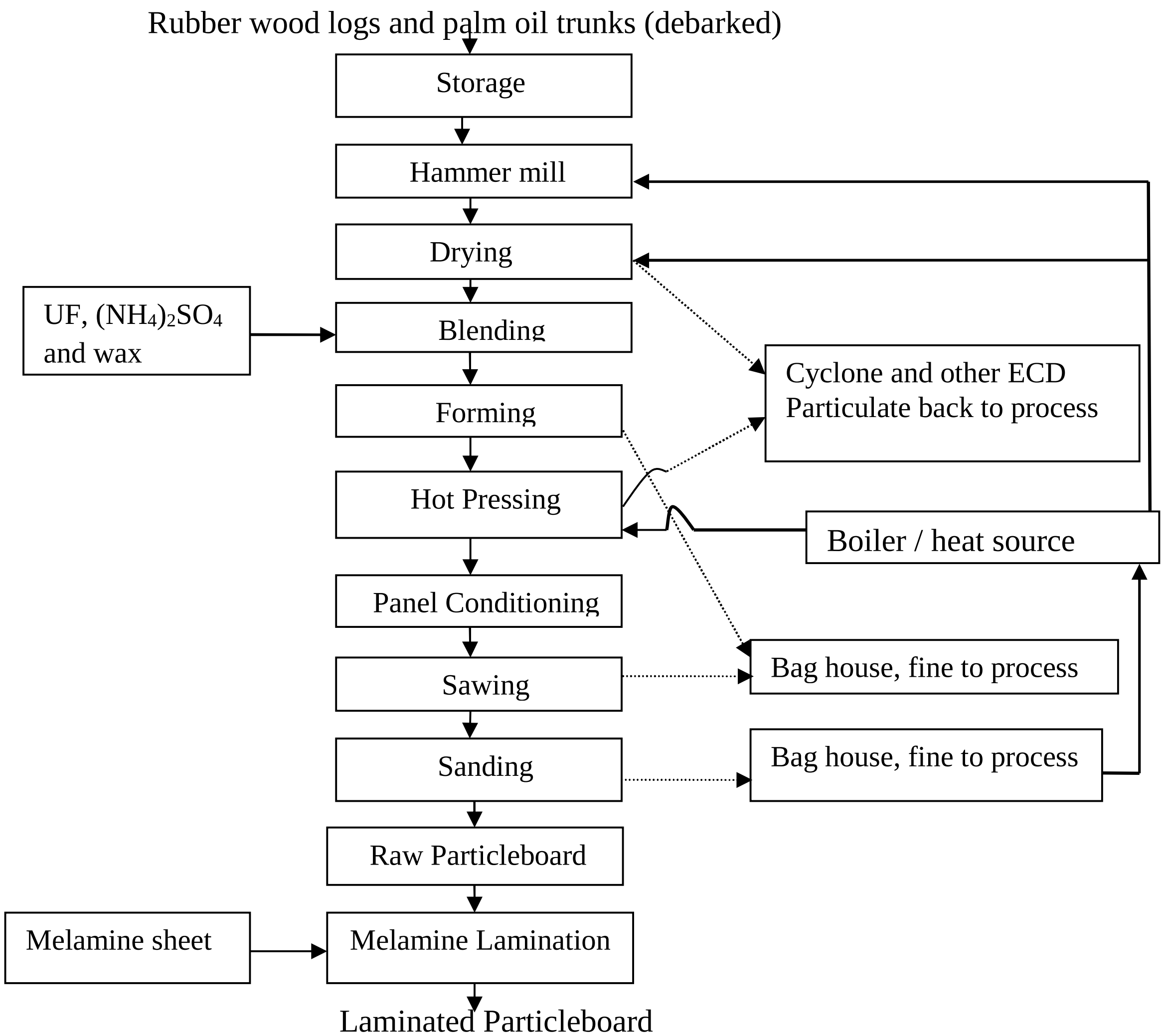


Fig.2.2: Melamine laminated particleboard production flow diagram, source [65]

Process description: The product has a density of 746 kg/m3, 16mm thickness, 1.22m width and 2.44 m length. Although some single-layer particleboard is produced, particleboard generally is manufactured in three layers. The outer layers are referred to as the surface or face layers, and the inner layer is termed the core layer. Face material generally is finer than core material. By altering the relative properties of the face and core layers, the bending strength and stiffness of the board can be increased. The general steps used to produce particleboard include raw material preparation, classifying by size, drying, blending with resin and sometimes wax, forming the resinated material into a mat, hot pressing, and finishing [63]. The following processes are carried out in the production of WPB.

Store: Rubber wood logs and palm oil trunks are delivered to the mill normally by truck; these woods are either fed directly to the mill or piled on the yard for future usage.

Refining; the rubber wood logs and oil palm trunks are forwarded to the refiner to be chopped in to particles of required size. This is a process of mechanically reducing the particle geometry into uniform sizes of desired dimensions; it is usually accomplished with the use of refiners, hammer mills, and occasionally flakers and hogs. Particulate emissions are addressed by bag houses and cyclones [65].

Drying: Particles are sent through dryers, normally rotary dryers of single-pass. Particles enter the dryers at moisture contents of 10 – 100% oven dry wood basis and are dried to a targeted MC of about 3 – 5% depending on whether the particles will be used for face or core layers. The dryers are normally direct-fired with sander dust. When wood dries at elevated temperatures in the dryers, air emissions consisting of particulates and volatile organic compounds (VOCs) are released. Emissions from dryers go to cyclones and control devices.

Blending: This is a process in which resin (urea formaldehyde), wax, catalyst (ammonium sulfate), and urea scavengers are distributed in the form of discrete droplets onto the wood particles. Waxes are added to impart water repellency and dimensional stability to the boards upon wetting [66].

Forming: Blended particles are distributed into a flat mat in usually multiple layers of three consisting of face and core layers—the size of particles, their moisture and resin content are controlled for the face and core layers to obtain desire panel properties.

Hot pressing: Formed mats are conveyed into large multi opening presses in which all openings close simultaneously. The presses operate at sufficient temperature (about 170^{o}C), pressure (about 5.2 MPa), and duration to cure the resin. The physical properties of the panel are controlled during pressing. As a result of the elevated temperature and resin curing, particulates and air emissions of VOCs, hazardous air pollutants (HAPs), and other related emissions are generated and go to emission control devices.

Cooling: Hot panels exiting the press are placed on a cooling wheel to enable the temperature of the panels to drop below a value at which UF resin could start to break down with time and emit formaldehyde gas. Limited amounts of air emissions occur at this point.

Sanding: Panels are sanded on both major surfaces to targeted thickness and smoothness. Sander dust coming off this process is used as fuel for the dryers. Particulate emissions are addressed by bag houses and cyclones.

Sawing: Relatively large panels are sawn to dimensions of panel width and length. The sized panels are then sent to lamination section. Panel trim is hammer milled into particles and sent back with the saw dust into the process before the former.

Melamine lamination; the sanded and sized panel is then laminated its two faces by melamine at an elevated temperature and pressure. The finished Particle board has a final dimension of 1.22m width, 2.44m length and an average dry density of 746 kg/m^3. Finally, the finished panels are stacked and prepared for shipping.

Particulate emissions are addressed by bag houses and cyclones. Other important processes are the boiler and wood fuel heater and their combustion of fuel to generate processing heat and particulates collection and control devices such as bag houses, cyclones. The boilers are generally fired with mostly wood residue, and oil fuels; with this combustion, air emissions of CO_2, CO, and others are generated. The emission control devices are used to reduce particulate and chemical emissions. The factory uses a combination of cyclones and bag houses to reduce particulates, VOC, and HAP emission levels [65].

B. Medium density fiberboard (MDF): is manufactured in a similar way to particleboard, using the same sorts of glues and additives. The big difference is in the way the wood fibers are treated before they are pressed. The wood is heated under pressure until the fibers and natural glues that bond them together soften, and then the fibers are rubbed apart to produce a much finer material for pressing. There are two types of MDF: Standard MDF, which uses urea formaldehyde as the adhesive and moisture resistant MDF, which uses melamine and urea formaldehyde. Moisture resistant MDF is used in kitchen cabinet factory and 3F uses one side melamine laminated MDF.

MDF does not warp or twist under normal conditions. It can be drilled, sanded, routed and re-sawn without splintering or chipping. Because of its consistent density, its face and edges can be machined to a profile, without the need for a separate edge strip. It can also be painted, stained or clear finished, and is often used for high-gloss enamel-finished items. In addition to being suitable for painting, MDF is also an excellent substrate for laminates, including wood veneers, vinyl foils and melamine. It can also be used in curved work, such as archways and curved panels. Like particleboard, it does not tolerate wet conditions. Moisture-resistant boards are able to cope with areas of high humidity and occasional wetting, but they still need to be protected from prolonged contact with moisture. It swells and shrinks in response to changes in humidity. In locations where dimensions are critical, it should be acclimatized for up to 48 hours prior to use to make sure that its moisture content is in balance with the surrounding atmosphere [14, 16].

MDF Production: MDF is an industrial type panel used for making furniture, cabinets, tables, countertops, and millwork [67]. In Evergreen Fibreboard, Malaysia, it is produced from 80% rubber woods, and 20% palm oil trunks [48]. These materials are chipped and refined to fibers or fiber bundles that are dried, blended with resin and wax, and then formed into a mat that is consolidated and cured under pressure and heat. It has a density of 741 kg/m3, 16 mm thicknesses, 1.22 m width and 2.44m length. A 3mm thin MDF, a subgroup of MDF products, is also included. The process flow diagram of MDF production line is given in figure 2.3.

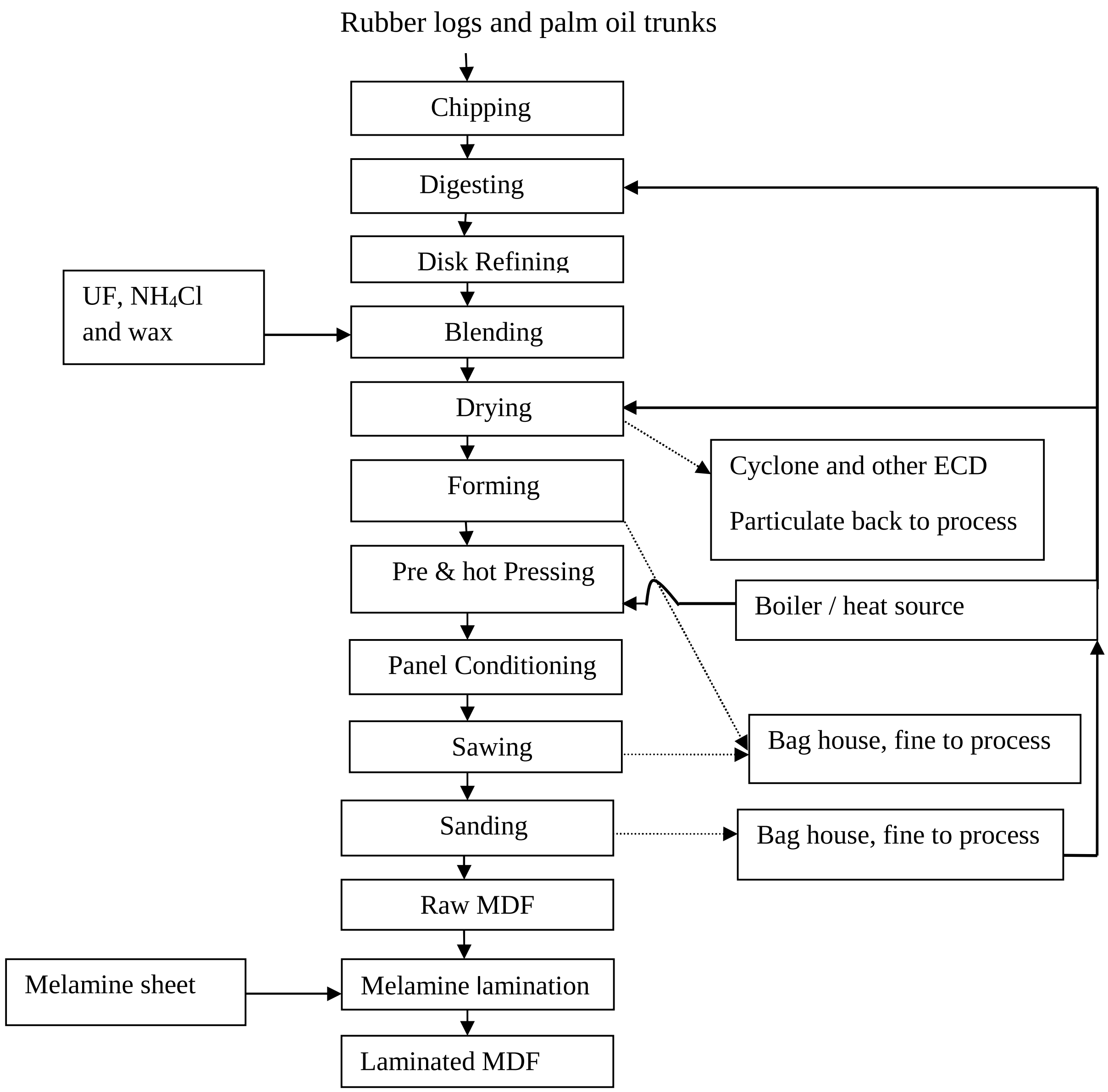


Fig.2.3: Melamine laminated MDF production line flow diagram, Source [67]

Process description: Rubber woods, palm oil trunks and small amount of residues are delivered to the mill by truck. These woods are either fed directly to the mill or piled on the yard for future usage. The following processes are carried out in the production of MDF.

Chipping: Directly after debarking the logs and trunks are fed through a disc chipper, creating the chip that will become fiber.

Digesting: The wood residue is placed in a pressurized vessel called a digester to cook the wood in preparation for refining into fibers. The wood is cooked with steam at pressure to soften the lignin binder material between its fibers.

Refining: The heated wood residue is then refined, a process of mechanically reducing it into fibers by shearing the wood between two rotating metal disks which separate the fibers at the lignin binder. This process is usually accomplished with the use of pressurized disk refiners a method for mechanically reducing wood into its individual fibers.

Blending: This process distributes the resin, wax, catalyst, and scavenger onto the fibers. Friction and contact between fibers is used to distribute the resin. The factory used 65% Urea-formaldehyde (UF) resin as adhesive (table 4.17). The resin and other additives are applied to the fibers in the refiner, coming out of the refiner in the blow line.

Drying: The fibers are sent through dryers, most commonly through flash tube dryers consisting of long tubes. Heated air is used to both dry and transport the fibers the length of the tube. The fibers enter the dryer at somewhat higher moisture contents than the 39% (oven dry basis) average residue entering the mill because of steam treating in the digester. The fibers are dried to a targeted moisture content of about 7-9% with resin applied. The dryers are normally direct-fired with natural gas and sander dust, generated during finishing the MDF. Heat sources based on wood fuel can also be used for drying. As wood dries at elevated air temperatures of up to 260°C in the dryers, particulates and air emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) are released [68].

Forming: The blended fibers are distributed into a flat mat usually in multiple layers of three consisting of face and core layers. The distribution of fibers, their moisture, and resin content can be controlled for the face and core layers to obtain desire panel properties and efficiency.

Hot pressing: The formed mats are pre-pressed to reduce their thickness and provide mat integrity and are then conveyed into large stack presses with multiple openings. Presses operate at a sufficient temperature of approximately 170°C and duration to cure the resin, and sufficient pressure of approximately 5.17 MPa to consolidate the mat to a desired density of 741 kg/m^3. As a result of the elevated temperature and resin curing, particulates and air emissions of VOCs, HAPs, and resin related emissions are generated. Hot presses are heated with steam.

Conditioning: The hot panels are placed on a cooling wheel to enable the temperature of the panels to drop below a value where the UF resin will start to break down with time and emit formaldehyde gas. Limited amounts of air emissions occur at this point.

Sanding: The panels are sanded on both major surfaces to targeted thickness and smoothness. Sander dust coming off this process can either be put back into residue prior to the blending process or used as fuel for the dryers.

Sawing: Sanded, conditioned panels are sawn to their required dimensions. These sized panels are then sent to the lamination section. Panel trim is hammer milled into particles and sent back into the process prior to the former.

Melamine lamination: the sanded and sized panel is then laminated its one face by melamine at an elevated temperature and pressure. The finished MDF has a final dimension of 1.22m width, 2.44m length and an average dry density of 741 kg/m^3. Finally, the finished panels are stacked and prepared for shipping.

