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A Comparison Study of Carbon and Energy Footprints Between Traditional Metallic and Non-Metallic Materials in the Oil and Gas Sector

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Abstract: This study assesses the carbon and energy footprints of the non-metallic (NM) and traditional metallic materials in the Oil and Gas applications following a “cradle to grave” Life Cycle Assessment in accordance with ISO 14040/44. The assessment aims to identify and mitigate non-metallics’ negative public image, and to provide scientifically-based data of the carbon footprint of NM’s. The study includes: the stages of production of raw material, transport of material to the manufacturing site, manufacturing, transport to installation, installation, and end of life. The study assesses nine NM products (such as steel reinforced thermoplastic pipe, and carbon steel with HDPE liner) which would replace their conventional products (such as steel tanks and butterfly valves). The assumptions in this study include material installation methods, transportation distances, mode of transportation, and others which are further discussed. The use of NM and traditional products is assumed to be identical, and therefore its carbon and energy footprint is excluded from the comparison. The study addresses materials and methods, which include the product system comparison between conventional and NMs, LCA inventory analysis for each comparison, and the geographical coverage and boundaries for each comparison. Moreover, the study specifies the measurement methodology for each comparison, for instance CO_{2eq}. The results and finding of this study are illustrated in charts for each comparison, and in summary, the assessment showed that the NM products have less global warming potential when compared to their respective traditional products in the Oil and Gas sector.

Keywords: Life Cycle Assessment, Global Warming, Oil and Gas Application, Non-Metallic (Polymers), Carbon Footprint

1. Introduction

For decades, the use of polymers is growing in many sectors and industries due its durability, weight and cost, and often replaces metals in various applications. In the oil and gas industry, polymers are used in coating, casing, piping, or vessel applications. This study assesses the carbon and energy footprints of the non-metallic (NM) and traditional metallic materials in the Oil and Gas products following a cradle-to-grave (the stages of production of raw material, transport of material to the manufacturing site, manufacturing, transport to installation, installation, and end of life) Life Cycle Assessment in accordance with ISO 14040/44 [12, 13]. The aim of this assessment is to identify and mitigate non-metallics’ negative public image, and to provide scientifically based data of the carbon footprint of NMs. The study assesses nine NM products which would replace their conventional products and discusses methods, materials selection, assumptions, and more. Since NMs are lighter than metallics, the transportation phase is expected to have less carbon footprint in the favor of NMs. Polymers do not require post-treatment work like polishing and finishing unlike their counterpart metals, which would require less energy footprint for non-metallics.

2. Material and Methods

2.1. Product Systems

The assessment comprises of Oil and Gas products which made up of material specified in the table below. The study covers stages of: raw material production, transport of material to the manufacturing site, manufacturing, transport to installation, installation, and end of life. It is assumed that during products' utilization, the impact to Global Warming Potential (GWP) or primary energy demand involved for the two product systems are similar. Therefore, the utilization phase is not covered in this study.

Table 1. *List of Non-metallic and conventional products included in the assessment.*

Product System	Product Name	Material Used for Conventional and Non-conventional Product
NM1	Glass Reinforced Epoxy (GRE Pipe)	Glass fiber, Epoxy Resin, Anhydrides
CP1	Carbon Steel pipe with external/internal Fusion bonded Epoxy (FBE) coating	Steel Billet (EAF Route), FBE
NM2	Downhole Full non-metallic casing	Glass fiber, epoxy, aromatic amines
CP2	Carbon Steel Casing with external FBE coating	Steel Casing based on API 5CT J55 standards, FBE coating
NM3	Polyvinyl chloride (PVC) pipe	PVC granulate
CP3	Ductile Iron pipe	Ductile Iron
NM4	PVC pipe	PVC granulate
CP4	Same as CP1	Same as CP1
NM5	Non-metallic valves (Butterfly valves)	Polypropylene (Body, Disc, hand Wheel), Stainless Steel (Stem), Cast iron (Gear Operator), Seats/Seals (Ethylene Propylene Diene Monomer (EPDM))
CP5	Butterfly valves	Cast iron and Phenolic resin
NM6	FRP Tanks	Glass fiber, polyester
CP6	Steel tanks	316 L Stainless Steel

2.2. Coverage and Boundaries

NM and conventional materials for Oil and Gas applications were evaluated from a cradle-to-grave perspective, covering the production, transportation, installation, and end-of-life (EoL) phase. The production step includes raw materials production and transportation, auxiliary material production, and the manufacturing process of the application. The installation step was considered within the boundaries. The utilization phase of the products was not considered within the boundaries assuming that NM and conventional materials have the same process. The end-of-life phase includes waste processing for reuse, recovery or recycling. All the life cycle phases evaluated for both materials rely on secondary data from the GaBi database [10, 14]. No primary data is used in this study.

For the geographical coverage, the study assumed the production, installation, and end of life to be in Saudi Arabia for conventional materials. For NM materials, the production is assumed to take place in Saudi Arabia, the United States, and Chine, while both of installation and end of life will be in Saudi Arabia.

2.3. LCA Inventory Analysis

Data was predominately collected using secondary research, including various research papers, reports, thesis and other reliable sources such as government websites (all referenced in the appendices). In the case that data was unavailable, we engaged with manufacturers to bridge data gaps and to resolve challenges pertaining to data collection. Data collection was finalized after quality assurance from three industry experts.

For the Oil and Gas products assessed within this study, each product system has four phases: production of raw material, transport of raw material to the manufacturing site, manufacturing, Installation and EoL. After manufacturing the product, it is transported to the installation site using a suitable mode of transportation, before it is available for the installation. The installation phase considers the installation of respective products. After the products' service life, it is transported to end-of-life where it is landfilled, incinerated, recycled, or left in-situ.

