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Life Cycle Assessment of Widely Used Refrigerator In Bangladesh

A THESIS SUBMITTED TO THE ACADEMIC FACULTY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

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CERTIFICATE OF RESEARCH

The thesis titled "**Life Cycle Assessment of Widely Used Refrigerator in Bangladesh**" submitted By Md. Imrul Quaeas (200032105) and Salem Mahmud (200032104) has been accepted as satisfactory inPartial fulfillment of the requirement for the Degree of Bachelor of Science in Technical Education in Mechanical Engineering.

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DECLARATION

We hereby declare that this thesis titled “Life **Cycle Assessment of Widely Used Refrigerator in Bangladesh**” is an authentic report of our study carried out as requirement for the award of degree B.Sc.TE in Mechanical Engineering at Islamic University of Technology (IUT), Gazipur, Dhaka, under the supervision of Dr. A. R. M. Harunur Rashid, Professor of MPE Department, IUT during January 2022 to March 2023.

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of anydegree.

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ABSTRACT

Refrigerators used in daily life are one of the indispensable tools. Uninterrupted power should be supplied to the refrigerators in order to maintain cooling service. Domestic refrigerator may be operating continuously to maintain proper food storage condition. The continuous operation of this equipment accounts more electrical consumption. A significant amount of waste heat is rejected by the condensers of refrigerator. The main objective of the present paper is to provide ideas about the environmental impacts of using refrigerators by life cycle assessment (LCA)

The life cycle assessment (LCA) of a refrigerator evaluates its environmental impact from raw material extraction to disposal/recycling. It considers raw material extraction, manufacturing processes, energy consumption, emissions, waste generation, and transportation. The use phase includes energy efficiency, refrigerant leakage, and related emissions. Disposal options like recycling, landfilling, or incineration are also assessed. The LCA provides a comprehensive understanding of the refrigerator's environmental performance and highlights areas for improvement. It guides manufacturers, policymakers, and consumers in making informed decisions to minimize the environmental impact.

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CHAPTER 1: INTRODUCTION

As a common modern industrial product, a refrigerator is an essential part of daily human life. Because Bangladesh is a globally important refrigerator producer and consumer, the refrigerator industry has been an important contributor to Bangladesh's economy, especially after Bangladesh's accession to the World Trade Organization (WTO) in 1995. Despite the global economic crisis, Bangladesh exported refrigerators worth $36.31million in 2017(Refrigerator Export Data of Bangladesh, 2018). However, the refrigerator industry has a negative impact on the environment, just as other electronic industries do. Typically, the photostatting process discharges wastewater with phosphorus, which can eutrophic ate local surface waters (Errol and Thoming, 2005; Zhang, 2010). The foaming process emits cyclopentane gas at a rate of 0.03 kg/h, which is harmful to human health (Liu, 2011). A running refrigerator consumes electricity, which can indirectly cause greenhouse gas emissions (Yuki et al., 2013). At the end of a refrigerator's life, the heavy metals contained in its components can pollute the air, soil, and water if the refrigerator is arbitrarily discarded or land filled directly as garbage (Liu and Chi, 2013).

To mitigate the negative environmental impact of refrigerators, most countries have environmental protection practices in place. For example, China has enacted a series of policies and regulations to replace the environmentally harmful components of refrigerators with environmentally friendly ones (Nan, 1995;International Organization for Standardization, 2006; Lu, 2006;The Central People's Government of People's Republic of China,2009). In recent years, to control serious pollution due to electronic waste, the European Union has passed and implemented the Waste Electrical and Electronic Equipment (WEEE) Directive and the Restriction on the Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment (Koh et al., 2012). These documents have undoubtedly become new technical barriers to the international trade of Bangladeshi refrigerators, which requires that a life-cycle inventory of Bangladesh's refrigerators be completed (Zhou and Gao, 2007).

Previous researchers have compared the environmental impacts of the materials used in refrigerators, including the energy consumption and greenhouse gas emissions of refrigerators with two different framers, HFC-245fa (pentafluoropropane) and pentane (Johnson, 2004), conducted a life-cycle inventory analysis of the production of HFC-134a from mine to refrigerator (McCullough and Lind-ley, 2003), studied the life-cycle climate performance (LCCP) of different refrigerating fluids based on measured data (Yunho et al., 2007), and measured the greenhouse gas emissions of refrigerants in their usage and disposal stages.(Campbell and McCullough, 1998). These studies consider the environmental impact of two or more types of materials used in refrigerators in isolation. Aging refrigerator components also waste energy, sometimes causing the refrigerator to consume 40e60% more energy than the labeled value; this consumption can be partially reduced by simply repairing old refrigerators (Meier, 1995; Akbari et al., 1997). Some studies use the idea of life-cycle assessment (LCA) to calculate the optimum service life of a refrigerator (Horie, 2004; Kim et al.,2006). The concept of LCA also is also used to design more environmentally friendly refrigerators (Gehin et al., 2009; Vendrusculo et al., 2009). These designs include extended product lifetimes and lower energy consumption. In recent years, the disposal and recycling of refrigerators has drawn increasing amounts of attention (Laner and Rechberger, 2007; Altekin et al., 2008). However, most of the published articles emphasize the development of disassembly technologies for recovering materials from waste refrigerators rather than the refrigerators' environmental impact (Lambert and Stoop, 2001; Nicol and Thompson, 2007). A refrigerator's life-cycle environmental impact was evaluated, and the secondary life cycle inventory (LCI) databases greatly increase the uncertainties of these studies (Zhang, 2010).

The growing demand for refrigerator devices and the equally growing concern about the environmental effects due to their use is pushing the industry, the scientific community and governments to identify efficient and sustainable solutions. So the outcome of this study will help to understand the life-cycle environmental impacts of Bangladeshi refrigerators and create a scientific basis for decision-makers to achieve environmental sustainability.

1.1 BACKGROUND OF THE STUDY

Refrigerators are widely used in Bangladesh due to the hot and humid climate. This life cycle assessment of widely used household and commercial refrigerators in Bangladesh will show the environmental impact and also identify areas where improvements can be made to reduce the environmental impact of refrigerators.

Refrigerators are indispensable appliances in modern households, providing a means to preserve food and maintain a comfortable living environment. However, their production, use, and disposal stages have significant environmental implications, such as greenhouse gas emissions, energy consumption, and resource depletion. The LCA methodology provides a systematic approach to assess the environmental impacts associated with a product throughout its entire life cycle, encompassing raw material extraction, manufacturing, distribution, use, and end-of-life disposal.

it is essential to provide a background that includes the following elements:

1. Refrigerator Usage in Bangladesh:

Describe the importance and prevalence of refrigerators in Bangladesh. Discuss the role of refrigerators in households, commercial establishments, and industrial sectors. Highlight the growing demand for refrigeration due to population growth, urbanization, and changing lifestyles.

2. Environmental Concerns:

Explain the environmental concerns associated with refrigerators. These may include energy consumption, greenhouse gas emissions, ozone depletion potential, and the use of refrigerants with high global warming potential. Emphasize the significance of addressing these concerns in the context of sustainable development and climate change mitigation.

3. Regulatory Framework:

Discuss the regulatory framework and policies related to refrigerators in Bangladesh. Highlight any specific regulations, standards, or labeling programs that aim to improve energy efficiency, reduce environmental impacts, or promote the use of environmentally friendly refrigerants. Explain how these regulations affect the market.

4. Previous Research and Gaps:

Provide an overview of existing studies or research related to LCA of refrigerators, both globally and within Bangladesh if available. Identify any research gaps or limitations in the current understanding of the environmental impacts of refrigerators in the context of Bangladesh. Explain how your thesis aims to address these gaps and contribute to the existing knowledge.

5. Objectives and Methodology:

Clearly state the objectives of your thesis, such as assessing the environmental impacts ofwidely used refrigerators in Bangladesh, identifying hotspots in their life cycle, or comparing different models or technologies. Describe the methodology you will employ, including data collection, system boundaries, impact assessment methods, and any specific tools or software used for the LCA analysis.

