

Research Article

# LCA Study: Carbon and Energy Footprint Assessment of Non-Metallic Materials Against Traditional Metallic Materials in Building and Construction Sector

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## Abstract

The study assesses the carbon and energy footprints of the non-metallic (NM) and traditional metallic materials in building and construction applications through a Life Cycle Assessment in accordance of ISO 14067 and 14040/44. The goal of this assessment is to address the misconceptions surrounding non-metallic materials and provide a fact-based understanding of their environmental impact, specifically their carbon footprint. Moreover, this scientific assessment is performed to evaluate the feasibility of switching from conventional metallic products to non-metallics (polymers). The assessed products in this sector include rebars, sand movement controls, claddings, manholes, window frames, and walkways, which are found in the assessment for each product system's metallic and non-metallic materials. The life cycle assessment of carbon and energy in this study includes the manufacturing, transportation, and end of life of each product in the listed products, while the use phase is assumed to be identical whether the product is metallic or non-metallic, except for sand movement control and walkways. The structure of this assessment starts with an introduction, followed by materials and methods which define all data and products assessed, and lastly a conclusion of the analysis. All in all, the study results show that non-metallic products are favorable with less carbon and energy footprint potential when compared to the corresponding metallic products in the building and construction sector.

## Keywords

Circular Economy, Life Cycle Assessment, Carbon Footprint, Climate Change, Non-Metallic Materials, Building and Construction Sector

## 1. Introduction

Recently, a noticeable expansion is observed in the use of polymers in the building and construction sector, which often replaces metallically manufactured products. The sector applications evaluated, in terms of carbon and energy footprints, in this assessment are rebars, claddings, sand movement control, walkways, manholes, and window frames. Since polymers

weigh less than metallic materials, the transportation phase is expected to have less carbon footprint in favor of non-metallic products.

This study assesses the carbon and energy footprint of the non-metallic (NM) and conventional metallic materials in building and construction sector following a “cradle to grave”

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Life Cycle Assessment according to ISO 14067 and 14040/44 standards [5, 6]. Additionally, the study identifies the main contributors in the value chain concerning the environmental impacts evaluated.

The NM materials evaluated are acrylic polymers, glass fiber reinforced polymers (GFRP), fiber reinforced plastic (FRP), unplasticized polyvinyl chloride (U-PVC), High pressure laminate cladding (HPL), while the conventional metallic products are wheel loaders, reinforced-concrete, aluminum and galvanized steel.

## 2. Material and Methods

### Product Systems

Several non-metallic and conventional products selected in the construction sector are compared in terms of their carbon and energy footprint during their lifetime. The study covers the lifetime stages of material production, transporting the materials, and the manufacturing stage. In case of sand movement control, the use phase is considered in this assessment, while it is overlooked for the other 5 product systems since it is assumed that the use phase is identical or idle in terms of emissions or energy usage.

**Table 1.** Product Systems.

Product System	Product Name	Material Used for Conventional and Non-conventional Product
NM1	Polymer for Sand Movement Control	Acrylic polymers
CP1	Mechanical sand removal	Wheel loaders
NM2	GFRP Rebar	Glass fiber reinforced polymers
CP2	Epoxy-coated steel (ECS) rebar	steel
NM3	FRP manhole	Fiber reinforced polymers
CP3	Concrete manhole	Concrete
NM4	U-PVC window frame	Polyvinyl chloride
CP4	Aluminum window frame	Aluminum
NM5	FRP walkway	Fiber reinforced polymers
CP5	Galvanized steel walkway	Steel
NM6	HPL Cladding	High pressure laminate
CP6	Aluminum Metal Cladding	Aluminum

### Coverage and Boundaries

The lifecycle stages for each conventional and non-metallic product are covered in Tables 1 to 6 of the next section. This study is based on GaBi database [7]. For sand removals, the system under study uses cradle-to-grave boundaries, including upstream production of the polymer emulsion, the application of the product and maintenance activities, as well as the mechanical sand removal including all upstream productions. The production of heavy-duty vehicles used for the mechanical sand removal as well as diesel consumption of the dump truck during idle time were excluded from the system boundary. Moreover, the use of wheel loader in particular during the mechanical sand removal might impact the integrity of the roadway surface resulting in additional damages and accelerated roadway maintenance cycles. For metallic and non-metallic rebars, production, transportation, concrete required for installation, and end-of-life phases were considered. For metallic and non-metallic manholes, window frame, walkways,

cladding, the use phase is excluded from this study as it is assumed to be the same for these applications whether the product is metallic or non-metallic. From a geographical perspective, the use and end-of-life phases is considered to be in Saudi Arabia, and all data collected and used were selected to represent the country and region.