Below tables detail the analysis for each product system:

Table 2. *GRE vs Carbon steel FBE pipes.*

Product System NM1		
Phase	**NM1: Glass Reinforced Epoxy (GRE Pipe)**	**CP1: Carbon Steel pipe with external/internal Fusion bonded Epoxy (FBE) coating**
Production and manufacturing	GRE pipes are mainly manufactured using Epoxy Resin and Glass Fiber. Glass Fiber (~90%) is being procured from China whereas the Epoxy resin is manufactured within the KSA. At the manufacturing site, Filament Winding, Curing, Mandrel Extraction, Calibration, Threading, and Forming processes are carried out to manufacture GRE pipes. [2] The power consumption for the manufacturing of a GRE pipe is calculated to be 5.1 MJ/kg. The background data used in the manufacturing of the NM1 is was taken from GaBi Database	The key materials used are Steel Billet (EAF route) and Epoxy resin. The production of materials is within the KSA. Pipe manufacturing LCI was taken from literature for welded pipes[1] [15]. The background datasets and the energy consumed in coating the Fusion Bonded Epoxy (FBE) on the Carbon Steel pipes is taken from the GaBi Database

1 Environmental Evaluation for Three Typical Steel Pipe Production Processes Based on Energy Materials and Life Cycle Assessment

Product System NM1		
Phase	**NM1: Glass Reinforced Epoxy (GRE Pipe)**	**CP1: Carbon Steel pipe with external/internal Fusion bonded Epoxy (FBE) coating**
Installation	For the installation, trench excavation, backfilling, and settlement are excluded as this is assumed to be the same for NM1 and CP1. But for the alignment of NM1 pipes we assumed that pipe sections are bonded with epoxy adhesives. For pipe laying of NM1 and CP1 diesel consumption data has been derived from the literature[2]. The energy required during the welding of the CP1 pipe are found to be 1.54 kWh per m of the pipe.	
Transportation	Refer to background data	
EoL	The pipes are assumed to be left in-situ	

Table 3. *Non-metallic casing vs carbon steel tubing.*

Product System NM2		
Phase	**NM2: Downhole Full non-metallic casing**	**CP2: Carbon Steel tubing J-55**
Production and manufacturing	The major materials involved in the manufacturing are Glass fiber and Epoxy. Filament Winding process is being used to produce the Downhole Full non-metallic casing. The energy consumption per kg of the casing is derived from the literature1. All the background datasets involved in the manufacturing of the NM5 have been taken from GaBi Database	Casing manufacturing LCI was taken from Chinese literature for welded pipes and the chemical composition has been adapted based on API 5CT J55 standards [4-6]. All the background datasets involved in the manufacturing of the CP2 have been taken from GaBi Database
Installation	Installation is assumed to same for both NM2 and CP2, except the energy consumption during the insertion of casing in the injection wells. We have considered the diesel consumption of 0.00239 kg and 0.00073 kg per m of CP2 and NM2 pipe respectively used in the machinery for laying the pipe and has been taken from literature10. This is chosen according to GaBi Database	
Transportation	Refer to background data	
EoL	The pipes are assumed to be left in-situ	

Table 4. *PVC vs ductile iron pipes.*

Product System NM3		
Phase	**NM3: PVC pipe**	**CP3: Ductile Iron pipe**
Production and manufacturing	The major materials involved in the manufacturing is the PVC granulate. Extrusion process for the piping manufacturing is being considered for the manufacturing and is taken from GaBi database	Centrifugal casting for the Ductile iron pipe manufacturing is being considered and is taken from GaBi database
Installation	For the installation, trench excavation, backfilling, and settlement are excluded as this is assumed to be the same for NM6 and CP6. But for pipe laying of NM6 and CP6 diesel consumption data has been derived from the literature and found to be 4.41×10-5 kg per kg of pipe. For pipe alignment of NM6 pipe, PVC prime[3] and PVC solvent[4] cement was used whose chemical compositions are taken from the Safety datasheets. The diesel consumption during the welding of the CP3 pipe has been calculated and found to be 1.13E-03 kg per meter of the pipe.	
Transportation	Refer to background data	
EoL	The pipes are assumed to be left in-situ	

Table 5. *PVC vs carbon steel FBE coated pipes.*

Product System NM4		
Phase	**NM4: PVC pipe**	**CP4: Carbon Steel pipe with external/internal FBE coating**
Production and manufacturing	The major materials involved in the manufacturing is the PVC granulate. Extrusion process for the piping manufacturing is being considered for the manufacturing and is taken from GaBi database	The major materials involved here are Steel Billet (EAF route) and Epoxy resin [9]. The production of materials is within the KSA. Pipe manufacturing LCI was taken from literature for welded pipes9. The background datasets and the energy consumed in coating the Fusion Bonded Epoxy (FBE) on the Carbon Steel pipes is taken from the GaBi Database
Installation	For the installation, trench excavation, backfilling, and settlement are excluded as this is assumed to be the same for NM4 and CP4. But for pipe laying of NM4 and CP4 diesel consumption data has been de-rived from the literature and found to be 4.41×10-5 kg per kg of pipe. The electricity consumption during the welding of the CP4 pipe has been found to be 0.59 kWh per meter of the pipe.	
Transportation	Refer to background data	
EoL	The pipes are assumed to be left in-situ	

Table 6. *non-metallic vs butterfly valves.*

Product System NM5		
Phase	**NM5: Non-metallic valves (Butterfly valves)**	**CP5: Butterfly valves**
Production and manufacturing	The materials involved in the manufacturing of valves are Polypropylene, Stainless Steel, Aluminium/Cast Iron, Seats/Seals: Buna-N, EPDM or FKM [3]. All the background datasets for the upstream materials, casting process and molding process for the manufacturing of valves is taken from GaBi database	The process starts with the manufacturing of ductile iron pieces for valves obtained from casting and hot molding, then the pieces are mechanically worked and assembled with valves components (e.g. handles, gaskets, balls, fittings, etc.). [1]

2 Khan, L. R., & Tee, K. F. (2015). Quantification and comparison of carbon emissions for flexible underground pipelines.

