Comparative Assessment of the Embodied Carbon of Alternative Interior Materials used in Addis Ababa: A Case Study of MDF and Plywood

Eden Mesfin Getahun

A Thesis Submitted to the Department of Architecture
College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Environmental Architecture

Office of Graduate Studies
Adama Science and Technology University

May, 2025
Adama, Ethiopia

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Declaration

I hereby declare that this Master Thesis entitled "Comparative Assessment of the Embodied Carbon of Alternative Interior Materials in Addis Ababa: A Case Study of MDF and Plywood" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Eden Mesfin Getahun	____________________	_______________
Name of student	Signature	Date.

Recommendation

I, the Advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Comparative Assessment of the Embodied Carbon of Alternative Interior Materials in Addis Ababa: A Case Study of MDF and Plywood," prepared under my guidance by Eden Mesfin Getahun submitted in partial fulfilment of the requirements for the degree of Masters of Science in Environmental Architecture. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Yared Girma (PhD)	______________	________________
Major Advisor	Signature	Date

Approval of Board of Examiners

I, the advisor of the thesis entitled "Comparative Assessment of the Embodied Carbon of Alternative Interior Materials in Addis Ababa: A Case Study of MDF and Plywood" and developed by Eden Mesfin Getahun hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Yared Girma (PhD)	__________	__________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Eden Mesfin Getahun have read and evaluated the thesis entitled "Comparative Assessment of the Embodied Carbon of Alternative Interior Materials in Addis Ababa: A Case Study of MDF and Plywood," and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Environmental Architecture.

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Finally approval and acceptance of the thesis/dissertation proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and College Graduate Committee (CGC).

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College Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

Acknowledgement

First and foremost, I would like to thank the almighty God for His protection and guidance throughout my study and research. Next, I would like to extend my gratitude to my advisor, Yared Girma (PhD), for his consultation and advice. I thank the staff of Maereg Manufacturing and Trading, especially Mr. Halefom, Manager, and Mr. Guta Teshome, Plywood Division Head, for their warm welcome and coordination throughout the data collection process. In addition, I would like to thank Mr. Juan, the Operations Manager at the ET Wood Manufacturing plant in Kombolcha, for his willingness to give me the required data.

In addition, I would like to extend my deepest gratitude to my father, Mesfin Getahun, and my friends Hanna Degefu and Elisabeth Tebabal for their invaluable assistance during the data collection process.

Finally, I would like to express my deepest appreciation to my family for their continuous support during my study time and research period.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

ALCA - Attributional Life Cycle Assessment

CH_4 - Methane

CLCA - Consequential Life Cycle Assessment

CO - Carbon Monoxide

CO_2 - Carbon Dioxide (often written as CO2 in the document)

CORRIM - Consortium for Research on Renewable Industrial Materials

EC - Embodied Carbon

FPL-GTR - Forest Products Laboratory - General Technical Report

GHG - Greenhouse Gas

$GtCO_2$ - Gigatonnes of Carbon Dioxide

GWP - Global Warming Potential

HCB - Hollow Concrete Block

IPCC - Intergovernmental Panel on Climate Change

ISO - International Organization for Standardization

LCA - Life Cycle Assessment

LCIA - Life Cycle Impact Assessment

MDF - Medium-Density Fibreboard

NOx - Nitrogen Oxides (includes NO, NO_2, etc.)

N_2O - Nitrous Oxide

UNEP - United Nations Environment Programme

VOC - Volatile Organic Compounds

Abstract

This study aims to assess the embodied carbon of two widely used interior materials in Addis Ababa, medium density fibreboard and plywood. The rapidly expanding interior design industry in the city frequently utilizes these materials, yet their specific environmental impact in the local context remains undetermined. Although numerous studies have investigated the embodied carbon of medium density fibreboard and plywood, their findings are not directly applicable to Ethiopia due to the significant influence of regional factors on embodied carbon values. The sample product selection used a purposive method during the preliminary research, where these materials' most widely used products were identified. Following the identification of the products and their respective manufacturers, primary data on input and output were collected from the manufacturing plants. For the medium density fibreboard, the plant was located at Kombolcha, South Wollo. The plywood plant is located in Burayu, Sheger City. Then the study assessed the embodied carbon of the materials through gate-to-gate life cycle assessment as per the ISO 14040/44 standard. This system boundary ensured data accuracy and quality within limited resources, such as time. Life Cycle Inventory Analysis was carried out as per the functional unit of 1 m³ for other materials. The inventory data was then analyzed through the OpenLCA software using the Intergovernmental Panel on Climate Change - Global Warming Potential impact category indicator. The result of the life cycle assessment indicated that the embodied carbon of medium density fibreboard is 285.95 kgCO2eq and plywood is 128.31 kgCO2eq. Medium density fibreboard has a 122.86% greater value than plywood's. The main reasons for this difference are the types and amounts of chemicals used and the energy used. The results of both materials are low compared to other countries' results. That is because the energy source used in both cases was hydropower, which has a significantly lower carbon impact than other energy sources like coal. Generally, in cases where the two materials can be used alternatively, designers should select plywood over medium density fibreboard.

Keywords: *embodied carbon, medium density fibreboard, plywood, life cycle assessment, Ethiopia*

CHAPTER ONE

1. INTRODUCTION

This thesis aims to start the conversation on sustainable material selection for interior design and contribute to sustainable interior construction practices in Addis Ababa and beyond. The main motivation behind this research was seeing the gap in the interior design industry of Addis Ababa, which does not consider environmental sustainability in material selection. The study compares the embodied carbon of two alternative interior materials in the city, medium-density fiberboard (MDF) and plywood. These two materials, among others, are being widely used for multiple applications like furniture, partition walls, decorative paneling, ceiling, flooring, and more. By exploring their environmental impact, we can provide the kind of insights that will really make a difference to future design practices and to the environment they create.

1.1 Background

Sustainable development has grown in importance in our society in recent years. As mentioned by Rees (2017), in order to fulfil their daily resource demands and absorb the trash that results, humanity now needs the equivalent of 1.6 earths. According to projections, we will require the equivalent of two planets by 2030 if present trends continue (Rees, 2017). Following that, the desire to further quantify the impact of human activities on the environment has attracted attention around the world, particularly the activities in the construction of buildings (Takano et al., 2014). As reported by the United Nations Environment Programme (UNEP), building construction has a 36% share of worldwide energy consumption and 40% of CO2 emissions (UNEP, 2018). The same report mentioned that in 2017 alone, CO2 emissions related to buildings were more than 11 GtCO2. The building sector is shifting towards sustainability by planning, creating, and managing structures that reduce negative effects on the environment, save resources, and improve the health and well-being of its occupants (U.S. Green Building Council, 2023).

Embodied carbon is the total carbon released when a product is created from both direct and indirect processes (Pomponi et al., 2011). It is also defined as the sum of greenhouse gas emissions (GHG) that are created during different stages of a material's or a building's life-cycle (Lützkendorf & Balouktsi, 2022). It is released to the environment before the product is used (Huang et al., 2018). Embodied carbon (EC), making up about 11% of the worldwide CO2 emissions from buildings, has a very significant impact on environmental sustainability (Daniel et al., 2022). That is why it is important to address it during material selection.

According to Lakshmi and Hima Bindu (2022), the existence of interior design dates back to ancient civilizations. Eventually, the trend of interior design and material use has changed following the changes in lifestyle and technology. Lakshmi and Hima Bindu (2022) also added that the use of interior design materials reflected the mindset of the people of the time. Until the industrialization, materials were not equally available among different classes. Therefore, selection of materials was a reflection of class and luxury. As mentioned by Alfuraty (2020), interior design has seen a change in design approaches in the 21st century as it has embraced the provision of sustainable and healthy environments. It depends on eco-friendly building materials and sustainable interior design solutions, resulting in environmentally responsible interior spaces. Embodied carbon is among the important concepts when talking about the environmental performance of materials (Pomponi et al., 2011). Therefore, when selecting materials for interior design, considering the embodied carbon associated with them has become a crucial part of minimizing the carbon footprint of the whole building.

In Addis Ababa, the interior design sector has seen a meteoric rise in popularity in recent years due to urbanization and the city's increasing desire for innovation and commercialization (Feseha, 2018). There are a lot of interior design companies and renovation projects in the city. This presents an opportunity to include sustainable practices into the design and construction processes. In the current trend, wood-based materials, especially plywood and MDF, are common interior materials because of their cost, processing simplicity, and adaptability for different uses. In Addis Ababa, they are being used alternatively for different applications such as doors, partition walls, decorative wall paneling, ceiling, flooring, furniture, and more. However, their effect on the environment needs further research.

1.2 Statement of the problem

The construction industry accounts for 40% of energy consumption, 30% of CO2 emissions, and 40% of synthetic waste generation (Asford, 1999). The practice of interior design is a significant part of the construction industry. This indicates that environmental interior design plays a significant part in sustainable development.

The awareness of sustainable design principles is increasing, but a gap exists in understanding the relationship between environmental sustainability and material selection within the context of interior design (Alfuraty, 2020). Even if the ideas of sustainability and environmental preservation have advanced, architects' and interior designers' choices in this area are still somewhat limited (Cargo, 2013). The building industry recognizes the need to minimize negative impact on the environment. Meanwhile, interior material selection often prioritizes functionality, aesthetics, and cost over environmental considerations (Ayalp, 2012).