### LCA Inventory Analysis

For product system NM1, polymer and mechanical sand removal were chosen due to the necessity to control drifting sand dunes dust blow across large stretches of highways; resulting in accumulated sand on the roads, which creates dangerous driving conditions in Saudi Arabia. Synthetic polymer emulsions primarily consist of acrylic polymers that are specifically produced for soil stabilization and dust control. Using the polymer emulsions, custom berms are designed as protective berms to act as a natural barrier and prevent the sand movement and build up on highways. The polymer product is diluted with water before application. When sprayed, the polymer solution creates a solid hard crust layer on the surface of the sand, which performs well for dust suppression, and

reduces sand particle drifting and accumulation on highway roads. Over time, the treated sand surface requires additional maintenance operations through a reapplication of polymer solutions. At the end of life, the polymer emulsion is assumed to be left in situ. In the next sections, all figures considered are based on communicated data provided by the manufacturers.

On the other hand, the conventional method in Saudi Arabia is to mechanically remove the sand accumulated on roads and move it back to one side of the road on regular basis. This LCA only addresses the use-phase of mechanical sand removal, which include fuel consumption and its emission.

**Table 2.** Sand movement control product system.

<b>Product System NM1</b>		
<b>Phase</b>	<b>NM1: Polymer for sand movement control</b>	<b>CP1: Mechanical sand removal</b>
Production	The manufacturing data of the polymer emulsion product are based on the available dataset in GaBi. Styrene butyl acrylate copolymer (50% solids) is selected as a suitable proxy.	Not included
Installation	To achieve the movement control of sand for 1 meter of highway road, an average surface of sand to be sprayed is 65 m <sup>2</sup> . During the application stage, an average transportation distance of concentrated synthetic polymer is assumed to be 700 km. The dilution and mixing of the product can be achieved by loading the concentrated polymer solution with water directly in the tanker, near the project site. The transportation distance for the tanker is a round trip taking into consideration the way back of the tankers with no load and therefore is assumed to be 100 km. The water used for the dilution is normally ground/brackish water pumped from desert bore holes. The spraying can be done either manually or via tanker with spraying container. In this study we only include the transportation of the polymer-water mixture to the project site via the tanker.	Not included
Use phase	Synthetic polymer emulsion-treated sand deteriorates over time in terms of surface crust and uniformity, due to damages related to improper use (e.g. driving over the surface crust) or wind and other environmental factors. An average maintenance plan can be conducted after 3.5 years. During maintenance, the hard crust surface of the sand requires a reapplication of the polymer product to maintain its initial design quality. The maintenance operations are similar to what was done during the initial application stage. On average, 21% of the initial sand surface treated requires reapplication of the polymer solution.	As an average, 13 m <sup>3</sup> of sand is accumulated annually per meter of highway road. The removal of sand requires the use of wheel loaders and dump trucks. The wheel loader diesel consumption data was based on the Volvo L150G Wheel loader [1]. The wheel loader consumes 0.16 liters of diesel per ton of sand removed. Once loaded, the dump truck will transport the sand to either side of the road. We assume an average distance of 10 meters. Both vehicles are assumed to remain on site (near the highway road) and would require regular fueling from nearby gas stations, using fuel tankers. We assume an average transport distance of 20 km between the project site and the gas station. The model includes the full round-trip distance of 40 km, taking into consideration the trip of the empty tanker back to the station. Besides the production of diesel, the model also includes the combustion of diesel during the maintenance operations.
End of Life	According to a publication from the U.S Department of Agriculture, synthetic polymer emulsions used for soil stabilization in general not harmful to the environment based on the literature. Moreover, the polymer product used is not expected to emit GHG emissions during the degradation stage at EoL. The synthetic polymer product used to fix the sand surface layer is assumed to be left in situ. The EoL life cycle stage is therefore not included in this study.	Not included

During the past decade, many trial projects have been conducted using FRP rebars, which so far have been successful [2]. In 2016, the Minnesota Department of Transportation (MnDOT) constructed its first glass fiber polymer (GFRP) reinforced bridge deck [3]. In a recently completed research project in 2020, the results have shown that GFRP performed well, proving sufficiently strong for use as an alternative to corrosion-susceptible steel rebars [10].