3 https://www.pvcfittingsonline.com/media/pdf_documents/30755sub.pdf

4 https://www.pvcfittingsonline.com/media/pdf_documents/31017sds.pdf

Product System NM5		
Phase	**NM5: Non-metallic valves (Butterfly valves)**	**CP5: Butterfly valves**
Installation	The valves are assumed to be assembled manually at the installation site. Thus, no energy consumption has been considered.	
Transportation	Refer to background data	
EoL	After the service life of the valves the valves are assumed to be 100% landfill as a base case scenario for both NM5 and CP5	

Table 7. *FRP vs stainless steel tanks.*

Product System NM6		
Phase	**NM6: FRP Tanks**	**CP6: Stainless Steel tanks**
Production and manufacturing	The major materials involved in the manufacturing of FRP tanks are Glass fiber and Polyester Resin. Glass fiber are produced in China, whereas Polyester is produced within the KSA. The materials are being transported to the site where Filament Winding process is carried out for the fabrication of shell, whereas the ends are contact moulded. Energy needed for the Filament Winding process is taken from the literature1. Rest all the background datasets and processes involved in the manufacturing is taken from GaBi database	Tanks manufacturing LCI has been taken from literature [7]
Installation	Diesel consumption by a fork lifter to lift the tanks is calculated based on the potential energy gained (m*g*h) by tank if lifted to height h. The total height up to which the tank is being lifted in assumed to be 7m. The fork lifter (fuel efficiency of 33%) and the fuel dataset is taken from GaBi database	
Transportation	Refer to background data	
EoL	left in-situ.	

2.4. Measurement

Global warming potential and total primary energy demand were selected because of their relevance to climate change and energy efficiency where both are strongly interlinked, of high public and institutional interest, and deemed to be the most pressing environmental issues of our time. The global warming potential impact category is assessed based on a 100-year timeframe (GWP_{100}) per the ISO 14067 GWP (based on IPCC AR5) characterization factors taken from the 5th Assessment Report (IPCC, 2013) as this is currently the most commonly used metric.

Table 8. *Unit of Measurement used in the assessment.*

Impact Category	Description	Unit	Reference
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare. [8, 16]	kg CO_2 equivalent	(IPCC, 2013) [11]
Primary Energy Demand (PED)	A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g., petroleum, natural gas, etc.) and energy demand from renewable resources (e.g., hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are considered.	MJ (lower heating value)	(Guinée, et al., 2002)

3. Results and Findings

3.1. NM1 Product System

The LCA of NM1 indicates that the total GWP of GRE pipe is lower than the CP1 (Carbon Steel with external/internal FBE coating) by 57%, this means by switching to the GRE pipe, 114.44 kg CO_2 emissions per functional unit can potentially be avoided.

It should be noted that the GWP during the Installation phase for CP1 is higher owing to high energy consumption during welding of the pipes as compared to the use of Epoxy based adhesives in NM1 for pipe alignment.