C. Glue: Thermal melt glues are considered as green adhesives because they contain around 10-50% natural (rubber latex), sustainable raw materials and some can be applied at lower temperatures thus saving energy and greatly reducing the risk of severe burns. But, the rest percentage is from synthetic sources (ethylene vinyl acetate) which produce some environmental problems. The first step in bond formation involves spreading the adhesive over the wood surface. The physical application of the adhesive can involve any one of a number of methods, including using spray, roller coating, doctor blade, curtain coater, and bead application technologies. After the adhesive application, a combination of some open and closed assembly times is used depending on the specific bonding process. Both give the adhesive time to penetrate into the wood prior to bond formation, but the open assembly time will cause loss of solvent or water from the formulation. Long open times can cause the adhesive to dry out on the surface causing poor bonding because flow is needed for bonding to the substrate. In the bonding process, pressure is used to bring the surfaces closer together. In some cases, heat and moisture are used during the bonding process, both of which will make the adhesive more fluid and the wood more deformable [17].

Although wood is a natural material, bonded wood products have caused some environmental concern. There are a number of problem areas, but the foremost area of concern has been formaldehyde emissions from the bonded products, mainly using UF resins. Formaldehyde can react with biological systems in reactions similar to those that are used for curing of adhesives. The problem can arise from both free and generated formaldehyde. Free formaldehyde is also a problem during the manufacturing operation and in freshly produced composites. Formaldehyde emissions from composites decrease with time after production. The rate is high initially, but slowly decreases due to diffusion limitations. On the other hand, formaldehyde can be generated by the decomposition of some formaldehyde copolymer adhesives, in particular the urea-formaldehyde adhesives. These adhesive bonds are more prone to hydrolysis, generating free formaldehyde. The biggest concern is with particleboard, due to the large volume of indoor usage and the high level of adhesive in the product. The formulations of formaldehyde adhesives were altered to reduce the amount of formaldehyde used and in some cases formaldehyde scavengers were added. The reduction in formaldehyde altered the curing rate and the strength of the product; thus, the process required much research. Although many of the formaldehyde concerns have been addressed through adhesive reformulation, products still need to meet the commercial standards [18, 19; 20]. The main concern, emissions, has focused on formaldehyde, but this is not the only compound emitted by bonded wood products. Other volatile compounds in the adhesive formulation have also been detected. In addition, a number of other volatiles are present in wood and additional ones can be generated by the heat and moisture in the production of the composite. Careful analysis has revealed the presence of formaldehyde, other aldehydes, methanol, and pinenes, many of which come from the wood itself rather than from the adhesive. During the use of the adhesives, volatiles from the monomers that are used to produce the polymers generate additional health concerns. Thus, free formaldehyde, phenol, methanediphenyl diisocyanate, polyethylene polyamines, etc., are all of concern depending on the type of adhesive used. Heating certainly increases the problem because it raises the vapor pressure of these reactive chemicals. In addition, many hot pressing methods cause other chemicals to be entrained in the steam from the presses [18].

D. PVC sheet: Polyvinyl chloride is one of the most commonly used materials in the furniture industry and is used to cover exposed structural components and doors. It is considered a toxic material, but the only danger is during production and destruction (if it is not burned in special incinerators, it produces dioxins). It can be colored and can imitate wood grain. A thermoplastic material, it is not heat-resistant and softens at temperatures between 75 and 95 ^{0}C. Vinyl foils are increasingly popular wood substitutes that give a very realistic wood grain finish to MDF and particle board. The particular benefits are economy, an extensive range of imitation, exotic wood effects, durability, and consistency of color and grain that make them ideal for fitted furniture, without the open graining and blemishes of real wood. Vinyl wrapped doors are made up of MDF panels which are cut, routed, profiled, sanded, then glued and covered with a vinyl film that is pressed to the door under vacuum. The back of the door is usually pre-laminated. The vinyl thickness is between 0.4mm and 0.7mm. There is a large range of colors, both plain and in wood grain, sometimes they are embossed to feel like wood grain or textured for effect [21].

2.1.3.2. Stainless steel/metal kitchen cabinets

Stainless steel is used to make complete cabinets though it is much less prevalent than wood cabinetry. There are whole cabinets (boxes and doors/drawers) made from stainless steel.

2.1.3.3. Plastic (PVC) kitchen cabinets

They use poly vinyl chloride or other plastics to construct the different parts of the cabinets.

2.2. Description of kitchen cabinet production processes in 3F

3F has 47 years of experience on furniture manufacturing. It started to produce furniture in 1967 by the owner ship of European and Ethiopian business men in Addis Ababa at Saris site. After 29 years of operation it was sold to Mr. Endale Yrga in 1996 and he expanded it by opening additional new factory at Alem Gena site in 2006. Currently it has 700 employees at the production of furniture in general and 40 employees at the kitchen cabinet department in particular. The company gets its power supply from Ethiopian electric power corporation (EEPCO). For the production of kitchen cabinets it imports two side white melamine laminated particle board and one side white melamine laminated MDF, Ethylene-vinyl acetate (EVA) glue, PVC sheet from Malaysia and solid lumber from Shashemane, Ethiopia. Malaysia is one of the world's largest exporters of tropical timber and has also established itself as a major producer and exporter of sawn timber, panel products (plywood, medium density fiberboard and particleboard), flooring, doors and other joinery products [12]. The kitchen cabinet manufacturing process is automated, process-controlled, and fairly linear (Fig.2.4). The main steps of producing kitchen cabinets in 3F involve the following steps:

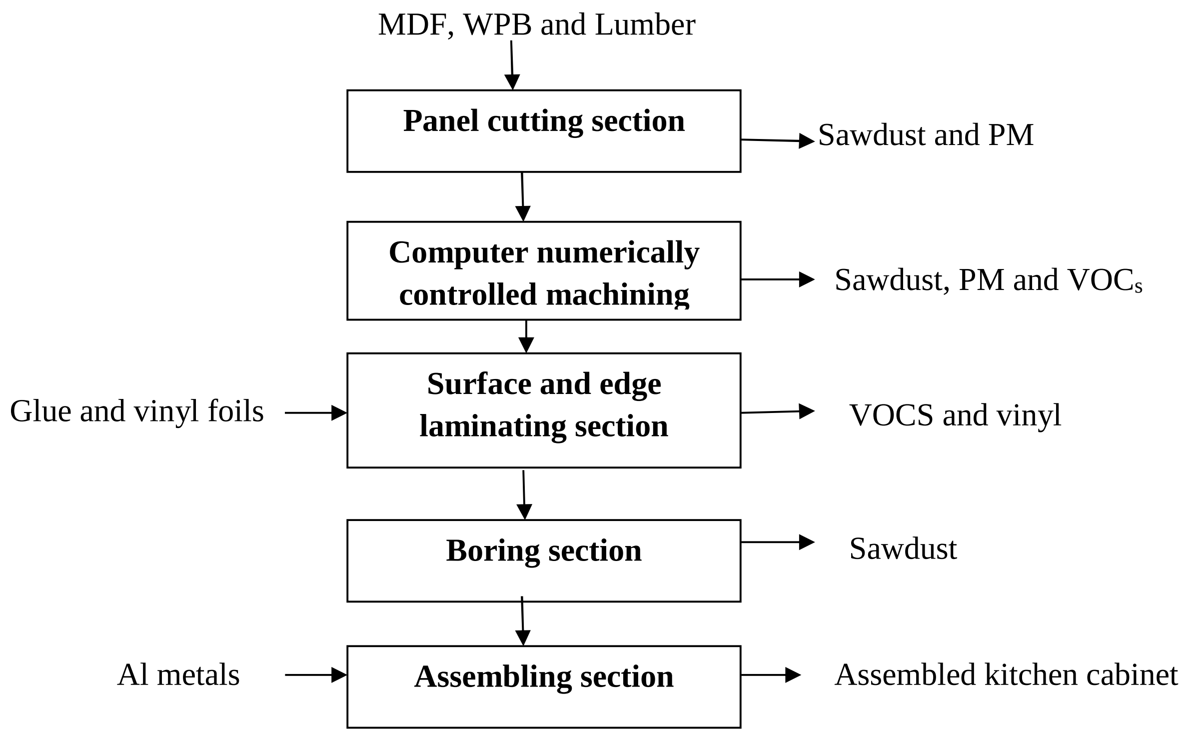


Fig.2.4: Process flow diagram of kitchen production in 3F

2.2.1. Panel Cutting section

It is the process of converting full-sized boards into the panels that make up the carcasses, doors, shelves and other components. They are used to cut large panels into smaller sizes. They range from small manually-operated table saws to highly-automated numerically controlled (NC) saws. Panel saws that are designed to cut laminated boards often have a scribing blade (also called a 'scorer') in front of the main saw blade. It cuts slightly into the underside of the panel before the main blade cuts through the full thickness. This helps to stop the problem of 'break-out' occurring on the underside of the board, where the surface chips out as the teeth pull through the material. On the other side of the main blade is a riving knife. This is a piece of steel shaped to match the curve of the saw blade. Its purpose is to stop the material on either side of the kerfs (the saw cut) from closing up and jamming the blade. This closing action is called binding or sneaking. If a board did bind on the blade, it would have a tendency to suddenly kick backwards and possibly damage the board or blade.

There are different types of ISO standardized saws in the market such as sliding table saws, wall saws and numerically controlled saws. The last one is used in Finfine Furniture factory to cut the full sized boards in to the required size. Numerically Controlled (NC) beam saws are controlled by a computer program and designed for high volume production work. After cabinet part sizes are generated on a computer, they are entered in to the production schedule. Parts are first cut to size on a panel saw. The loading and stacking mechanisms are often automated, and the saws can cut several panels at once (figure 2.5). During cutting, a board (MDF, WPB, etc), fine dust of wood, board trimmings and glue particles are produced. Furthermore most of these products also contain other chemicals designed to improve the board's performance. Depending on the end use of the board, they may include moisture inhibitors, insecticides, fungicides and fire retardants. Again, these chemicals are incorporated in the dust generated during processing of these boards. There are various problems with exposure to these dusts. Firstly, in some people it may trigger an asthmatic attack or some other form of allergic reaction. But more seriously, workers who breathe in these dusts over a long period of time run the risk of developing cancer in their nose, lungs or other parts of their respiratory system. But, most of the dust particles are sucked by pneumatic suction which is mounted at the cutting machine [13]. However, most fine and nano-scale particles or "particulate matter" is difficult to control once it is suspended in the air as aerosol.

Fig.2.5: Panel cutting machine; source: photographed at the factory

Particulate Matter 2.5 ($PM_{2.5}$): The term "particulate matter" describes solid and liquid particles found in the air we breathe. Particulate matter that is smaller than 0.0025 millimeters in diameter is called $PM_{2.5}$ and may not be visible to the naked eye. In a cabinet and counter top manufacturer, $PM_{2.5}$ is released into the air during the sawing and sanding of wood and other materials. Because of their small size, $PM_{2.5}$ can lodge deeply into the lungs. Numerous studies have linked PM to aggravated cardiac and respiratory diseases such as asthma, bronchitis and emphysema, and to heart disease [14].

Volatile Organic Compounds (VOCs): VOCs are a group of organic chemicals that easily evaporate into the air. In a cabinet and counter top manufacturing facility, VOCs are released from manufacturing products including fillers, sealers, basecoats and topcoats. Short-term health effects of exposure to VOCs may include eye, nose, and throat irritation, headaches, loss of muscle coordination, and nausea. Over longer periods, VOCs can damage the liver, kidneys, and central nervous system [14].

2.2.2. Computer Numerically Controlled (CNC) machine

Parts that need routing, chamfering or grooving are machined on a CNC machining center to create 3D designs which are programmed on the computer to draw on door panels, countertops and light shield of the kitchen cabinets. Chamfering is a shallow cut made on the edge of the sized MDF which is used as a door, light shield and countertop of the kitchen cabinets. This makes them good for looking. Edge of the panels is smoothened via sanding process. Then parts are sent to the edge and surface processing section. This section also produces large amount of wood dusts, particulate maters and volatile organic compounds. But, it has vacuum dust collector, to minimize these emissions, which is an integral part of the CNC machine.

2.2.3. Edge and Surface Laminating Section

There are various types of edge treatments used in kitchen cabinet manufacturing. Edge stripping with laminates is used in 3F, where boards that are faced with white melamine laminate are edge banded on the visible edges with a vinyl foil. The edging is usually done in an edge banding machine, which applies the hot melt glue as it rolls the edging onto the board using pressure rollers. It works at 190^{o}C to melt the glue and 220^{o}C to laminate the vinyl foil with the chamfered and visible edge of MDF or/and particle board. The machine also trims the edges and snips the ends. The edge tape can vary in thickness, depending on the function of the panel and the type of laminate specified. Most cabinet carcasses and doors use edge banding strips that range between 0.07 mm and 2.00 mm in thickness. Note that the thickness of the edging will affect the gap between doors and drawers, so it is important to establish these thicknesses before these components are cut to size.

The exposed flat panel surfaces are laminated by vinyl foils of different colors and liquid glue using hot press machines operated at 120^{o}C, 50 Pa for duration of 2 minutes.

This section produces around 40% by weight of the total vinyl foil as waste trimmings, glue sprays (20% by weight), small amount of sawdust (0.5% by weight) and gas emissions. The glue sprays are suppressed using water absorber. Hence, it minimizes emission of VOCs and PM during spraying of the glue to the surface of the panel. It produces insignificant amount of water pollution because the amount of effluent water is small compared to the whole factory activity.

2.2.4. Drilling machine

Cabinet parts then are drilled and wooden dowel pins are inserted using a boring machine. The purpose of drilling or boring machine is to drill the laminated kitchen body and doors to make them easy for assembling. This section produces small amount of sawdust compared to the above sections.

2.2.5. Assembling section

The following finished kitchen cabinet parts are checked and assembled in this section. Visual quality control checks on the quality of the finishes should be carried out before proceeding to assemble the parts.

Bases: They are made from solid wood coated with paints which are diluted by organic solvents. This enables the base to be installed on-site, along the full length of the wall where the cabinets go, and leveled before the cabinets are positioned on top. According to Briggs [15] paints used to mark lumber are not integral to the product and would not be included unless they accounted for at least 2% of inputs (by mass). Since this cut off criterion is in line with that of ISO 14044 and it is less than 2% its impact is not included in this study.

Carcasses: they are the basic framework of a cabinet. They are generally made from whiteboard (two sides laminated white melamine particleboard in case of 3F) and consist of a back, base, two invisible or visible sides, and two rails. The rails are used to fix the underside of the bench top to the carcass. Sometimes the front rail is turned on edge, rather than on flat, especially when a sink or hot plate is mounted above. This avoids the problem of the installer having to cut away part of the rail to allow for the deep inset. The joints and fasteners used in assembling carcasses are depending on the materials involved and the design of the cabinets. Chipboard screws are used in the factory to fasten each finished boards of the carcass (carcass construction) edges, but they are designed particularly for particleboard. They differ from normal wood screws in having a coarser thread and no taper in the shank. Operators insert them using an air powered variable-speed drill or screw driver. There are various ways of attaching the back of the carcass (thin MDF) to the end panels. 3F uses a method of an internal back is cut to the inside width of the cabinet and fixed through the sides of the end panels. There are other ways of fixing a back panel, although these aren't used in 3F kitchen cabinets.

Drawers: they are made from manufactured board off-cuts. Generally they contain an open box with a front, back and sides made from white melamine particleboard and MDF base. A separate drawer front is fitted to match the cabinet doors and it is laminated by vinyl foil. There is generally 12-13 mm of free space between the inside of the carcass and the outside of the drawer sides to allow for the runners.

Doors: they are made from chamfered, decorated MDF and laminated by vinyl foil**.** The hinge cup is inserted into a 35 mm hole, with the edge of the hole generally 3 mm from the door edge. The mounting plate is fixed to the carcass, and the hinge arm is slid over the plate and locked into position.

These assembled cabinet parts are pressed using the cabinet press machine. This section is almost done manually with simple compressed air powered machines.

Countertop: It usually refers to a horizontal work surface in kitchens. It is frequently installed upon and supported by cabinets. The surface is positioned at an ergonomic height for the user and the particular task for which it is designed. It may be constructed of various materials, such as hard wood or marble, with different attributes of functionality, durability, and aesthetics. The countertop may have built-in appliances', or accessory items relative to the intended application. 3F uses hard wood and marble counter tops. So, short description of marble industry will add value to the paper. Marble industry is one of the most environmentally unfriendly industries. Its waste is generally a highly polluting waste due to both its highly alkaline nature (PH around 12), and its manufacturing and processing techniques, which impose a health threat to the surroundings. Cutting the stones produces heat, slurry, rock fragments, and dust. Although marble waste, in general, includes non-radioactive by-products, and thus it does not induce climate changes at wet condition, it does destroy plant life. The weathering of the worn steel grit and blades used in processing marble transfer some quantities of toxic metals like Chromium. This endangers the quality of surface and ground waters nearby. Marbles usually contain the chemical compounds CaO, MgO, SiO_2, Al_2O3, Fe_2O_3, Na_2O, TiO_2 and P_2O_5. During the cutting process of the finished marble in to the required dimension at the kitchen cabinet manufacturing factory at dry condition it release gases that contribute to global warming and climate changes [22, 23].