6. Significance and Potential Implications:

Highlight the significance of your research in terms of environmental sustainability, policy-making, and consumer awareness. Discuss the potential implications of your findings, such as informing sustainable product design, supporting energy efficiency initiatives, or guiding consumers towards more environmentally friendly choices.

In this study we will try to analyze in the production, use, and disposal phases of a refrigerator in Bangladesh. Here we will focus just impact of refrigerators on climate change, human health, and ecosystems.

1.2 PROBLEM STATEMENT

Refrigerators play a crucial role in maintaining food safety and preserving perishable items, making them an essential household appliance in Bangladesh. However, the widespread use of refrigerators also raises concerns about their environmental impact throughout their life cycle. It is imperative to evaluate the environmental performance of refrigerators in order to identify opportunities for improvement and implement sustainable practices.

The specific problem formulation of this thesis are :

I. Data availability
II. Lack of standardization and Regulatory environment
III. Economic impact of the alternative refrigerants
IV. Selection of Refrigerants
V. Limited knowledge and scope on Bangladesh’s context
VI. Technical difficulties of OpenLCA Software knowledge

1.3 OBJECTIVES OF THE STUDY

The specific objectives of the Life Cycle Assessment (LCA) of widely used refrigerators in Bangladesh for the thesis are as follows:

Data Collection: Gather comprehensive data on the life cycle stages of widely used refrigerators in Bangladesh, including raw material extraction, manufacturing processes, transportation, use, and end-of-life treatment options.

Environmental Impact Assessment: Quantify and evaluate the environmental impacts associated with each life cycle stage of refrigerators in Bangladesh, focusing on key impact categories such as greenhouse gas emissions, energy consumption, water usage, waste generation, and resource depletion.

Hotspot Identification: Identify the hotspots or stages in the life cycle of refrigerators that contribute significantly to their overall environmental impact in the context of Bangladesh. This analysis will help prioritize improvement efforts and target interventions where they can have the most significant positive effect.

Comparative Analysis: Compare the environmental performance of different types or models of refrigerators available in the market in Bangladesh. This analysis will assess the variation in environmental impacts among different products and inform consumers and manufacturers about more sustainable options.

Improvement Strategies: Evaluate and recommend strategies for reducing the environmental footprint of refrigerators throughout their life cycle. This may include optimizing manufacturing processes, improving energy efficiency during use, promoting recycling and responsible disposal practices, and exploring alternative refrigeration technologies with lower environmental impacts.

Policy Recommendations: Provide recommendations for policymakers in Bangladesh to develop and implement effective regulations, standards, and incentives that promote the adoption of environmentally friendly refrigeration technologies and practices. These recommendations should be based on the findings of the LCA and consider the unique sociolect-economic context of Bangladesh.

Awareness and Education: Raise awareness among consumers, manufacturers, and policymakers about the environmental implications of refrigerator use and advocate for sustainable decision-making in the selection, use, and disposal of refrigerators. This objective aims to promote behavioral changes and support the transition towards more sustainable refrigeration practices in Bangladesh.

Finally Understanding the environmental impacts using refrigerator and identifying opportunities for improvement Supporting sustainable product design.

By addressing these objectives, this thesis will contribute to the knowledge base on sustainable consumption and production practices in Bangladesh and provide valuable insights for policymakers, manufacturers, and consumers to make informed decisions regarding refrigeration technology and its environmental consequences.

1.4 SCOPE AND LIMITATION

Scope:

Geographic Scope: The life cycle assessment (LCA) will focus on widely used refrigerators in Bangladesh. The study will consider the entire life cycle of the refrigerators, including manufacturing, use, and end-of-life stages.

Functional Unit: The LCA will use a defined functional unit to compare the environmental performance of different refrigerators. This could be based on the cooling capacity, energy consumption, or any other relevant parameter.

Inventory Analysis: The LCA will include a comprehensive inventory analysis, considering all the materials, energy, and emissions associated with the refrigerators throughout their life cycle. This will involve data collection on raw material extraction, manufacturing processes, transportation, use phase energy consumption, and waste management.

Impact Assessment: The study will assess the environmental impacts associated with the refrigerators using appropriate impact assessment methods. This may include evaluating categories such as greenhouse gas emissions, resource depletion, ozone depletion, acidification, and eutrophication.

Comparative Analysis: The LCA will compare the environmental performance of different types of refrigerators commonly used in Bangladesh. This may involve comparing refrigerators based on their energy efficiency, refrigerants used, insulation materials, and manufacturing processes.

Limitations:

Data Availability: The availability of comprehensive and reliable data may be a limitation, especially for specific environmental indicators or for certain stages of the life cycle. The study will need to rely on available data sources and make assumptions where necessary.

System Boundaries: The LCA will need to define clear system boundaries, considering which processes and impacts are included and excluded. Boundaries need to be carefully justified, and potential limitations arising from excluding certain stages or impacts should be acknowledged.

Uncertainty: LCA studies involve inherent uncertainties due to data gaps, assumptions, and modeling choices. The study should conduct sensitivity analyses to assess the robustness of the results and acknowledge the potential limitations arising from uncertainty.

Simplifying Assumptions: LCA studies often require simplifications and assumptions to make complex systems more manageable. These assumptions may impact the accuracy and representativeness of the results, and their limitations should be recognized.

Technological Advances: The LCA results may be influenced by changes in technology, regulations, and market dynamics. The study should acknowledge that the environmental performance of refrigerators may evolve over time due to improvements in energy efficiency, use of alternative refrigerants, or changes in manufacturing processes.

Social and Economic Factors: While the LCA primarily focuses on environmental impacts, social and economic factors play a role in the life cycle of refrigerators. The study may not fully capture the social and economic implications of different refrigerator types and their life cycles.

CHAPTER 2: LITERATURE REVIEW

In this section extensive literature review has been discussed about opinion of different scholars,the refrigeration system,life cycle assessment and different refrigerating agents that are used in a refrigerator.

Several LCA studies have been conducted on refrigerators in different parts of the world. A study by Bovea et (2021) examined the environmental impact of refrigerators in Spain andfound that the use phase was responsible for over 90% of their total environmental impact.

Another study by Zhang (2020) assessed the environmental impact of refrigerators in China and found that the production phase was responsible for the majority of their environmental impact.

The environmental impact of refrigerator can be minimized by using sustainable and eco-friendly refrigerants, such as hydrocarbons, and by adopting a closed-loop system that reduces waste generation." Dr. Md. Rabiul Islam.

These are the base papers for our thesis

Author	Focused on	Source
Rufeng Xiao, You Zhang	A life-cycle assessment of household refrigerators in China	LCA of Refrigerator by Elsevier 2020, Feb 2020, pages 400-409
B K Mandal, A Sarkar, S Paul	Thermodynamic ,chemical and physical Property Analysis of refrigerants	Property Analysis of refrigerants by Elsevier 2020, Feb 2020, pages 400-409
Alessandro Cascini and Marco Bortolini	Life Cycle Assessment of a commercial refrigeration system under different use configurations	LCA for Refrigerator by Elsevier 2020, Feb 2020, pages 390-409
Prof. Jignesh and K Vaghelaa	Thermodynamic Cycle Analysis and Field of application	Property Analysis ofrefrigerants by Elsevier 2020, Feb 2020, pages 400-409
Atilla Gencer Devecioglua, Vedat Oruca	Life Cycle Assessment by buseing an Alternative Refrigerant	Comparative evaluation of alternatives refrigerants,Published by Elsevier Energy Procedia 109 (2019) 153 – 160

2.1 REFRIGERATION SYSTEM

A refrigeration system is a mechanical system designed to remove heat from a space orsubstance and maintain it at a lower temperature than its surroundings. It works by extracting heat from a low-temperature source and releasing it to a higher-temperature medium, usually the surrounding air or water.

Components of a typical refrigeration system include:

Compressor: The compressor is the heart of the refrigeration system. It compresses and raises the pressure of the refrigerant, which increases its temperature and makes it easier to transfer heat.