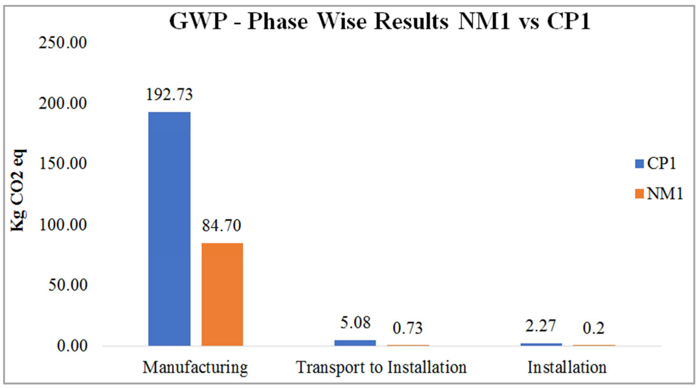

Figure 1. *GWP results for NM1 and CP1.*

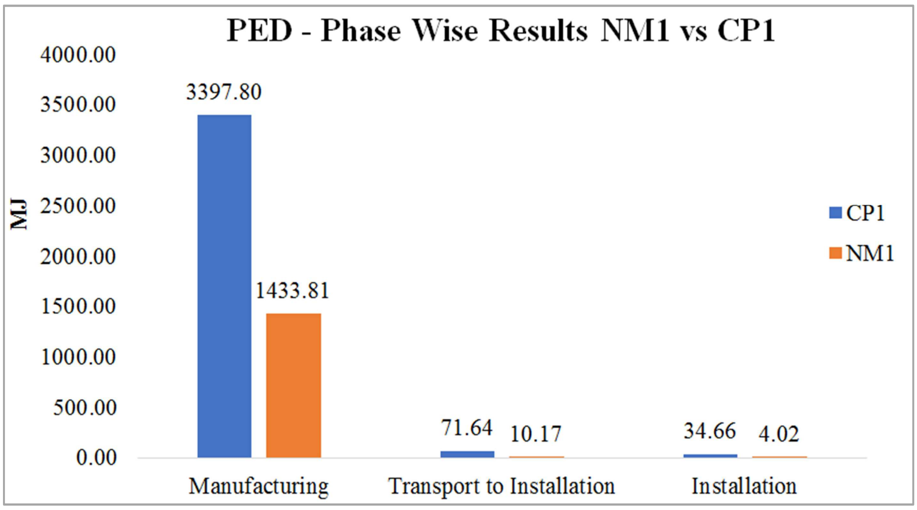

Figure 2. *PED results for NM1 and CP1.*

Figures 1 and 2 depict the GWP and PED for the GRE and Carbon Steel pipe with external/internal FBE coating. Figure 1 shows that the GWP for manufacturing the GRE pipe is lower than that of the Carbon Steel pipe with external/internal FBE coating. Considering impacts from the manufacturing process for CP1 as 100% Steel Cold Rolled Coil (EAF route) contributes the highest (~54.44%) whereas, for NM1, Glass fiber contributes (~34.20%), Epoxy Resin (~35.66%), and Electricity (26.22%). Further going down in the lifecycle, Transport to installation results have high impacts for the CP1 owing to the high weight of CP1 (74.6 kg) compared to NM1 (17.9 kg) and the scaling of the impacts of CP1 by 1.66 to match the functional unit.

Installation: trench excavation, backfilling, and settlement are considered the same for the NM1 product system, thus were excluded from the study. As seen in Figure 1, results for installation are higher for the CP1 because of the high electricity consumption in the welding of the pipes.

EoL results show zero impacts to the total results as the pipes are left in-situ after the service life.

3.2. NM2 Product System

The LCA analysis of NM2 indicates that the total GWP and primary energy demand of NM2 (Downhole full non-metallic casing) are lower than CP2 (Carbon Steel Casing with external FBE coating) by 27.19%. By switching from CP2 to NM2, 30.76 kg CO_2 eq. can be saved per functional unit. PED of NM2 is also lower than CP2 by 28% which resulted in the savings of 545.54 MJ per functional unit.

Figure 3 and Figure 4 depict the GWP and PED for the Downhole Full non-metallic casing vs Carbon Steel Casing. Figure 3 shows that the GWP for the Downhole Full non-metallic casing is lower than Carbon Steel Casing. The value differs considerably because of the manufacturing process. Considering impacts from manufacturing process for CP2 as 100% Steel alloy contributes the highest (~54.88%) whereas for NM2, Epoxy resin contributes the highest (~36.68%). Further going down in the lifecycle, Transport to installation results have high impacts for the CP2 owing to the high weight of CP2 (54.3 kg) compared to NM2 (16.7 kg), and the scaling of the impacts of CP2 by 1.333 to match the functional unit.

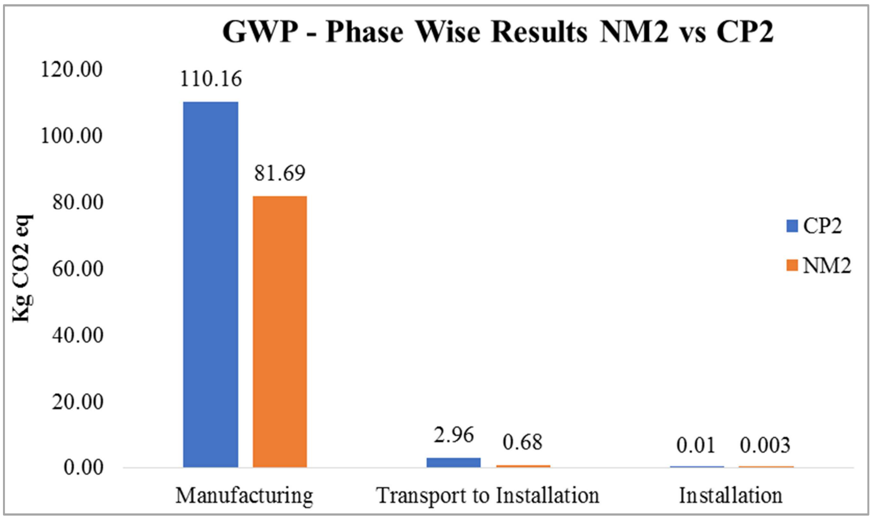

Figure 3. *GWP results for NM2 and CP2.*

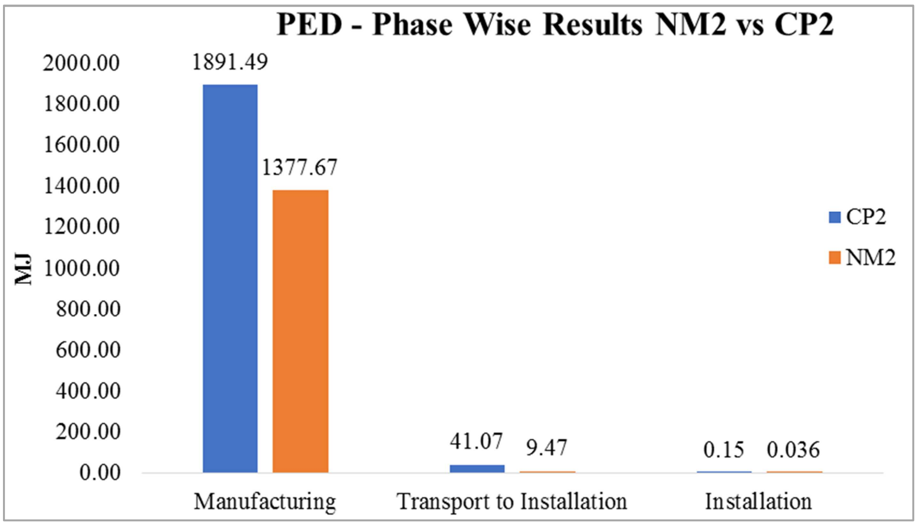

Figure 4. *PED results for NM2 and CP2.*

Installation results are higher for the CP2 because of the high weight of CP2 (54.3 kg) compared to NM2 (16.7 kg), and the scaling of the impacts of CP2 by 1.333 to match the functional unit.