For GFRP rebar reinforced bridge structure, production stage means producing the fiber reinforced rebars including the transport of key raw materials necessary to produce the rebar. The construction stage includes the production of concrete and the energy requirement for its pumping, the transportation of the GFRP rebar and concrete to construction site, as well as waste treatment of packaging materials of the rebars.

During the manufacturing stage of reinforcing rebars used in reinforced concrete, the conventional steel rebar, an unfinished tempered steel is first coated with epoxy resin to enhance its corrosion resistance, as the steel rebar are susceptible to corrosion in corrosive environments. In addition to the Coated steel rebars produced, predesigned concrete mixtures according to ASTM standards are prepared during the construction phase of the reinforced structure. After the construction phase, the concrete bridge structure requires regular maintenance operations to clean the corroded part of the structure and replaced the demolished surface of the concrete. The end-of-life phase includes the impacts associated with the deconstruction of the concrete structure at the end of its service life and the disposal or recycling of the concrete and rebar waste.

**Table 3.** Rebars Product System.

<b>Product System NM2</b>		
<b>Phase</b>	<b>NM1: GFRP Rebar</b>	<b>CP2: Epoxy-coated steel (ECS) rebar</b>
Production	<p>GFRP rebars are manufactured through pultrusion of resin-impregnated bundles of fibers. The resin can either be vinyl ester or epoxy. The production of vinyl ester resin was estimated and modelled under a conservative approach. The below summarizes the input process data for 1 kg of Vinyl ester resins:</p> <ul style="list-style-type: none"> <li>0.13 kg of Methacrylic acid</li> <li>0.52 kg epoxy resin</li> <li>0.35 kg styrene</li> <li>3 MJ of thermal energy from natural gas</li> <li>0.333 kWh of electricity</li> </ul>	<p>The material and energy requirement of the coating process are based on data from previous case study done by the international Zinc Association (IZA) comparing four different rebars used in a reinforced concrete bridge structure. The below summarizes the input for the manufacturing of 1,013 kg of the ECS rebar:</p> <ul style="list-style-type: none"> <li>1000 kg of steel rebar</li> <li>12.8 kg of epoxy resin</li> <li>108 MJ of thermal energy from natural gas</li> <li>110 kWh of electricity</li> </ul>
installation	<p>Identical to the ECS rebar system product, the inbound transport of materials to the construction site is included in the assessment. We assume an average distance from a ready-mixed concrete plant to a construction site of 100 km. The distance for GFRP rebar transportation was also estimated to be 700 km from fabrication facility to construction site. The energy required to pump the concrete is accounted for within the model, while the laying of the rebar for the bridge construction requires only manual work force. Waste treatment of the packaging materials included in the production of the GFRP rebar was also included in the model.</p>	<p>The concrete mixture proportions are based on literature data from the construction of a flood mitigation channel (FMC) in the southwest Saudi Arabia. The recently published study included information on the concrete mix designs when ESC rebar as well as when opting for GFRP [8]</p>
Use phase	<p>As GFRP rebars are corrosion resistant, so the maintenance life cycle stage is not considered. Other maintenance operations (e.g related to cracking of concrete) are assumed to be the same for both GFRP rebar and ECS rebar, and therefore are excluded for both product systems.</p>	<p>Concrete bridges deterioration can be caused by various deterioration mechanisms, such as corrosion. Therefore, the conditions of the bridge require regular inspections periodically to conduct maintenance operations. Due to the lack of information on this lifecycle stage, the maintenance plan of the bridge structure is assumed to require a one-time repair operation during the service life of the structure (35 years). Unpredictable minor repairs as well as sealants quantities were not included. The maintenance plan is assumed to be built around completing a partial depth overlay on 50% of the total surface of the deck.</p>