In recent years, different studies have shown the environmental performance of MDF and plywood. Among them, Jia et al. (2019) assessed the lifecycle of plywood in China, and Prakash et al. (2025) studied the carbon footprint of plywood production through gate-to-gate LCA. Additionally, ErdıL and Yilgör (2020) studied the carbon footprint of MDF production in Turkey. Wilson (2008) showed the environmental impact of MDF in its cradle-to-grave lifecycle. These studies are conducted in the context of different countries and with different system boundaries. These studies are representative only of their respective regions and manufacturing plants. That is because the energy source, input types, and input ratios differ. Especially for wood-based materials, the types of adhesive chemicals used differ from place to place. Most countries' energy sources are also different, leading to different energy carbon factors and embodied carbon results.

In Addis Ababa, different engineered wood types are used in the interior design industry. MDF and plywood are widely used for many applications, including architectural elements like walls and doors. Although these materials have different benefits, their environmental impacts have not been studied within the local context. This lack of data hinders informed decisions in sustainable material selection in the industry.

1.3 Objectives of the Study

1.3.1. General objective

The general objective of the study is to compare the environmental performance of local MDF and plywood products widely used in interior projects in Addis Ababa by assessing their embodied carbon.

1.3.2 Specific objective

The specific objectives of this study are:

1. To quantify the embodied carbon emissions associated with the production of the materials through gate-to-gate Life Cycle Assessment (LCA).
2. To compare the embodied carbon of the materials as per the assessment results.
3. To compare the embodied carbon of each material in a typical interior application case.
4. To comare the embodied carbon of the materials with imported materials.

1.4 Research questions

The study will answer the following questions:

1. What is the quantified embodied carbon emission associated with the production of the materials as determined through gate-to-gate LCA?
2. How does the embodied carbon of the materials compare based on the assessment results?
3. How does the embodied carbon of each material compare in a typical interior application case?
4. How does the embodied carbon of these materials compare with imported materials?

1.5 Significance of the study

This research focuses on promoting sustainable interior design practices in Addis Ababa and beyond. It will advance sustainability efforts by identifying ways to achieve environmental goals by interior materials selection. It evaluated the respective embodied carbon footprints of the alternative interior materials to quantify their environmental impact and provide helpful information for material choices. The final recommendations will guide local architects, interior designers, and other stakeholders toward more environmentally responsible choices of interior materials. It will expand the existing body of research on the sustainable built environment in the Ethiopian context, filling a crucial knowledge gap in the interior design sector. In addition, it will serve as an input for researches that will relate by context and scope.

1.6 Scope of the Study

1.6.1. Spatial Scope

The spatial scope of the study for interior material use trend is set to Addis Ababa. This is set due to the rapid urbanization and the advancement of interior design practices in the city. To study the production processes of those materials, the spatial scope extends further to the locations of their respective manufacturing plants in Sheger city and Kombolcha.

1.6.2. Temporal Scope

Temporaly, the study will consider the current state of embodied carbon associated in the production of the widely used MDF and plywood products.

1.6.3. Thematic Scope

MDF and Plywood are being widely used for multile interior desgn applications in Addis Ababa, and have gained popularity in recent years. Besides, they can be used alternatively for similar applications. The study identified the most commonly used local MDF and plywood products in the city. A gate-to-gate Life Cycle Assessment was performed on the selected products to evaluate their embodied carbon, and compare them. The ultimate goal is to compare the materials, and offer recommendations for more sustainable material options in the region's interior design industry.

1.7 Limitation of Research

The study was limited to locally manufactured MDF and plywood products being widely used for interior design in Addis Ababa and is not generalizable to other material types or geographical locations. It relied heavily on primary data from local manufacturers, who were not always comprehensive. Especially, the manufacturer of the selected MDF product was not willing to give any data. As a result, the second manufacturer in the sampling result was used. The second manufacturer of the MDF gave limited summarised data and did not give permission to take photos of the manufacturing process. In cases where primary data was unavailable, secondary sources from LCA databases were used, introducing potential uncertainties. Specifically, the CORRIM database was used for incomplete inventory data. Furthermore, the gate-to-gate LCA approach restricts the study's scope to the material production phase, excluding impacts from raw material extraction and end-of-life. The study's findings are also subject to the potential exclusion of indirect emissions. This study also does not assess economic and social factors, and is constrained by limited access to complete information, as well as the time and resource limitations at hand.

1.8 Definition of Terms

- **Environmental Performance:** refers to the measurable results of an organization's or a product's interaction with the environment. It encompasses aspects such as resource consumption, emissions, waste generation, and impact on ecosystems (ISO, 2013).
- **Embodied Carbon:** The total greenhouse gas emissions associated with the extraction, processing, manufacturing, transportation, and construction of building materials (UNEP, 2018).
- **Life Cycle Assessment (LCA):** A comprehensive methodology for evaluating the environmental impacts of a product or process (ISO, 2006).
- **Medium-Density Fibreboard (MDF):** an engineered wood product made from wood fibers, resins, and adhesives that are bonded together under heat and pressure (Suchsland & Woodson, 2009).
- **Plywood:** Plywood is a wood-based panel product composed of thin layers of wood veneer (plies) that are glued together with the grain of each ply running perpendicular to the adjacent layers (Suchsland & Woodson, 2009).
- **Sustainable Construction:** Sustainable construction encompasses building practices that aim to minimize the environmental impact of construction projects throughout their life cycle. It involves the use of environmentally responsible materials and resource management, and aims to maximize building performance, energy efficiency, and occupant health (Kibert, 2016).

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

This chapter covers a theoretical framework about the sustainability of materials and the LCA methodology with its standardized framework. It defines and describes the variable embodied carbon. In addition, it covers empirical review of literature on the matter of building materials' embodied carbon, and gaps in literature.

2.2 Theoretical Framework

2.2.1. Environmental Sustainability of Building Materials

According to Kellert (1993), environmental sustainability in building materials refers to minimizing adverse environmental effects at every stage of the material's life cycle, from raw material extraction to manufacturing, transportation, use, and recycling or disposal at the end of its useful life. This means cutting back waste and pollution, saving energy and water resources, lowering greenhouse gas emissions, and encouraging the use of recycled and renewable materials (Kellert, 1993). In general, the Rs principle, which is found in literature in a variety of formats with varying numbers of Rs, defines the sustainable approach to resources. This concept may be applied to architecture and construction in the form of the 5R principle: refuse, reduce, repair, reuse, and recycle (Eklova, 2020).

The choice of building materials has a great impact on the environment linked to the entire life cycle of the building (Ding, 2018). Ding (2018) also added that the environmental impact of building materials is conditional on the stage of the life-cycle studied, building type, type of energy associated, and methods used for each process. Environmental performance in the case of construction materials can be assessed by using a variety of metrics and approaches to determine the environmental load throughout the material's life cycle (ISO, 2013).

According to Ding (2018), when selecting building materials in the design phase, the following standards should be considered:

- ✓ **Low emissions during manufacturing:** manufacturing emissions, especially CO2, contribute greatly to greenhouse gas emissions that bring global warming (Lewis et al., 2024).
- ✓ **Materials with recycled content:** Materials that have recycled content have a significantly lower impact on the environment (Ding, 2018).
- ✓ **Low energy intensity:** reduced energy use will minimize the associated emissions and resource depletion (Ding, 2018).
- ✓ **Biological content:** the effect of the materials on exposed humans and the environment during the use of the materials should be considered.

2.2.2. Metrics of Environmental Sustainability of building materials

2.2.2.1. Embodied Carbon

Embodied Carbon includes the emissions related to materials over the whole life cycle of a building, and it is a key indicator of environmental sustainability (Lützkendorf & Balouktsi, 2022). It is produced during the production, shipping, installation, upkeep, and disposal of building materials for roads, buildings, and other infrastructure (Lewis et al., n.d). According to Daniel et al. (2022), embodied carbon (EC) makes up about 11% of worldwide CO2 emissions from buildings, and it substantially impacts environmental sustainability. Embodied carbon is released before the product is used, in contrast to operational carbon, which results from the energy usage throughout a material's or a product's lifespan (Huang et al., 2018).

2.3. Approaches to Embodied Carbon Assessment

2.3.1. Life Cycle Assessment Methodology

Life cycle assessment (LCA) is a key methodology for evaluating the environmental impacts of building materials across their entire life span (ISO 14040, 2006). LCA studies make it possible to conduct a thorough examination of all the inputs and outputs related to a material, including the extraction of raw materials, manufacturing procedures, transportation, and end-of-life care. This methodology has been extensively used in assessing the environmental footprint of diverse building materials, including concrete, steel, timber, and engineered wood products (Blengini & Garbarino, 2010). LCA studies use different impact categories, including global warming potential (GWP), energy consumption, resource depletion, and air pollution, thereby providing a multi-dimensional assessment of environmental impacts. Attributional Life Cycle Assessment (ALCA) measures the environmental costs of a system based on its current condition (ISO, 2006). Consequential LCA (CLCA), on the other hand, evaluates the possible environmental effects of a particular choice or modification to the product system while considering market reactions and possible changes in production and consumption patterns (Weidema, 2007).

2.3.1.1. The LCA Framework

The LCA framework is a standardised framework that is set out in ISO 14040/44 (GreenVoyage2050, n.d.). It makes it possible to compile, and assess a product system's inputs, outputs, and any environmental effects across the course of its life cycle. According to the ISO 14040/44 standard, the LCA framework has the following phases: goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO, 2006a, 2006b).

A. Goal and Scope definition

The goal of an LCA study shall clearly state the intended application, the intention behind carrying out the study and the intended audience (Quist, 2025). In defining the scope, the following points shall be addressed: functional unit, system boundary, data quality requirements, cut-off criteria, and more.

B. Inventory Analysis

Inventory analysis includes the data collection and calculation procedures to quantify the inputs and outputs associated per functional unit (ISO, 2006a, 2006b). This will help breakdown the data to a manageable and clear quantification.