2.3. Description of Life Cycle Assessment

This thesis is aimed at analyzing the environmental impacts associated with kitchen cabinet production. However, it intends not only to assess the environmental performance of the production process itself, but also to expand the scope to include the up and downstream processes, which leaves the Life Cycle Assessment (LCA) an ideal method to carry out such study. As environmental awareness increases, industries and businesses have started to assess how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing "greener" products and using "greener" processes [24]. Green products are environmentally friendly products since they cause minimal environmental impact during their manufacture, use and disposal [25]. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance since it also improves efficiency of their manufacturing system beyond the purpose of corporate social responsibility [24]. Therefore, companies started to use environmental system analysis (ESA) in general and LCA in particular which is one tool of ESA.

LCA is an environmental assessment tool that aimed at analyzing the environmental effects associated with a product or a process or a single activity over the entire course of its life or duration, i.e. from cradle to grave. Such assessment can be achieved by building a system model to quantify the consumption of energy and materials, in the meantime calculating the emissions and wastes released to the environment within the entire life cycle of the system, which usually involves the computation of the effects of extraction of the raw materials, main production processes, transportation, use phase, reuse, recycling and/or final waste disposal process [26]. According to ISO 14040 [27], there are at least four steps for conducting an LCA, as it is shown in figure 2.6.

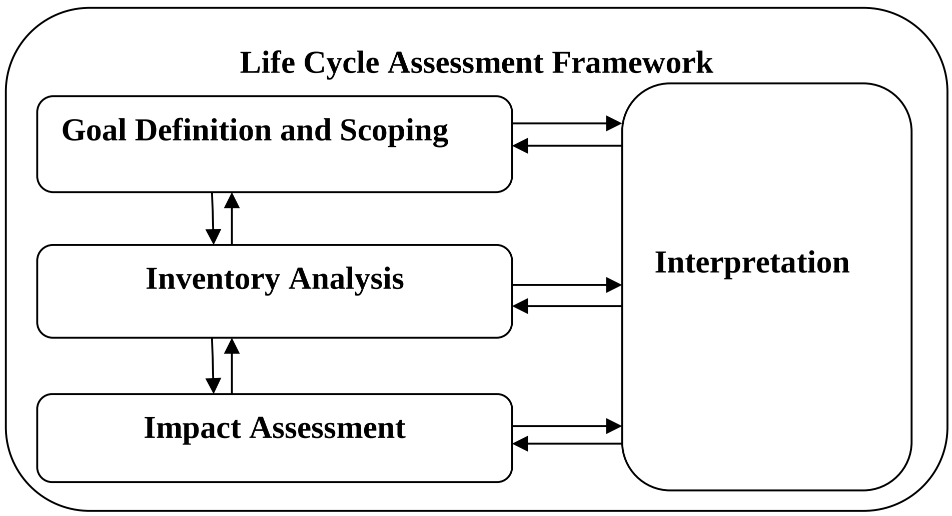


Fig.2.6: Phases of LCA: Source; ISO 14040 [27]

2.3.1. Goal Definition and Scoping

It is defining and describing the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment [28]. To initiate an LCA, the goal must be clearly determined by stating the intended application and reasons for performing the study. Then according to the goal, the scope is thus to be determined in relation to temporal, geographical and technological coverage [27, 29].

2.3.2. Inventory Analysis

This phase is about to gather all the necessary data (e.g. the resources used, energy use, emissions, and products come out of each process) to generate the mass and energy flow within or between technical system and environment, i.e. to establish a system model based on the requirements of the goal and scope definition [29]. Data collection is generally the most time consuming aspect of an LCA study. Data has to be collected for all single processes in the life cycle. Due to difficulty involved in data collection, both primary (data originally collected specifically for the purposes of that study) as well as previously published data are often used [33]. No formal demands exist for calculation in LCA except for those described for allocation procedures. Various LCA software programmes have been developed for this purpose which can be selected according to the type and amount of data to be managed [34].

2.3.3. Impact Assessment

It enables to translate the inventory results into environmental impacts. Then to elucidate the magnitude of the potential environmental impact by characterizing the inventory results into real environmental load, for example global warming, acidification, Eutrophication and so on [31]. Knowing that there are certain amounts of pollutants discharged is not enough for an LCA. Once the environmental flows (from the input and output data) have been identified and measured, they are categorized into impact categories. Typical impact indicators include abiotic depletion, acidification, climate change, human toxicity, ecological toxicity, Eutrophication, fossil fuel depletion, photo-oxidant smog formation and stratospheric ozone depletion. LCA practitioners and scientific experts, such as the Intergovernmental Panel on Climate Change (IPCC) or the World Health Organization (WHO), have developed methodologies to translate the inputs and outputs into these potential environmental impacts. There are two types of Impact Categories:

Midpoint approach: The LCIA mid-point approach is also known as problem-oriented approach [35]. The term mid-point refers to the category indicator for each impact category which is expressed in the mid pathway of impact between LCI results and end-point [36]. Mid-point translates the category impact into real phenomenon for example climate change and acidification [37]. Examples of methodology that were developed using the midpoint approach are CML 2001 [35], EDIP 97 and TRACI [38].

Endpoint approach: The end-point LCIA methodology is also known as damage-oriented approach [35]. The term 'end-point' refers to the category indicator for each impact category located at the end of impact pathway. Examples of end-point methodology are Eco-indicator 95 and 99, EPS92, 96 and 2000 [39]. There are several factors affecting the level of confidence and suitability of LCA research results which include option of LCIA methodology either using the mid-point or end-point approach. End-point impact category is less comprehensive and possesses higher level of uncertainty compared to mid-point impact category [40]. Nevertheless mid-point impact category is difficult to be interpreted especially in the process of decision making because the mid-point impact category is not directly correlated with the area of protection (that is damage to human health, ecosystem quality and resource depletion) which is practiced by the end-point.

The environmental impact can be evaluated using the following steps;

2.3.3.1. Selection of Environmental Impact categories

The first step in an LCIA is to select the impact categories that will be considered as part of the overall LCA. The items identified in the LCI have potential human health and environmental impacts. For an LCIA, impacts are defined as the consequences caused by the input and output streams of a system on human health, plants and animals, or the future availability of natural resources. Typically, LCIAs focus on the potential impacts to three main categories: human health, ecological health, and resource depletion [41].

2.3.3.2. Classification

The purpose of classification is to organize and possibly combine the LCI results into impact categories. For LCI items that contribute to only one impact category, the procedure is a straightforward assignment. For example: carbon dioxide (CO_2) emissions can be classified into the global warming category. Generally, the following environmental themes are considered in selection and classification of environmental impacts using:

- **Material and energy depletion potential**: it concerns the extraction of nonrenewable raw materials and energy carriers.
- **Global warming potential:** an increasing amount of CO_2 in the earth's atmosphere leads to more absorption of radiative energy, and consequently, to an increase in temperatures on Earth. This is referred to as global warming. CO_2, N_2O, CH_4, and aerosols all contribute to global warming.
- **Human toxicity:** exposure of humans to toxic substances causes health problems. Exposure can take place through air, water, or soil, especially via the food chain.
- **Eco-toxicity:** exposure of flora and fauna to toxic substances cause health problems in them. Eco-toxicity is defined for water (aquatic eco-toxicity) and soil (terrestrial eco-toxicity)

- **Eutrophication potential:** addition of nutrients to water or soil will increase the production of biomass. This in turn leads to reduction in the oxygen concentration, which affects higher organisms like fish, can lead to undesirable shifts in the number of species in an ecosystem, and thus to a threat to biodiversity. Main elements in this section are nitrogen containing substances, phosphates, and organic materials.
- **Ozone depletion (ODP):** depletion of the ozone layer leads to an increase in the amount of UV light reaching the earth's surface. This may lead to human diseases and may influence ecosystems in a negative way.
- **Photochemical oxidant creation potential (POCP)** - Reaction of NO_x with volatile organic substances leads, under influence of UV light, to photochemical oxidant creation, which causes smog.

For LCI items that contribute to two or more different impact categories, a rule must be established for classification. There are two ways of assigning LCI results to multiple impact categories [31].

• Allocate a representative portion of the LCI results to the impact categories to which they contribute. This is typically allowed in cases when the effects are dependent on each other.

• Assign all LCI results to all impact categories to which they contribute. This is typically allowed when the effects are independent of each other.

2.3.3.3. Characterisation

Impact characterization uses science-based conversion factors, called characterization factors, to convert and combine the LCI results into representative indicators of impacts to human and ecological health. Characterization factors also are commonly referred to as equivalency factors. Characterization provides a way to directly compare the LCI results within each impact category. In other words, characterization factors translate different inventory inputs into directly comparable impact indicators.

Impact indicators are typically characterized using the following equation:

$$\text{Impact Indicators} = \text{Inventory Data} \times \text{Characterization Factor}$$

For example, all greenhouse gases can be expressed in terms of carbon dioxide (CO_2) equivalents by multiplying the relevant LCI results by a CO_2 characterization factor and then combining the resulting impact indicators to provide an overall indicator of global warming potential. The equivalence factors for environmental impact categories are given in the table 2.1.

2.3.3.4. Normalization

Normalization is an LCIA tool used to express impact indicator data in a way that can be compared among impact categories. This procedure normalizes the indicator results by dividing to a selected reference value. There are numerous methods of selecting a reference value, including:

- The total emissions or resource use for a given area that may be global, regional or local;
- The total emissions or resource use for a given area on a per capita basis;
- The ratio of one alternative to another (i.e., the baseline); and
- The highest value among all options.

Table 2.1: Equivalence factors for environmental impacts

Impact category	Indicator	Characterization Model	Characterization factor	Equivalency Unit
Abiotic depletion	Ultimate reserve/annual use	Guinea & Heijungs 95	Abiotic depletion potential	kg sb. eq.
Climate change	Infrared Radiative forcing	Intergovernmental Panel on Climate Change	Global warming Potential	kg CO_2 eq.
Stratospheric ozone depletion	Stratospheric ozone breakdown	World Metrological Organization model	Stratospheric O_3 layer depletion potential	kg CFC-11 eq.
Human toxicity	Predicted and Accepted daily Intake	EUSES, California Toxicology model	Human toxicity Potential	kg 1,4 DCB eq.
Ecological toxicity	PEC, PNEC	EUSES, California Toxicology model	AETP, TETP etc.	kg 1,4 DCB eq.
Photo oxidant smog formation	Tropospheric Ozone production	UN-ECE Trajectory model	Photo-oxidant Chemical potential	kg C_2H_6 eq.

Source; ISO 14044, [42]

2.3.3.5. Weighting

The weighting step (also referred to as evaluation) of an LCIA assigns weights or relative values to the different impact categories based on their perceived importance or relevance. Weighting is important because the impact categories should also reflect study goals and stakeholder values. As stated earlier, harmful air emissions could be of relatively higher concern in an air non-attainment zone than the same emission level in an area with better air quality. Because weighting is not a scientific process, it is vital that the weighting methodology is clearly explained and documented. Although weighting is widely used in LCAs, the weighting stage is the least developed of the impact assessment steps and also is the one most likely to be challenged for integrity. In general, weighting includes the following activities [41].

- Identifying the underlying values of stakeholders.
- Determining weights to place on impacts.
- Applying weights to impact indicators.

2.3.4. Interpretation

Evaluating the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results [28]. In other words it enables people to understand the result of the study and identify the components that have the most signification environmental impacts [32].

3. Methods

3.1. Goal and scope definition

The "Cradle" to "gate" perspective LCA of kitchen cabinet production in 3F follows the procedure as laid down in ISO 14044 [30]. The LCA procedure comprises four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation of results. The goal of this study is stated under the objective part (section 1.2). The scope of this study describes the functional unit of the studied product, the product system and its boundaries, data collection and processing procedures, and environmental impact categories considered. The inventory analysis phase quantifies the natural resources and other inputs and the environmental emissions and other outputs for each process in the product system. The impact assessment phase translates the natural resource inputs and environmental emissions into their contributions to a range of selected impact categories. The final phase, i.e. interpretation, interprets the results from the preceding phases of the LCA. Open LCA 1.4 software is employed to supplement and analyze primary data collected on kitchen cabinet production at 3F. Publically free databases such as USLCI and ILCD were incorporated in the software.

3.1.1. Functional unit

Functional unit must reflect the function of the investigated product. For this study, material flows, fuel and electricity use, and emissions data were normalized to a per-production of one unit L-shaped system cabinet. Therefore, all the emissions were calculated in relation to the production of one L shaped design finished kitchen cabinet.

3.1.2. System boundary

The system boundary is an interface between a product system and the environment or other product systems. In this project the processes investigated are rubber wood and oil palm trunks harvesting, MDF and particle board production, kitchen cabinet manufacturing and associated transportation. The Impact due to transportation of all imported and local materials, electric generation and fuel or oil production is also considered. However, depreciation of the capital goods is excluded in this paper. The system boundary is shown clearly in the figure 3.1 and table 3.1.

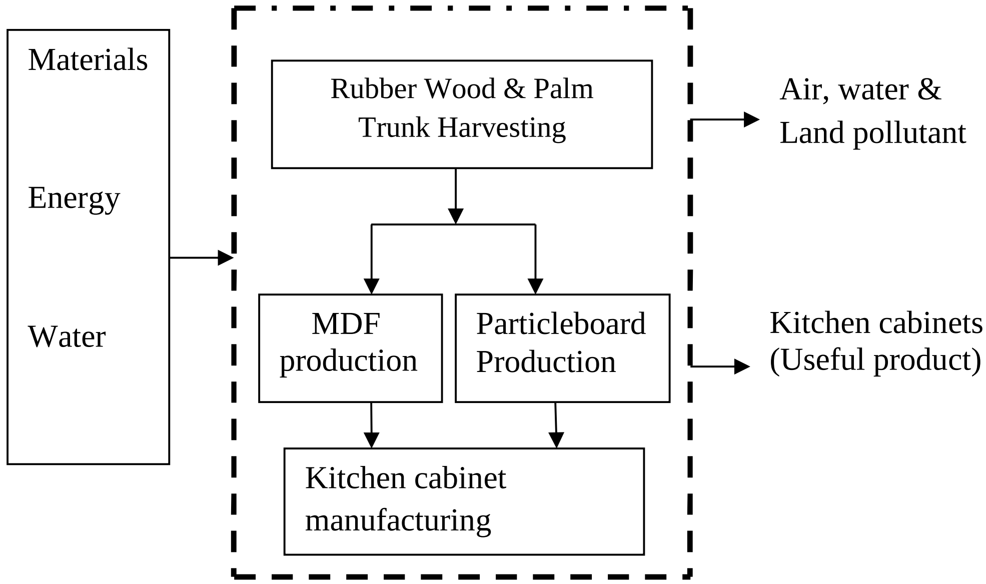


Fig.3.1: System boundary for the LCA of kitchen cabinet product

Table 3.1: System boundary definition criteria

Processing category	Included	Excluded	
		Insignificant environmental impact	Difficult to obtain representative data
Production of seedlings	-	✓	-
Plantation of rubber tree	-	✓	-
Plantation of palm oil tree	-	✓	-
Harvesting of rubber wood	✓	-	-
Transportation of rubber woods to MDF & particle board plants	✓	-	-
Harvesting of OPT	✓	-	
Transportation of OPT to MDF & particle board plants	✓	-	-
Production of UF resin	✓		
Production of ammonium sulfate	-	✓	-
Production of wax	✓		-
Manufacturing of particle board	✓	-	-
Manufacturing of MDF	✓	-	
Transportation of MDF & WPB from the plant to Muar port	✓	-	-
Transportation of MDF & WPB from Muar port to Djibouti port	✓	-	-
Transportation of MDF & WPB from Djibouti port to factory gate	✓	-	-
Manufacturing of kitchen cabinets	✓	-	-

3.1.3. Data collection

The kitchen cabinet products of 3F are not standardized but they are on the way to be standardized by the factory. But, it has advanced machineries and technologies. The availability of the advanced technology forced the researcher to choose this factory from other kitchen cabinet manufacturing factories which are present in Ethiopia. The factory produces U shaped, L shaped, straight run, and mini L shaped without overhead cabinets. According to company sources, the L shaped kitchen cabinet is frequently requested by customers hence takes the larger share in the list of products of the company's kitchen cabinets. Therefore, judgment or purposive sampling method was used in sampling the product in this research.

The inventory data used in this study are representative of the period between 2013 and 2014. Whenever possible and feasible, average (one year) or typical process-specific data were collected. The remaining data were obtained from the literature and LCI databases.

Data concerning the consumption of fuel during rubber wood and oil palm harvesting are representative of the typical operations carried out in Malaysia. Such operations include tree felling, bucking, forwarding, road hauling and unloading. The emissions generated during fuel combustion were taken from the USLCI database [55].