EoL results show zero impacts to the total results as the casing is left in-situ after the service life.

3.3. NM3 Product System

The LCA analysis of NM3 indicates that the total GWP and PED of NM3 (PVC pipes) is lower than the CP3 (Ductile Iron pipe) by 70% and 54% respectively.

It should be noted that installation GWP and PED has higher values for NM3 as compared to that of CP6, this is because of the use PVC primer and PVC solvent cement.

In conclusion, the manufacturing stage of the CP3 is the main driver leading to higher GWP and PED results.

Figure 5 and Figure 6, depict the GWP and PED for PVC pipe and Ductile Iron pipe. As seen in Figure 5, the GWP for manufacturing the PVC pipe is lower than Ductile Iron pipe. Considering impacts from the manufacturing process for CP3 as 100%, Cast Iron contributes the highest (~95.71%), whereas for NM3, PVC granulate contributes the highest (~66.32%). Further going down in the life cycle, Transport to installation results have high impacts for the CP3 owing to the high weight of CP3 (kg) and the scaling of the impacts by 1.66 to match the functional unit.

Installation: trench excavation, backfilling, and settlement are considered the same for the NM6 product system, thus being excluded from the study. As seen in Figure 5, installation results are higher for the NM3 even though CP3 impacts has been scaled by 1.66 to reach the functional unit. These higher impacts result from the PVC primer and PVC solvent cement in the pipe alignment for NM3.

EoL results show zero impacts total results as the pipes are left in-situ after the service life.

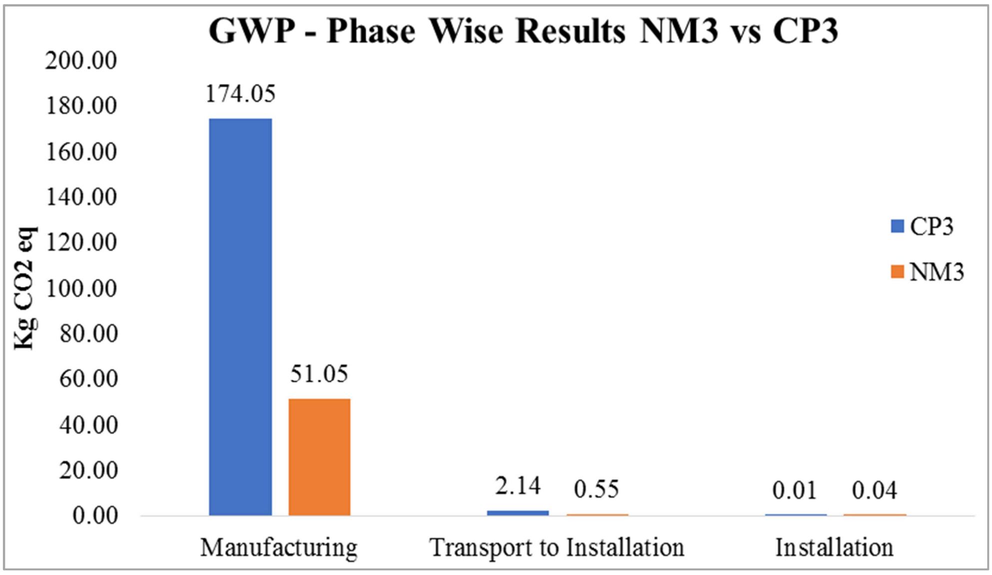

Figure 5. *GWP results for NM3 and CP3.*

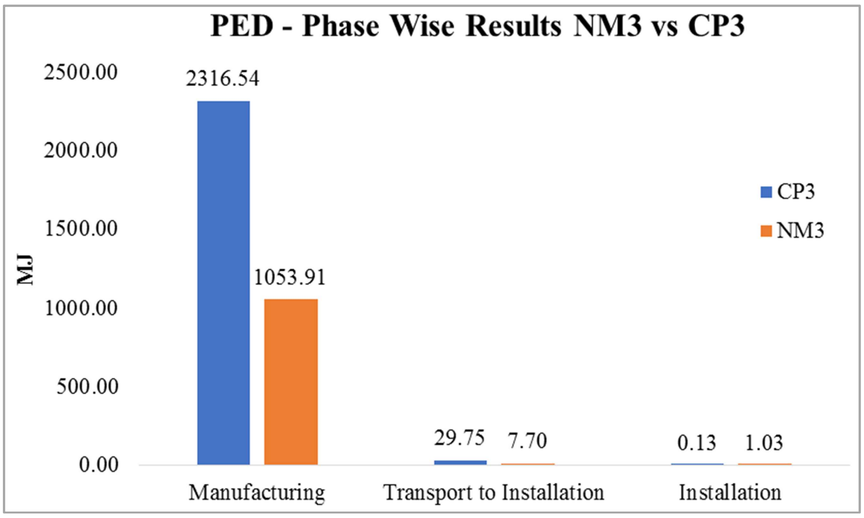

Figure 6. *PED results for NM3 and CP3.*

3.4. NM4 Product System

The LCA analysis of NM4 indicates that the total GWP and PED of NM4 (HDPE pipes) is lower than the CP4 (Carbon Steel pipe with external/internal FBE coating) by 88.22% and 77.49% respectively. By switching from CP4 to NM4, 70.59 kg CO_2 eq. can be saved per functional unit. In conclusion, the manufacturing stage of the CP4 is the main driver leading to higher GWP and PED results.