C. Impact Assessment

According to ISO (2006), the Life Cycle Impact Assessment phase includes the conversion of life cycle inventory data with respective environmental impacts. This stage includes the classification of inventory data to impact categories, characterization, and quantification of the environmental impacts .

D. Interpretation

The results of the impact assessment shall be analyzed and take the form of conclusion and recommendation in a concise manner (Quist, 2025). This will include the identification of significant environmental hot spots in the product system.

2.3.1.2. LCA tools

LCA tools are software that quantify the environmental impacts of a product throughout its life cycle (International Organization for Standardization, 2006). These tools are used by researchers and others to evaluate sustainability. They offer an organized strategy for assessing environmental performance by combining life cycle inventory data with impact assessment techniques (Finnveden et al., 2009). Some of the most widely used tools are OpenLCA, SimaPro, One-click LCA, and Sphera (formerly known as GaBi) (LCA-software.org, 2025). OpenLCA is an open-source LCA program that provides professional environmental, social, and economic life cycle evaluations globally. For academic research on embodied energy and carbon, openLCA's open-source nature and adaptable framework provide clear benefits by enabling visible methodological modifications and the creation of customized models that are not easily accessible in commercial software (Mutel, 2017). Additionally, because of its accessibility, studies can be validated more easily, which promotes collaborative research (Weidema et al., 2013).

2.4.Medium Density Fibreboard (MDF)

Medium Density Fibreboard, commonly known as MDF, is an engineered wood product made from wood fibers, resins, and adhesives that are bonded together under heat and pressure (Suchsland & Woodson, 2009). MDF is one of the goods with the fastest rate of growth in the global market for wood-based panels. (Ayrilmis & Winandy, 2009). MDF is available in various thicknesses, can be easily machined and finished to a high standard, and has been widely adopted in both furniture and construction, where it substitutes solid wood and other wood-based panels (Popovska et al., 2016).

Figure 1: *MDF Board*

(Source: Suchsland & Woodson, 2009)

2.4.1. Production Process

According to Gul et al. (2017), the production process of MDF consists of material preparation, fiber formation, fiber treatment, mat forming, hot pressing, board treatment, and warehouse. In the material preparation stage, a chipper machine turns the wood into chips. After that, the chips are screened to distinguish the necessary sizes (Halvarsson et al., 2010). After that, the confirming chips are sent to the chip washer through a belt conveyor that has an iron remover mounted above it. Then, these chips are moved to the fiber separation area. To soften the chips in the fiber separation phase, they are heated for three to five minutes at 160 to 180°C and 6 to 8 bar of pressure. To make the softened chips resistant to swelling, 1-2 weight percent of paraffin wax is applied (Ibrahim et al., 2006). The softened chips are then delivered to the grinding chamber. In grinding chamber, the materials are mechanically decomposed with the function of water and heat. Pulps are formed. These pulps are then flowing in the blow line. While passing through the blow valve, urea formaldehyde resin is added to the pulp. After that, the pulp in the form of fiber enters the dryer (Buyuksari et al., 2012). During fiber treatment, moisture within the fibers is vaporized and meticulously regulated to achieve a final moisture content between 8% and 13% (by weight). Subsequently, in the mat forming stage, the fibers are uniformly distributed onto a conveyor belt. A prepress operation then removes any trapped air, enhancing the mat's structural integrity (Kargarfard et al., 2007). In the board trimming section, the board is conveyed to longitudinal and transversal saws for trimming (Kargarfard & Jahan-Latibari, 2011). Edge dust is removed to ensure a clean surface. Sanding then refines the board to the specified dimensions and finish. Finally, the board is inspected for quality and moved to storage (Lee et al., 2006).

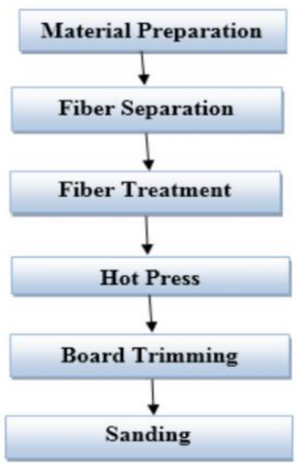

Figure 2: *Production process flow of MDF*
(Source: Gul et al., 2017)

2.4.2. Material Applications in Interior Design

MDF is widely used in building and furniture, replacing solid wood and other wood-based panels in both industries because it is readily machined, comes in a variety of thicknesses, and can be polished to a high degree (Popovska et al., 2016). MDF can be used as the main component for flooring and in the manufacturing of window boards, different types of furniture, wall paneling, architraves, and ornamental facades. Additionally, interior trim pieces, moldings, and door skins are made of it (Stark et al., 2010).

Figure 3: *MDF wall paneling*

(Source: Willow A., 2022)

Figure 4*: Treated MDF Flooring*

(Source: Porta Timber, 2023)

Figure 5: *MDF for furniture*

(Source: Willow A., 2022)

2.5.Plywood

In building projects, plywood is one of the most well-known multipurpose engineered wood-based panel materials (Venable, 2022). A composite material that is supplied in panels is created by binding wood fiber sheets and resin with plywood. Face veneers are usually of a better grade than core veneers in a standard plywood panel. In order to improve resistance to bending forces, the core layers serve to increase the distance between the outer layers, which are subject to the highest bending stresses.

Figure 6: *Plywood Board*

(Source: Suchsland & Woodson, 2009)

2.5.1. Production Process

Multiple Multiple layers or plies of softwood veneer are adhered together to create plywood panels, with each veneer layer's grain direction perpendicular to the ones next to it (Venable, 2022). According to Jones (2021), the detailed process of plywood production starts with log selection. At this point, logs of both hardwood and softwood are meticulously categorized according to their species and quality. The conditioned logs are then measured for crosscutting as the following step in the plywood-making process. A debarking equipment will be used to remove the bark after the logs have been cut to length. Then the logs will be stripped into thin veneers using a rotary lathe. The peeling process usually results in damp veneers. To strengthen the binding, they need to be dried. The veneers are trimmed and allowed to dry before being assembled into finished sheets. They are also divided into face, core, and back veneers at this point. After the sheets are correctly assembled, adhesives are used to join them (Jones, 2021). The type of plywood being produced will determine which adhesives are used at this stage. After that, the assembled panels are pre-pressed in a cold press with regulated hydraulic pressure and room temperature. To ensure excellent bonding, the pre-pressed panels will then be put into a hot press. Once the plywood passes the pressing stage, it will then be sanded to make it have a smooth surface, and its thickness will be uniform.

Log infeed
Log debarking
Peeling
Drying
Adhesive application
Cold pressing
Hot Pressing
Painting
Smoothing/sanding
Board Trimming

Figure 7: *Process flow of plywood production*

(Source: Author, 2025)

2.5.2. Material Applications in Interior Design

Plywood is another engineered wood used in many ways in interior design. It is used for different decorative and structural purposes. Its multilayer composition prevents warping, so it is a strong and solid material for furniture that ranges from shelf units and cabinets to chairs and tables (Sharonply, 2022). Additionally, plywood is used in interior design to create wall paneling that provides a warm, textured alternative to conventional drywall. It is also used for custom architectural elements like room dividers and ceiling treatments that enable the creation of distinctive and versatile spaces (Afyun, 2023).

Figure 8: *Plywood wall paneling*

(Source: Venable, 2022)

Figure 9: *Plywood for furniture*

(Source: Venable, 2022)

Figure 10: *Plywood credenza*

(Source: Pinterest, 2023)

2.6.Empirical Literature Review

2.6.1. Global Studies on Embodied Carbon of Building Materials

Several studies were conducted on the embodied carbon of different building materials in the context of different countries and varying system boundaries. Most of these studies focus on materials associated with the conventional construction practices. From those materials, cement, concrete, HCB, brick, steel, timber, ceramic and gypsum take the lead.

Among the studies conducted on concrete, McGrath et al. (2012), Hammond, G. & Jones, C. (2008), Flower, D. J. M. & Sanjayan, J. G. (2007) all concluded that cement is the most responsible input for the high embodied carbon result of concrete due to its production process. In addition, steel and brick are the building materials with high values of embodied carbon.

2.6.2. Embodied Carbon of MDF in the case of different regions

ErdıL and Yilgör (2020) studied the carbon footprint of MDF manufacturing in Turkey. Their main motivation for the study was the increasing greenhouse gas emissions, mainly CO_2, that are leading to global warming. The study used Pareto analysis to quantify the carbon footprint associated with the manufacturing processes of MDF in a selected manufacturing plant. They set up two scenarios where the carbon footprint was expected to be minimized. The study concluded that varying sources of energy brought significant differences in the carbon footprint of the production processes, where the use of natural gas had the most negative impact.

A life cycle assessment of MDF conducted in the US by Wilson (2008) showed the environmental impact of the material in its cradle-to-gate life cycle. The embodied carbon within the specified system boundary was found to have different values when different types of inputs were used. In conclusion, emissions created on-site made a significant contribution. Specifically, 93% of biogenic CO_2, and a large percentage of other emissions - 14% of CO_2 fossil, 27% of methanol, 77% of methanol, 77% of CO, 12% of NO_x, 38% of total particulates, and 90% of VOC.

2.6.3. Embodied Carbon of Plywood in the case of different regions

Different studies show that the embodied carbon of plywood varies in different regions. The studies have different system boundaries affecting the outcome. A study conducted by Jia et al. (2019) assessed the lifecycle of plywood production in China. The assessment followed a cradle-to-gate approach. The study used a process based LCA. Among the processes included, the drying and compositing processes were responsible for most of the embodied carbon as they contributed to 76.41% of the total embodied carbon. The main contributors to this result are the chemicals, heat energy & electricity used in that stage.