Inventory data for medium density fiberboard (MDF) production are average production data taken from Evergreen Fibreboard Berhad (MDF producer) annual report and from CORRIM report [66]. Specific emission data were taken from the USLCI database [55].

Data on the production of particle board were also taken from Evergreen Fibreboard Berhad (MDF producer) annual report and from Consortium for Research on Renewable Industrial Raw Materials (CORRIM) report [66]. Specific emission data were taken from the USLCI database [55].

Inventory data for the production of kitchen cabinets are average production data collected at Finfine Furniture Factory. These data were collected through measurements, questioner, observations and interviews with designers, technical supervisors, individual operators and marketers. The prepared questioner is presented in appendix II B. These data were also supplemented by USLCI database [55]. Furthermore, all the energy required in the kitchen cabinet production process is generated from hydropower. So, the emissions associated with the production of hydropower energy were taken from ELCD database [32].

Inventory data for the production of polyvinyl chloride sheet (PVC), glue and wax were collected from USLCI and ELCD databases.

The transport of urea formaldehyde resin, PVC sheet, MDF, particle board, glue, ammonium sulfate catalyst and lumber was accounted for using average distance mainly taken from Google map [57] and port distance [58]. Emission factors for each mode of transport were derived from the IPCC [60]. Inventory data for the production of fuels (diesel) were taken from the USLCI database [55].

The variables which were considered in this research are raw materials depletion, energy consumption, and emissions released to the environment due to one unit system kitchen cabinet product, from cradle to gate. The first two variables was measured by conducting material and energy balance at each unit operations (unit processes) within the system boundary. While the third variable is usually measured by air pollution measuring instruments and water pollution measuring devices. But, conducting LCA is resource intensive, so developing database regarding pollutant emissions is difficult at this stage with in this limited time and finance which makes using LCA database more feasible. Therefore, emission data were adopted from USLCI and ELCD databases using Open LCA software due to lack of time, sophisticated measuring instruments (for example air pollution measuring instruments) and finance.

Actual factory data for the kitchen cabinet manufacturing is the preferred data source. The actual factory data may include estimates or extrapolations, but should be based on measured values. Records of actual raw material inputs, measured stack and out flowing emissions and energy purchases by fuel type are examples of this type of data. Because this data reflects actual conditions and efficiencies it is considered the most accurate. However, there are some difficulties with this type of data. One difficulty is incomplete measurement and record keeping for some emission categories. The other difficulty is the factory produces several furniture products at the same plant which creates difficulty in assigning energy use and emissions to individual products. Process studies are helpful in resolving these kinds of problems. It is a physical/chemical analysis of what occurs within a process under regular conditions. Data is generated from physical models of processes (often called input output process models) such as mass-balance equations and energy analyses.

3.1.4. Data Quality

All the primary data related to the inputs and outputs of the process were obtained directly from the factory. So, these data have high quality. The secondary data were taken from trusted published journals and internationally acceptable databases such as USLCI and ELCD databases. Therefore, the quality of the data is not questionable.

3.1.5. Data analysis (Impact assessment method)

The impact assessment phase in LCA consists of three mandatory and two optional steps as described in section 2.3.3. This study uses CML 2001 baseline life cycle impact assessment method as implemented in the Open LCA software to characterize the inventory results. It considers nine environmental impact categories: acidification, global warming, eutrophication, freshwater aquatic eco-toxicity, ozone depletion, human toxicity, terrestrial eco-toxicity, photochemical oxidation creation and abiotic depletion.

3.1.6. Cut-off criteria

The environmental impacts associated with the production of machinery and infrastructure, human labor, manufacturing of transportation vehicles, metal ingredients, plastic ingredients, plantation of rubber tree, plantation of palm oil and personnel-related environmental impacts (for example the transportation of laborers to the working field) are not counted in.

4. Result and Discussion

4.1. Life cycle inventory Result

The entire life cycle of kitchen cabinet manufacturing system investigated in this study is presented in figure 3.1. The processes in this system consist of the following sub systems and the associated transportations.

- Log harvesting and transportation
- MDF production and transportation
- Particleboard production and transportation
- Kitchen cabinets manufacturing

4.1.1. Log harvesting

The inventory data for rubber wood and oil palm trunk harvesting is summarized in the following tables. Table 4.1 shows the plantation density, life span and average volume of green wood of both trees.

Table 4.1: Plant capacity per hectare, tree life span and green wood volume/tree

Parameters	Data /estimation	
	Rubber wood	Oil palm trunks
Capacity of plantation	400 trees/ ha	140 trees/ha
Life span of trees	25 years	25 years
mass of green woods	270kg/tree	1507.50 kg/tree
Calculated value	$180m^3$or 108t/ha	211.05t/ha

Density of air dries RW= $600kg/m^3$, Rubber wood yield= 60% and MC= 60%: Source: [54]

Table 4.2: Inventory data for OPT and rubber wood harvesting process

Processes	Oil palm trunks			Rubber wood		
	Name	Unit	Value	Name	Unit	Value
Felling	Oil palm trees Chainsaw	kg hour	2217.50 0.2	Rubber tree Chainsaw	kg hour	537.9 0.3
Processing	Felled OP trees Harvester	kg hour	2217.50 0.17	Felled rubber tree Harvester	kg hour	537.9 0.23
Forwarding	Green OPT Forwarder	kg hour	1507.5 0.186	Round wood Forwarder	kg hour	384.2 0.0474
Transporting	Air dry OPT Truck (100km)	kg t*km	343.05 34.305	Air dry rubber wood Truck (100km)	kg t*km	384.2 38.42
unloading	Air dry OPT Loader	kg hour	343.05 0.05	Air dry rubber wood Loader	kg hour	384.2 0.056

Where t*km is tone kilometer

Table 4.3: Unit process and equivalent unit processes for harvesting

Process	Total	Equivalent process
Chainsaw	0.5h	Chain sawing, hand felling, NE-NC-RNA
Harvester	0.4h	Delimbing, slide boom delimber/RNA
Forwarder	0.2334h	Loader operation, large, INW/RNA
Transport	72.73 t*km	Transport, combination truck, short-haul, diesel powered –RNA
Loader	0.106h	Loader operation, large, INW/RNA

Source: USLCI [55]

Inventory data of rubber wood and OPT harvesting are adopted from the USLCI database using Open LCA software. Input and output flows which have large contribution to each defined impact category are summarized in table 4.4 bellow. The detailed input output flows are given in appendix I (table A 2).

Table 4.4: Life cycle inventory for rubber wood and OPT harvesting per functional unit

Flow	Unit	Category	Value
Input			
Oil, crude	Kg	Resource, ground	10.357
Diesel	m^3	product	1.43×10^{-2}
Gasoline	m^3	Product	1.80×10^{-4}
Lubricants	Kg	product	0.206
Output			
Nitrogen oxides	Kg	emission to air	0.801
Ethane, 1,1,1-trichloro-, HCFC-140	Kg	emission to air	9.704×10^{-10}
Carbon dioxide, fossil	Kg	emission to air	45.179
Carbon monoxide, fossil	Kg	emission to air	0.3442
Methane, tetrachloro-, R-10	Kg	emission to air	1.20×10^{-10}
Acroline	Kg	emission to air	2.204×10^{-5}
PAH, polycyclic aromatic hydrocarbons	Kg	emission to air	3.992×10^{-5}
Mercury	Kg	emission to water	3.611×10^{-8}
COD, Chemical Oxygen Demand	Kg	emission to water	1.285×10^{-2}
Benzene	Kg	emission to water	6.166×10^{-5}
Barium	Kg	emission to water	4.51×10^{-2}

4.1.2. Transportation of raw materials

The transport of the raw materials begins from their respective domestic factories to the MDF factory; Evergreen Fibreboard (JB) Sdn. Bhd. and WPB factory; Allgreen Timber Products Sdn. Bhd., Malaysia. Then a truck transfers the WPB, MDF, PVC and glue for 96 kilometers from the company to the Port of Muar, Malaysia [57]. A container ship transports these materials to Djibouti port, Djibouti. The map in figure 4.2 shows the route of the ship from the port in Muar to the port of Djibouti. The total distance traveled by the container ship from Muar port to Djibouti, is 6789 kilometers. Finally, these materials are transported from Djibouti port to the factory gate by semi trailer and full trailer trucks and whose carrying capacity is 40 feet and two 20 feet container respectively. The distance traveled by a truck from Djibouti to *Alem Gena* is about 854.8 kilometers. Therefore, the total distance traveled in the transport chain is 7,719.8 kilometers.

Fig.4.1: Shipping direction, Source: port distance [58].

The emission data are calculated using the following emission models.

Emission Models: The following models are the equations used in calculating the emissions for the trucks and ship for the transport chain. Equation 1 is the emission factor formula [56]. The basis of the formula is on the type of fuel a certain transport system is using.

$$EF = C_f \times EC_f \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (4.1)$$

Where: EF = Emission Factor, g/l

C_f = specific emission, g/kWh

EC_f = Energy content of fuel, kWh/l

Equation 4.2 is the formula for calculating the total emissions of truck transport [56]. The total emissions are based on the carrying capacity of the truck as well as its emission factor and fuel consumption.

$$E = (FC \times EF) \times d \times \left(\frac{1}{Cc}\right) \times L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

Where E = total emission in gram d = Total distance, km

EF = Emission Factor, g/l L = load

FC = Fuel Consumption, l/km Cc = Cargo Capacity

Equation 3 shows the formula for computing the emissions for ship transport [56]. The total emissions for ship transport are based on the type of engine that the ship uses as well as the cargo capacity and speed of the ship.

$$E = \left(C_f \times \frac{EP}{S}\right) \times d \times \left(\frac{1}{C_c}\right) \times \left(\frac{1}{U}\right) \times L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

Where: E = Total Emissions, kg Cc = Cargo Capacity

Cf = specific emission, g/kWh U = Cargo Utilization, %

EP = Engine Power, kW L = load

S = Speed, km-ph d = Total distance, km

There are at least three transportation processes which are identified in the cradle to gate life cycle of kitchen cabinet production. These are,

- Transportation of urea formaldehyde, wax and catalyst to particle board production factory (Allgreen Timber Product Factory).
- Transportation of urea formaldehyde, wax and catalyst to MDF production plant (Evergreen Fibreboard (JB) Factory).
- Transportation of MDF, particle board, PVC sheet and glue from their respective factories to kitchen cabinet manufacturing factory, Ethiopia. The major environmental emissions from each transportation process are determined below.

i. Transportation of raw materials to Allgreen Timber Product Factory and Evergreen Fibreboard (JB) Factory

Adhesives and waxes are transported from Evergreen Adhesive and Chemicals. Sdn. Bhd., Johor, Malaysia. While ammonium sulfate catalyst and Urea scavengers are from Guran chemical factory, Kedah, Malaysia (table 4.5). The truck which transported these raw materials is a Volvo FH16 truck, which has an engine, built in 2007. The truck's diesel engine runs on Malaysian diesel fuel (HHV: 45 MJ/kg; density: 0.85kg/l; empty trip 3.9 km/l). The energy content of the Malaysian diesel is 10.6 kWh per liter while its sulfur content is 0.001 % by weight [59].There is no data on emission factors but, revised emission factors for the combustion of diesel by heavy duty diesel vehicles are adopted from IPCC [60]. The carrying capacity of a full trailer truck is 9.4 tone chemicals per trip (such as UF, wax, catalyst and urea scavenger).Therefore, the amount and delivery distance of these chemicals transported per functional unit is calculated in table 4.5. The total emissions due to transportation of each chemical to the WPB and MDF plant are then calculated in table 4.6 and 4.7 respectively.

Table 4.5: Amount and delivery distance of raw materials to Allgreen Timber Product Factory and Evergreen Fibreboard (JB) Factory

Raw material	Origin of raw material	Delivery dist. (km/r. trip) and amount (kg/fu)			
		WPB* plant		MDF** plant	
		Distance (km)	Weight (kg)	Distance (km)	Weight (kg)
Melamine & urea formaldehyde resin	Evergreen Adhesive & chemicals Sdn. Bhd.Johor, Malaysia.	314	25.769	48.4	11.683
Wax		314	0.875	48.4	0.709
Ammonium sulfate catalyst	Gurun, Kedah, Malaysia.	1234	0.252	1484	0.015
Urea scavenger		1234	0.98	1484	0.174

*Allgreen Timber product Sdn. Bhd. **Evergreen Fibreboard (JB) Sdn.Bhd. Fu = functional unit, r. trip = round trip

Source: [61, 62]

Table 4.6: Emissions due to raw material transportation to Allgreen Timber Product Factory

Emission elements	CO_2	NO_x	CH_4	NMVOC	N_2O	CO
Average fuel consumption: (km/l)[a]	3.3	3.3	3.3	3.3	3.3	3.3
Emission factor: (grams/l)[a]	2670.07	35.71	0.17	6.80	0.09	30.61
Load capacity: (tone)	9.4	9.4	9.4	9.4	9.4	9.4
Emission rate: (g/t-km)	86.076	1.15	0.005	0.22	0.003	0.987
Emissions due to UF&M trans. (g)	696.48	9.305	0.04	1.78	0.024	7.985
Emissions due to wax trans.(g)	23.65	0.316	0.001	0.06	0.001	0.271
Emissions due to catalyst trans.(g)	26.77	0.358	0.002	0.07	0.001	0.307
Emissions due to urea scavenger (g)	104.09	1.391	0.006	0.27	0.004	1.194
Total emissions (grams)	**850.99**	**11.37**	**0.049**	**2.18**	**0.029**	**9.757**

[a] Estimation emission factors for European diesel heavy duty vehicles. Note: it is converted to g/l. ρ_{diesel}=0.85kg/l

Table 4.7: Emissions due to raw material transportation to Evergreen Fibreboard (JB) Factory

Emission elements	CO_2	NO_x	CH_4	NMVOC	N_2O	CO
Average fuel consumption: (km/l)[a]	3.3	3.3	3.3	3.3	3.3	3.3
Emission factor: (grams/l)[a]	2670.07	35.71	0.17	6.80	0.09	30.61
Load capacity: (tonne)	9.4	9.4	9.4	9.4	9.4	9.4
Emission rate: (g/t-km)	86.076	1.15	0.005	0.22	0.003	0.987
Total emissions due to UF&M trans. (g)	48.67	0.65	0.0028	0.124	0.0017	0.558
Total emissions due to wax : (g)	2.95	0.04	0.0002	0.008	0.0001	0.034
Total emissions due to catalyst :(g)	1.92	0.03	0.0001	0.005	0	0.022
Total emissions due to urea scav.:(g)	22.23	0.3	0.0013	0.057	0.0008	0.255
Total emissions (grams)	**75.77**	**1.02**	**0.0044**	**0.194**	**0.0026**	**0.869**

[a] Estimation emission factors for European diesel heavy duty vehicles. Note: it is converted to g/l. ρ_{diesel}=0.85kg/l

ii. Transportation of PVC, WPB, MDF and Glue from the EFB to Muar port

3F imported one side melamine laminated MDF (including thin MDF) and two side melamine laminated particle board, PVC sheets and glue from Malaysia. The truck, which transports these raw materials from the company, is the same as the above truck which transports the adhesives, waxes and urea scavengers. Therefore, the engine model and emission factors are not changed. The total distance from EFB to Muar terminal is 96km [57]. The amount and round trip distance for the transportation of each raw material per functional unit is given in table 4.8. Finally, the individual and total emissions are given in table 4.9.

Table 4.8: Amount and delivery distance of raw materials from EFB to Muar port.

Raw material	Origin of raw material	Amount (kg/fu)	Truck capacity (tone)	Delivery dist.(km/round trip)
WPB	Evergreen Fibreboard Bhd. Johor, Malaysia.	261.1	16.2	192
MDF		100.78	16.2	192
PVC		1.23	29.702	192
Glue		4.5	9.29	192

Source: company data report

Table 4.9: Emissions due to raw material transportation from EFB to Muar

Emission elements	CO_2	NO_x	CH_4	NMVOC	N_2O	CO
Average fuel consumption: (km/l)	3.3	3.3	3.3	3.3	3.3	3.3
Emission factor: (grams/l)[a]	2670.07	35.71	0.17	6.80	0.09	30.61
Emission rate : (grams/km)	809.11	10.82	0.05	2.06	0.03	9.28
Truck capacity: (tone)	See table 4.8					
Emission rate: (g/t-km)	See table 4.8					
Emissions due to WPB trans.(g/fu)	2503.81	33.48	0.155	6.37	0.093	28.70
Emissions due to MDF trans.(g/fu)	966.42	12.92	0.060	2.46	0.036	11.08
Emissions due to PVC trans.(g)	6.43	0.086	0.0004	0.016	0.0002	0.07
Emissions due to glue trans.(g)	75.25	1.006	0.0046	0.192	0.0023	0.86
Total Emissions (grams/fu)	**3551.91**	**47.49**	**0.22**	**9.04**	**0.132**	**40.71**

[a] Estimation emission factors for European diesel heavy duty vehicles.

iii. Transportation of PVC, WPB and MDF from Muar port to Djibouti port

The ship used in transporting the raw materials from the port of Muar to the port of Djibouti is a container ship with a service speed of 19 knots or 35 kilometers per hour. The ship was built in 2003 with a shaft power of 8914.7 kW. An average one way trans-oceanic distance from Malaysian port, Muar to the Djibouti port is taken as 6984.29 km [58]. To get the specific emission or energy of engine in g/kWh, the estimation emission factors for European diesel ship transportation (at 40% efficiency) is used. The emission factor calculated is dependent on the mass of containers in the container ship. It carries 10,000 twenty feet equivalent units (teu) that is 10,000 twenty feet ISO standard containers. The emissions are allocated to each of the containers inside the ship. It is assumed that each container is equal in terms of the contribution to the emissions. The product of the total distance traveled and the number of containers transported is multiplied to the calculated emission rate to get the total emissions in grams. Table 4.10 shows the total emissions calculated for transporting the 0.0461 containers (functional unit) by a container ship.