Condenser: The condenser is a heat exchanger where the high-pressure, high-temperature refrigerant transfers heat to the surrounding medium (air or water). As the refrigerant cools down, it condenses into a liquid form.

Expansion valve: The expansion valve is a throttling device that reduces the pressure and temperature of the refrigerant as it flows from the high-pressure side (condenser) to the low-pressure side (evaporator). This pressure drop allows the refrigerant to expand and evaporate.

Evaporator: The evaporator is another heat exchanger where the low-pressure, low- temperature liquid refrigerant absorbs heat from the space or substance being cooled. This heat absorption causes the refrigerant to evaporate into a gas or vapor.

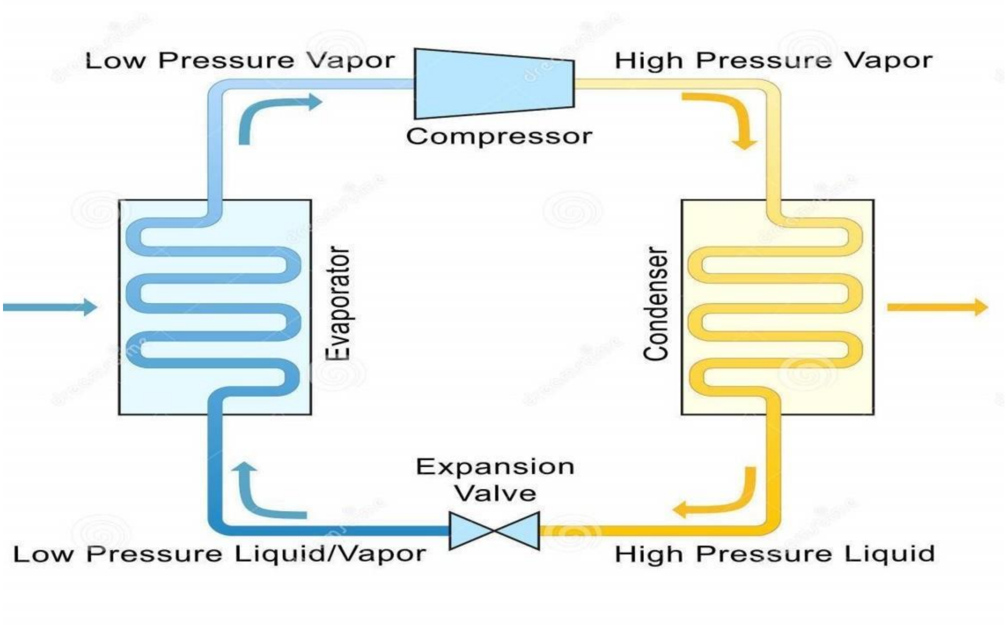

Figure 1 : Refrigeration system

Refrigerant: The refrigerant is a fluid with specific thermodynamic properties that enable it to absorb and release heat efficiently. Common refrigerants used in refrigeration systems include hydrofluorocarbon (HFCs), hydrochlorofluorocarbon (HCFCs), and natural refrigerants like ammonia (NH3) and carbon dioxide (CO2).

Expansion tank: In some refrigeration systems, an expansion tank is used to accommodate the change in volume of the refrigerant as it transitions between the liquid and gas phases.

Refrigeration controls: These include various sensors, switches, and valves that monitor and regulate the operation of the refrigeration system. They ensure proper temperature and pressure control, as well as safety features like overload protection and system diagnostics.

2.2 REFRIGERATING AGENTS

Refrigerating agents, also known as refrigerants, are substances used in refrigeration and air conditioning systems to transfer heat from one location to another. They undergo a phase change from a low-pressure gas to a high-pressure liquid state and back, absorbing and releasing heat in the process. Refrigerants play a crucial role in maintaining low temperatures inside refrigeration systems.

Historically, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbon (HCFCs) were commonly used as refrigerants due to their desirable properties. However, these substances have been found to contribute to ozone depletion and have significant global warming potential.As a result, international agreements such as the Montreal Protocol have been established to phase out the production and use of these harmful substances.

It's important to choice of the refrigerant depends on the specific application, system requirements, and environmental regulations in place. The transition towards more sustainable and environmentally friendly refrigerants is an ongoing process.

There are several types of refrigerants used in various cooling systems. Here are some of the basic types of refrigerants.

Halo-Carbon or Organic Refrigerants		
Refrigerant Number	**Chemical Formula**	**Chemical Name**
R-11	CCl_3F	Trichloromonofluoromethane
R-12	CCl_2F_2	Dichlorodifluoromethane
R-13	$CClF_3$	Monochlorotrifluoromethane
R-14	CF_4	Carbontetrafluoride
R-21	$CHCl_2F$	Dichloromonofluoromethane
R-22	$CHClF_2$	Monochlorodifluoromethane
R-30	CH_2Cl_2	Dichloromethane(methylenechloride)
R-40	CH_3Cl	Chloromethane (methylchloride)
R-113	$C_2Cl_3F_2$	Trichlorotrifluoroethane
R-114	$C_2Cl_2F_4$	Dichlorotetrafluoromethane
R-115	C_2ClF_5	Monochloropentafluoroethane

R-123	CF_3CHCl_2	Dichlorotrifluoroethane
R-124	CF_3CHClF	Monochlorotetrafluoroethane
R-134 a	CF_3CH_2F	Tetrafluoroethane
R-152 a	CH_3CHF_2	Difluoroethane
Inorganic Refrigerants		
Refrigerant Number	**Chemical Formula**	**Chemical Name**
R-717	NH_3	Ammonia
R-718	H_2O	Water
R-729	-----	Air
R-744	CO_2	Carbon dioxide
R-764	SO_2	Sulfur dioxide
Azeotrope Refrigerants		
Refrigerant Number	**Chemical Formula**	**Chemical Name**
R-500	R-12/152a (73.8/26.2)	-
R-502	R-22/115 (48.8/51.2)	-
R-503	R-23/13 (40.1/59.9)	-
R-504	R-32/115 (48.2/51.8)	-
Hydro-Carbon Refrigerants		
Refrigerant Number	**Chemical Formula**	**Chemical Name**
R-170	C_2H_6	Ethane
R-290	C_3H_8	Propane
R-600	C_4H_{10}	Butane
R-600a	C_4H_{10}	Isobutene
R-1120	$C_2H_4Cl_3$	Trichloroethylene
R-1130	$C_2H_4Cl_2$	Dichloroethylene
R-1140	C_2H_4	Ethylene
R-1270	C_3H_6	Propylene

Table 1: Refrigerants

2.3 LIFE CYCLE ASSESMENT(LCA)

The LCA system typically refers to Life Cycle Assessment, which is a methodology used to evaluate the environmental impacts of a product or process throughout its entire life cycle, from the extraction of raw materials to disposal.Topics and steps of the LCA methodology are regulated by the ISO 14040-14044.