A recent study in India by Prakash et al. (2025), followed a gate-to-gate approach from four different manufacturing plants. The LCA method used was an input-output method. The embodied carbon result of the four manufacturing plants had a 270 kg CO_2/m^3 difference due too differences in the machinery and chemicals used. Generally, the highest contributors to the embodied carbon result of all four plants is the adhesive chemicals used and energy.

2.6.4. Embodied Carbon of Building Materials in Ethiopia

According to Taffese and Abegaz (2019), there is a big gap in knowledge over the embodied energy and carbon of building materials in less developed countries, and Ethiopia is no exception. As a result, the researchers took the initiative to study the case of the five most commonly used construction materials in Ethiopia: cement, hollow concrete block (HCB), sand, reinforcement bars (rebars), and coarse aggregates. These materials are known to be the main sources of waste created during construction in the country. The study continued to assess five mixed-use buildings to evaluate the embodied carbon and energy of the materials. The system boundary used was the cradle-to-site lifecycle boundary. The process-based method was used, whereby the flow of different activities was analysed. To quantify the embodied energy and carbon, since there was no data for the Ethiopian case, the Senegalese embodied energy and carbon coefficients of the materials were used. The outcome of the study showed that HCB, cement, and rebars were responsible for 94% of the embodied energy and 98% of the carbon emissions. The study highlighted that there is no previous research on this issue and recommended various methods to cut down embodied energy and carbon.

2.7.Gaps in Literature

Research that studied the embodied carbon of the two materials is representative only of their respective regions and manufacturing plants. That is because the energy source, input types, and input ratios used are different. The types of adhesive chemicals used are especially different from place to place. The energy source of most countries is different from that of Ethiopia, leading to different carbon factors and final results. When it comes to embodied carbon studies in Ethiopia, the only available study was made for cement, sand, coarse aggregate, steel, and HCB. Therefore, not having studies on the embodied carbon of the two materials in Ethiopia is a major literature gap.

CHAPTER THREE

3. METHODS AND MATERIALS

3.1. Study Area

The study includes three different locations: Addis Ababa, Sheger City (Burayu sub-city), and Kombolcha (South Wollo). Addis Ababa is the primary study area for identifying prevalent MDF and plywood products used for interior design. The city's growing interior design industry offers a significant opportunity to observe contemporary material selection patterns. Addis Ababa is located at the center of Ethiopia with coordinates 9°1′48″N 38°44′24″E on an elevation of 2,355 meters above sea level. Following the identification of these widely used products, data regarding their production processes were collected from their respective manufacturing facilities located in Sheger City (Burayu sub-city) and Kombolcha (South Wollo).

Sheger city (Oromo: Magaalaa Shaggar) is a new city in the Oromia region that centers around Addis Ababa. It is selected because the most widely used plywood material in Addis Ababa is manufactured there. Whereas Kombolcha town is located in the North-central Ethiopia, in the Amhara region. It has an absolute location of 11°5′N 39°44′E, and is situated at an elevation of 1,878 meters above sea level. Kombolcha is the third study area because the sample MDF product is manufactured there.

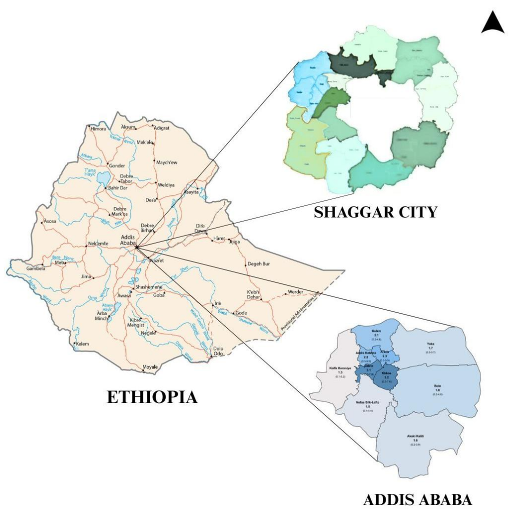

Figure 11: *Study Area Location Map - Addis Ababa and Sheger City*

(Source: Author, 2025)

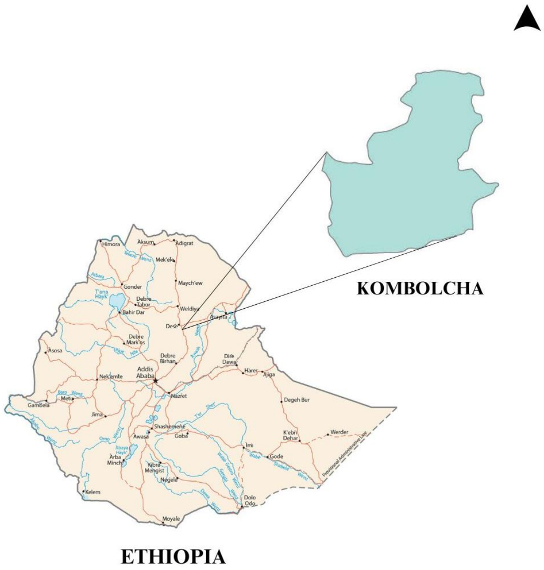

Figure 12: *Study Area Location Map - Kombolcha*

(Source: Author, 2025)

Specifically, for the commonly used plywood type, data was obtained from Maereg manufacturing plant located in Tatek Industry Zone, Burayu Sub-city, Sheger City. Whereas, data about the widely used MDF type was gathered from ET Wood Manufacturing plant situated in Kombolcha Industrial Park, South Wollo. The data gathered from these three locations provided key inputs to assess the environmental performance of the specific interior materials used in Addis Ababa, based on their production processes.

3.2. Research Type and Approach

This research analyzes and then compares the environmental impact of two alternative interior design materials by using the metrics of embodied carbon. It is an applied quantitative research type that investigates the embodied carbon of locally manufactured MDF and plywood. These two materials were initially selected for the study due to their growing popularity in the interior design sector and their many applications. The study utilizes a Life Cycle assessment (LCA) methodology per the ISO 14040/44 standards to quantify the environmental impacts of the two materials. The ISO 14040/44 set of standards offers a global framework for LCA of products and services to ensure a standardized assessment and reliable results. The specific LCA model will be a gate-to-gate analysis focusing on production processes from raw material intake to finished product. This system boundary is helpful in focusing attention on material inputs, direct emissions, and energy use during the manufacturing process. This focus on the production

stage allows for increased data accuracy and availability. Especially with the limitation of resources at hand, like time, the system boundary enables the collection of reliable data.
The research approach is deductive since it is based on a set of theories and standards that define the sustainability of materials, which will then be applied to the collected data from the study areas. The existing theories on how higher embodied carbon has a negative impact on the environment and contributes to greenhouse gas emissions that lead to global warming are the foundational knowledge of the whole study. This theory is then used to compare which of the two materials makes the more significant contribution to global warming as a result of its higher embodied carbon.

3.3. Sampling

The study's target population is all locally manufactured MDF and plywood products used for interior design. A purposive sampling strategy was used to select the specific material brands for the study. This purposive selection is targeted towards the widely used brands of the materials in the market since they represent the industry's dominant trend of material use.
This initial brand selection was based on the preliminary research conducted during the proposal phase, where an unstructured interview was used to specify the most widely used brands in the market. The largest wholesale suppliers of these materials are situated at Dir Tera in Mercato, the center of wood products wholesale supply. These 7 largest wholesale suppliers were asked which brands are widely used through an unstructured interview.

According to their responses, the widely used MDF brand is produced by TY Wood Manufacturing at Eastern Industrial Zone, Dukem. While the preliminary research identified TY Wood Manufacturing as the most widely used MDF brand, access to primary production data was not permitted by the manufacturer. As a result, the data collection for MDF focused on the second most widely used brand, ET Wood Manufacturing. The widely used plywood is produced by Maereg Manufacturing and Trading in Tatek Industry Zone, Burayu subcity, Sheger city. After identifying these key brands, the study sought data specific to those brands by contacting the manufacturers directly.

3.4. Data Collection

3.4.1. Primary Data

For the primary data input for the LCA, information on the manufacturing process was gathered from the manufacturers of the two brands via unstructured interviews, and the data was recorded in a table (Appendix 1 and 2). The interview asked the production process of the materials including the inputi88i-s and outputs associated. This includes raw materials, and types of waste generated throughout the manufacturing process within the manufacturing plants. The collected data was then calculated as per the functional unit and logged in a table.

3.4.2. Secondary Data

Secondary data from material databases was used to check for missing or incomplete data, such as emissions. Generic data from the reputable LCI database by CORRIM (Consortium for Research on Renewable Industrial Materials) was used, matched as closely as possible to the identified brands' specifications in terms of material type, and other relevant production parameters. CORRIM is a non-profit research organization that has been working on the LCA data of different wood-based materials since 1996 and is a suitable source of LCI data for different types of wood-based products (Lippke et al.,2004). In addition, relevant articles and publications were used to study the environmental data of the materials.

3.5. Life Cycle Assessment Framework

3.5.1. Goal and Scope Definition

This study aims to assess the embodied carbon associated with the production of the MDF and plywood products using a gate-to-gate perspective. This comparison will help select materials based on their environmental impacts. The scope of the analysis is further explained in terms of functional unit and system boundary below.

A. Functional Unit

The functional unit used for both plywood and MDF products is $1m^3$. Volume is the most widely used standard unit in wood-based productions. In addition, it allows for a fair comparison between the materials without being influenced by varying material density and different dimensions of boards. Every input and output is calculated per 1 m^3 of product for both materials.

B. System Boundary

The system boundary for both materials is set to be gate-to-gate. This means the study focuses on the materials' lifecycle at the stage where their production takes place inside the manufacturing plant. This is set because data availability and accuracy decrease when the system boundary expands, and major resources like time are limited.