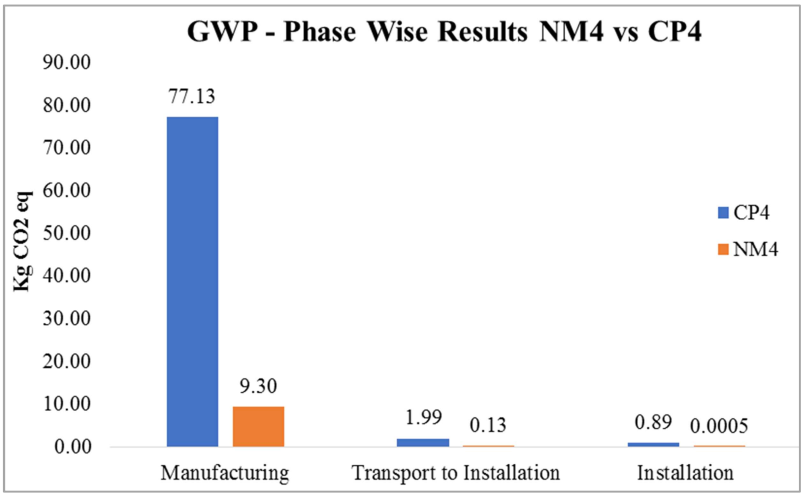

Figure 7. *GWP for NM4 and CP4.*

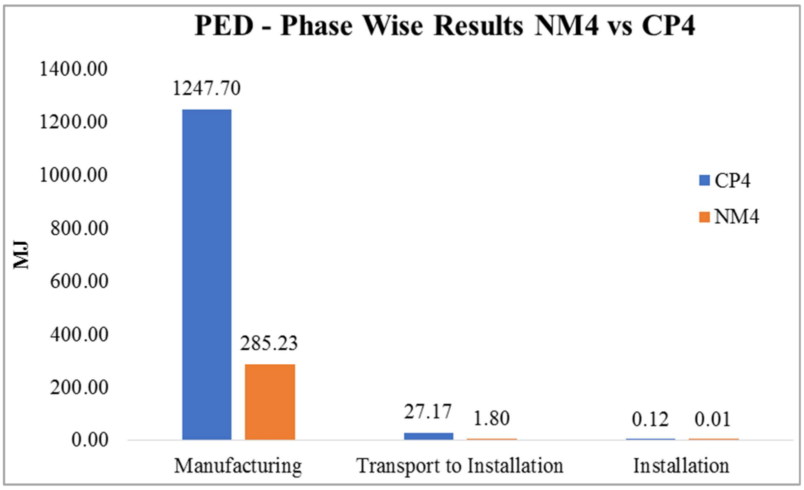

Figure 8. *PED results for NM4 and CP4.*

Figure 7 and Figure 8 depict the GWP and PED for HDPE pipe vs Carbon Steel pipe with external/internal FBE coating. As seen in Figure 7, the GWP for manufacturing the HDPE pipe is lower than the Carbon Steel pipe with external/internal FBE coating. Considering impacts from the manufacturing process for CP4 as 100% Steel Cold Rolled Coil (EAF route) contributes the highest (~52.90%) followed by thermal energy (~32.46%), whereas, for NM4, HDPE granulate contributes the highest (~61.53%). Further going down in the life cycle, Transport to installation results have high impacts for the CP7 owing to the high weight of CP7 (28.7 kg) compared to NM4 (3.17 kg) and the scaling of the impacts of CP7 by 1.66 to match the functional unit.

Installation: Trench excavation, backfilling, and settlement are considered the same for the NM7 product system, thus excluding the study. Pipe laying has been considered in the installation phase. As seen in Figure 7, results for installation are higher for the CP4 because of the high electricity consumption in the welding of the pipes.

EoL results show zero impacts total results as the pipes are left in-situ after the service life.

3.5. NM5 Product System

The LCA analysis of NM5 indicates that the total GWP and PED of NM5 (Non-metallic butterfly valves) is lower than the CP5 (Metallic butterfly valves) by 87.3% and 66% respectively. By switching from CP5 to NM8, 160.97kg CO_2 eq. and 315.51 MJ can be saved per functional unit. In conclusion, the manufacturing stage of the CP5 is the main driver leading to higher GWP and PED results.