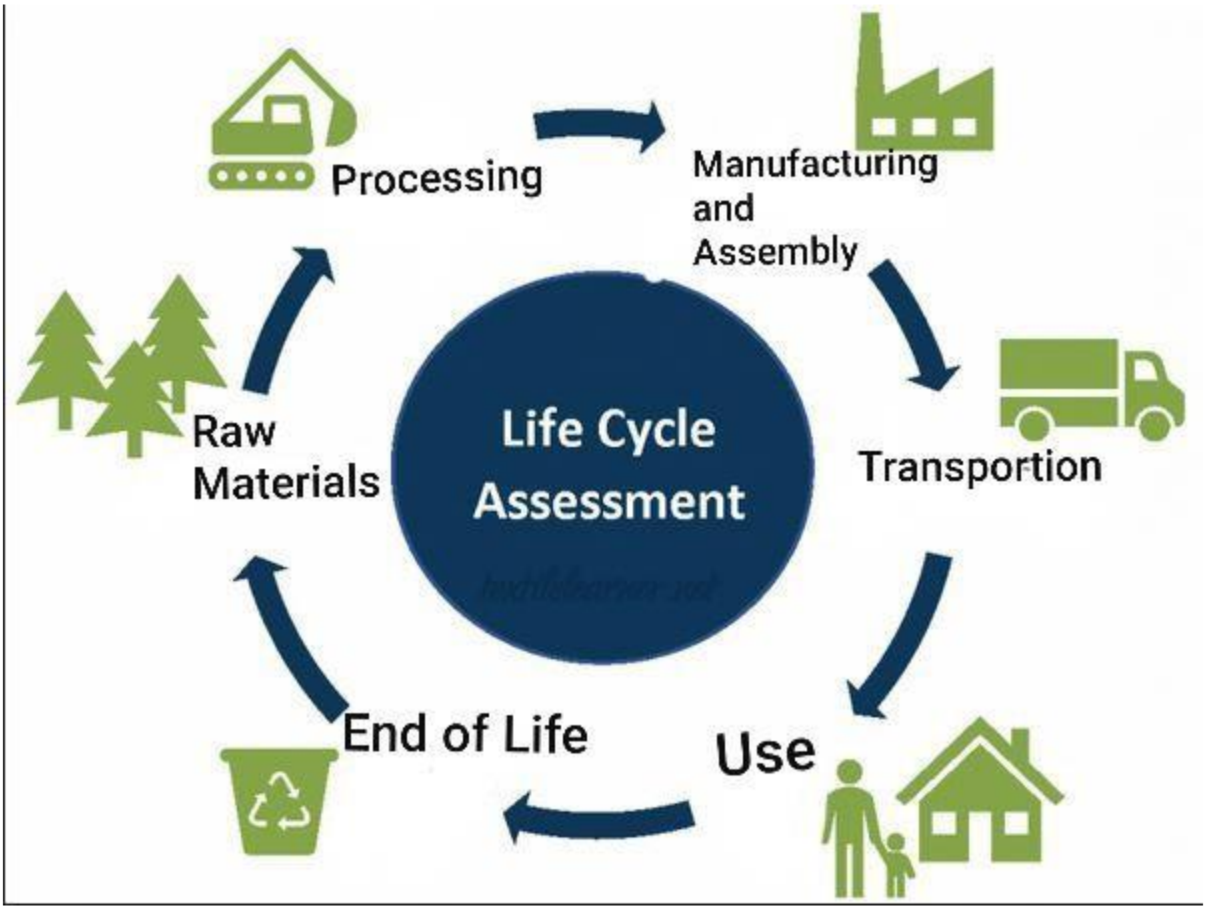

Figure 2 : Life Cycle Assessment Process

The LCA system involves several stages, including defining the goal and scope of the assessment, conducting an inventory of the inputs and outputs associated with the product or process, evaluating the environmental impacts of these inputs and outputs, and interpreting the results of the assessment.The results of an LCA can be used to identify opportunities for improving the environmental performance of a product or process, to compare the environmental impacts of different products or processes, and to inform policy and decision-making.

The LCA system is widely used in industry, government, and academia to support sustainable development and environmental management.
The purpose of LCA is to assess the potential environmental burdens and benefits of a product or system and identify opportunities for improvement. It provides a holistic view of the environmental impacts, including resource use, energy consumption, and emissions to air,water, and soil, as well as waste generation
In this study OpenLCA software is used as support.

Chapter 3: Methodology

We used OpenLCA software for our data analysis and calculate the environmental impact indicators, such as carbon footprint,energy consumption,water use,and waste generation.First-hand data from representative Bangladeshi refrigerator manufacturing company (Walton,LG, Samsung,and Sharp) are collected as the input variable for OpenLCA software.Then the secondary data(ODP & GWP) sources literature review,databases,surveys and statistical books of Refrigerator Export Data of Bangladesh-2019 were used.

We selected the direct-cooling single-door refrigerator as our research object because the single-door refrigerator is the most popular type and accounts for nearly half of market sharein Bangladesh, in which the direct-cooling refrigerator occupied 90.3% market share (Internet Consumer Research Center 2019). The reasons for the popularity of this type of refrigerator are probablythe following:

I. A Bangladeshi family most often consists of four people and a refrigerator with a volume of approximately 220 L is appropriate to meet such a family's daily needs

II. Bangladeshi people prefer to use single-door refrigerators weighing approximately 50-70 kg;

III. Bangladeshi people prefer energy-saving refrigerators with reasonable prices

3.1 Flowchart of the process

A flowchart is a graphical representation of a process or system, illustrating the sequence of steps or activities involved. It uses various symbols and arrows to depict the flow of information, materials, or actions within the process. An LCA involves the analysis of the environmental impacts of a product throughout its entire life cycle, from the extraction of raw materials to its disposal or recycling.Here's a flowchart of the refrigerator life cycle.

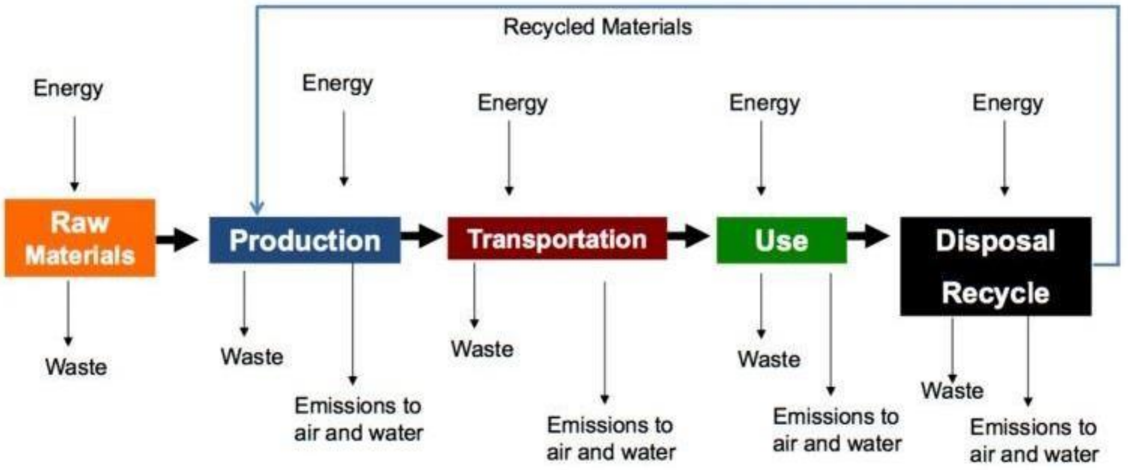

Figure 3: Flowchart of the process

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Typically, an LCA flowchart would include the following stages:

1. Raw material extraction and processing
2. Manufacturing and assembly
3. Transportation and distribution
4. Use phase (including energy consumption and refrigerant leakage)
5. End-of-life options (such as recycling or disposal)

Each stage would be broken down into specific processes and inputs/outputs, and the environmental impacts associated with each would be analyzed. This information would then be used to evaluate the overall environmental impact of the refrigerator and identify areas for improvement.