Table 4.10: Emissions due to ship transportation

Emission elements	CO_2	NO_x	N_2O	NMVOCs	CH_4	CO
Emission factor (g/kg diesel) [a]	3140	42	1.3	4.7	0.18	11
Emission factor (g/l diesel)[b]	2670.07	35.71	1.11	4	0.15	9.35
Energy con. of diesel (kWh/l)	10.6	10.6	10.6	10.6	10.6	10.6
Energy of engine (g/kWh)[c]	671.1	8.98	0.28	1.01	0.04	2.35
Engine Power (kW)	8914.70	8914.70	8914.70	8914.70	8914.70	8914.70
Speed (km ph)	35	35	35	35	35	35
Cargo Capacity (containers)	10,000	10,000	10,000	10,000	10,000	10,000
Cargo Utilization (%)	80	80	80	80	80	80
Emission Rate (g/cont-km)	21.37	0.286	0.0089	0.032	0.0013	0.075
Total distance (km/trip)	6789	6789	6789	6789	6789	6789
Number of containers/ fu [d]	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461
Emissions (g/fu)	**6,688**	**89.51**	**2.79**	**10.02**	**0.41**	**23.47**

[a] Note: Taken from Table 1-49, IPCC Reference Manual, [b] ρ_{diesel}=0.85kg/l, [c] using equation 1
[d] total portion of the 20 feet container(0.032 for PB+0.013for MDF+8.3E-4 for PVC+9.68E-4 for glue).

iv. Transportation of PVC, WPB and MDF from Djibouti port to factory gate

The company transports its raw materials from the port of Djibouti to the factory gate using different types of heavy duty vehicles, but most of the raw materials are transported using Trakker 380HP truck, which has an engine, built in 2007. The truck's diesel engine runs on the 10% ethanol mixed diesel. The energy content of this ethanol mixed diesel is 9.77 kWh per liter. The number of containers a full or semi trailer truck can bring is used for cargo capacity instead of the maximum weight in tons because the capacity of the truck is constant for the type of container that is transported. The truck can carry two 20 feet containers therefore 12 trucks are needed to move the total containers per annum. The round trip distance from the Djibouti port to the factory gate is taken as 1709.6 km [57] based on these; emissions that arise due to transportation are calculated. Since Ethiopia has no its own data on emission factor the emission factor data is taken from the IPCC [60]. The amount of 20 feet container needed to transport these raw materials per functional unit is calculated and gives 0.032 for PB, 0.013 for MDF, 8.3×10^{-4} for PVC and 9.68×10^{-4} for glue. Furthermore, the factory brings lumber from Shashemane which is 250km far from the factory gate. Assumed average fuel consumption for the truck is 3.3 km/l. The total emissions are calculated in Table 4. 11.

Table 4.11: Emissions calculated for truck transport in Ethiopia

Emission elements	CO_2	NO_x	CH_4	NMVOC	N_2O	CO
Average fuel Consumption: (km/l)	3.3	3.3	3.3	3.3	3.3	3.3
Emission factor: (grams/l)[a]	2670.07	35.71	0.17	6.80	0.09	30.61
Cargo capacity: (containers)	2	2	2	2	2	2
Emission rate: (g/cont-km)	404.56	5.41	0.026	1.03	0.014	4.64
Total distance travelled: (km/r.trip)	1709.6	1709.6	1709.6	1709.6	1709.6	1709.6
Total cargo capacity: (cont./fu)	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461
Emissions: (grams)	31,884.4	426.38	2.05	81.18	1.1	365.69
Emission due to lumber trans.(grams)	3,438.7	45.99	0.22	8.76	0.45	39.4
Total Emission (grams/fu)	**35,323.1**	**472.37**	**2.27**	**89.94**	**1.55**	**405.1**

[a] Estimation emission factors for European diesel heavy duty vehicles.

4.1.3. Particle Board Manufacturing

The inputs, outputs and emission data are given in tables 4.12, 4.13, 4.14 and 4.15. But, the harvesting of rubber wood and OPT processes are not included in this section because it is determined separately in section 4.2.2 above.

Table 4.12: Materials flow

Input	Product	Co-product
Wood particles	Particleboard	Wood dust
Resins (UF)		
Catalyst ($(NH_4)_2SO_4$)		
Urea scavenger		
Wax, melamine		

Table 4.13: Breakdown of material components of particleboard panel

Panel type [a]		kg/fu	Percentage (%)
Particle board		263.1	100
Panel composition	Wood particles	235.2	89.4
	Resin (UF)	23.8	9
	Catalyst ($(NH_4)_2SO_4$)	0.252	0.1
	Urea scavenger	0.98	0.4
	Wax	0.875	0.3
	Melamine resin	1.969	0.8

[a] Oven-dry weight of particleboard panel and its components.

Table 4.14: Fuel, electricity, and energy[1] use in the manufacturing of particleboard

Fuel for process heat	Unit	Unit/fu	MJ/fu	Perc. (%)
Natural gas	m^3	10.5	406	
Sander dust	kg	8.75	183.75	
Distillate fuel oil	Liter	0.021	0.77	
In process generated wood fuel	kg	0.73	15.05	
Sub total			605.57	74.6
Fuel for equipment	Unit	Unit/fu	MJ/fu	
Diesel	Liter	0.091	3.54	
LPG	Liter	0.12	3.08	
Gasoline and kerosene	Liter	0.007	0.26	
Sub total			6.88	0.9
Electricity	Unit	Unit/fu	MJ/fu	
Electricity from grid	kWh	55.3	199.15	24.5
Total energy			811.6	100

1 Higher heating values (HHV) used; coal 26.2 MJ/kg, DFO 45.5 MJ/kg, LPG 54.0 MJ/kg, natural gas 54.4MJ/kg, RFO 43.4 MJ/kg, gasoline 54.4 kg, wood/bark 20.9 MJ/kg, and electricity 3.6 MJ/kWh.

Table 4.15: Output flows for the production of particleboard per functional unit

Output		
Flows	Category	kg/fu
Carbon dioxide, fossil	emission to air	38.756
Nitrogen oxides	emission to air	2.390
Formaldehyde	emission to air	8.938×10^{-4}
Methane, fossil	emission to air	0.176
Methanol	emission to air	5.994×10^{-4}
Benzene	emission to air	1.818×10^{-3}
Sulfur dioxide	emission to air	3.597×10^{-2}
VOC, volatile organic compounds	emission to air	2.051×10^{-2}
PAH, polycyclic aromatic hydrocarbons	emission to air	9.509×10^{-7}
Particulates, > 2.5 um, and < 10um	emission to air	1.336×10^{-3}
Toluene	emission to air	2.857×10^{-3}
Acrolein	emission to air	1.414×10^{-6}
Barium	emission to water	9.805×10^{-3}
Formaldehyde	emission to water	7.187×10^{-3}
Suspended solids, unspecified	emission to water	9.636×10^{-2}
Boiler flay ash	emission to land	0.035
Wood waste	emission to land	0.14

Major contributors to the defined impact categories

4.1.4. Medium Density Fiberboard (MDF) Production

The inputs, outputs, emissions data of the factory are summarized in the following tables bellow. Note that the harvesting process is not included here because it is determined separately in section 4.2.2.

Table 4.16: Materials flow, Source [68]

Inputs		Product Output	product density [kg/m^3]	Co-products	
Type	Quantity [kg/fu]			Type	Quantity [kg/fu]
Wood particles	107.84	Medium density fiber board (MDF)	741	Bark mulch	1.75
Resins (UF)	11.3			Wood boiler fuel	0.309
Catalyst ($(NH_4)_2SO_4$)	0.015			Wood ash	0.264
Urea scavenger	0.174				
Wax	0.7086			Emission gases is given in table 4.19	
Melamine resin	0.383				

Table 4.17: Breakdown of material components of MDF panel

Panel type [a]		kg/fu	Percentage (%)
MDF		101.2	100
Panel composition	Wood particles	89.76	88.69
	Resin (UF)	10.2	10.08
	Melamine resin	0.383	0.38
	Catalyst ($(NH_4)_2SO_4$)	0.015	0.01
	Urea scavenger	0.174	0.17
	Wax	0.71	0.7

[a] Oven-dry weight for panel and components

Table 4.18: Fuel, electricity, and energy use in the manufacture of MDF

Fuel for process heat	Unit	Unit/fu	MJ/fu	Percentage (%)
Natural gas	m^3	5.848	225.35	
Sander dust	kg	9.52	199.24	
Distillate fuel oil	Liter	0.037	1.5	
In process generated wood fuel	kg	7.344	152.86	
Bark hog fuel purchased	kg	32.096	670.75	
Sub total			1,249.7	85.7
Fuel for equipment	Unit	Unit/fu	MJ/fu	
Diesel	Liter	0.058	2.31	
LPG	Liter	0.103	2.72	
Gasoline and kerosene	Liter	0.018	0.68	
Sub total			5.71	0.4
Electricity	Unit	Unit/fu	MJ/fu	
Electricity from purchasing	kWh	56.4	203.04	13.9

Continued				
Total energy			**1,458.45**	**100**

Higher heating values (HHV) used; coal 26.2 MJ/kg, DFO 45.5 MJ/kg, LPG 54.0 MJ/kg, natural gas 54.4 MJ/kg, RFO 43.4 MJ/kg, gasoline 54.4 kg, wood/bark 20.9 MJ/kg, and electricity 3.6 MJ/kWh

Table 4.19: Output flows for the production of MDF per functional unit

Output		
Flows	Category	kg/fu
Acetaldehyde	emission to air	$6.123x10^{-5}$
Benzene	emission to air	4.897×10^{-4}
Carbon dioxide, biogenic	emission to air	12.925
Carbon dioxide, fossil	emission to air	14.057
Carbon monoxide, fossil	emission to air	2.378×10^{-2}
Nitrogen oxides	emission to air	1.947
Dioxins	emission to air	1.102×10^{-7}
Formaldehyde	emission to air	4.506×10^{-4}
Methane, fossil	emission to air	2.100×10^{-2}
Methane, tetrachloro-, R-10	emission to air	2.974×10^{-6}
Methanol	emission to air	6.870×10^{-5}
Particulates, > 2.5 um, and < 10um	emission to air	3.38310^{-2}
Particulates, unspecified	emission to air	0.106
Sulfur dioxide	emission to air	4.113×10^{-3}
Toluene	emission to air	3.385×10^{-4}
Mercury	emission to air	2.313×10^{-7}
VOC, volatile organic compounds	emission to air	3.006×10^{-3}
Acrolein	emission to air	2.653×10^{-4}
Barium	emission to water	3.829×10^{-3}
Ammonia, as N	emission to water	1.367×10^{-3}
BOD5, Biological Oxygen Demand	emission to water	0.136
Boiler flay ash	emission to land	0.264
Wood waste	emission to land	0.301

Major contributors to the defined impact categories, outputs of the Open LCA software

4.1.5. Kitchen Cabinet Manufacturing

The detailed processes of kitchen cabinet production have been stated earlier, which can be referred to figure 2.2. Material flows and input components of the L-shaped design kitchen cabinet per functional unit are given in table 4.20 and 4.21 respectively.

Table 4.20: Materials flow

Input	Product	Co-product
WPB	Complete L shaped kitchen cabinet	Wood dust
MDF		PVC trimmings
PVC and Glue (EVA)		Glue vapors
Lumber		Wood panel trimmings

EVA = ethylene vinyl acetate, PVC= poly vinyl chloride, WPB= wood particle board, source: factory data

Table 4.21: Input material components for one set L shaped finished kitchen cabinet

Inputs	unit/fu	Output
WPB	0.35 m^3	Complete set L shaped cabinet
MDF	0.136 m^3	
Lumber	0.255m^3 or 111.18kg	
Glue (EVA)	4.5kg	
PVC	7.87 m^2	

EVA= ethylene vinyl acetate, lumber density=436kg/m^3

The factory used electricity to cut the wood panels, to chamfer, to laminate, to drill and press the cabinet parts. The power consumption per functional unit is calculated from the manual of each machine based on power consumption per hour (table 4. 22). During electric power failure it was used its own generator; unfortunately it is not operational this year. Hence, the only source of energy is electricity from the Ethiopian Electric Power Corporation (EEPCo). It produces electric power from a hydropower source. Inventory data for this study are based on hydropower electric production in Norway from the ELCD database as a proxy to model electricity production in Ethiopia and the major inventory results are summarized in table 4.23 below. The factory produce on average 5 kitchen cabinets per day out of which the three are L- shaped kitchen cabinets. Then the environmental emissions due to the manufacturing of one set L shaped kitchen cabinet are determined using the open LCA software by feeding the input materials (table 4.21). Finally, the inventory results which have significant impact with 0.02% and above are summarized in table 4.24.

Table 4.22: On-site energy use in the manufacture of kitchen cabinet

Energy for process	Consumption of electricity	Unit/day	MJ/day	MJ/fu	Per. (%)
Fuel	-	0	0	0	0
Electricity[1]	kWh/min.	kWh/day	MJ/day	MJ/fu	Per. (%)
Panel cutting machine	0.31	37	133.2	26.6	12.5
CNC router machine	0.35	3.5	12.6	2.5	1.2
Soft forming	0.38	30.7	110.52	22.1	10.4
Lamination	0.33	140	504	100.8	47.4
Drilling	0.197	5.9	21.24	4.2	2
Edge banding	0.21	50.4	181.44	36.3	17
Hinge boring	0.018	2.2	7.92	1.6	0.7
Cabinet press	0.067	26	93.6	18.7	8.8
Total energy	**-**	**295.7**	**1,064.52**	**212.8**	**100**

[1] Note, electricity 3.6 MJ= 1kWh. Source: calculated from factory manual

Since the onsite emission data of MDF and particleboard manufacturing are determined in section 4.2.4 and 4.2.5 above the environmental burdens associated with manufacturing of MDF and WPB are disconnected manually from the system of kitchen cabinet manufacturing. But, it includes the production of lumber from harvesting to final product, production of PVC, production of diesel for transportation and production of electricity from hydropower. Therefore, the inventory data for production of kitchen cabinet is given in table 4.24.

Table 4.23: Life cycle inventory of hydroelectric power production

Output			
Flow	Unit /fu	Category	Value
Energy	MJ	product	212.8
Carbon dioxide	kg	emission to air	1.442
Hydrogen sulfide	kg	emission to air	7.438×10^{-7}
Carbon monoxide	kg	emission to air	3.782×10^{-4}
Nitrogen dioxide	kg	emission to air	5.054×10^{-4}
Sulfur dioxide	kg	emission to air	1.328×10^{-4}
Silver	kg	resource use	2.095×10^{-7}
Lead	kg	resource use	2.728×10^{-5}
Copper	kg	resource use	1.261×10^{-4}
COD	kg	emission to water	8.897×10^{-4}

Major contributors to the defined impact categories: output of the software (ELCD database).

Table 4.24: Output inventory for the production of one complete set kitchen cabinet.

Flow	Unit/fu	Category	Value
Input			
Diesel for transportation	m^3	Product	0.035
Output			
Nitrogen oxides	kg	emission to air	3.94×10^{-4}
Formaldehyde	kg	emission to air	2.16×10^{-2}
Carbon dioxide, fossil	kg	emission to air	0.6081
N_2O	kg	emission to air	6.873×10^{-6}
Methane, fossil	kg	emission to air	5.382×10^{-3}
Methane, tetrachloro-R-10	kg	emission to air	1.957×10^{-8}
Methane, bromo- Halon 1001	kg	emission to air	3.012×10^{-10}
Dust, unspecified	kg	emission to air	2.980×10^{-2}
Benzene	kg	emission to air	5.405×10^{-5}
Sulfur dioxide	kg	emission to air	2.943×10^{-3}
Methanol	kg	emission to air	2.999×10^{-2}
Barium	kg	emission to air	4.147×10^{-2}
Chromium VI	kg	emission to air	1.236×10^{-9}
COD	kg	emission to water	2.191×10^{-4}
PVC trimmings	kg	emission to land	0.492
Wood waste	kg	emission to land	1.000
Ethylene vinyl acetate vapors	kg	emission to land	1.71

Major contributors to the defined impact categories; output of the open LCA software

4.2. Life Cycle Impact Assessment

According to ISO 14044, LCIA comprises four elements namely: the classification, characterization, normalization and weighting where normalization and weighting are the optional elements.