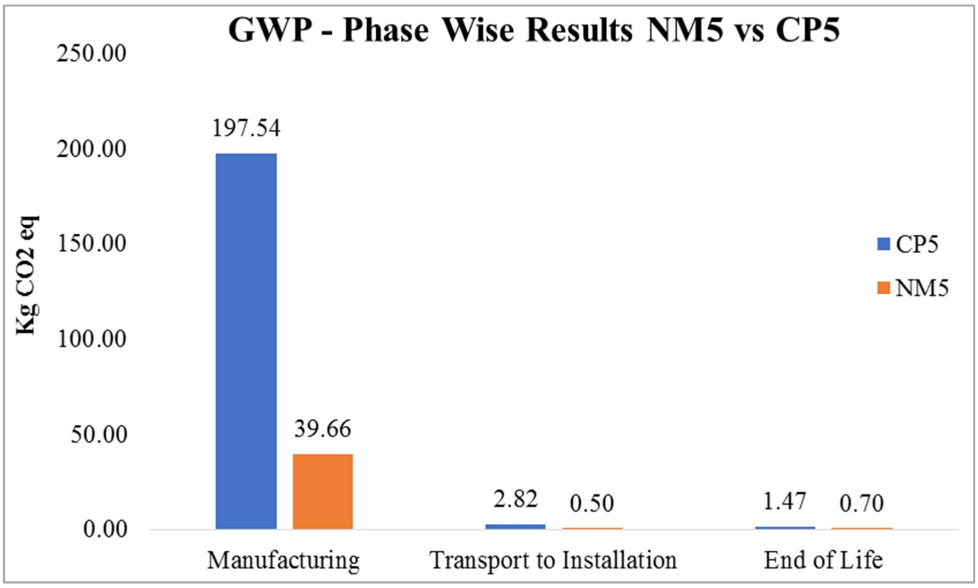

Figure 9. *GWP results for NM5 and CP5.*

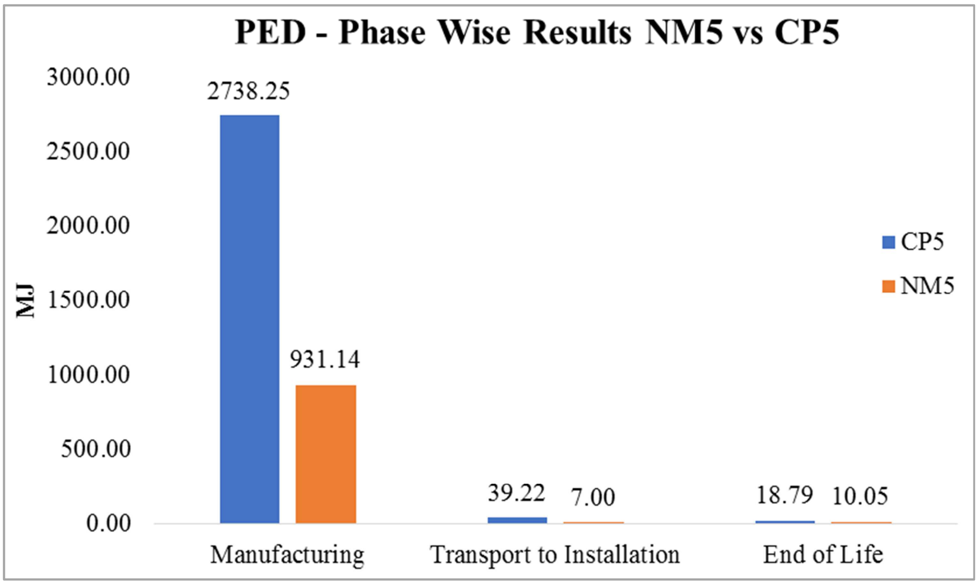

Figure 10. *PED results of NM5 and CP5.*

Figure 9 and Figure 10 depict the GWP and PED for Non-metallic Butterfly valves and Metallic Butterfly valves. As seen in Figure 9, the GWP for manufacturing the NM5 is lower than CP5. Considering impacts from the manufacturing process for CP5 as 100% Valve body (of Ductile Cast iron part) contributes the highest (~61.47%), whereas, for NM5, Valve body (of Polypropylene material) contributes the highest (~56.54%). Further going down in the life cycle, Transport to installation results have high impacts for the CP5 owing to the high weight of CP5 (69 kg) compared to NM5 (12.32 kg).

Installation process for the NM5 product system considers the manual assembly of the valve part. Thus, no energy consumption is considered.

EoL results: As a base case scenario, 100% landfill is considered for the NM8 product system.

3.6. NM6 Product System

The LCA analysis of NM6 indicates that the total GWP and PED of NM6 (Non-metallic butterfly valves) is lower than the CP6 (Metallic butterfly valves) by 22% and 10% respectively. By switching from CP6 to NM6, 48.15 kg $CO_{2\ eq.}$ and 1848.07 MJ can be saved per functional unit.

In conclusion, the manufacturing stage of the CP6 is the main driver leading to higher GWP and PED results.

