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Comparative Life Cycle Assessment of Galvanized Steel Roofs and Aluminium Roofing Sheets in Lagos, Nigeria

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ABSTRACT

The quest for sustainable roofing materials to provide building occupants the best experience and preserve our ecosystem has been ongoing for decades. However, significant progress has been made as more innovations and research are carried out. Factors like availability of resources, climate and socio-economic concerns may influence choice of roofing material in specific locations. Considering these, a comparative life cycle assessment (LCA) of popular roofing materials in Lagos, an industrial Nigerian city with high annual precipitation was studied. A cradle-to-grave LCA from raw material extraction, production, distribution, use to disposal/recycling for galvanized steel roof and aluminium roof was done using Ansys Granta Edupack software, version 2023 R1. The results indicated that aluminium roofs are more durable although, the extraction, production and recycling processes of aluminium are presently less eco-friendly compared to galvanized steel. Recommendations were also made on how to make galvanized roofs more durable and how to make the production process of aluminium roofs more sustainable ecologically.

Keywords: *Life Cycle Assessment (LCA), Galvanized Steel Roofs, Aluminium Roofing Sheets, Environmental Sustainability, Roofing Materials, Cradle-to-Grave Analysis, Durability, Recycling, Carbon Footprint, Sustainable Building Practices.*

1.0 INTRODUCTION

Shielding from discomforting weather conditions like; rainfall, wind, cold and sunshine are not the only functions of roofs as they also provide aesthetic and beautify the entire building structure. Presently, there exist several roofing designs including Gambrel, Hipped, Gable, Butterfly, Dove, Flat, Mansard and so on. The type of roofing designs used in a location may depend on different factors ranging from cultural heritage, modernisation to sometimes economic concerns [1].

However, roofing materials will be the focus of this study. The use of roofing materials may vary in different places base on availability of raw materials and resources, climatic conditions, financial factors, cultural style, and more recently sustainable practices. This is why clay tiles and metals are used in hot climates as they resist heat and keep the building cold, while slates are used in cold climates as they can handle heavy snow and ice. Due to socio-cultural factors clay tiles are also used in Mediterranean countries and thatch roofs in Sub-Sahara Africa, while sustainability concerns have led to the use of green roofs and solar tiles in modern times [2].

As a result of climatic factors, metals like galvanized steel sheets, aluminium roofing sheets and stone-coated steel roofing materials are very common in a tropical city like Lagos. Although, over the years, industrial emissions have greatly influenced the weather conditions and have adverse effects on roofs in Lagos, a major industrial city in Nigeria and an economic hub in West Africa [3].

Thus, the need to assess the environmental sustainability of commonly used roofing materials in Lagos through LCA analysis will help provide data to practitioners and stakeholders for well informed decisions in near future.

The aim and objective of this work will be to assess the environmental sustainability of roofing materials used in Lagos, Nigeria by comparing the life cycle assessment of galvanized steel and aluminium roofing sheets using Granta Edupack.

The scope of this work is limited to comparative cradle-to-grave life cycle assessment from extraction, production, distribution, use to disposal/recycling of galvanized steel and aluminium alloy (AA3105, H14) using tables and charts from Ansys Granta Edupack software, version 2023 R1.

2.0 CRITERIA FOR SUSTAINABLE ROOFING MATERIALS IN LAGOS, NIGERIA

Some of the factors to be considered when checking how sustainable a roofing material are energy efficiency, recyclability, durability and overall environmental impact. Recyclability is simply if the material could be reused in the same or another form at the end of life while, energy efficiency covers the thermal properties and how the roofing material would behave towards heat gain in a hot day or towards heat loss in a cold day from the building. For a city like Lagos in southern Nigeria with high annual precipitation and industries, durability of roofs will primarily depend on the resistance of the roofing material to industrial emissions and toxic rainfall [3].

2.1 SELECTED ROOFING MATERIALS

2.1.1 Galvanized Steel Sheets

Galvanized steel sheets are one of the most common roofing materials in not just Lagos but, in the entire Nigeria, and most of West Africa. It is produced by coating steel with zinc layer and the principal raw material used in steel production is iron. That is why it is sometimes called corrugated iron sheets, and many houses in Nigeria and the West African region are roofed using this material. Although, it is gradually becoming an old fashion but still in use [7].