Product System NM2		
Phase	NM1: GFRP Rebar	CP2: Epoxy-coated steel (ECS) rebar
End of Life	At the EoL, the environmental impacts related to the deconstruction of the concrete structure and waste treatment is considered. According to the sector experts from the participating manufacturers, the GFRP rebar mixed with concrete can be crushed in stone size, to create new aggregate for reinforced concrete. GFRP and Concrete recycling assumes a 10% recycling. The remaining concrete is sent to landfill (Public Investment Fund, 2017). We assume a transportation distance of construction waste to either landfill or recycling rates to be 20km. The deconstruction material and energy requirements as well as the crushing of concrete are assumed to be the same as in the ECS reinforced structure model. Moreover, we assume that the energy requirements to crush the concrete mixed with GFRP rebar are similar to crushing the concrete alone.	<p>This overlay will be completed in three parts:</p> <ol style="list-style-type: none"> <li>1. Hydro demolition of the upper layer of the concrete structure to 4 cm</li> <li>2. Cleaning of rebar and surrounding concrete to remove present chloride ions to the greatest extent possible</li> <li>3. Placement of a concrete overlay using the same mixture proportions as in the original construction.</li> </ol> <p>Hydro demolition, using high-pressure water, is used to break up and remove the top 4 cm of concrete and clean the rebar. The below shows the material and energy requirements per cubic meter of concrete (International Zinc Association, 2015): 1,188 MJ through diesel 101,524 L of water</p> <p>The End-of-life cycle stage comprises the impacts associated with deconstruction of the bridge structure at the end of its service life and the disposal and recycling of the concrete and rebar. It is assumed that only 10% of this waste is recycled while the other 90% is disposed in landfills. In this study, steel recycling uses the value of scrap allocation approach and assumes an 85% recovery rate. The remaining rebar is sent to landfill. Concrete recycling assumes a 10% recycling as well. The remaining concrete is sent to landfill. For the epoxy coating used in the rebar manufacturing, the 10% of the waste is recycled in an incineration plan, including all energy credits generated. We assume a transportation distance of construction waste to either landfill or recycling rates to be 20km. The remaining waste is sent to landfill. Deconstruction operations require diesel for breaking the concrete and gasoline to cut the steel reinforcement [4]. Diesel is considered to fulfil all the energy requirements of the deconstruction. The recycled concrete is crushed into gravel with half coming from diesel fuel and half from electricity [4].</p>

For the following product systems (i.e. NM3 to NM6) two phases have been considered: Production (includes installation) and EoL. After manufacturing the product, it is transported to the site for installation. Maintenance is considered if required in any structure. After the products' service life, end-

of-life is considered with options of treatments such as recycling, landfill, or incineration. In case of NM3 product system, EoL is not considered as products are assumed to be left on site after use, while the use-phase is considered for NM5.

**Table 4.** Manhole Product System.

Product System NM3		
Phase	NM3: FRP Manhole	CP3: Concrete Manhole
Production	FRP manhole is manufactured from (Glass fiber- 60%, Polyester resin- 30% and Sand- 10%) using the Extrusion and Blow molding process. The information on the weight of the FRP manhole along with the concrete slab	The on-site manufacturing and installation have been considered for concrete reinforced manhole based on the data from NCPA [11]. The information on the weight of the

**Product System NM3**

Phase	NM3: FRP Manhole	CP3: Concrete Manhole
	specification required during installation of the manhole has been taken from BMTPC [9]. The manufacturing phase has been developed using secondary data.	concrete reinforced manhole along with the fuels, electricity and concrete mix design have been taken from the above-mentioned source. The manufacturing phase has been developed using secondary data.

*Table 5. Rebars Product System.***Product System NM4**

Phase	NM4: U-PVC window frame	CP4: Aluminum window frame
Production	The manufacturing of the U-PVC window frame is developed using the GaBi LCI data. The information on the weight of the U-PVC window frame along with service life and EoL has been taken from literature.	The manufacturing of the aluminum window frame is developed using the GaBi LCI data. The information on the weight of the aluminum window frame along with service life and EoL has been taken from literature.
End of Life	In the end-of-life phase, the collection and recovery rate have been considered as 95%. The recycling and the incineration rate of PVC material has been considered as 59% and 35% respectively and rest is landfilled. The recycling rate for the steel part is considered to be 92%, and net scarp approach has been applied, while the rest is landfilled.	

*Table 6. Walkways Product System.***Product System NM5**

Phase	NM5: FRP Walkway	CP5: Galvanized steel walkway
Production	Walkways are structural member made up of grating and handrail. The FRP composition for grating (Glass fiber- 62% and Isophthalic resin-38%) and handrail (Glass fiber- 56% and Isophthalic resin-44%) has been considered in the assessment. The GaBi extrusion process has been considered for the manufacturing of the FRP components.	The manufacturing of the galvanized steel grating and handrail are based on the GaBi datasets. The stamping & bending along with the cutting process have been considered for the electrogalvanized steel dataset to represent the steel grating manufacturing. The steel has been considered to represent the handrail part of the walkway. The information on the weight of the galvanized steel walkway has been derived from the same source used for the FRP walkaway.
Use phase	Not included	Three coatings have been considered during its service life of 20 years. The waste generated due to material replacement in the maintenance phase is treated similar to Product's EoL
End of Life	After the products' service life, the end-of-life is considered with options of treatments such as recycling, landfill, or incineration. For FRP product three scenarios (scenario: 1-100% landfill, scenario: 2- 100% re-cycling with cut off (no burden, no credit), scenario: 3-100% incineration) have been considered. For galvanized steel product three scenarios (scenario: 1-100% landfill, scenario: 2- 80% recycling & 20% landfill, scenario: 3- 50% recycling & 50% landfill) have been considered.	