The production process of the plywood product included in this study is presented below.

Production Process	Process Descrption	Input	Output
Log infeed	Logs are cut to have consistent lengths of 120cm and 240cm and added to the debarking machine	Eucalyptus log, Electricity	120cm & 240cm logs
Log debarking	The bark is removed from the logs	Logs, Electricity	Debarked logs, bark
Peeling	The logs go through peeling machine to form long and short veneers	Debarked logs, Electricity	Veneers, wood waste
Drying	The veneers are dried to 0% moisture content	Veneers, thermal energy (electricity)	Dried veneers, water vapor
Adhesive application	The adhesive is prepared and coated over the veneers	Urea formaldehyde, iron oxide, water, wheat flour, thermal energy (electricty)	Veneer (painted)
Cold pressing	The veneers are cross layered and put under cold pressure for 30 minutes	Adhesive painted veneers, electricity	Plywood
Hot Pressing	The plywood goes through hot pressing for 20-25 minutes in 170 degrees celcius	Plywood, thermal energy (electricity)	Plywood
Smoothing/sanding	The pressed plywood gets sanded to have smooth surface and uniform thickness	Plywood, electricity	Smooth plywood, saw dust,
Painting	The plywood is painted one coat of the adhesive mxture on the exterior	Urea formaldehyde, iron oxide, water, wheat flour, thermal energy (electricty)	Plywood
Board Trimming	The board gets trimmed to have the appropriate dimensions	Plywood, electricity, saw dust,	Plywood panels, trims, saw dust,

Table 1: *Plywood production process at Maereg Wood Manufacturing*
(Source: Author, 2025)

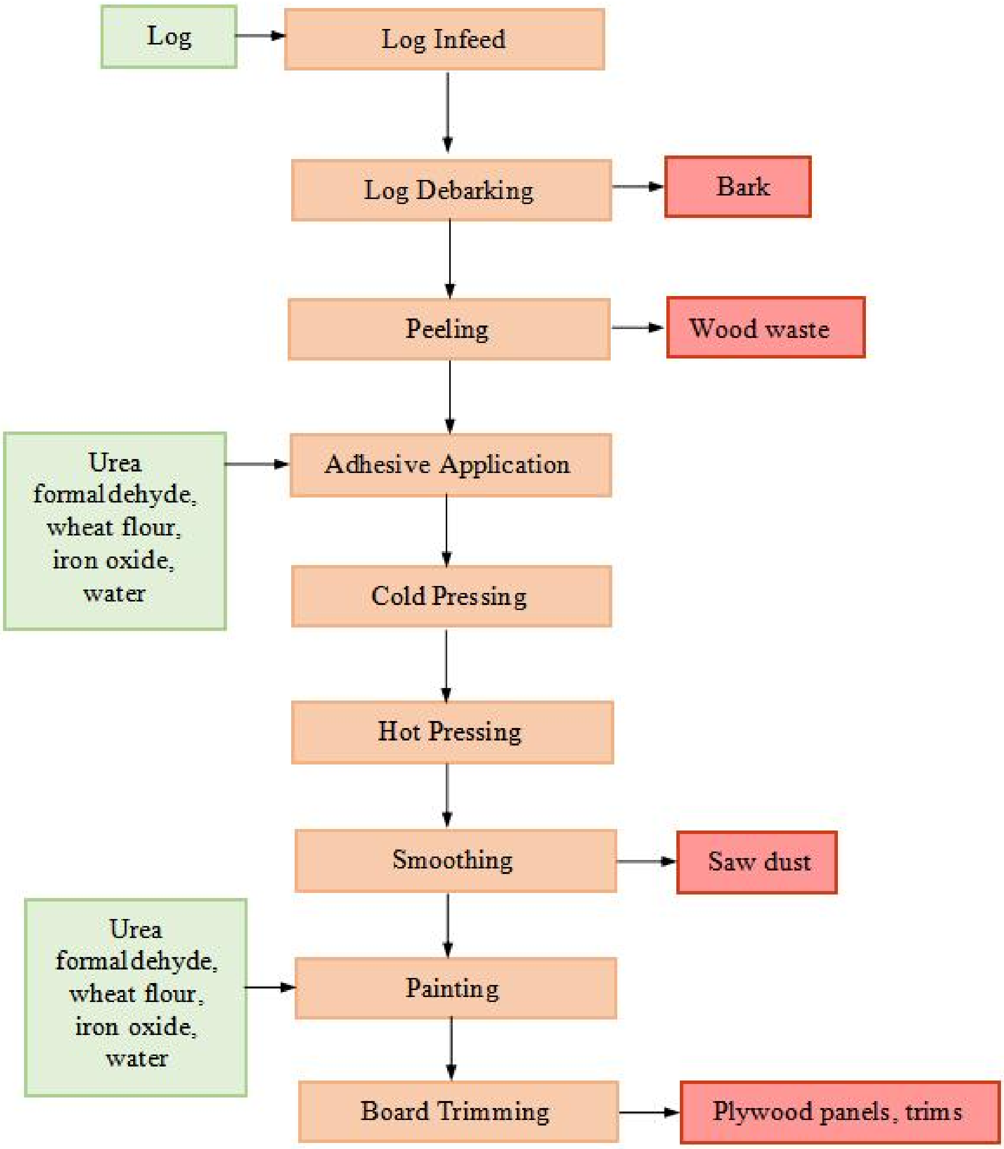

Figure 13: *Plywood Production Flow Chart*

(Source: Author, 2025)

Figure 14: *Pile of veneers at the plant*

(Source: Author, 2025)

Figure 15: *Urea formaldehyde for adhesive*

(Source: Author, 2025)

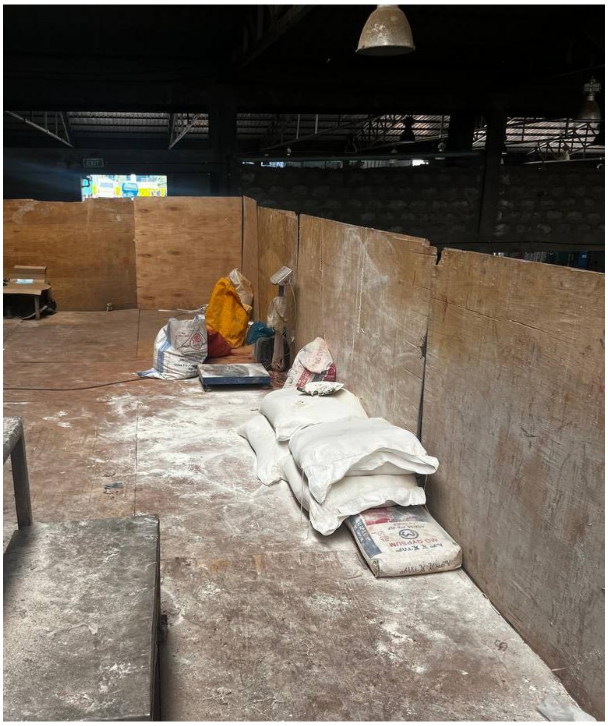

Figure 16: *Wheat flour for adhesive mixture*

(Source: Author, 2025)

Figure 17: *Adhesive mixing at the plant*

(Source: Author, 2025)

The production process of the MDF product included in this study is illustrated below.

Production Process	Process Descrption	Input	Output
Wood Preparation	Log debarking, chipping and washing	Logs (mostly eucalytus), water, electricity	Clean wood chips, water polluted with dust
Fiberizing	The chips are physically pulped into fibers	Wood chips, water, electricity, thermal energy	Wood fibers
Drying	Drying the damp fibers to reach the required moisture content level	Wet wood fibers, thermal energy, electricity,	Dried wood fibers
Resin Blending	The fibers get mixed with resin, wax and other additives	Dried fibers, resin, wax, electricity	Resin coated fibers
Mat formation	The resin coated fibers are formed to be a mat	Resin coated fibers, electricity	Fiber mat
Hot pressing	The mat is pressed under high pressure and temperature to set the resin	Fiber mat, thermal energy, electricity	Raw MDF board
Cooling & Conditioning	The hot boards are cooled and stabilized	Hot MDF board, electrical energy	Conditioned MDF boards
Sanding	Boards get sanded to have smooth finish & standard thickness	MDF board, electicity	Sanded MDF boards
Sawing	The boards are cut to size	MDF boards, electricity	Finished MDF boards

Figure 18: *Production process of MDF at ET Wood Manufacturing*

(Source: Author, 2025)