These roofing materials are cheap to purchase and readily available as they are easy to find virtually everywhere in Nigeria. They are quick to install and easy for the building structure to carry as they are light in weight. However, they get hot during sunshine and produce dissonant sounds during rainfall causing discomfort for building occupants. Also, they easily get rust as the zinc layer slowly leach away leading to a leaking roof [8].

2.1.2 Aluminium Roofing Sheets

In recent times, aluminium roofing sheets have increasingly become popular roofing materials in Lagos and Nigeria at large. Although, they are metallic roofs like galvanized steel sheets but possess distinct characteristics. They are more durable as they are highly corrosion resistant. They are also easier to handle as they are lighter than steel roofs and reflects heat to keep the house cool during hot weather. However, they are more expensive than steel roofs. They also produce dissonant sounds during rainfall causing discomfort for building occupants just like steel roofs [9].

Presently, there are many different aluminium alloys in existence with around 400 wrought and 200 cast alloys, and more added every year. A popular choice for roofing is aluminium 3105, a wrought aluminium alloy which is about 98% pure aluminium [12]. It can simply be written as AA3105 and available in H12, H14, H16, H18, H25 tempers [10, 11].

3.0 METHODOLOGY

3.1 GOAL AND SCOPE DEFINITION

The goal of this life cycle assessment is to compare the environmental impacts of galvanised steel and aluminium roofing sheets used in Lagos, Nigeria.

3.1.1 System Boundary

This study is a cradle-to-grave LCA analysis covering the assessment of environmental footprints during the extraction phase of principal raw materials (aluminium and iron), primary production phase of galvanised steel and aluminium alloy (AA3105, H14), distribution phase, use phase and disposal/recycling phase.

Figure 3.1: Cradle-to-Grave Life Cycle Diagram [5].

3.1.2 Functional Unit

The functional unit chosen for the study is 1kg for each roofing material (i.e., galvanized steel and aluminium roofing sheet) being compared.

3.1.3 Assumptions

The assumptions used in this study are:

1. The selected roofing materials are galvanized steel roofs and aluminium roofing sheets.
2. The selected location is Lagos, a major industrial city in Nigeria [3].
3. *Aluminium alloy, AA3105* was used in this study as it is a popular roofing material choice [12].
4. *Granta Edupack 2023 R1* was used for the comparative study.
5. The database used for the simulation is *Advanced Level 3 Eco Design*.
6. *H14* been the most common temper was selected out of the three available options (H14, H18 and O) in *Granta Edupack 2023 R1* [10].
7. Average values (to 2 decimal places) were estimated from range of values provided in the simulation.
8. For production phase assessment, the primary production of virgin grade of the selected roofing materials was studied.
9. Petrol-engine vehicles are assumed to be used in transporting roofing materials from factories to wholesalers and retailers in marketplaces as PMS among other petroleum products contribute the highest emissions in Nigeria [4].

3.2. LIFE CYCLE INVENTORY (LCI)

The inventory analysis of this life cycle assessment covers five primary phases:

3.2.1 Raw Material Extraction Phase

This involves the extraction and mining of principal raw materials which are aluminium and iron. The annual world extraction and production of these principal components are also discussed from simulation values.

3.2.2 Production/Manufacturing Phase

This study focuses on the embodied energy, carbon footprint and water usage during the primary production of virgin grade galvanized steel and aluminium alloy (AA3105, H14). These values are obtained using the simulation result.

3.2.3 Transportation/Distribution Phase

The quantity of carbon emissions during transportation of galvanized steel and aluminium roofing sheets from the manufacturing site to retailers and wholesalers in marketplaces is estimated using simulation values and current petrol price in Lagos, Nigeria.

3.2.4 Use Phase

The use phase assessment is centred around durability of the selected roofing materials by comparing the resistance of galvanised steel and aluminium roofs to factors relevant to the location, Lagos, which is an industrial city with heavy annual rainfall.