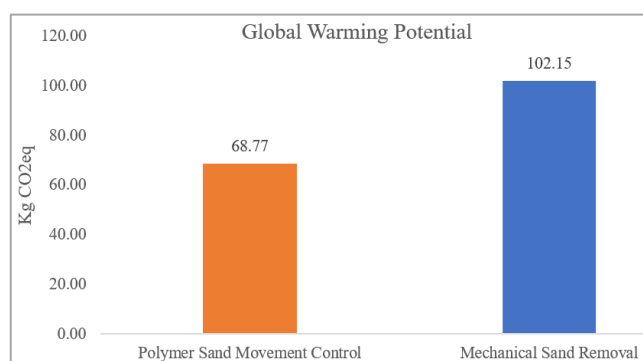
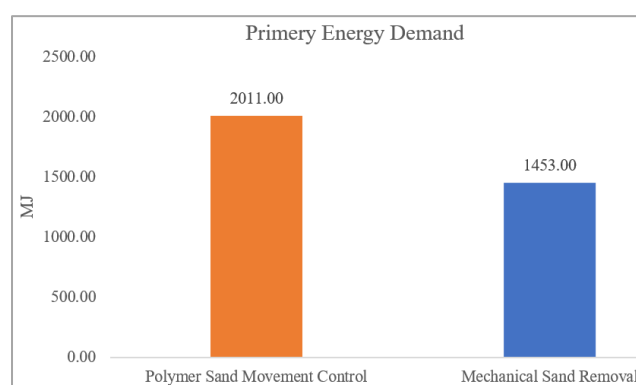
**Table 7.** Cladding Product System.

Product System NM6		
Phase	NM6: HPL Cladding	CP6: Aluminum Metal Cladding
Production	High pressure laminate cladding are applied as vertical exterior walls coverings such as cladding, balcony paneling as well as horizontal exterior ceiling applications. The manufacturing of the HPL cladding is developed using the GaBi LCI data. The information on the weight of the HPL cladding along with service life and EoL has been taken from literature.	Aluminum cladding are applied as exterior walls coverings. The composition of the aluminum metal cladding is “Rock wool: 58.9%; Aluminum cladding material: 27.6%; Bitumen: 8.4%; Steel: 1.9%; Zinc: 1.8% and Polyamide: 1.4%” in which the major impact is being contributed from aluminum cladding material. The manufacturing of the aluminum cladding material is developed using the GaBi LCI data. The information on the weight of the aluminum cladding along with service life and EoL has been taken from a published literature.
End of Life	After the products’ service life, the end-of-life is considered with options of treatments such as recycling, landfill and incineration. For HPL cladding three scenarios (scenario: 1-100% landfill, scenario: 2- 100% recycling with carbon correction, scenario: 3-100% incineration have been considered. In End of life for recycling of HPL the energy for shredding is considered as 0.0041 kwh/kg of wood and the credit has been taken with spruce log wood. For aluminium cladding product recycling has been considered for aluminium and steel. The rockwool and rest of the aluminium after recycling have been considered for landfill.	

### 3. Results, Findings, and Conclusion

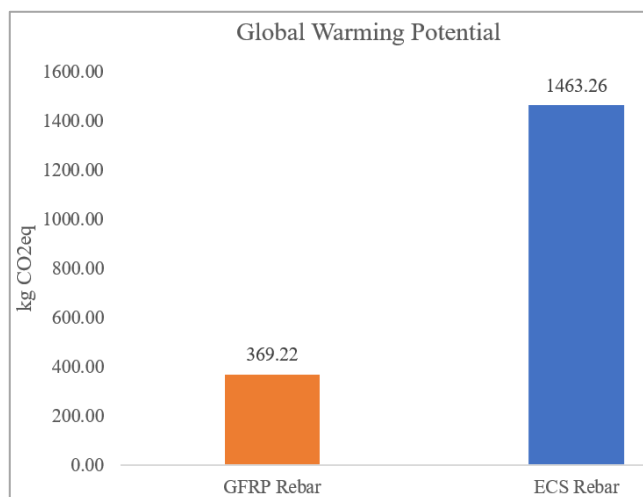
#### NM1 Product System

Given the assessment conducted for non-metallic against the conventional products, it is concluded that opting for the NM product would requires higher primary energy, but emits less GHG emissions compared to the mechanical sand removal. This can be explained by the fact that on one side, system boundaries for the conventional solution includes the production and combustion of Diesel, whereas for the NM product, the system results in carbon embodied in the polymer and without being emitted. Shown below are the calculated CO<sub>2e</sub> and primary energy demand.