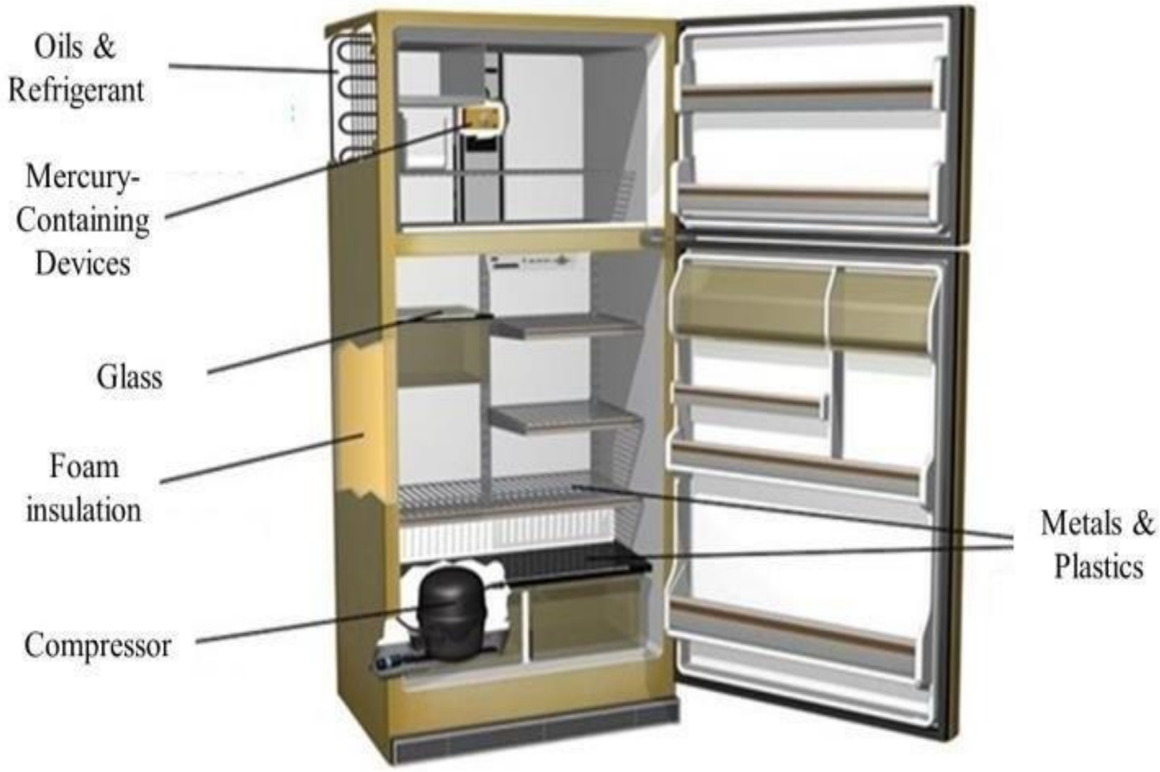


Figure 4: Materials used in a Refrigerator

Raw materials extraction and processing:

Identify the materials used to make the refrigerator (e.g. steel, plastic, copper, aluminum). Determine the environmental impacts associated with the extraction and processing of these materials (e.g. energy use, greenhouse gas emissions, water use).Identify the manufacturing processes used to create the refrigerator (e.g. molding, stamping, welding).
The raw materials used in the production of a refrigerator can vary depending on the specific model and manufacturer. However, some common materials that are typically used include:

1. **Steel:** Refrigerators are made primarily of steel, which is used for the outer casing, interior shelves, and other structural components.
2. **Aluminum**: Aluminum is used for the door handles and other smaller components.
3. **Plastic**: Plastic is used for various components such as the interior liners, door bins, and some exterior parts.
4. **Copper:** Copper is used in the compressor and other electrical components.
5. **Glass**: Glass is used for the shelves and sometimes for the door panels.
6. **Insulation**: The insulation material used in refrigerators can vary, but commonly used materials include foam, fiberglass, and cellulose

During the production stage, a refrigerator undergoes several processes to be manufactured and assembled. Here is an overview of the typical steps involved in the production of a refrigerator:

Design and Planning: The manufacturer designs the refrigerator, considering factors such as capacity, features, energy efficiency, and aesthetics. Engineers create detailed drawings and specifications for the production process.

Component Manufacturing: Various components of the refrigerator, such as

- ✓ compressor,
- ✓ condenser,
- ✓ evaporator,
- ✓ shelves,
- ✓ drawers, and
- ✓ outer casing,
- ✓ Freezer Compartment
- ✓ Meat Compartment
- ✓ Storages

- ✓ Thermostat Control
- ✓ Shelf
- ✓ Crisper
- ✓ Doors
- ✓ Magnetic Gasket

are manufactured separately. This may involve processes like metal forming, injection molding for plastic parts, glass production for shelves or doors, and electronic component assembly.

Assembly Line: The refrigerator assembly begins on a production line. Workers or robotic systems start with the outer casing and gradually add components, following a predetermined sequence. The process may involve attaching the compressor and condenser, installing the evaporator, fitting the shelves and drawers, and connecting electrical and control systems.

Insulation and Sealing: Refrigerators require proper insulation to maintain temperature efficiency. Insulating foam is injected between the inner and outer walls of the refrigerator to prevent heat exchange with the surroundings. The doors and other openings are sealed tightly to prevent air leakage.

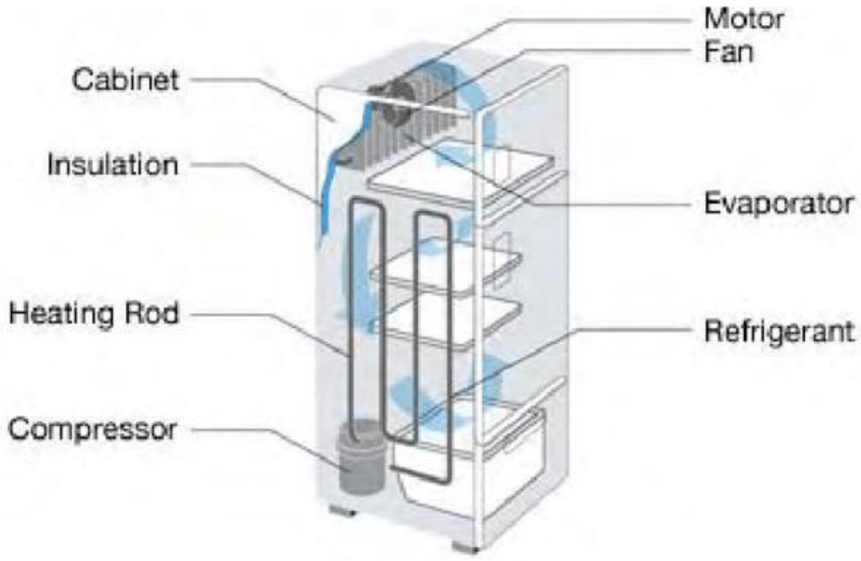


Figure 5: Parts of a Refrigerator

Testing and Quality Control: Once the refrigerator is assembled, it undergoes rigorous testing to ensure it functions correctly and meets quality standards. Tests may include checking temperature consistency, energy efficiency, noise levels, and proper functioning of features like defrosting, ice-making, and temperature control.

Finishing Touches: After passing quality control, the refrigerator goes through finishing processes. This may include cleaning, applying protective coatings, attaching logos or labels, and packaging preparations.

Packaging and Distribution: The refrigerators are packed in protective materials and boxes for shipping. They are labeled, palletized, and prepared for distribution to retailers or warehouses. Logistics and transportation play a crucial role in delivering the refrigerators to the market.

Transportation and distribution:

Determine the distance the refrigerator travels from the manufacturing plant to the end user. Identify the mode of transportation (e.g. truck, ship, plane) and the associated environmental impacts (e.g. fuel use, emissions).The transportation and distribution stage in a life cycle assessment (LCA) of a refrigerator involves assessing the environmental impact associated with the transportation of the refrigerator from the manufacturing facility to the end-user, as well as the distribution process throughout its lifetime. Here are some key considerations for this stage:

Distance and Mode of Transportation: The LCA evaluates the distance the refrigeratortravels and the mode of transportation used, such as road, rail, sea, or air. Different modes of transportation have varying energy consumption and emissions profiles.

Packaging: The packaging materials used for transportation and distribution are also evaluated. This includes assessing the environmental impact of materials such as cardboard, plastics, and foam, as well as their recyclability or potential for reuse.

Energy Consumption: The energy consumed during transportation is an important factor. This includes the fuel consumption of vehicles or vessels used for transportation, as well as any auxiliary energy required for refrigeration during transit.

Emissions: The emissions associated with transportation, including greenhouse gas emissions (e.g., carbon dioxide, methane), nitrogen oxides (NOx), and particulate matter, are considered. Emission factors specific to the mode of transportation are typically utilized.

Logistics Optimization: Optimizing the distribution network and routes can help reduce the environmental impact. Efficient planning and coordination of deliveries can minimize distances traveled and decrease energy consumption.

Return Logistics: For refrigerator disposal or recycling, the transportation and logistics involved in the return of the product to a recycling or disposal facility are also considered.