3.2.5 Disposal/Recycling Phase

This study focuses on the embodied energy and carbon footprint during the recycling of galvanized steel and aluminium alloy (AA3105, H14). These values are estimated using values from the software.

4.0 RESULTS AND DISCUSSION

4.1 EXTRACTION OF PRINCIPAL RAW MATERIALS - ALUMINIUM AND IRON

From the simulation, Table 4.1 was obtained and indicates that aluminium is more abundant in nature than iron. It shows that the abundance of aluminium and iron in the earth's crust have average values of 83,200ppm and 52,000ppm respectively. However, the annual world production and extraction of aluminium is less than iron as shown in the table. The annual average world production of aluminium and iron are 57.3million tonnes/year and 2.23billion tonnes/year respectively. Thus, the extraction of iron yearly is higher than that of aluminium even though aluminium is more abundant in nature than iron. Perhaps, aluminium extraction process requires more input of resources making it an expensive process when compared to iron extraction process, leading to lesser production of aluminium annually.

Table 4.1: Abundance and Extraction of Aluminium and Iron

	Aluminum, 3105, H14	Coated steel, steel, galvanized
Geo-economic data for principal component		
Principal component	Aluminum	Iron
Typical exploited ore grade (%)	30.4 - 33.6	45.1 - 49.9
Minimum economic ore grade (%)	25 - 39	25 - 70
Abundance in Earth's crust (ppm)	82300 - 84100	41000 - 63000
Abundance in seawater (ppm)	0.0005 - 0.005	0.0025 - 0.003
Annual world production, principal component (tonne/yr)	5.73e7	2.23e9
Reserves, principal component (tonne)	2.69e10	1.59e11

4.2 PRIMARY PRODUCTION PHASE ASSESSMENT FOR GALVANIZED STEEL AND ALUMINIUM ALLOY (AA3105, H14)

The energy demand, carbon emission and water usage during the primary production of galvanized steel are less than those of aluminium alloy (AA3105, H14) in Table 4.2 and Figure 4.1. Average embodied energy, CO_2 footprint and water usage during primary production of virgin grade galvanized steel are 40.05MJ/kg, 3.02kg/kg and 59.25l/kg respectively. While average embodied energy, CO_2 footprint and water usage during primary production of virgin grade aluminium alloy (AA3105, H14) are 193.5MJ/kg, 13.8kg/kg and 1200l/kg respectively. These simulation results indicate that the primary production of galvanized steel is more eco-friendly as it requires lesser input of resources and releases lesser emissions when compared to that of aluminium alloy (AA3105, H14).

	Aluminum, 3105, H14	Coated steel, steel, galvanized
Primary production energy, CO2 and water		
Embodied energy, primary production (virgin grade) (MJ/kg)	184 - 203	38.1 - 42
Embodied energy, primary production (typical grade) (MJ/kg)	112 - 132	22.5 - 26.4
CO2 footprint, primary production (virgin grade) (kg/kg)	13.1 - 14.5	2.87 - 3.16
CO2 footprint, primary production (typical grade) (kg/kg)	8.12 - 9.48	1.71 - 2.01
Water usage (l/kg)	1140 - 1260	56.3 - 62.2

Table 4.2: Primary Production of Galvanized Steel and Aluminium Alloy (AA3105, H14)