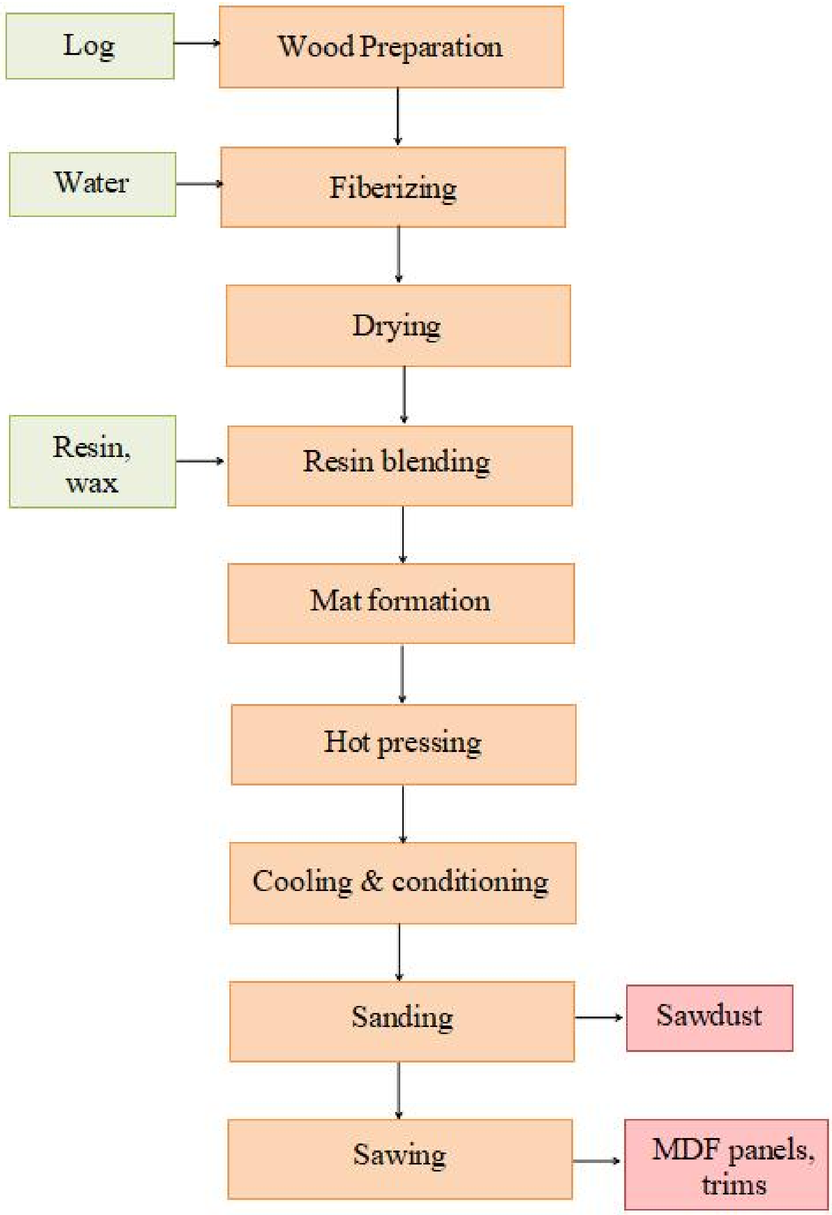

Figure 19: *MDF production Process Flow Chart*

(Source: Author, 2025)

3.6. Reliability and Validity

Different measures were taken to ensure the reliability and validity of the study. For reliability of the results, the standard method of LCA was used as per ISO 14040. The data collection procedures and formats used for both materials were consistent. In addition, academically suitable databases were used for incomplete data. To ensure the validity of measurements, the most relevant life cycle inventory data was used by linking data sources that could represent the context well. The system boundary and functional units used were matched along both materials, allowing a fair comparison. To check for consistency, existing studies and industry standards were referred to.

3.7. Ethical Considerations

Before the beginning of data collection, a permission letter was obtained from the Department of Architecture. The purpose of the study was clearly stated in the letter. In addition, consent was asked for orally from all participants. The study did not require any personal information from the participants. The data collected from all participants is used only for the research in this document.

CHAPTER FOUR

4. RESULT AND DISCUSSION

The products for the embodied carbon assessment were purposively selected based on preliminary research conducted during the proposal stage, which identified commonly used materials in Addis Ababa's interior design sector. The table below highlights the results from that preliminary study.

Material	Product Manufacturer	Market position	Address	Remark
MDF	TY Wood Manufacturing	First mostly used	Eastern Industrial Zone, Dukem, Oromia Regiom	Excluded from study due to lack of permission for data collection
	ET Wood Manufacturing	Second mostly used	Kombolcha, South Wollo, Amhara Region	Selected as a sample for MDF
Plywood	Maereg Manufacturing and Trading	First mostly used	Burayu, Sheger City, Oromia Region	Selected as a sample for plywood
	DMA Wood Manufacturing	Second mostly used	Assela, Oromia Region	Excluded from sample pool based on sampling criteria

Table 2: *Summary on the widely used MDF and plywood products in Addis Ababa*

(Source: Author, 2025)

This indicates that the MDF and plywood products of the listed manufacturers are being widely used in Addis Ababa. For the purose of the research, one product sample for each material was selected. For MDF, the second option, that is the product manufactured by ET Wood Manufacturing was selected as a sample. This was done because the first widely used manufacturer was not willing to give any data, hence removed from the study.

For the plywood product, the product manufactured by Maereg Manufacturing and Trading was selected as a sample. The manufacturer was cooperative, as a result the second option was excluded from the study.

Following this, the manufacturing plants of the selected products were visited, and the required data for the assessment of the materials' embodied carbon through LCA, was collected.

4.1. Life Cycle Inventory Analysis

The tables below show the data collection sources for input and output data considered in the system boundary of the materials. The data for the inputs associated with the manufacturing process was obtained mainly through unstructured interview. For incomplete data, such as quantification of outputs and emissions was obtained from CORRIM database. The data used from this database was under "Rest of the World" section, which is the second best option to be used since local data was not available.

For the plywood, the input data was provided associated with the respective production process stage. The inventory data on all major inputs and outputs, calculated as per the functional unit is provided below.

Stage	Input	Unit	Quantity per functional unit	Data Source
Log Infeed	Eucalyptus wood	m^3	2	Manufacturer
Wood processing (debarking & peeling)	Electricity	kWh	52.98	CORRIM
Wood Drying	Electricity	kWh	48.71	CORRIM
Adhesive mixing and application	Ureaformaldehyde	kg	55.56	Manufacturer
	Water	L(Kg)	55.56	Manufacturer
	Wheat Flour	kg	16.6	Manufacturer
	Irod Oxide	kg	0.055	Manufacturer
Painting & Pressing	Electricity	kWh	26.37	CORRIM
Sanding & trimming	Electricity	kWh	8.51	CORRIM

Table 3: *Lifecycle Inventory Analysis of Plywood*

(Source: Author, 2025)

Output	Unit	Quantity per functional unit
Plywood	m^3	1
Bark	kg	107
Sawdust	kg	9.45
Wood waste	kg	26.1
Methane (CH4)	kg	0.0527
Carbonmonoxide CO	kg	2.94
CO2 (biogenic)	kg	1.24
Dust	kg	1.01
Formaldehyde (CH2O)	kg	0.0309
Methanol (CH3OH)	kg	0.0753
Nitric oxide (NO)	kg	0.455

Table 4: *Lifecycle Inventory Analysis of Plywood*
(Source: Author, 2025)

Inventory data of MDF production was given as a summary, instead of the respective production processes. That data is then calculated as per the functional unit and illustrated a follows.

Input	Unit	Quantity per functional unit	Data Source
Wood	kg	675	Manufacturer
Ureaformaldehyde Resin	kg	125	Manufacturer
Water	L	75	Manufacturer
Wax (Paraffin)	kg	12	Manufacturer
Hardener Additives	kg	3	CORRIM
Electricity	kWh	225	CORRIM

Table 5*: Lifecycle Inventory Analysis of MDF*
(Source: Author, 2025)

Output	Unit	Quantity per functional unit
MDF board	m^3	1
Carbondioxide (CO2)	kg	1.90
Methane (CH4)	kg	0.055
Nitrous oxide (N2O)	kg	0.0053
VOCs (including formaldehyde)	kg	2.3
Wood waste	kg	95
Dust	kg	1.5
Carbonmonoxide (CO)	kg	3.4

Table 6: *Lifecycle Inventory Analysis of MDF*

(Source: Author, 2025)

4.2. Life Cycle Impact Assessment

The impact assessment tool used was OpenLCA. OpenLCA is recommended for academic research due to its adaptable framework, which allows methodological modifications and customized models (Mutel, 2017). The impact assessment method used in the software OpenLCA was the IPCC 2013 (Intergovernmental Panel on Climate Change) to quantify the embodied carbon of both materials. IPCC offers a standard scientific method for impact assessment, especially embodied carbon. Among the impact categories that IPCC 2013 covers, Global Warming Potential (GWP) is the major indicator for identifying the immediate impact of embodied carbon on the environment and global warming.

4.3. Quantity of the Embodied Carbon Emissions Associated with the Production of Plywood

For the plywood product, the process flow was created as an input-output model, and the total embodied carbon was found to be 128.31 kgCO2eq. According to the result, the urea-formaldehyde adhesive and emissions associated with it contributed greatly to the total embodied carbon of the product. The second input that contributed greatly was the electricity used to perform the production.