Use phase:

Determine the expected lifetime of the refrigerator and the energy use associated with its operation.Calculate the environmental impacts associated with the energy use (e.g. greenhouse gas emissions, water use).
In the usage stage, the following types of data may be collected for a refrigerator:

Energy consumption: Refrigerators consume energy to operate, and data can be collected on the amount of energy used over a period of time. This data can help identify areas where energy efficiency can be improved.

Temperature data: Refrigerators are designed to maintain a specific temperature range to keep food fresh. Data can be collected on the temperature inside the refrigerator to ensure it is within the correct range.

Door openings: Each time the refrigerator door is opened, cold air escapes, and warm air enters. Data can be collected on the frequency of door openings to help identify opportunities toreduce energy consumption.

Maintenance data: Data can be collected on the frequency of maintenance tasks, such as cleaning the condenser coils or replacing the air filter. This data can help identify patterns and ensure the refrigerator is being properly maintained.

Food storage data: Data can be collected on the types of food stored in the refrigerator, how long they are stored, and how often they are accessed. This information can help identify ways to improve food storage practices and reduce waste.

User behavior data: Data can be collected on how users interact with the refrigerator, such as how often they open the door or adjust the temperature settings. This information can be used to design more user-friendly refrigerators in the future.

End-of-life:

In the context of a life cycle assessment (LCA) analysis for a refrigerator, the end-of-life stage typically refers to the disposal or recycling phase of the appliance. This stage involves activities such as the collection, transportation, and treatment of the refrigerator at the end of its useful life. The end-of-life stage is crucial in LCA because it considers the environmental impacts associated with the disposal or recycling process, including energy consumption, emissions, and waste generation. By analyzing this stage, manufacturers and policymakers can identify opportunities for improvement in terms of waste management and resource recovery.

During the end-of-life stage of a refrigerator, there are several possible scenarios for its disposal or recycling:

Landfill: Historically, refrigerators were often sent to landfill sites, which can contribute to environmental problems. Refrigerators contain substances that can be harmful if released into the environment, such as chlorofluorocarbons (CFCs) or hydrofluorocarbons (HFCs) found in the cooling systems. Proper disposal of these substances is crucial to prevent ozone depletion and greenhouse gas emissions.

Recycling: Recycling is a more environmentally friendly option than landfilling. Refrigerators can be dismantled, and the components, such as metals (steel, copper, aluminum), plastics, and glass, can be recovered and reused in the manufacturing of new products. Additionally, the refrigerants and foam insulation can be safely captured and treated to prevent their release into the atmosphere.

Energy recovery: Another option is to use the refrigerator as a source of energy through processes like incineration or waste-to-energy facilities. These methods involve combusting the appliance to generate heat or electricity. However, it's important to ensure that the combustion process is carried out in an environmentally responsible manner to minimize emissions.

It is actually noting but the specific end-of-life management practices for refrigerators can vary depending on regional regulations, infrastructure, and recycling capabilities. Some countries have implemented stringent regulations to ensure the proper disposal and recycling of refrigerators to minimize their environmental impact.

When conducting an LCA analysis, it is important to consider the end-of-life stage and evaluate the environmental impacts associated with different disposal or recycling scenarios. This analysis helps stakeholders identify opportunities for improvement, such as promoting recycling initiatives, optimizing waste management systems, or developing more sustainable end-of-life practices for refrigerators.

3.2 System Boundary

Based on the ISO 14040 standard and the research objective, we divided the life cycle of a refrigerator into a production stage (including raw material extraction, parts production and assembly),a transportation stage, a usage stage, and a disposal stage. The geographic boundaries of the refrigerator's transportation were within the territory of Bangladesh. The system's boundary is shown below

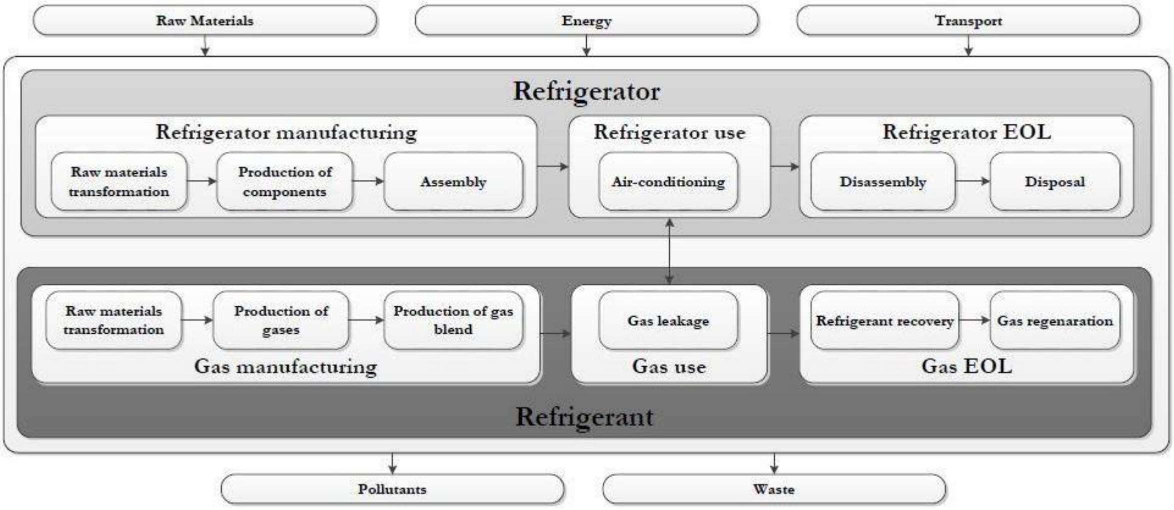


Figure 6: System Boundary

Here is a table outlining the raw material extraction to disposal stage that are involved in the production of a refrigerator, along with some additional information about the associated environmental impacts.

Step/Stage	Inputs	Outputs	Environmental impacts
Mining of metal ores	Iron ore, aluminum ore, copper ore	Mined metals	Habitat destruction, soil erosion, water pollution, greenhouse gas emissions
Extraction of fossil fuels	Coal, natural gas, petroleum	Fuel for energy-intensive processes	Air pollution, water pollution, greenhouse gas emissions
Extraction of refrigerants	Fluorocarbons, hydro chlorofluorocarbons	Refrigerant chemicals	Ozone depletion, greenhouse gas emissions
Manufacturing of components	Mined metals, fossil fuels, refrigerants	Refrigerator components (compressor, condenser, evaporator)	Energy use, waste generation, water pollution
Assembly of refrigerator	Refrigerator components, additional energy	Refrigerator	Energy use, waste generation, air pollution, water pollution
Transportation to Retailers	Refrigerators	Refrigerators	Greenhouse gas emissions
Use Phase	Electricity	Colling effects	Greenhousegas emissions,energy consumption, water
End-of-Life Management and Recycling	Steel, copper, aluminum, plastics	Refrigerators	Land use, energy consumption, waste generation, water pollution

Table 2: Raw material extraction to disposal stage and Environmental impacts

3.3 Functional unit

The functional unit was defined as “the complete life cycle of a 61 kg direct-cooling single door refrigerator made in Bangladesh, used for 10 years (24 h/day), and disposed of in Bangladesh through a state-of the- art recycling system.”

3.4 Data collection

First-hand data from representative Bangladeshi refrigerator manufacturing company (Walton, LG, Samsung, and Sharp) are collected for this study. Then literature review and statistical year books of Refrigerator Export Data of Bangladesh-2019 were used as secondary data sources to guarantee the consistency of our data set. Details of the data sources and a description of the data collections can be found in table. The data's quality was qualitatively evaluated with the assumption that primary data were of higher quality than secondary data.