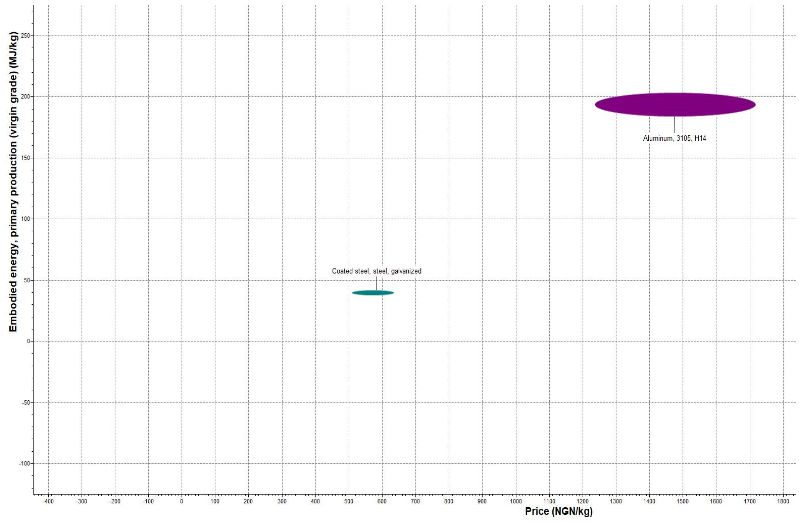


Figure 4.1: Plot of Primary Production Embodied Energy against Price in Nigerian Naria (NGN)/kg for Virgin Grade Galvanized Steel and Aluminium Alloy (AA3105, H14)

4.3 DISTRIBUTION PHASE ASSESSMENT FOR GALVANIZED STEEL AND ALUMINIUM ALLOY (AA3105, H14)

In Table 4.3, the average price of galvanized steel and aluminium alloy (AA3105, H14) are NGN571/kg and NGN1,480/kg respectively. An article published on BBC News Pidgin on 30th October 2024, reports the price of petrol in Lagos is now NGN1,025/L. Also, CO_2 emitted per Litre of petrol is estimated to be 2.27kg/L in Nigeria (Akpojotor *et al*, 2016). Thus, conversion factors for calculating CO_2 emission during the transportation of roofing materials were assembled in Table 4.4.

In the light of these, the mass of roofing material transported per Litre of petrol used was calculated in Table 4.5 to be 1.80kg/L and 0.69kg/L for galvanized steel and aluminium alloy (AA3105, H14) respectively. Again, CO_2 emitted per kg of roofing material transported was estimated to be 1.26kg/kg and 3.28kg/kg for galvanized steel and aluminium alloy (AA3105, H14) respectively. Hence, indicating that transporting aluminium roofing sheets contributes more to climate change compared to galvanized steel sheets.

Table 4.3: Price of Galvanized Steel Sheets and Aluminium Alloy (AA3105, H14)

	Aluminum, 3105, H14	Coated steel, steel, galvanized
Price		
Price (NGN/kg)	1240 - 1720	509 - 633

Table 4.4: Conversion Factors For Calculating CO_2 Footprint

Conversion Factors

Price of Petrol in Lagos (NGN/L)	1,025
CO_2 Emitted Per Litre of Petrol (kg/L)	2.27

Table 4.5: CO_2 Footprint in Transportng Galvanized Steel Sheets and Aluminium Alloy (AA3105, H14)

	Aluminium, 3105, H14	**Galvanized Steel**
Average Price Per Mass of Roofing Material (NGN/kg)	1,480	571
Mass of Roofing Material Transported Per Litre of Petrol Used (kg/L)	0.69	1.80
CO_2 Emitted Per kg of Roofing Material Transported (kg/kg)	3.28	1.26