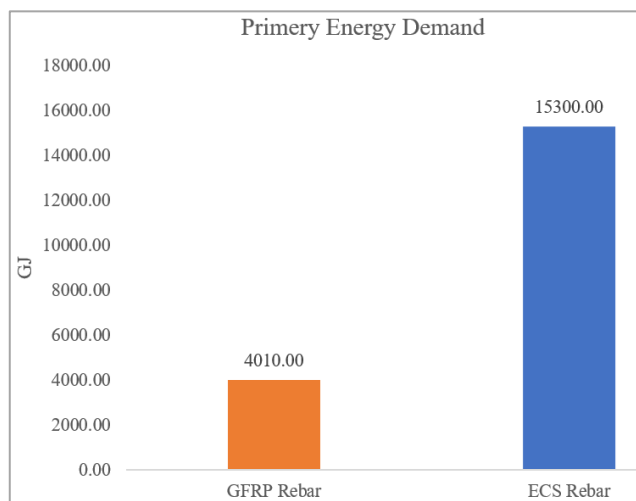
**Figure 1.** GWP results of NM1.**Figure 2.** PED results of NM1.

#### NM2 Product System

Material selection, in this product system, is a key contributor through the environmental performance of a reinforced concrete structure, and that significant reductions in GHG emissions can be achieved by opting for the GFRP rebar instead of ECS rebar. In fact, when comparing GHG emissions of the production of the rebars, the results show that the carbon footprint for each type is comparable. Yet, when assessing the products during their entire life cycle, the results indicate that avoided emissions can be achieved when opting for GFRP under all analyses conducted. This can mainly be due to the impacts linked with ECS rebar, higher steel rebar and concrete requirements, the reconstruction of the steel reinforced structure, and the corrosion related maintenance operations related to this type of rebar. Compared to GFRP rebar, the primary energy demand was found to be higher when using ECS rebars due to the same abovementioned reasons.