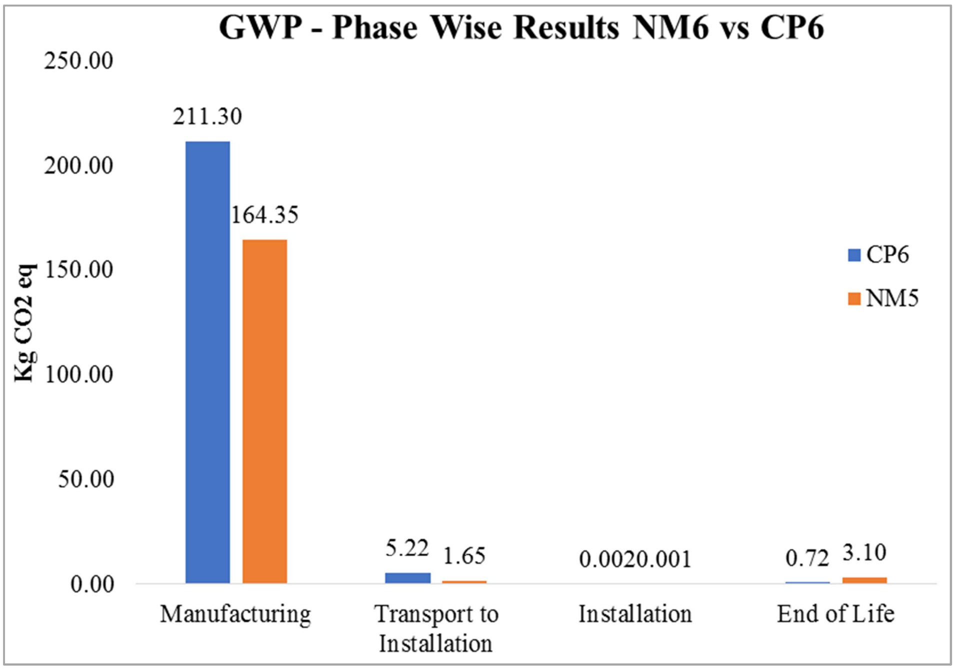

Figure 11. *GWP results for NM6 and CP6.*

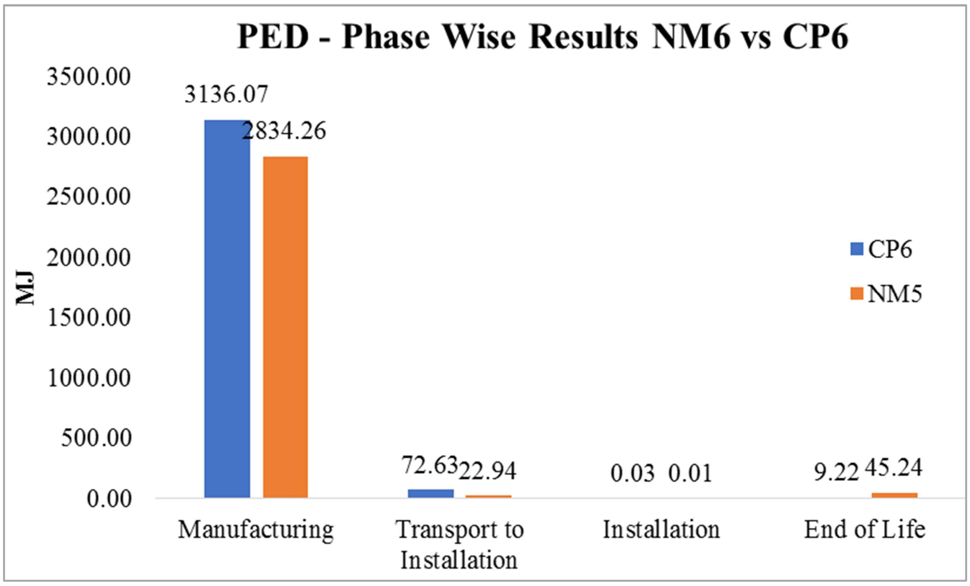

Figure 12. *PED results for NM6 and CP6.*

Figure 11 and Figure 12 depict the GWP and PED for FRP and Stainless-Steel tanks. As seen in Figure 11, the GWP for manufacturing the NM6 is lower than CP6. Considering impacts from the manufacturing process for CP6 as 100% Steel Alloy contributes the highest (~88.83%) whereas, for NM6, Glass fiber contributes the highest (~46.79%) followed by the Electricity (~26.23%). Further going down in the life cycle, Transport to installation results have high impacts for the CP6 owing to the high weight of CP6 (128 kg) compared to NM6 (40.4 kg).

Installation process for the NM9 product system considers Diesel consumed by the forklift to lift the FRP tanks. Since CP6 has a higher weight than NM9, installation results for CP6 is higher than NM6.

EoL results: As a base case scenario, 100% landfill is considered for the NM6, whereas 25% landfill and 75% recycling for CP6 has been considered. The EoL results for the CP6 is not showing the recycling credits because of the cut-off approach.

4. Conclusion

4.1. NM1 Product System

1) The GRE Pipe, which has a 50-year service life, has lower GWP impacts when compared to the Carbon Steel pipe with external/internal FBE coating, which have a 30-year service life.
2) By switching from Carbon Steel pipe with FBE coating to GRE Pipe, 114.44 kg CO_2 and 2056.10 MJ of Primary Energy would be saved per functional unit.

4.2. NM2 Product System

1) The Downhole Full non-metallic casing, which has a 20-year service life, has lower GWP impacts when compared to the Steel casing with external FBE coating, which has 15-year service life.
2) By switching from Steel casing to Downhole Full non-metallic casing, 30.76 kg CO_2 and 65.99 MJ of Primary Energy could be saved per functional unit.

4.3. NM3 Product System

1) The PVC pipe, which has 50-year service life, has lower GWP impacts when compared to the Ductile Iron pipe, which has 30-year service life.
2) By switching from Ductile Iron pipe to PVC pipe, 124.55 kg CO_2 and 1283.78 MJ of Primary Energy could be saved per functional unit.

4.4. NM4 Product System

1) The HDPE pipe, which has 50-year service life, has lower GWP impacts when compared to the Carbon Steel pipe with external/internal FBE coating, which has 30-year service life.
2) By switching from Carbon Steel pipe with FBE coating to HDPE pipe, 70.59 kg CO_2 and 987.95 MJ of Primary Energy could be saved per functional unit.

4.5. NM5 Product System

1) The non-metallic butterfly valves, which have 20-year service life, has lower GWP im-pacts when compared to the metallic butterfly valves, which have 20-year of service life.
2) By switching from metallic to non-metallic valves, 48.15 kg $CO_{2\ eq}$. and 315.51 MJ of Primary Energy could be saved per functional unit.

4.6. NM6 Product System

1) The NM6, which has 20-year service life, has lower GWP impacts when compared to the CP6, which has 20-year service life.
2) By switching from FRP tanks to Stainless steel tanks, 160.97 kg $CO_{2\ eq}$. and 1848.07 MJ of Primary Energy could be saved per functional unit.

Abbreviations

NM: Non-Metallic
CP: Conventional Product
LCA: Life Cycle Assessment
GWP: Global Warming Potential
PED: Primary Energy Demand
GRE: Glass Reinforced Epoxy
FRP: Fiber Glass Reinforced
FBE: Fusion Bond Epoxy
PVC: Polyvinyl Chloride
EAF: Electric Arc Furnace

Conflicts of Interest

The authors declare no conflict of interest.

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