CHAPTER 4: RESULT ANALYSIS AND DISCUSSION

The latest European directives related to the manufacture and use of refrigeration systems (i.e. European Regulation 842/2006; European Directive 40/2006), define a clear and undeniable strategy: the use of high GWP refrigerants should be gradually restricted and equipment manufacturers must adapt their products to the use of refrigerants with no environmental impact. The issuing of the European Directive 29/2009 (as known as “20/20/20 climate and energy package”) further accelerated the sustainability program: the European Legislative Proposal 2012/0305 define impending times of decommissioning of hydro fluoro carbon (HFC) gases with GWP greater than 150(2017-2020).

Furthermore, refrigerating systems, as well as all other energy related products, must provide high efficiency and low energy consumption in order to minimize indirect pollutant emissions (European Directive 125/2009). So,the new challenge is the identification of technological solutions that guarantee high performance, low energy consumption and the use of fluids with lower GWP index. Aprea et al. (2012) tested the effect of the substitution of R-134a with R-744 (CO2) in some refrigerating systems on the Total Equivalent Warming Impact (TEWI) value: the study demonstrates that the indirect contribution to global warming provided by R-744 is often greater than that of R-134a. Davies & Caretta (2003) do not focus on refrigerant substitution but concentrate on the identification of design techniques that improve the performance of direct expansion systems regardless of the gas used: they predict substantial savings ofenergy even in the case of adoption of conventional HFCs (R-404a).

Output from open of LCA

Category	Subcategory	Sheet metal		Phosphating		Spraying		Refrigerating system	
		Cabinet	Door	Cabinet	Door	Cabinet	Door	Compressor	Accessory
Energy	Electricity (kWh)	0.348	0.051	0	0	0.334	0.087	2.519	0
	Natural gas (m^3)	0	0	0	0	0.176	0.046	0.048	0
	Steam (kg)	0	0	6.176	1.601	0	0	0	0
	Compressed air (m^3)	0.784	0.115	0	0	0.752	0.195	0.048	0
Material(g)	Water (m^3)	0	0	0.005	0.001	0	0	0.033	0
	Steel	13,076.923	1923.076	0	0	0	0	14,926	2166.667
	Copper	0	0	0	0	0	0	1258	50
	Aluminum	0	0	0	0	0	0	1581	608.323
	Sodium silicate	0	0	3.529	0.915	0	0	0	0
	Sodium carbonate	0	0	2.646	0.686	0	0	0	0
	Sodium hydroxide	0	0	0.882	0.228	0	0	0	0
	Silane coupling agent	0	0	2.646	0.686	0	0	0	0
	Fluorozirconate	0	0	2.646	0.686	0	0	0	0
	Epoxy resin	0	0	0	0	88.229	22.881	0	0
	High impact polystyrene (HIPS)	0	0	0	0	0	0	0	0
	Isocyanate	0	0	0	0	0	0	0	0
	Cyclopentane	0	0	0	0	0	0	0	0
	Polyether polyol	0	0	0	0	0	0	0	0
	Pentafluoropropane (HFC-245fa)	0	0	0	0	0	0	0	0
	Polyvinyl chloride (PVC)	0	0	0	0	0	0	0	0
	Color master batch	0	0	0	0	0	0	0	0
	Rubber	0	0	0	0	0	0	0	0
	Magnetic powder	0	0	0	0	0	0	0	0
	Corrugated paper	0	0	0	0	0	0	0	0
	Expandable polystyrene (EPS)	0	0	0	0	0	0	0	0
	R600a (Isobutane)	0	0	0	0	0	0	0	0
Emissions to air (g)	Fly ash	0	0	0	0	0.086	0.022	2.094	0
	Sulfur dioxide	0	0	0	0	0.035	0.009	0	0
	Nitrogen dioxide	0	0	0	0	0.311	0.080	0.022	0
	Non-methane hydrocarbon (NMHC)	0	0	0	0	0.749	0.194	1.205	0
Emissions to water (g)	Chemical oxygen demand (COD)	0	0	2.751	0.713	0	0	5.528	0
	Suspended solid (SS)	0	0	1.334	0.345	0	0	2.211	0
	Oil waste	0	0	0.043	0.011	0	0	0.176	0
	Ammonia nitrogen	0	0	0.175	0.045	0	0	0.221	0
Solid waste (g)	Waste steel	145.299	21.367	0	0	0	0	7.407	0
	Waste epoxy resin	0	0	0	0	2.646	0.686	0	0
	Waste high impact polystyrene (HIPS)	0	0	0	0	0	0	0	0
	Waste polyurethane	0	0	0	0	0	0	0	0

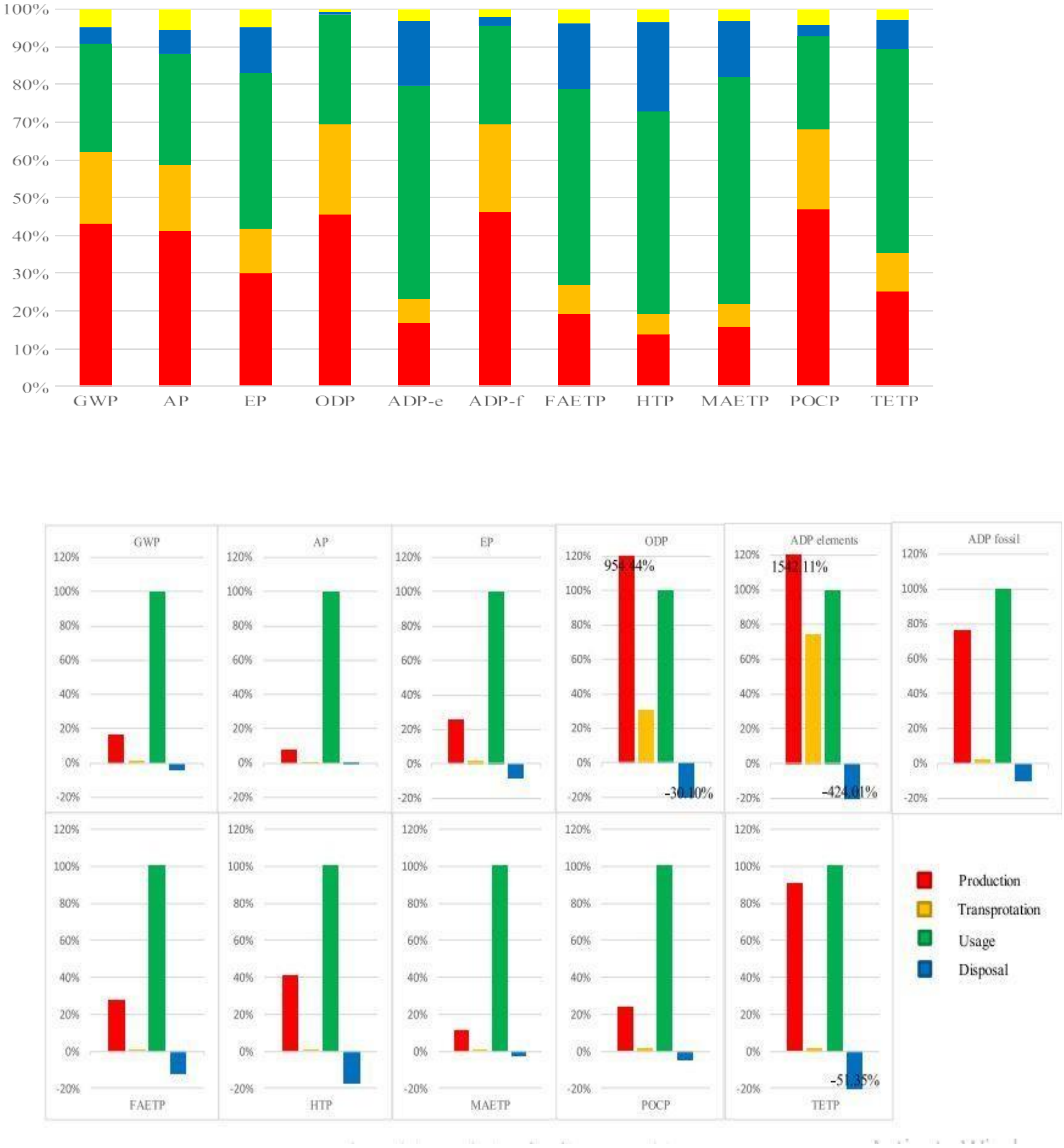


Figure 7: Relative contributions of a refrigerator to each impact category

4.1 Climate change

ODP And *GWP*

Ozone Depletion Potential (*ODP*) of a chemical compound is the relative amount of degradation it can cause to the ozone layer.Global Warming Potential (*GWP*) is a measure of how much a given mass of a gas contributes to global warming. *GWP* is a relative scale which compares the amount of heat trapped by greenhouse gas to the amount of heat trapped in the same mass of Carbon Dioxide. The *GWP* of Carbon Dioxide is by definition *1*. Be aware that GWPs are highly controversial.