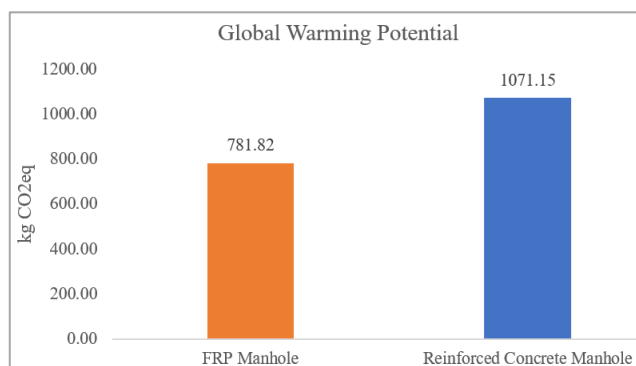


*Figure 3. GWP results of NM2.*



*Figure 4. PED results of NM2.*

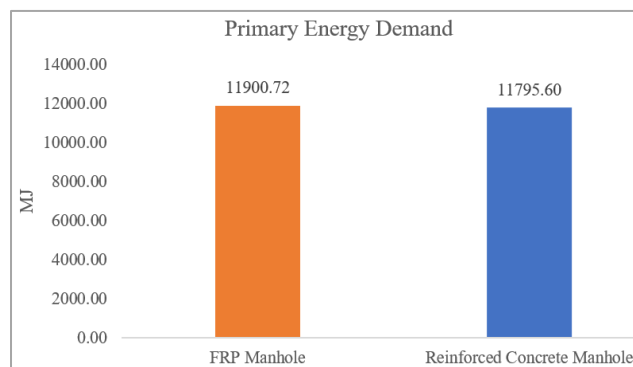
#### NM3 Product System



*Figure 5. GWP results of NM3.*

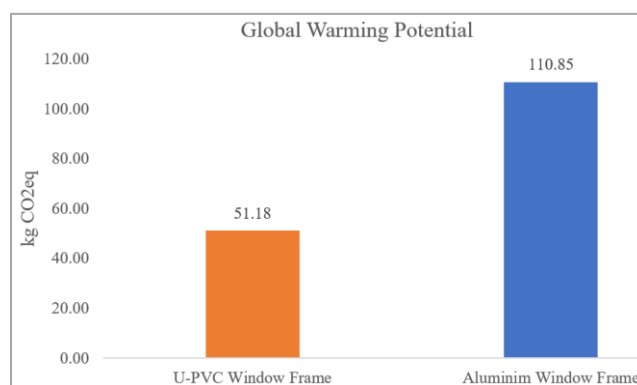
The total GWP for FRP manhole is 781.82 kgCO<sub>2</sub>eq with 3.5m<sup>3</sup> volume over a period of 100 years. The LCA analysis

of NM3 indicates that the total GWP of the NM material (FRP manhole) is 27% lower than the conventional material (Reinforced concrete manhole). By switching from the CP to NM material 289.32 kg CO<sub>2</sub>eq/functional unit can potentially be avoided. The total PED for FRP manhole is 11900.72 MJ which is higher than the conventional product.

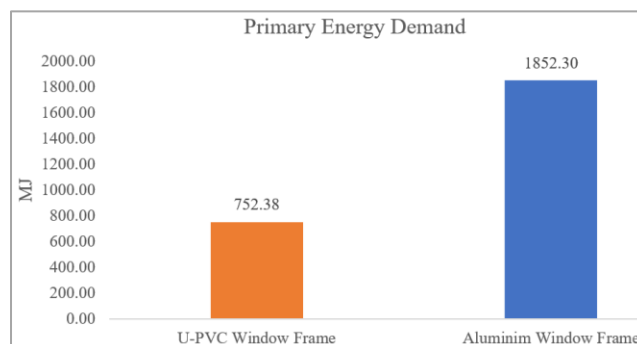


*Figure 6. PED results of NM3.*

#### NM4 Product System



*Figure 7. GWP results of NM4.*



*Figure 8. PED results of NM4.*

The total GWP for U-PVC window frame is 51.18 kgCO<sub>2</sub>eq for 1.82 m<sup>2</sup> area over a period of 50 years. The LCA analysis



of NM4 indicates that the total GWP of the NM material (U-PVC window frame) is 117% lower than the conventional material (Aluminum window frame). By switching from the CP to NM material 59.67 kg CO<sub>2</sub>eq/functional unit can potentially be avoided.

#### NM5 Product System

The total GWP for FRP walkway with landfill scenario in EoL is 218.40 kgCO<sub>2</sub>eq for 1m length, 2 m width and 1 m height over a period of 20 years. The LCA analysis of NM5 indicates that the total GWP of the NM material (FRP walkway) is 81% lower than the conventional material (Galvanized steel walkway). By switching from the CP to NM material 933.52 kg CO<sub>2</sub>eq/functional unit can potentially be avoided.

The scenario analysis has been conducted based on the landfill, incineration and recycling cases for both products. The results indicate that the FRP walkway is having lower values in all the three scenarios. The lower weight is one of the factors saving the material impacts. The FRP walkway is having GWP values of 218.40 kgCO<sub>2</sub>eq (landfill scenario), 208.71 kgCO<sub>2</sub>eq (recycling with cut off scenario) and 221.66 kgCO<sub>2</sub>eq (incineration scenario) whereas the galvanized steel walkway is having GWP values of 1151.92 kgCO<sub>2</sub>eq (100% landfill scenario), 753.87 kgCO<sub>2</sub>eq (80% recycling and 20% landfill scenario) and 900.89 kgCO<sub>2</sub>eq (50% recycling and 50% landfill scenario).

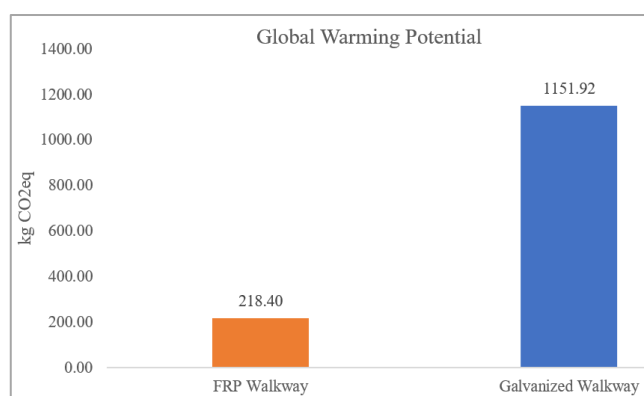


Figure 9. GWP results of NM5.