4.2.1. Impact categories definition and classification

Impacts are defined as the consequences that could be caused by the input and output streams of a system on human health, plants, and animals, or the future availability of natural resources. Typically, LCIAs focus on the potential impacts to three main categories: human health, ecological health, and resource depletion. In this study the contributions of the inventory data per functional unit to the selected environmental impact categories are calculated using CML 2001 baseline characterization method. It is an impact assessment method which restricts quantitative modeling to early stages in the cause-effect chain to limit uncertainties. The frame work of impact categories for characterization modeling at mid point and end point level is illustrated in figure 4.2.

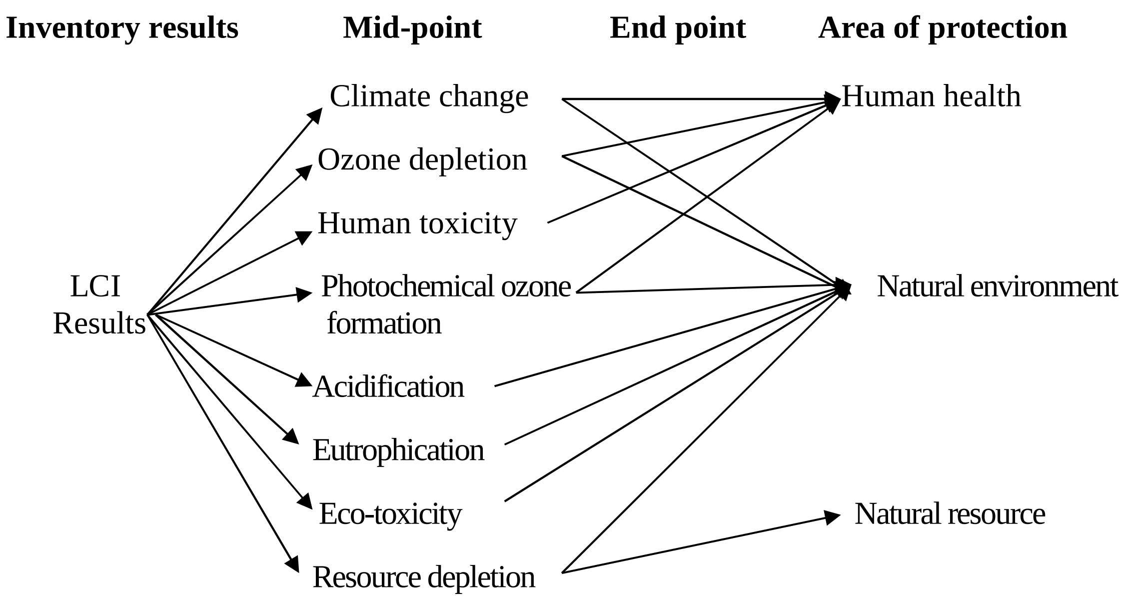


Fig.4.2: Framework of impact categories for characterisation

The inventory results of this study are grouped in to the following main midpoint impact categories; their definitions are given in section 2.3.3.

- climate change -GWP100a
- acidification potential - AP generic
- eutrophication potential- EP generic
- freshwater aquatic eco-toxicity- FAETP 100a
- human toxicity- HTP 100a
- resources -depletion of abiotic resources - ADP
- photochemical oxidation (summer smog)- high NOx POCP
- stratospheric ozone depletion -ODP 10a and
- terrestrial eco-toxicity -TETP 100a

The purpose of classification is to organize and combine the LCI results into the above impact categories. Therefore, the inventory results of each stage are classified in to their corresponding impact categories. Furthermore, to eliminate double counting the impacts caused due to transportation of raw materials are incorporated in to their corresponding stages (WPB, MDF and kitchen cabinet production). Finally, the classified LCI results (flows) are characterized using a scientific characterization factor.

4.2.2. Characterization

The impact of each emission or resource consumption is modeled quantitatively, according to the environmental mechanism. The result is expressed as an impact score in a unit common to all contributions within the impact category by applying the so-called characterization factors. For example, kg of CO_2 equivalents for greenhouse gases contributing to the impact category Climate Change. Here, the characterization factor of CO_2 for climate change is 1, whilst methane has a characterization factor of 25, reflecting its higher climate change potential. Impact characterization in this study is based on the characterization indicators demonstrated at table A 2 (appendix I). Impact indicators are typically characterized using the following equation.

$$\text{Impact Indicators} = \text{Inventory Data} \times \text{Characterization Factor} \text{ ------ Eq 5.1}$$

For the climate change indicator example given above the characterized value is calculated as follow.

$$\text{Climate change} = \sum_{k} GWP_{ak} \text{ x } M_k = 1 \text{ x } M_{CO2} + 25 \text{ x } M_{CH4}$$

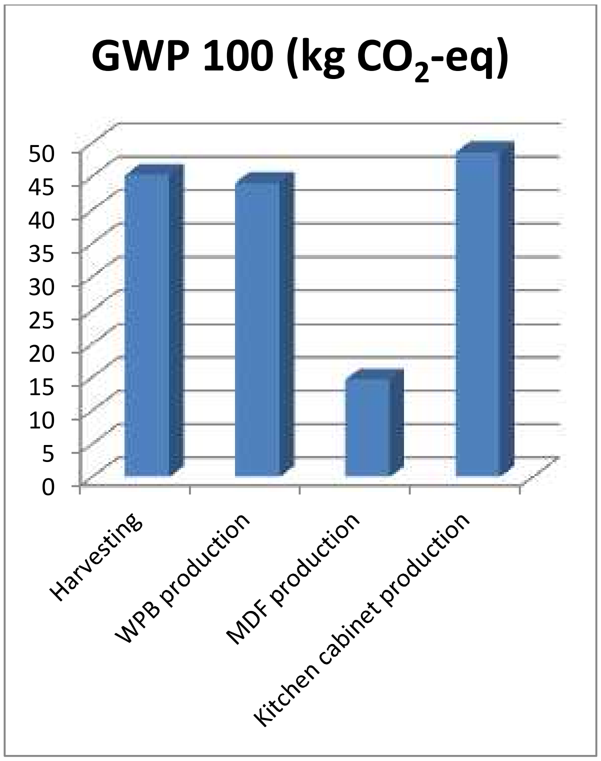
Where, GWP_{ak} is the Global Warming Potential for substance k integrates over years a;

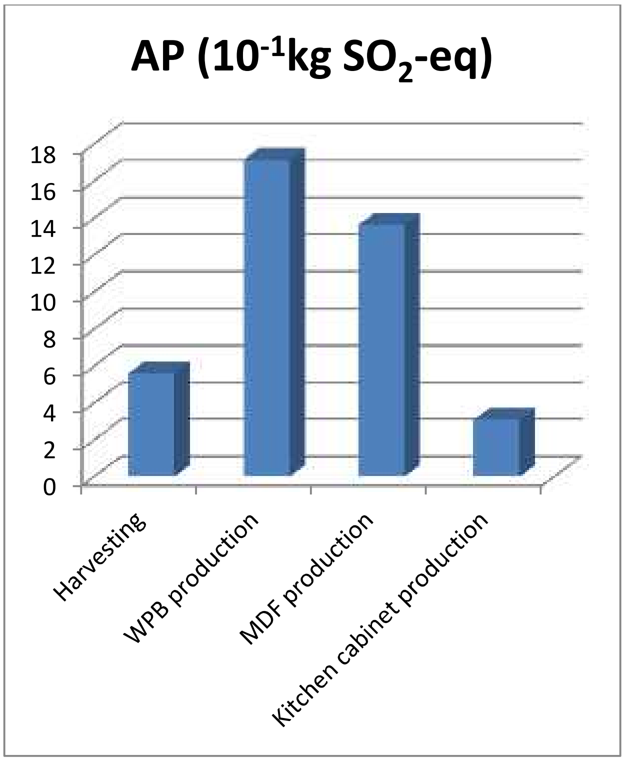
M_k is the quantity of substance k emitted

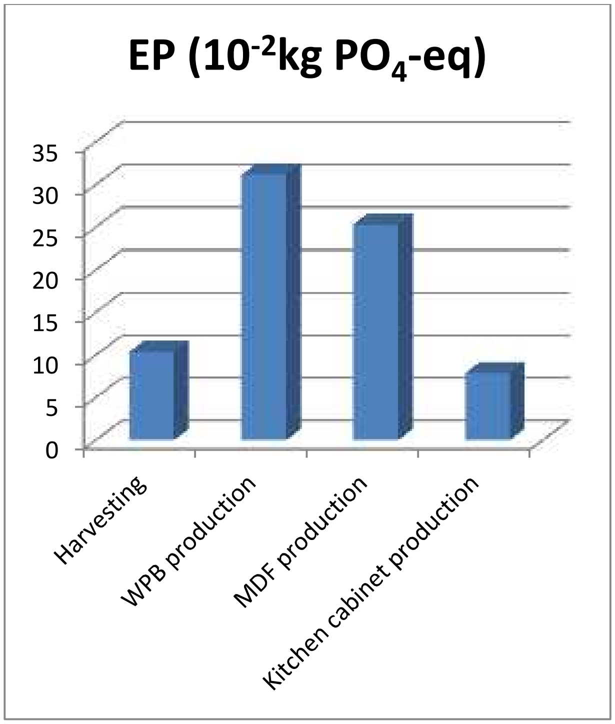
The characterized value for harvesting, WPB, MDF and kitchen cabinet production stages are calculated using the CML2001impact method but their associated transportation impacts are calculated manually. Therefore, the overall characterized value for the manufacturing of one kitchen cabinet is summarized in table 4.25. Using these values, the environmental load of each life cycle stages has been translated into specific environmental impacts; these results are illustrated in figure 4.3.

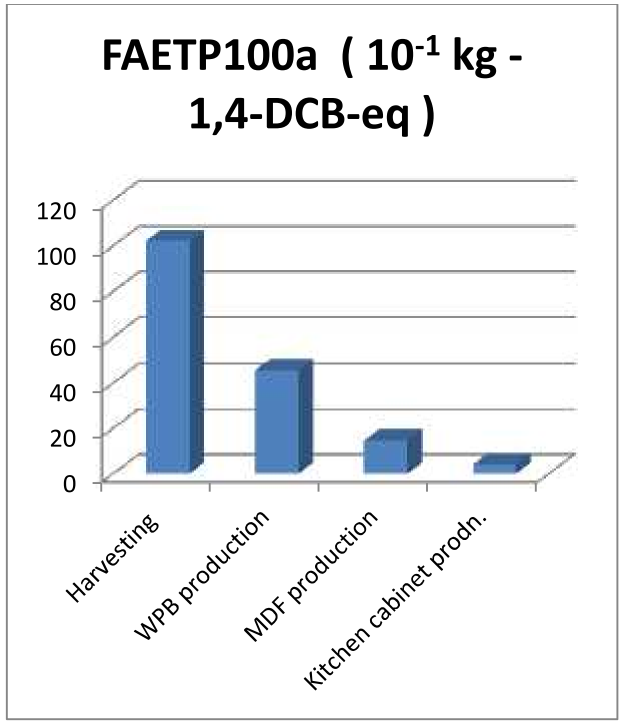
Table 4.25: Contribution from each stage to the potential impacts

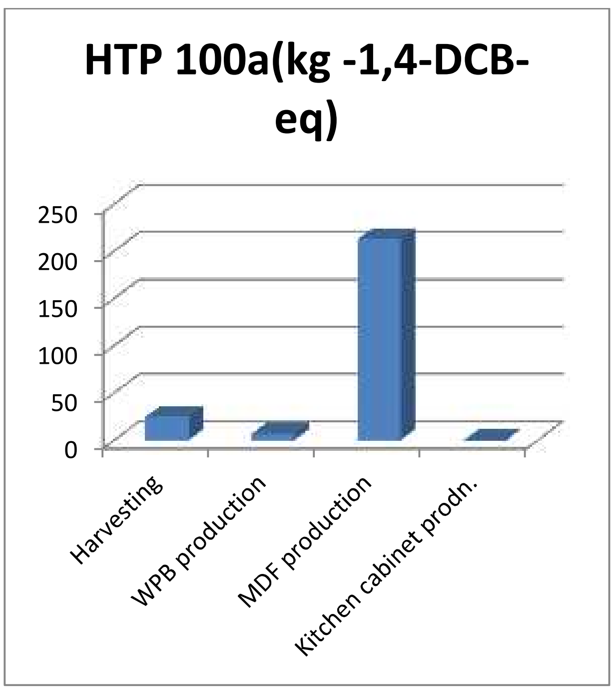
Impact category	Unit	Harvesting	WPB production	MDF production	Kitchen cabinet prodn.
GWP 100	kg CO_2-eq	45.179	44.025	14.66	48.593
AP	kg SO_2-eq	0.562	1.715	1.364	0.308
EP	kg PO_4-eq	0.104	0.312	0.253	0.079
FAETP 100a	kg -1,4-DCB-eq	10.202	4.560	1.468	0.412
HTP 100a	kg -1,4-DCB-eq	24.63	7.011	213.127	0.157
high NOx POCP	kg ethylene eq	9.29E-3	0.029	0.002	0.102
ODP 10a	kg CFC-11-eq	8.78×10^{-10}	6.2×10^{-25}	3.718×10^{-6}	2.612×10^{-8}
TETP 100a	kg -1,4-DCB-eq	3.6×10^{-4}	0.038	0.007	0.039
ADP	kg antimony-eq	0.208	0.023	0.017	0.515

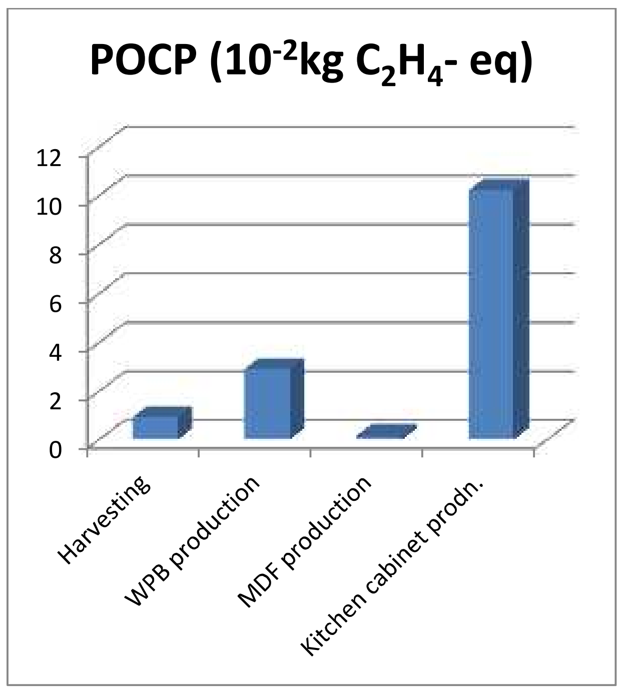


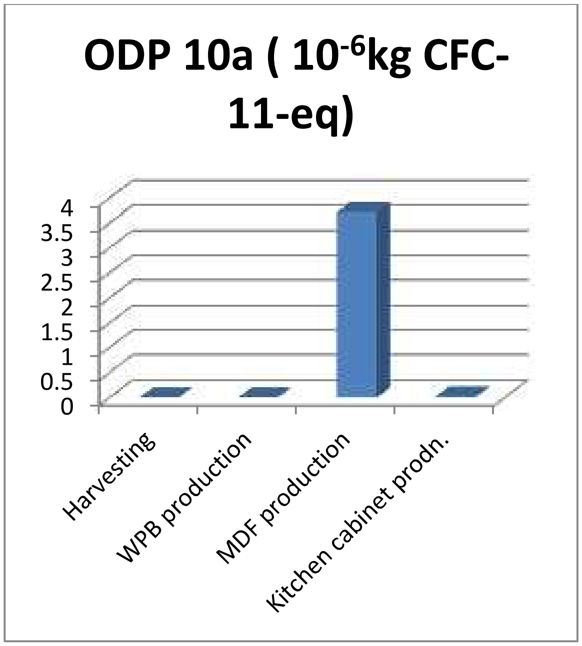


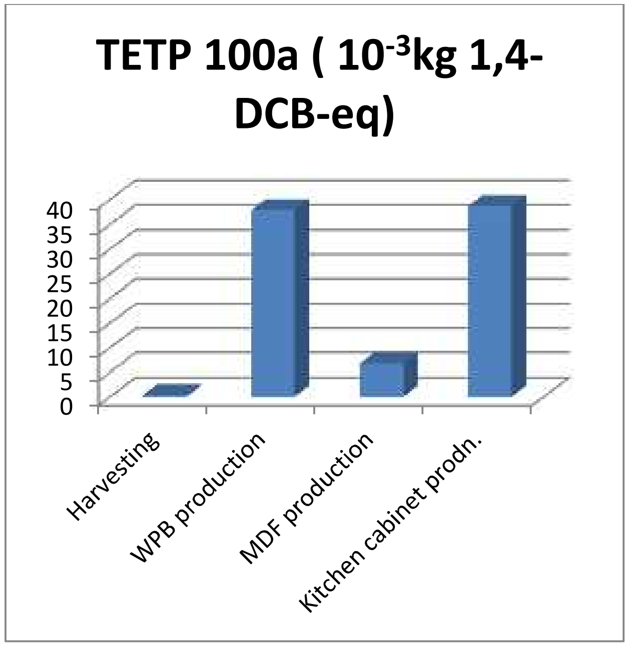

EP (10-2kg PO4-eq)
35
30
25
20
15
10
5
0
Harvesting
WPB production
MDF production
Kitchen cabinet production


FAETP100a (10-1 kg -1,4-DCB-eq)
120
100
80
60
40
20
0
Harvesting
WPB production
MDF production
Kitchen cabinet prodn.