Refrigerant	Ozone Depletion Potential (*ODP*)	Global Warming Potential (*GWP*)
R-11 Trichlorofluoromethane	1.0	4000
R-12 Dichlorodifluoromethane	1.0	2400
R-13 B1 Bromotrifluoromethane	10	1200
R-22 Chlorodifluoromethane	0.05	1700
R-32 Difluoromethane	0	650
R-113 Trichlorotrifluoroethane	0.8	4800
R-114 Dichlorotetrafluoroethane	1.0	3.9
R-123 Dichlorotrifluoroethane	0.02	0.02
R-124 Chlorotetrafluoroethane	0.02	620
R-125 Pentafluoroethane	0	3400
R-134a Tetrafluoroethane	0	1300
R-143a Trifluoroethane	0	4300

Refrigerant	**Ozone Depletion Potential (*ODP*)**	**Global Warming Potential (*GWP*)**
R-152a Difluoroethane	0	120
R-245a Pentafluoropropane	0	1300
R-401A (53% R-22, 34% R-124)	0.037	1100
R-401B (61% R-22, 28% R-124, 11% R)	0 04	1200
R-402A (38% R-22, 60% R-125, 2% R-290)	0.02	2600
R-404A (44% R-125, 52% R-143a)	0	3300
R-407A (20% R-32, 40% R-125)	0	2000
R-407C (23% R-32, 25% R-125, 52%)	0	1600
R-502 (48.8% R-22, 51.2% R-115)	0.283	120
R-507 (45% R-125, 55% R-143)	0	3300
R-717 Ammonia - NH_3	0	0
R-718 Water - H_20	0	
R-729 Air	0	
R-744 Carbon Dioxide - CO_2		1*

Table 3 : Refrigerant ,ODP and GWP

4.1.1 ATMOSPHERIC HAZARDS

The halogenated refrigerants are a family of chemical compounds derived from the hydrocarbons (methane and ethane) by substituting chlorine and fluorine atoms in the place of hydrogen.The emission of chlorine and fluorine atoms present in halogenated refrigerants is responsible for the major environmental impacts with serious implication for the future development of the refrigeration based industries. The discovery of the ozone-depleting properties of CFCs and HCFCs refrigerants, and of their global warming potential led to different protocol and amendments.

4.1.2 Effects on Ozone Layer

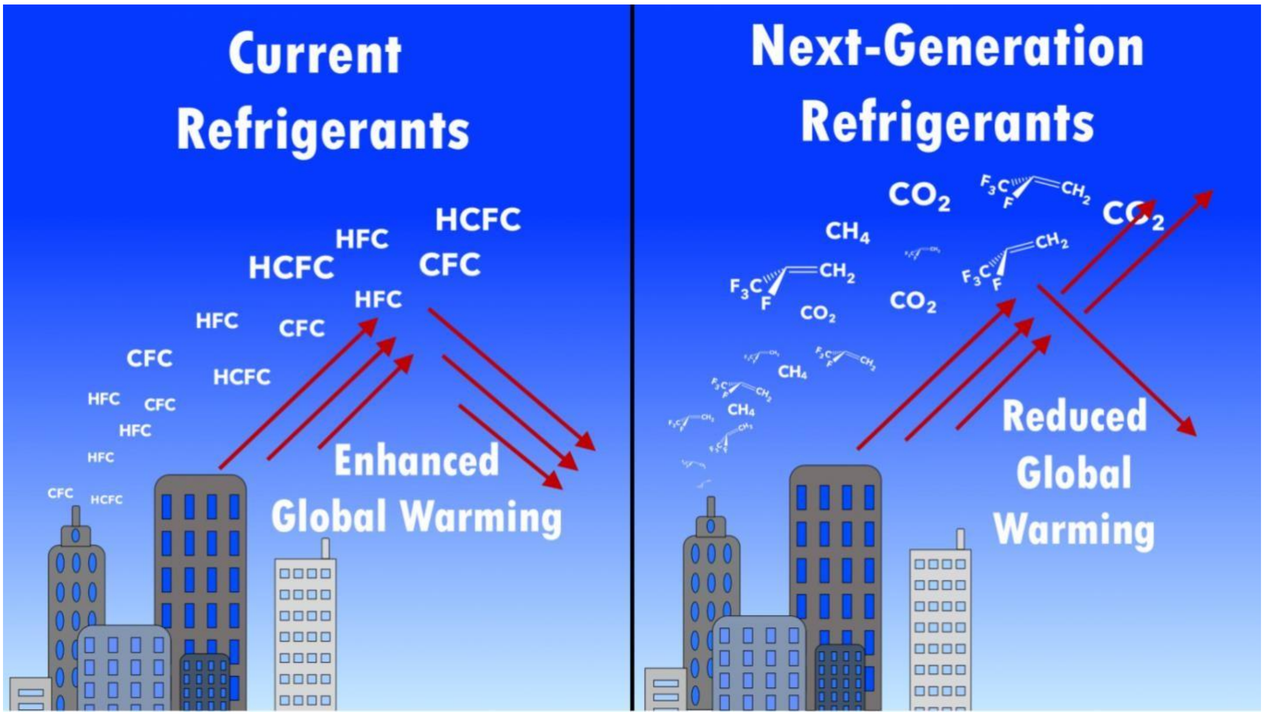
The first crucial environmental impact that struck the refrigeration based industries is ODP due to artificial chemicals into the atmosphere. The chlorine based refrigerants are stable enough to reach the stratosphere, where the chlorine atoms act as a catalyst to destroy the stratospheric ozone layer (which protects the earth surface from direct UV rays).Molina and Rowland [2] gave the detail effect of chlorine on the ozone layer. About 90% of the ozone exists in the stratosphere between 10 and 50 km above the earth surface.

4.1.3 Effect on global worming

The second major environmental impact is GWP, which is due to the absorption of infrared emissions from the earth, causing an increase in global earth surface temperature. While solar radiation at 5800 K and 1360 W/m2arrives the earth, more than 30% is reflected back into space and most of the remaining radiation passes through the atmosphere and reaches the ground. By radiating energy with a spectral peak in the infrared wavelength range this solar radiation heats up the earth approximately as a black body. This infrared radiation cannot pass through the atmosphere because of absorption by GHG including the halogenated refrigerants. As a result, temperature of atmosphere increases, which is called as the global warming. During the formulation of Kyoto protocol, countries around the world have voluntarily committed to reduce the GHG emissions. HFC refrigerants have relatively large values of atmospheric lifetime and GWP compared to chlorine based refrigerants.

5.1 RECOMMENDATION

The environmental impact of refrigerators can be reduced through the use of
1.Eco-friendly refrigerants
2.Energy-efficient models design
3.Proper maintenance and use
4.responsible disposal at the end of their life.
5.Using solar energy to power
6. Natural refrigerants such as hydrocarbons or CO2 can significantly reduce the Environmental impact



5.2 Conclusion

Refrigerants are the key substances used in all the conventional refrigeration and air conditioning systems. To ensure the safety of environment, use of CFCs are banned as per the guidelines by Montreal Protocol.In addition, Application developments of ammonia and carbon dioxide with the emphasis on economic efficiency improvement are likely to continue.So lastly can say the use of high GWP refrigerants should be gradually restricted and equipment manufacturers must adapt their products to the use of refrigerants with no environmental impact

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