Input	Direct contribution [kg CO2 eq]
Electricity from hydroelectric power plants	3.34968
Urea Formaldehyde Binder	134.39
Wood Logs	-0.0087
Wheat Flour	-9.42

Table 7: *Direct Carbon Contributon of inputs computation result from OpenLCA*

(Source: Author, 2025)

Impact category UUID	Impact category	Reference unit	Result
2ec5f90d-021d-3d5e-8c e2-b940103bda8b	IPCC GWP 500a - IPCC 2013 GWP 500a	kg CO2 eq	128.31

Table 8: *Total Embodied Carbon of plywood result from OpenLCA*

(Source: Author, 2025)

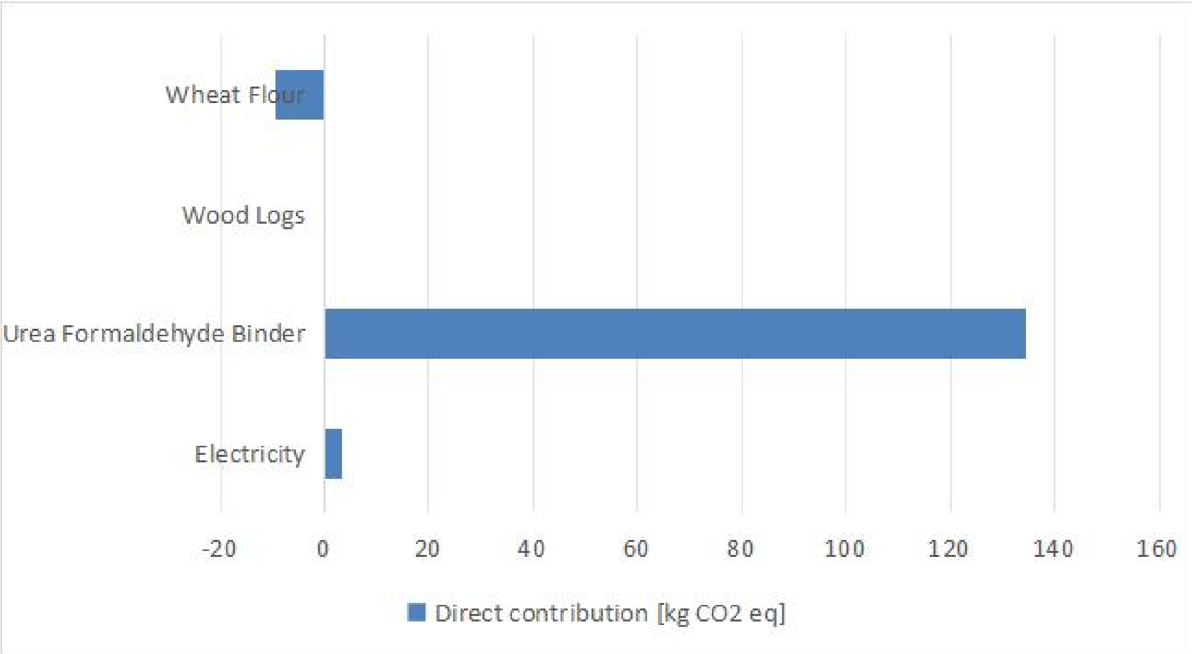

Figure 20: *Direct Contributioin of Inputs*

(Source: Author, 2025)

4.4. Quantity of the Embodied Carbon Emissions Associated with the Production of MDF

The embodied carbon for the MDF product was found to be 285.954 kgCO2eq. According to the result, the urea-formaldehyde binder and paraffin wax contributed greatly to the total embodied carbon of the product. The second input that contributed was the hardener additives, which are chemicals that cause harmful emissions. Next, electricity had the third place in carbon contribution.

Input	Direct contribution [kg CO2 eq]
Electricity from hydroelectric power plants	5.4
Urea Formaldehyde Binder	255.21
Paraffin Wax	19.40
Wood	-0.036
Hardener additives (methanol, ammonium sulfate, ethylhexanol..)	5.98

Table 9: *Direct carbon contribution of inputs computation result from OpenLCA*

(Source: Author, 2025)

Impact category UUID	Impact category	Reference unit	Result
2ec5f90d-021d-3d5e-8ce2-b940103bda8b	IPCC GWP 500a - IPCC 2013 GWP 500a	kg CO2 eq	285.954

Table 10: *Total Embodied Carbon of MDF result from OpenLCA*

(Source: Author, 2025)

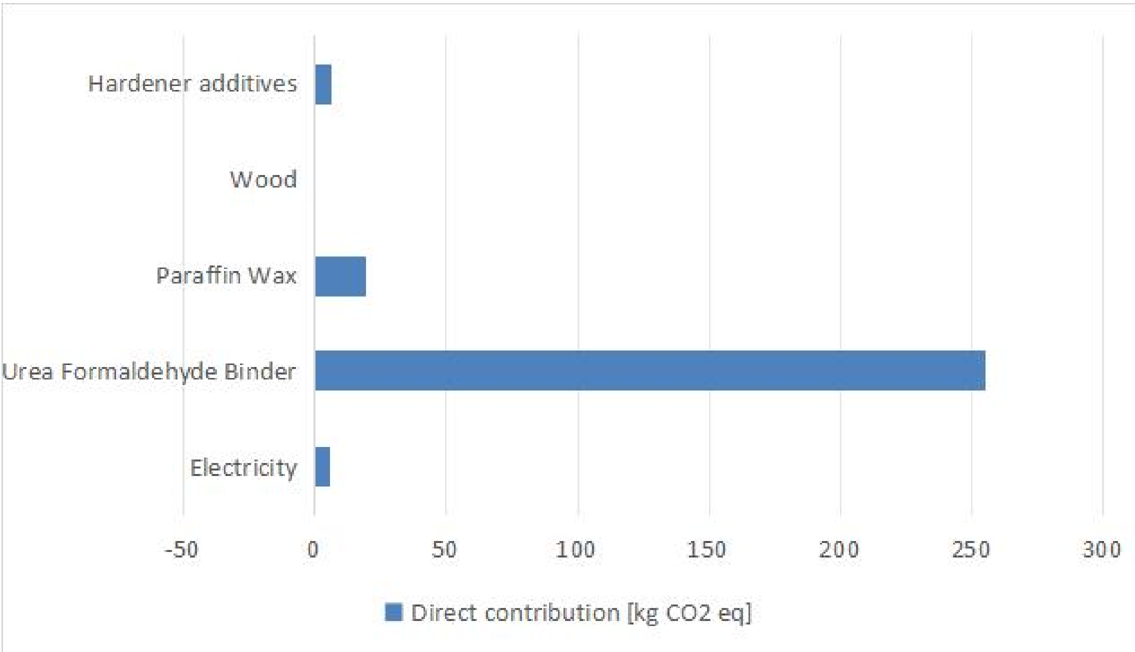

Figure 21: *Direct Contributioin of Inputs*

(Source: Author, 2025)

As the result indicates, the highest contributors for embodied carbon of the MDF product are the chemicals and emissions associated with the urea formaldehyde binder, paraffin wax and hardener additives.

4.5. Comparison of the embodied carbon result of the materials

The results show a clear difference between the embodied carbon of the plywood and MDF products used. The embodied carbon of the MDF product within the specified product system is 122.86% hgher than that of plywood. The difference of 157.64 kgCO2eq indicates that the MDF board contributes more to the greenhouse gas emissions during its production stages. Several factors contribute to this difference including the amount and type of inputs and the energy used for the productions.

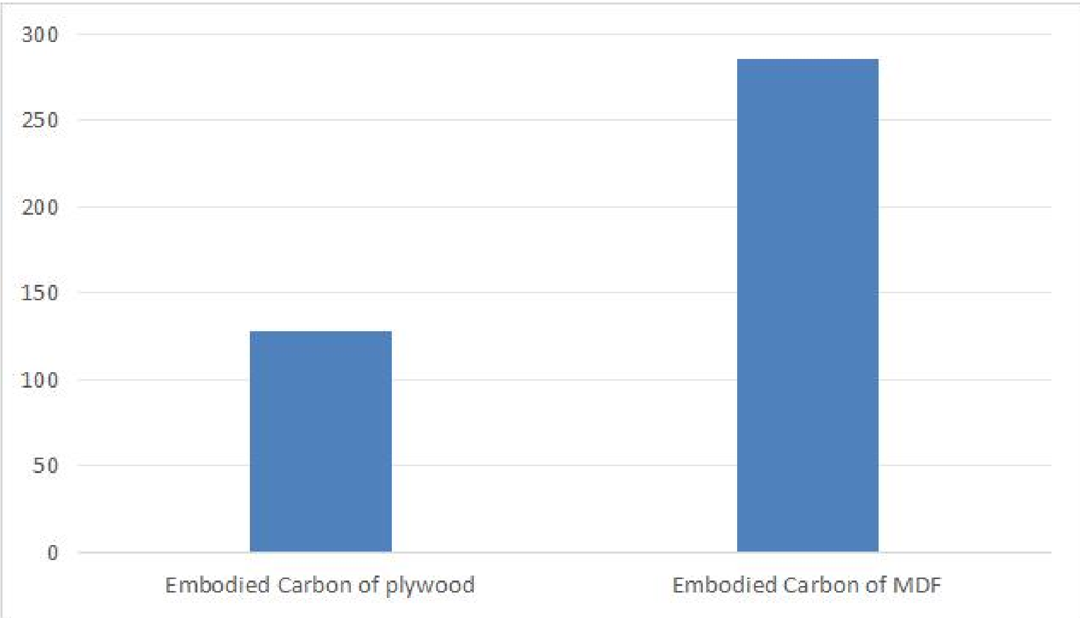

Figure 22: *Embodied Carbon Comparison of the MDF and Plywood products*

*(*Source: Author, 2025)

4.6. Embodied carbon of the materials in an interior application case: Wall Paneling

A typical interior application of wall paneling using a 12 mm thick material was selected as a case study. That is because wall paneling is the most common application where the two materials can be used alternatively. For the comparison, a $1m^2$ of wall paneling was considered. Based on the assessment of the embodied carbon of the materials, the comparison for this specific application was calculated as follows:

Since the functional unit used for the LCA was volume, the $1m^2$ sample measurement has to be converted to volume respective to the 12 mm thickness for both materials.

$1\ m^2 \times 0.012\ m = 0.012\ m^3$

Embodied Carbon of MDF was found to be 285.95 kgCO2eq per $1m^3$. Applying that to the $1m^2$ paneling, the following result is found:

EC of MDF per m^3 = 285.95 kgCO2eq

EC of $1m^2$ MDF wall paneling = 0.012 m^3 x 285.95 kgCO2eq = 3.43 kgCO2eq

Embodied Carbon of Plywood was found to be 128.31 kgCO2eq per $1m^3$. Applying that to the $1m^2$ paneling, the following result is found:

EC of Plywood per m^3 = 128.31 kgCO2eq

EC of $1m^2$ Plywood wall paneling = 0.012 m^3 x 128.31 kgCO2eq = 1.54 kgCO2eq

Material	**Thickness**	**EC for $1m^2$ interior wall paneling (kgCO2eq)**
MDF	12 mm	3.43
Plywood	12 mm	1.54

Table 11: *EC of the materials in wall paneling interior application*
(Source: Author, 2025)

Based on these calculations, MDF demonstrates a higher embodied carbon footprint compared to plywood for the same $1m^2$ of a 12 mm thick wall paneling application.