HTP 100a(kg -1,4-DCB-eq)
250
200
150
100
50
0
Harvesting
WPB production
MDF production
Kitchen cabinet prodn.


POCP (10-2kg C2H4- eq)
12
10
8
6
4
2
0
Harvesting
WPB production
MDF production
Kitchen cabinet prodn.





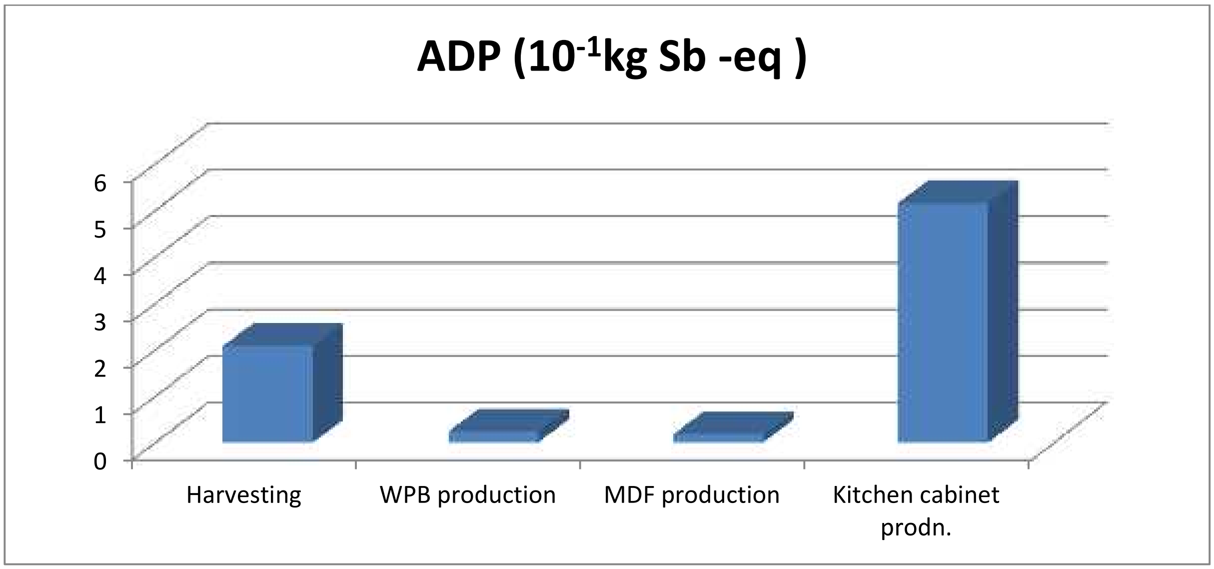


Fig.4.3: Results of characterization using CML 2001 impact method

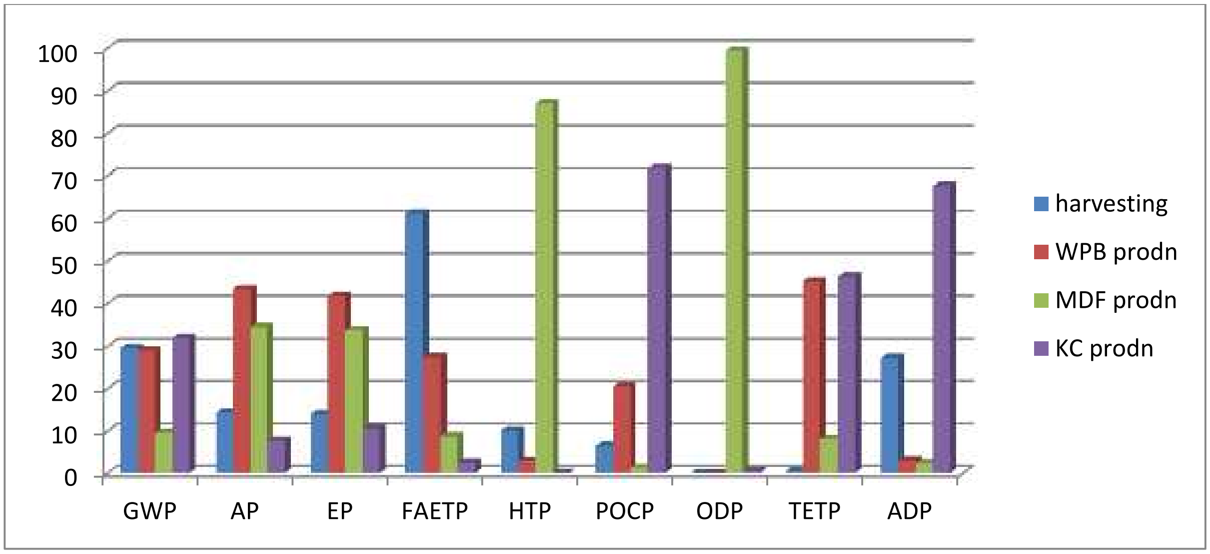


Fig.4.4: Percentage comparison of environmental impact contribution among the four life cycle stages

Although most of the raw materials used for the production of kitchen cabinets are from renewable resources the major environmental burden contributor stages over the cradle to gate life cycle of kitchen cabinet are identified from the inventory and impact assessment results. These results suggested that:

- The harvesting stage has a significant contribution to fossil CO_2 (global warming potential), fresh water aquatic eco toxicity potential and non-renewable resource depletion. These impacts are due to the production and consumption of diesel, none renewable energy. It consumed during rubber wood and oil palm trunks felling, processing, forwarding and transportation of these wood logs to the particle board and MDF plants.
- The particle board production stage contributes more to almost all the inventory parameters and impact assessment categories considered. This stage is a remarkable hot spot for air emissions such as fossil carbon dioxide, nitrogen oxides, methane and sulfur oxides and consequently, for the impact categories that consider these parameters (global warming, acidification, eutrophication and terrestrial eco-toxicity). These environmental impacts are the result of the energy requirements in the particleboard production process, which are fulfilled by on-site fuel oil burning at the boiler, and during drying and pressing. They are a function of the fuel burned and resin use.

- The medium density fiberboard production stage is identified as the largest contributor to dioxins emissions (human toxicity), mainly due to the wood fuels burned at the boiler and dryer. In addition to human toxicity it also causes acidification and eutrophication potential. This is due to emissions of nitrogen oxides during the production of wax and urea formaldehyde resin. As almost all the energy consumed by the MDF production processes comes from renewable fuels, it is also the most contributing stage to renewable energy consumption.
- The kitchen cabinet production stage is identified as the largest contributor to fossil carbon dioxide emissions (global warming potential) mainly due to long transportation of raw materials. It also contributes photochemical ozone creation potential, terrestrial eco-toxicity potential, and abiotic resource depletion potential. The first two impacts are caused due to the emission of formaldehyde and methanol during panel cutting and processing at 3F. While the third impact is caused from the production of diesel in the refinery plant. As almost all the onsite energy consumed during the manufacturing of kitchen cabinet at 3F are generated from hydropower, it has not significant impact to non renewable energy consumption.
- The working environment is smoggy and full of suspended particulate maters so it has significant long term respiratory impacts on the employee of the factory.

4.2.3. Normalization

Normalization enables the impact categories to be distinguished. There are two reasons why normalization is conducted, firstly to identify the impact categories that should be given more attention and secondly, to obtain the magnitude of environmental degradation produced during the life cycle of the product. Normalization is determined based on the formula shown as follows [70].

$$\boldsymbol{N}_{\mathrm{k}} = \boldsymbol{S_k}/\boldsymbol{R_k} \quad \text{----------------------------------} \text{ Eq 5.2}$$

Where k is impact category N is normalization indicator

S is characterized value R is reference value

The overall characterized impact values of each impact categories (table 4.25) is normalized to the global value (table 4.26) so as to determine the normalized score (Table 4.27) using equation 5.2.

Table 4.26: World normalization factor for major impact categories; source [69]

Impact category	unit	World normalization factor
GWP 100	kg CO_2-eq/a	$4.15 \times 10^{+13}$
AP	kg SO_2-eq/a	$3.35 \times 10^{+13}$
EP	kg PO_4-eq/a	$1.32 \times 10^{+11}$
FAETP 100a	kg -1,4-DCB-eq/a	$1.81 \times 10^{+12}$
HTP 100a	kg -1,4-DCB-eq/a	$5.67 \times 10^{+13}$
high NOx POCP	kg ethylene eq/a	$9.59 \times 10^{+10}$
ODP 10a	kg CFC-11-eq/a	$8.99 \times 10^{+8}$
TETP 100a	kg -1,4-DCB-eq/a	$1.40 \times 10^{+11}$
ADP	kg antimony-eq/a	$1.57 \times 10^{+11}$

Table 4.27: Normalized value of the overall factory impact

Impact category	Factory emissions (S_k) (kg)	World value (R_k) (kg)	Normalized value (N_k)
GWP 100	152. 457	$4.15 \times 10^{+13}$	3.67×10^{-12}
AP	3.949	$3.35 \times 10^{+13}$	1.18×10^{-11}
EP	0.749	$1.32 \times 10^{+11}$	5.67×10^{-12}
FAETP 100a	16.642	$1.81 \times 10^{+12}$	9.19×10^{-12}
HTP 100a	244.923	$5.67 \times 10^{+13}$	4.32×10^{-12}
high NOx POCP	0.1423	$9.59 \times 10^{+10}$	1.48×10^{-12}
ODP 10a	3.744×10^{-6}	$8.99 \times 10^{+8}$	4.16×10^{-15}
TETP 100a	0.0837	$1.40 \times 10^{+11}$	5.98×10^{-13}
ADP	0.763	$1.57 \times 10^{+11}$	4.86×10^{-12}

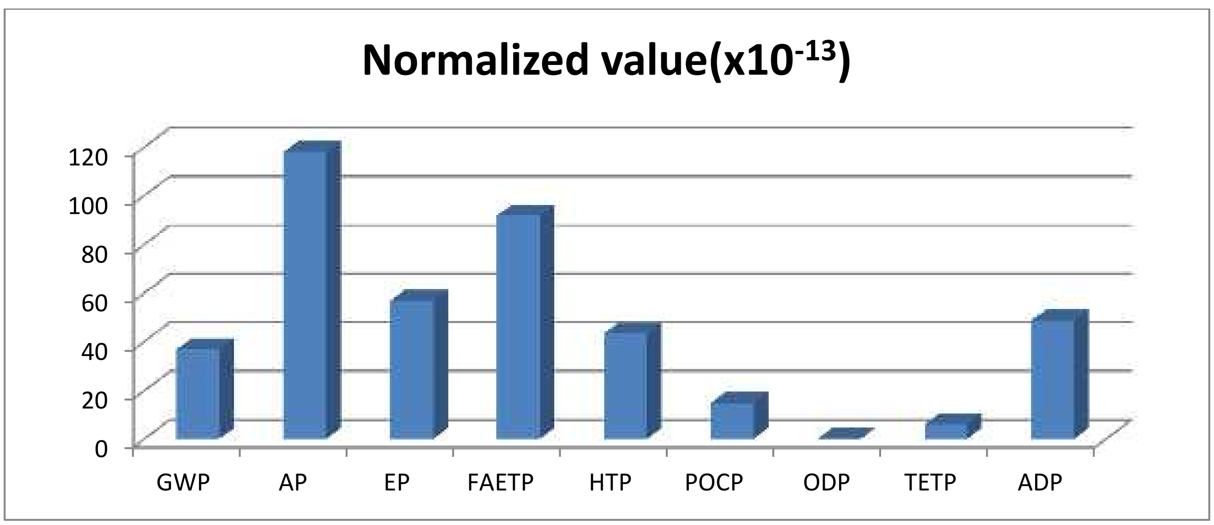


Fig 4.5: Normalized value of the overall factory impact

Figure 4.5 indicates that, the factory scores relatively large acidification potential, fresh water aquatic eco-toxicity potential, Eutrophication potential, abiotic depletion potential, human toxicity potential and global warming potential in decreasing order of magnitude. Therefore, the major contributors in each stage are described as follow.

Acidification and Eutrophication are largely caused from the emission of nitrogen oxides and sulfur oxides during the production of wax and urea formaldehyde resin, which are the input materials for WPB and MDF production plant. Fresh water aquatic eco-toxicity is coming from the spillage of diesel and grease at the harvesting stage. Human toxicity is caused due to the emission of dioxins, nitrogen oxides and formaldehyde from the combustion of wood fuels in the MDF plant, production of wax, and production and use of urea formaldehyde resin respectively.

While global warming and abiotic depletion potential is caused due to the production and consumption of fossil fuels at the harvesting stage, kitchen cabinet production stage (transportation of raw materials) and WPB production stage.

Therefore, substituting urea formaldehyde resin by less toxic resins; optimizing fuel and resin consumption; preventing leakage in process equipments; energy conservation on drying processes, hot pressing processes and boiler are the basic measures to mitigate impacts on the environment. In addition, since all operations require energy use, the type of fuel source should be considered. Fossil-based fuels emit greater amounts of emissions that contribute to global warming, ozone depletion, resource depletion, and more [73]. While non-fossil-based, renewable fuels such as biomass, solar and hydro electric energy can have many benefits such as reduced fuel loads on managed forest lands, reduction in wood waste that would traditionally end up in a landfill [74], and a reduction in global warming emissions since CO_2 emitted from biomass combustion is considered carbon neutral [75]. Most life cycle assessments performed on wood products have occurred in other countries, primarily Europe and Canada. Results from this study for MDF and WPB production have similarities to a LCI conducted at the CORRIM [65, 67], but there is no similar previous study on kitchen cabinet manufacturing. Hence, making comparisons between this study and previous studies on kitchen cabinet would be difficult due to the absence of previous studies.

Sensitivity analysis: according to the emission model equation, equations 4.2 and 4.3 the total emission due to transportation is directly proportional to the total distance traveled by a truck and ship, and inversely proportional to the cargo capacity. Therefore, the total emission increases if the distance traveled by a truck increases and cargo capacity decreases. If the factory changes its suppliers from Malaysia to China the emission due to transportation will be large compared with the Malaysian suppliers. Generally the Malaysian company (Evergreen Fibreboard Sdn. Bhd.) uses advanced technologies which are equivalents with the Europeans. The change of raw material processing and product manufacturing technology changes the magnitude of the impact. Furthermore, the use of advanced emission control devices such as cyclones, bag houses, and catalytic thermal oxidizers plays a great role in minimizing potential impacts. But, the large impact is caused due to formaldehyde emissions during MDF, particle board and kitchen cabinet production. This is solved by replacing the toxic formaldehyde resin by renewable resins rather than technological advancement.

5. Conclusion and Recommendations

5.1. Conclusions

Production of industrial products has impacts on the environment, beginning with the extraction of raw materials, through processing, and subsequent manufacturing including the associated transportation. This study covered the cradle to gate life cycle assessment of kitchen cabinet manufacturing in 3F, aiming at assessing the environmental performance of harvesting, manufacturing of raw materials used and manufacturing of kitchen cabinet, the targeted product. Raw materials used for kitchen cabinet manufacturing in 3F are particle board (47.2% of the total wood used per functional unit), MDF (18.4% by weight), lumber (34.4% by weight), ethylene vinyl acetate glue, PVC sheet and mostly marble as counter top. Therefore, several parameters could be chosen to measure the associated environmental burdens, mainly regarding emissions to the air, water and soil; and resources depletion. Most impact assessment methods including CML 2001 baseline are developed based on European and ISO standards. Hence, now a day's CML 2001 has been directly used by more countries throughout the world.