4.4 USE PHASE ASSESSMENT FOR GALVANIZED STEEL AND ALUMINIUM ALLOY (AA3105, H14)

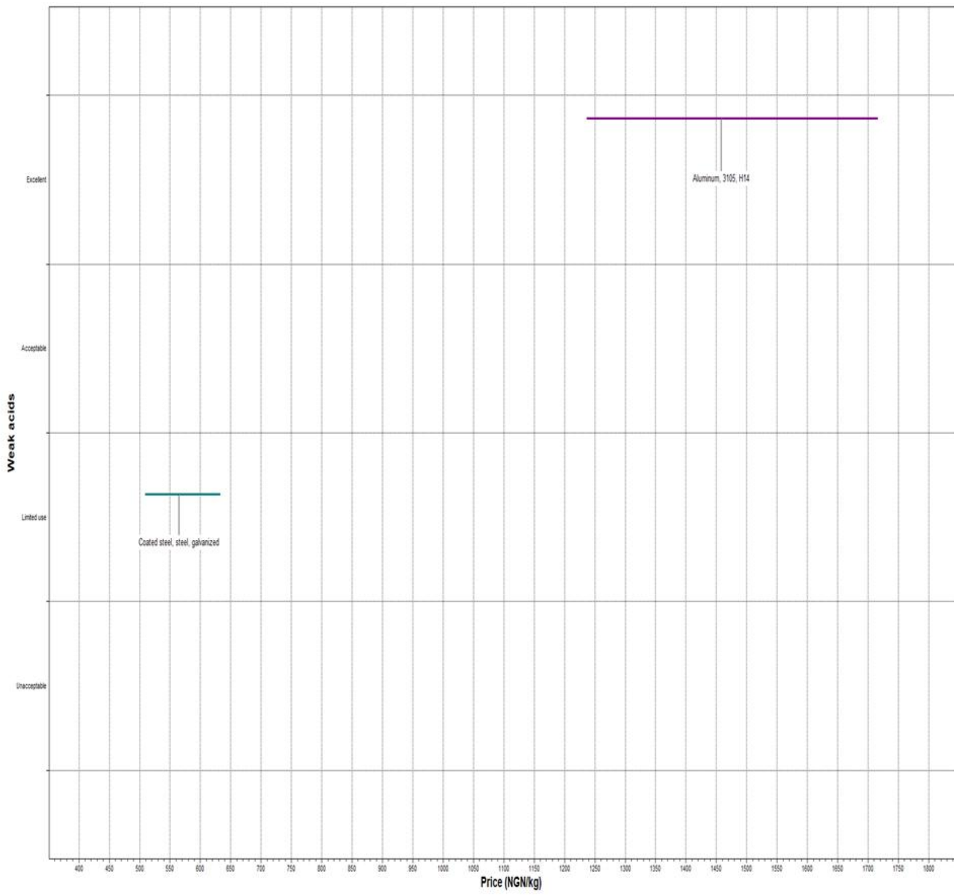
Table 4.4 illustrates the resistance of galvanised steel and aluminium alloy (AA3105, H14) to various durability factors. From the table, both materials exhibit the same behaviour towards all other factors except for weak acids, strong acids and strong alkalis. However, alkaline rains are generally not common in Nigeria and acid rains are weakly acidic normally.

Hence, for a Nigerian city like Lagos, the main durability factor that distinguishes aluminium and galvanized steel roofs is their resistance to weak acids. In Table 4.4 and Figure 4.2, aluminium alloy (AA3105, H14) displayed an excellent resistance to weak acids compared to galvanised steel which has limited resistance to weak acids thus, justifying the long-lasting nature of aluminium roofs over galvanised steel roofs.

Table 4.6: Durability of Galvanized Steel and Aluminium Alloy (AA3105, H14)

	Aluminum, 3105, H14	Coated steel, steel, galvanized
Durability		
Water (fresh)	Excellent	Excellent
Water (salt)	Acceptable	Acceptable
Weak acids	Excellent	Limited use
Strong acids	Excellent	Unacceptable
Weak alkalis	Acceptable	Acceptable
Strong alkalis	Unacceptable	Limited use
Organic solvents	Excellent	Excellent
Oxidation at 500C	Unacceptable	Unacceptable
UV radiation (sunlight)	Excellent	Excellent
Galling resistance (adhesive wear)	Limited use	Limited use
Flammability	Non-flammable	Non-flammable

Figure 4.2: Plot of Reaction to Weak Acid against Price in Nigerian Naria (NGN)/kg for Galvanized Steel Roof and Aluminium Roofing Sheet (AA3105, H14)