4.7. Comparison of the embodied carbon of the materials with imported alternatives

Further comparative analysis was conducted with materials imported from China to further contextualize the embodied carbon of materials used in Addis Ababa. This comparison includes the estimated embodied carbon from the manufacturing phase in China and the significant contribution from international transportation to Addis Ababa.

For this analysis, average values were assumed for materials imported from China, based on representative global LCA databases and freight emission factors as specific data within the system boundary in the case of China was scarce.

Average EC of the materials in China (Green Building Encyclopaedia, 2011):

MDF: ~ 550 kg CO2eq/m3

Plywood: ~ 350 kg CO2eq/m3

Transportation Emissions to Addis Ababa via Djibouti (Dantful. (2025), Climatiq. (2021), Climatiq. (2019)):

- ✓ **Sea Freight (China to Djibouti)**: Using an average sea distance of approximately 11,500 km and an emission factor of 0.01614 kg CO2eq/tonne-km.
- ✓ **Road Freight (Djibouti to Addis Ababa):** Using a road distance of approximately 770 km and an emission factor of 0.069 kg CO2eq/tonne-km.

Average material density values were used to convert mass data to volume where MDF has a density of 700 kg/m^3 and plywood has 600 kg/$m^{3.}$ Then for 1m^3 of MDF, we have the following values:

Manufacturing EC: 550 kg CO2eq

Sea Freight: (700 kg/1000) x 11,500 km x 0.01614 kg CO2eq/tonne km = 129.8 kg CO2eq

Road Freight: (700 kg/1000) x 770 km x 0.069 kg CO2eq/tonne km = 37.2 kg CO2eq

Total EC for Imported MDF: 550 + 129.8 + 37.2 = 717 kg CO2eq per m^3

Similarly, for plywood we have the following values:

Manufacturing EC: 350 kg CO2eq

Sea Freight: (600 kg/1000) x 11,500 km x 0.01614 kg CO2eq/tonne-km = 111.4 kg CO2eq

Road Freight: (600 kg/1000) x 770 km x 0.069 kg CO2e/tonne-km = 31.9 kg CO2eq

Total EC for Imported Plywood: 350 + 111.4 + 31.9 = 493.3 kg CO2eq per m^3

Material	**EC when locally produced (kgCO2eq/m^3)**	**EC when produced in China (kgCO2eq/m^3)**	**EC when produced in China and imported to Ethioia (kgCO2eq/m^3)**
MDF	285.95	550	717
Plywood	128.31	350	493.3

Table 12: *Summary of EC of local and imported materials*
(Source: Author, 2025)

These results indicate that the imported materials have significantly higher embodied carbon. The primary contributors for the result are the embodied carbon values associated with the manufacturing processes and the intercontinental transportation.

4.8. Discussion

In the LCA of materials carried out in the context of different regions, where the system boundary is gate-to-gate, the embodied carbon amount is mainly a result of the energy used during the production process. That is due to the carbon factor of the type of energy that they use is signifcantly high. In the case of Ethiopia, however, the energy source is considered to be clean compared to other countries' sources. That is due to the fact that Ethiopia uses hydroelectric power, that is generated from a renewable resource. This energy generated from renewable resource has a carbon footprint sgnificantly lower than other sources used worldwide. Accordng to IPCC, the carbon factor for hydroelectric power is 24 gCO2-eq/kWh. This value is less than fossil fuel sources like coal (around 820 gCO2-eq/kWh) or natural gas (around 490 gCO2-eq/kWh). This major difference in carbon factor of different energy sources indicates that both materials, when manufactured in Ethiopia, have significantly lower negative impact on the environment due to their less embodied carbon values.

The biggest factor contributing to the embodied carbon results are the chemical inputs used in the manufacturing processes. The quantity and type of chemicals used in the MDF product had higher contributions to its embodied carbon compared to that of the plywood's. The second factor that caused such a difference in the embodied carbon of the materials is the energy used. The production process of MDF is energy intensive as it has more production processes that require the use of electricity.

When it comes to the practical application of the materials in interior design, a case of $1m^2$ wall paneling was considered. For a 1m2 wall paneling application, using MDF has a 3.43 kgCO2e per m^2 embodied carbon value. Where as, plywood has a 1.54 kg CO2e per m^2 embodied carbon value. This indicates that using plywood for interior application has nearly half less embodied carbon.

Finally, the EC of the materials was compared to imported alternatives. The major foreign supplier for these materials in Addis Ababa's market is China. The embodied carbon of imported materials was three times larger than locally produced materials. The major contributors for this difference were the embodied carbon in the manufacturing of the materials in China and the emissions related to the intercontinental transportation.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Embodied carbon, among other indicators of a material's environmental performance, has a direct contribution to the greenhouse gas emissions that cause global warming. As a result, it should be considered when selecting materials for different constructions including interior design.

The study evaluated and compared the embodied carbon of two alternatively used interior materials in Addis Ababa - MDF and plywood. These materials are used for a number of applications in interior design. Inorder to proceed with the study, brands that are widely used were selected sincethey represent the trend and pattern of material selection. The method used to quantify their embodied carbon is a gate-to-gate LCA as per the ISO standard. This gate to gate boundary was used because data availability and accuracy decreases when the system boundary expands, and significant resources like time are limited. Production input and output data was gathered from the respective manufacturers of the materials. Following that, the gathered data was calculated per the functional unit of $1m^3$. The collected data was inserted in the software OpenLCA and the embodied carbon was calculated. The results of both materials was greatly influenced by the type of energy used as well as the ratio and types of chemicals used. The energy source being hydroelectric power made a significant drop in the final result for both materials. However it is still significant as it has impact on the environment and minimised use is recommended.

In general, the embodied carbon result for the MDF product was 285.954 $kgCO2eq/m^3$ and for the plywood product was 128.31 $kgCO2eq/m^3$. The embodied carbon of plywood is significantly lower that MDF, making it more environmentally sustainable. The energy intensive production process of MDF and the chemicals used to bind the fibers were the major contributors to the final value. In conclusion, locally produced plywood has less embodied carbon than locally produced MDF. In addition, these results compared to imported materials' embodied carbon was 1/3 lower highlighting that locally produced MDF and plywood have less negative impact on the environment.

5.2. Recommendation

Based on the findings of the study, it is clear that the plywood product has lower embodied carbon than the MDF. Consequently, the following recommendations are provided.

- ✓ In cases where the two materials can be used alternatively for interior applications like partition wall, doors, windows, ceiling, furniture, and decorative elements; plywood should be selected over MDF. While MDF presents advantages like cost and ease of customization, the negative environmental impact associated with its production makes it the unfavorable one.
- ✓ Awareness regarding this finding should be created among architects and interior designers in Addis Ababa so that their material selection for design and construction will be environmentally responsible.
- ✓ More efficient production processes lead to less use of energy, therefore it is recommended that policy makers in the manufacturing industry set a clear standard for manufacturing plants.
- ✓ Locally manufactured materials should be promoted in the interior design industry as imported materials showed higher negative environmental impact.
- ✓ Further research should be encouraged to create knowledge base for material selection that prioritizes environmental sustainability.
- ✓ Further study should be conducted with wider system boundary and scope to have an all-round knowledge based understanding of the matter.

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APPENDIX

Appendix 1: Plywood manufacturing process data collection table

plywood manufacturing input and output data				
Production stage	**Input/output**	**Unit**	**Quantity**	**Remark**
Raw Material Input	Wood (type)			
Adhesive Input	Adhesive type 1			
	Adhesive type 2 (if any)			
Overall	Electricity			
Overall	Emission type 1			
	Emission type 2 (If any)			
	Emission type 3 (If any)			
	Emission type 4 (If any)			

Appendix 2: MDF manufacturing process data collection table

MDF manufacturing input and output data				
Production stage	**Input/output**	**Unit**	**Quantity**	**Remark**
Raw Material Input	Wood (type)			
	Bark and other wood waste (If any)			
	Chip Wood (If any)			
Adhesive Input	Adhesive type 1			
	Adhesive type 2 (if any)			
Wax application	Wax (type)			
Overall	Electricity			
Overall	Emission type 1			
	Emission type 2 (If any)			
	Emission type 3 (If any)			
	Emission type 4 (If any)			

Appendix 3: Preliminary material selection trend study data summary

Material	Product Manufacturer	Market position	Address	Remark
MDF	TY Wood Manufacturing	First mostly used	Eastern Industrial Zone, Dukem, Oromia Regiom	Excluded from study due to lack of permission for data collection
	ET Wood Manufacturing	Second mostly used	Kombolcha, South Wollo, Amhara Region	Selected as a sample for MDF
Plywood	Maereg Manufacturing and Trading	First mostly used	Burayu, Sheger City, Oromia Region	Selected as a sample for plywood
	DMA Wood Manufacturing	Second mostly used	Assela, Oromia Region	Excluded from sample pool based on sampling criteria

Appendix 4: Photos of parts of the plywood manufacturing process


1.4.6
MF9011

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10th Of Ramadan City
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Urea Formaldehyde Resin
Spreacol
Glue Powdwe.
MADE IN EGYPT
Wt.25 kg
IRRITANT


Appendix 5: Photos of the MDF manufacturing plant at Kombolcha