Since rubber wood and oil palm trunks are waste of the rubber and palm oil industries the impacts associated with the plantation management is allocated to these industries rather than the wood factories. But, the harvesting of RW and OPT after 25 years is allocated to the MDF and WPB factories. This stage emits fossil carbon dioxide, diesel and grease spillage. Consequently these parameters cause global warming, freshwater aquatic eco-toxicity and non renewable energy depletion. The WPB and MDF production consumes both renewable and none renewable energy. This includes the energy required to produce upstream materials such as urea formaldehyde, wax and fossil fuels. The WPB production stage dominates in the production of terrestrial eco toxicity; acidification and eutrophication, and global warming impacts which are due to the emission of formaldehyde, nitrogen oxides and fossil carbon dioxide, respectively.

The MDF production contributes to human toxicity due to the burning of wood at the drying process. Due to the use of small MDF per functional unit, this stage has less impact compared to the WPB production stage. The production of kitchen cabinet and its associated transportation is responsible for the formation of photochemical ozone, terrestrial eco-toxicity, none renewable energy depletion and global warming. The first two impacts are caused due to the emission of formaldehyde and methanol during panel cutting, glue spraying and processing. While the other two impacts are due to the use of petroleum and emission of fossil CO_2 during raw material transportation from Malaysia to the factory gate respectively.

The normalized value indicated that acidification, fresh water aquatic eco-toxicity, eutrophication, abiotic depletion potential, human toxicity and global warming are more of an impact from the kitchen factory chain. Therefore, it is more convenient to take measure on the processes which emits parameters caused these impacts. Hence, substituting urea formaldehyde resin by less toxic resins; optimizing fuel and resin consumption; preventing leakage in process equipments; production of raw materials locally; energy conservation on drying processes, hot pressing processes and boiler are the basic measures to mitigate impacts on the environment.

5.2. Recommendations

Several recommendations are given in this section, in order to improve the environmental performance of the kitchen cabinet manufacturing in 3F.

- Consumption of diesel causes global warming potential and non renewable energy depletion, so production of the raw materials locally will cut off the environmental impacts that associated with the long transportation of raw materials from Malaysia to the factory gate.
- The manufacturing of WPB and MDF in Addis Ababa, Ethiopia will cut off the global warming potential by 46.97 kg CO_2 equivalents per functional unit or 32.88 ton CO_2 equivalents per annum.
- The factory does not have a custom of specific data recording and documenting. In a condition like this it is difficult to collect an average data from this factory. Therefore, it should develop such awareness so as to clearly know its input and outputs related to environment.
- A detail and well organized data gives a more accurate result in LCA. For the case of Finfine Furniture factory (3F) data should be collected readily from the design, production, and marketing departments who have a relatively regular record and documented data.
- A more satisfactory result will be obtained if the boundary of the LCA is further expanded. This is done by including the impact associated with product distribution, use and disposal.

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Appendix I

Table A.1: Annual production and raw material consumption of the kitchen cabinet factory

Types of KC	Quantity produced per annum (number)	Amount of raw material consumed per	
		Unit kitchen cabinet	Annum
Full U shaped kitchen cabinet	150	WPB= 0.4744 m^3	71.16 m^3
		MDF= 0.179 m^3	26.79 m^3
		Lumber= 0.345 m^3	51.75 m^3
		PVC= 10.64 m^2	1596m^2
		Glue = 6kg	900kg
		Marble*= 0.024 m^3	-
Full L shaped kitchen cabinet	700	WPB= 0.35 m^3	245 m^3
		MDF= 0.136 m^3	95.2 m^3
		Lumber= 0.255 m^3	178.5 m^3
		PVC= 7.87 m^2	5509m^2
		Glue= 4.5kg	3150kg
		Marble*= 0.018 m^3	-
Tall, and single straight kitchen cabinets	450	WPB= 0.07 m^3	31.95 m^3
		MDF= 0.026 m^3	11.7 m^3
		Lumber=0.114 m^3	51.3 m^3
		PVC=2.66m^2	1,197m^2
		Glue = 1.9kg	855kg
		Marble*= 0.008 m^3	-

*the factory uses marble, particle board, solid wood as countertop so it is difficult to estimate.

Source; calculated from the factory design manual.

Table A.2: Open LCA output of cumulative emissions cradle-to-product gate for the production of kitchen cabinet.

Input			
Flow	**Unit/FU**	**Category**	**Value**
Oil, crude	kg	Resource, ground	35.846
Electricity	kWh	Product	59.1
Diesel	m^3	product	4.965×10^{-2}
Lubricants	kg	product	0.206
Silver	kg	Resource , ground	2.095×10^{-7}
Lead	kg	Resource, ground	2.728×10^{-5}
Copper	kg	Resource, ground	1.261×10^{-5}
Output			
Nitrogen oxides	kg	emission to air	5.762
Acetaldehyde	kg	emission to air	6.123×10^{-5}
Acroline	kg	emission to air	2.888×10^{-4}
Benzene	kg	emission to air	2.362×10^{-3}
Ethane, 1,1,1-trichloro-, HCFC-140	kg	emission to air	9.704×10^{-10}

Continued			
Carbon dioxide, biogenic	kg	emission to air	12.925
Carbon dioxide, fossil	kg	emission to air	146.532
Carbon monoxide, fossil	kg	emission to air	0.848
Methane, fossil	kg	emission to air	0.206
NMVOCs	kg	emission to air	0.111
Methane, tetrachloro-, R-10	kg	emission to air	2.994×10^{-6}
Methane, bromo- Halon 1001	kg	emission to air	3.012×10^{-10}
Methanol	kg	emission to air	3.066×10^{-2}
Mercury	kg	emission to air	2.313×10^{-7}
Methanol	kg	air, low population density.	8.75×10^{-3}
Barium	kg	emission to air	4.147×10^{-2}
Chromium VI	kg	emission to air	1.236×10^{-9}
Nitrogen dioxide	kg	emission to air	5.054×10^{-4}
Di Nitrogen oxide	kg	emission to air	6.873×10^{-6}
Dust, unspecified	kg	emission to air	2.98×10^{-2}
Hydrogen sulfide	kg	emission to air	7.438×10^{-7}
PAH, polycyclic aromatic hydrocarbons	kg	emission to air	4.088×10^{-5}
Particulates, > 2.5 um, and < 10um	kg	emission to air	3.516×10^{-2}
Particulates, unspecified	kg	emission to air	0.106
Sulfur dioxide	kg	emission to air	0.043
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	emission to air	1.102×10^{-7}
Formaldehyde	kg	emission to air	2.252×10^{-2}
Formaldehyde	kg	air, low population dn.	1.929×10^{-2}
Toluene	kg	emission to air	3.195×10^{-3}
VOC, volatile organic compounds	kg	emission to air	2.352×10^{-2}
Mercury	kg	emission to water	3.611×10^{-8}
COD, Chemical Oxygen Demand	kg	emission to water	1.285×10^{-2}
Benzene	kg	emission to water	6.166×10^{-5}
Barium	kg	emission to water	5.874×10^{-2}
Formaldehyde	kg	emission to water	7.187×10^{-3}
Suspended solids, unspecified	kg	emission to water	9.636×10^{-2}
Ammonia, as N	kg	emission to water	1.367×10^{-3}
BOD5, Biological Oxygen Demand	kg	emission to water	0.136
COD	kg	emission to water	1.109×10^{-3}
Boiler flay ash	kg	emission to land	0.299
Wood waste	kg	emission to land	0.144
PVC trimmings	kg	emission to land	0.492
Wood waste	kg	emission to land	1.000
Ethylene vinyl acetate vapors	kg	emission to land	1.71

Table A.3: Characterization factor of selected impact categories

Impact category	Sub category	Parameters	Characterization factor
Global warming (IPCC, 2007)	GWP 100 years (kg CO_2-eqv/kg)	CO_2 CH_4 N_2O	1 25 298
Photochemical OCP (Jenkin & Hayman, 1999) (Heijungs etal, 1992) (Guinée, 2002)	High NOx POCPs (kg ethylene / kg)	NO_2 CO NMVOC CH4	0.028 0.027 0.416 0.006
Acidification (Guinée, 2002)	AP- generic (kg SO_2-eqv/kg)	NOx	0.5
Human toxicity (Guinée, 2002)	HTP 100 yrs (kg -1,4-DCB-eq/kg)	PM_{10}	0.82
Eutrophication (Guinée 2002)	EP- generic (kg PO_4-eqv/kg)	NOx	0.13
Abiotic resource depletion (Guinée 2002)	ADP (kg antimony eq./kg)	Copper Lead Natural gas Oil Fossil fuel	1.94×10^{-3} 1.35×10^{-2} 1.87×10^{-2}/ m^3 2.01×10^{-2} 4.81×10^{-4}/ MJ

Appendix II

Questionnaire or survey forms

The information from this survey will be used in my M.Sc. thesis which is life cycle assessment of kitchen cabinets. It is hoped that the output of the study will be used to show the competitive position of wood in the marketplace over other types of materials. This survey is designed specifically for particleboard, MDF and Kitchen cabinet production. Questions will be concentrated on annual production, electricity production and usage, fuel use, material flows, and environmental emissions. I realize that you may not have all the information requested, especially when it comes to specific equipment and processing groups. The data you are able to provide will be greatly appreciated. I intend to maintain the confidentiality of data and companies participating in this survey. Please contact me if you have any questions.

Company: ____

Country: _________________________________

Should I have a follow-up question about the data, please provide the name and the following information for the contact in your company.

Name: ___________________________ Title: ________________________

Telephone: _______________________ E-mail: ______________________

If you have questions about the survey, please contact me. Either mail or fax completed survey to:

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Addis Ababa University
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A. TO WPB and MDF factories

1. Annual Production (Please provide units of measurement if different than stated.)

Parameter	Unit	
WPB or MDF production in 2013/4 (2.44m * 1.22m*16mm thickness)	m^3	
Estimated average density of panels	kg/m^3	
Number of production lines and their year of installations	No	
Materials sold (e.g. sander dust)	Kg	

2. Annual Wood Use for PB/MDF production (Please provide units of measurement.)

Wood type (list as Eucalyptus, rubber wood, palm oil trunks, etc.)	MC of wood as delivered (% on oven dry weight basis)	Annual Use Weight (list as tons or kg oven dry, or volume—give units)
Total wood use		

MC = moisture content PB= particle board

3. Annual Energy Consumption (Total use for boilers, oil heaters, forklifts, etc. Please provide units of measurement if different.)

Purchased electricity		kWh	
Coal		Tons (oven dry)	
Hog fuel	Self generated	Tons (oven dry)	
	Purchased	Tons (oven dry)	
	Wood waste	Tons (oven dry)	
	Sander dust	Tons (oven dry)	
	Residual fuel oil	Liter	
	Distillate fuel oil	Liter	
	Liquid propane gas	liter	
	Natural gas	m^3	
	Gasoline and kerosene	Liter	
	Diesel	liter	
	Others		
Purchased steam (if any)		kg. (at temperature ^{0}C?)	

Characteristics of heat sources

1. Do you have a boiler, fuel cell, or oil heater? Check appropriate boxes.
   - ☐ Boiler
   - ☐ Fuel cell
   - ☐ Oil heater
   - ☐ Other
2. If you have a boiler, what is its heat source? Check appropriate box.
   - ☐ Hogged fuel
   - ☐ Oil
   - ☐ Natural gas
   - ☐ Other
3. If you have a fuel cell, what is its heat source? Check appropriate boxes.
   - ☐ Hogged fuel
   - ☐ Oil
   - ☐ Natural gas
   - ☐ Other
4. If you have an oil heater, what is its heat source? Check appropriate box.
   - ☐ Hogged fuel
   - ☐ Oil
   - ☐ Natural gas
   - ☐ Other

Other Related Information on an annual basis

1. For dryer(s), fill the annual fuel consumption for the heat source type you use if known:
   Steam ____________ kg.
   Natural gas direct-fired ____________ m3
   Sander dust or other wood fuel direct fired ____________ Tons (oven dry weight)
   Others (please specify) ____
2. For dryer(s) specify the following:
   - ✓ Type of dryer(s) (i.e. rotary triple pass, etc.) ____________________________
   - ✓ How is dryer(s) heated (direct fired, heat exchanger, etc.) ______________________
   - ✓ Do you recycle dryer exhaust, if so to where ____________________________

4. Formulation and usage of resin, catalyst, and other components

Component type	% solids by weight	Total annual use (kg.) on a solids or wet basis–please state units and basis
Urea formaldehyde		
Catalyst		
Wax		
Water		
Others(please specify)		

5. Annual water use (check source (s) and give amount):
   - ✓ Municipal water source Liter ____________________
   - ✓ Well water source Liter ____________________
   - ✓ Recycled water Liter ______________________

6. Transportation method and average distance to deliver wood furnish (check method(s))

Wood furnish delivery method	Average haul one way (km)	% of Total Shipping
Truck		
Rail		
Others		
Transportation method used to deliver resin		
Truck		
Rail		
Others		
Transportation method used to ship panels		
Truck		
Rail		
Others		

7. **Energy Use by Unit Process** –most factories won't have specifics, however, if you can provide the approximate use of energy in percentage of total production, this will be extremely helpful to me.

Breakdown of natural gas use	Percent (%) or annual m^3 use
Dryer	
Boiler	
Oil heater	
Emission control devices	
Others	
Total	
Breakdown of Electricity Use	Percent (%) or Annual kWh use
Refiners	
Screens	
Blenders	
Dryers	
Formers	
Press	
Coolers	
Trim saws	
Sanders	
Boilers	
Emission control device	
Others	

8. **Process and Material Flows**

Annual Material Flow; This is a general material flow survey for PB/MDF factory. This survey is designed to trace all wood coming into the plant and out. You have already provided the input material and the output panel production, what I now need to track is by-products through the operation and where they go.

Unit process	Material type	Amount of material (kg or tons oven dry)	Where does it go? (back into a specific unit process, boiler, sold, etc.)
Screen	Screen over		
	Screen fines		
Saw and trim	Saw trim		
Sanding	Sanding dust		
Bag house	Bag house dust		
Cyclone	Cyclone dust		
Others			

9. Emission Control Devices and Environmental Emission

Mention the emission control devices used in your factory. Then list all compounds that are collected and known for the factory from all control device sources.

____

____

____

____.

9.1. Solid emissions to land from all known sources (please provide units of measurement)

Emission	Quantity (i.e., tones, kg.)	Method of disposal or end use (i.e., landfill)
Wood waste		
Boiler ash or flay ash		
Recovered particulates from pollution abatement equipment		
Others		

9.2. Emissions to water from all known sources (please provide units of measurement)

Emission	Quantity (i.e., tons, kg.)	Method of disposal or end use (i.e., sewer)
Suspended solids		
Dissolved solids		
COD		
BOD		
Chlorides		
Oil and grasses		
Others		

B. To kitchen cabinet manufacturing factory (3F)

1. What are the raw materials used in kitchen cabinet manufacturing section?

   ____

   ____

2. From which country you import them? If some of them are domestic raw materials from which part of the country you bring them?

   ____

   ____

3. What is the mode of transportation usage to bring these raw materials from their source?

   ____

   ____

4. If they are Trucks what kind of track are they (their models) including their masses in kg?
____
____

5. What is the carrying capacity of the truck s (kg)? ____
____

6. The amount of fossil fuel it consumes in Littre per km?
   A. Benzene _______________________________________
   B. Diesel ____
   C. Others if any ____

7. How many pieces of raw material they contain per one trip?
____
____

8. What is the total distance in km from the potential source to Djibouti port (for foreign raw materials) and from Djibouti port to the factory gate?
____
____

9. Who are your principal potential suppliers(name of the organizations) for,
   A. MDF ____
   B. Particle board ____
   C. Lumber ____
   D. Glue ____
   E. PVC ____

10. Who are your potential customers?
   A. Foreigners
   B. Domestic customers
11. The running time of the factory is ____________days per year, _________hour per year.
12. The production capacity of the kitchen cabinet factory is _________________________________
13. Estate the amount of raw materials consumption annually?
____

Declaration

I declare that this thesis entitled "Life Cycle Assessment of Kitchen Cabinet: the case of Finfine Furniture Factory" is my original work and has not previously been submitted in any form for another degree, diploma or an award at any university or other institution of the tertiary education. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature and discussions. All reference materials contained therein have been acknowledged.

Name: **Hiluf Tekle**

Signature: ________

Place of Submission: **Addis Ababa, Ethiopia**

Date of submission: _____________________________

This thesis has been submitted to the university with our approval as the university advisors.

Name: **Tassisa Kaba (PhD)** **Name:** **Anteneh Tesfaye (PhD)**

Signature: __________________ **signature:** _____________

Date: ___________________ **date:** _________________