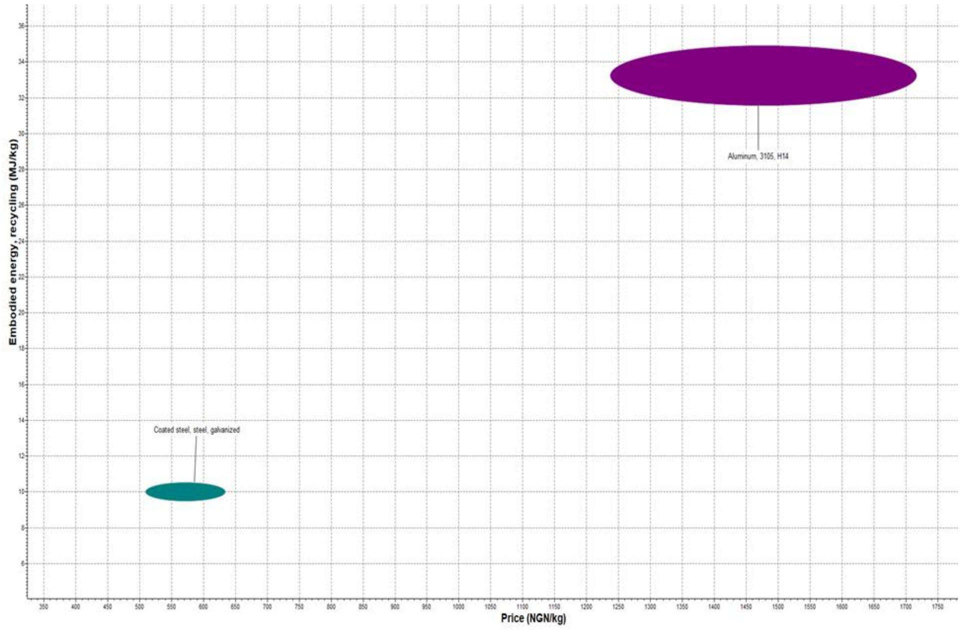
4.5 DISPOSAL/RECYCLING PHASE ASSESSMENT FOR GALVANIZED STEEL AND ALUMINIUM ALLOY (AA3105, H14)

Again, the energy demand and carbon emission during the recycling of galvanized steel are less than those of aluminium alloy (AA3105, H14) from the results in Table 4.5 and Figure 4.3. Average embodied energy and CO_2 footprint during the recycling of aluminium alloy (3105, H14) are 33.25MJ/kg and 2.62kg/kg respectively. While average embodied energy and CO_2 footprint for galvanized steel are 10.02MJ/kg and 0.79kg/kg respectively. These simulation results indicate that the recycling of galvanized steel is more eco-friendly as it requires lesser input of resources and releases lesser emissions when compared to that of aluminium alloy (AA3105, H14). Thus, substantiating why the average percentage of recycled galvanized steel in current supply, 52%, is higher than that of recycled aluminium alloy (AA3105, H14) in current supply, 45%, although, a huge chunk of both still goes to landfill.

Table 4.7: Embodied Energy and Carbon Footprint in Recycling of Galvanized Steel Sheets and Aluminium Alloy (3105, H14)

	Aluminum, 3105, H14	Coated steel, steel, galvanized
Recycling and end of life		
Recycle	✓	✓
Embodied energy, recycling (MJ/kg)	31.6 - 34.9	9.53 - 10.5
CO2 footprint, recycling (kg/kg)	2.48 - 2.75	0.749 - 0.828
Recycle fraction in current supply (%)	42.8 - 47.2	49.4 - 54.6
Downcycle	✓	✓
Combust for energy recovery	✗	✗
Landfill	✓	✓
Biodegrade	✗	✗

Figure 4.3: Plot of Recycling Embodied Energy against Price in Nigerian Naria (NGN)/kg of Galvanized Steel and Aluminium Alloy (3105, H14)



5.0 CONCLUSION AND RECOMMENDATIONS

Based on simulation results, it can be inferred that it is more environmentally sustainable to extract, produce, distribute and recycle galvanized steel compared to aluminium alloy (AA3105, H14). However, aluminium alloy (AA3105, H14) has excellent resistance to acid rain thus, more durable compared to galvanized steel for a city like Lagos with heavy annual precipitation and industrial emissions.

Furthermore, it is recommended that to make the extraction, production and recycling of aluminium alloy (AA3105, H14) more environmentally sustainable then, industry 4.0 components should be implemented to properly automate and control the electrolytic extraction and production process of aluminium. Also, upgraded electrode materials and advance cell designs should be used to improve the process energy efficiency. In addition, inert anodes and the use of biofuels are better options to lower production emissions.

On the other hand, it is recommended that regular maintenance like promptly applying UV and moisture-resistant paints and seals on galvanized steel when zinc layer starts fading away would help curtail corrosion rate and increase durability.

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