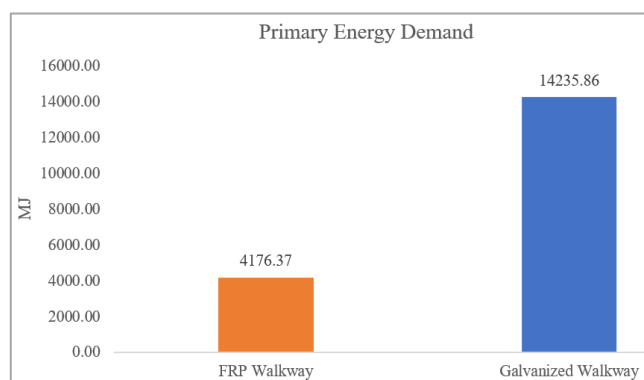


Figure 10. PED results of NM5.

#### NM6 Product System

The total GWP for HPL cladding with landfill scenario in EoL is 45.89 kgCO<sub>2</sub>eq for covering 1m<sup>2</sup> façade over a period of 50 years. The LCA analysis of NM6 indicates that the total GWP of the NM material (HPL cladding) is 31% higher than the conventional material (Aluminum cladding). By switching from the CP to NM material 10.81 kg CO<sub>2</sub>eq/functional unit can potentially be added. The total PED for HPL cladding is 284.77 MJ which is lower than the conventional product.

The scenario analysis has been conducted based on the landfill, incineration and recycling cases for both products. The results indicate that the HPL cladding is having lower values in recycling scenario and almost equal values to that of conventional product in the incineration scenario. The HPL cladding is having GWP values of 45.89 kgCO<sub>2</sub>eq (landfill scenario), 25.74 kgCO<sub>2</sub>eq (recycling with carbon correction scenario) and 35.88 kgCO<sub>2</sub>eq (incineration scenario) whereas in the aluminum cladding the recycling benefit has been taken for aluminum along with steel and rock wool has been landfilled.

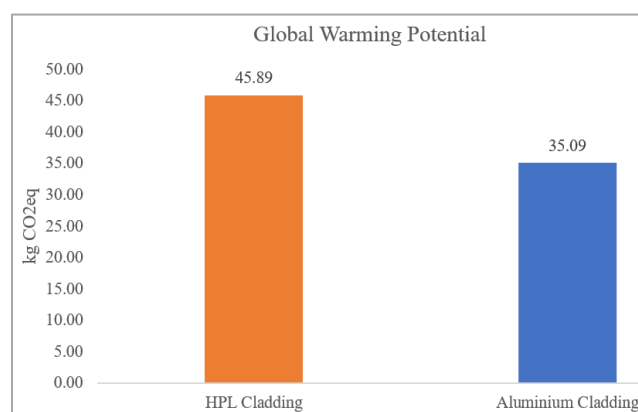


Figure 11. GWP results of NM6.

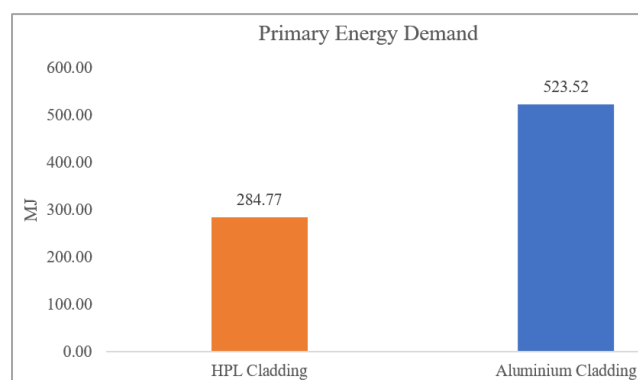


Figure 12. PED results of NM6.

## Abbreviations

EoL	End of Life
HPL	High Pressure Laminate Cladding

PED	Primary Energy Demand
GWP	Global Warming Potential
FRP	Fiber Reinforced Polymers
GFRP	Glass Fiber Reinforced Polymers
U-PVC	Unplasticized Polyvinyl Chloride
ECS	Epoxy-Coated Steel
IZA	International Zinc Association
FMC	Flood Mitigation Channel
MJ	Megajoules
GHG	Green House Gases
NM	Non-Metallic
CP	Conventional Product
LCA	Life Cycle Assessment

## Conflicts of Interest

The authors declare no conflicts of interest.

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