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The Impact of Operating Electric Ship on Environment at Kigamboni -Ferry in Dar Es Salaam Tanzanian

[1]Ally Kategire, [2]Benjamin Mbeba Meli and [3]Lucas Pastory Mwisila
[1]Ally Kategire, P.o Box 30150, Mafia, TAMESA-PWANI, Tanzania, East Africa; email;
allykategile81@gmail.com

[2]Benjamin Mbeba Meli,
Dares Salaam Maritime Institute, Department of Science and Management, P.o Box 6727,
Dares Salaam, Tanzania, East Africa, email: benjaminmbeba@gmail.com /
Benjamin.meli@dmi.ac.tz

[3]Lucas Pastory Mwisila,
Dares Salaam Maritime Institute, Department of Science and Management, P.o Box 6727,
Dares Salaam, Tanzania, East Africa, email: lmwisila@yahoo.com/ lucas.mwisila@dmi.ac.tz
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Abstract

This paper utilized data from the study conducted at Kigamboni-Magogoni ferry in Dar es Salaam, The maritime industry plays an indispensable role in global trade, responsible for transporting approximately 80% of the world's goods. Despite its significance, the industry faces mounting pressure to address its environmental footprint, largely due to its reliance on fossil fuels, which contribute to greenhouse gas (GHG) emissions, air pollution, and subsequent climate change. In recent years, the quest for more sustainable maritime solutions has gained momentum, with electric ships emerging as a promising alternative. This paper explores the environmental implications of operating electric ships, with a particular focus on their impact on marine ecosystems in Tanzania. Tanzania, with its extensive coastline and strategic location along major shipping routes, is uniquely positioned to benefit from advancements in maritime technology. However, the adoption of electric ships in this region presents both opportunities and challenges. This study employs a mixed-methods approach to assess the environmental benefits and potential drawbacks associated with the introduction of electric ships in Tanzanian waters. Through surveys, interviews with industry experts, and observational analysis, the research provides a comprehensive evaluation of the current and projected impacts of electric ships on the environment. The findings of this paper highlight several key environmental benefits of electric ships. First and foremost, the transition from conventional diesel-powered vessels to electric ships significantly reduces GHG emissions, contributing to global efforts to combat climate change. Electric ships also have the potential to lower air pollution levels, particularly in port cities like Dar es Salaam, where emissions from traditional ships have been a growing concern. By reducing the release of pollutants such as sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM), electric ships can improve air quality and public health in coastal communities. The paper recommends for further studies should be done in the same area in order to see consistence or inconsistence of the findings of the study.

Key words: *Electric Ships, Battery Electric Ships, Hybrid Electric Ships, Diesel-Electric ships and Nuclear-Electric ships.*

Introduction

The shipping industry is a significant contributor to global greenhouse gas emissions, accounting for approximately 2-3% of the world's total emissions from fuel consumption (corbett.2014),(Smith et al., 2014) By adopting sustainable practices, such as using electrical ships, the maritime sector could significantly reduce its carbon footprint and contribute to global climate change mitigation efforts.

Traditional marine fuels, particularly heavy fuel oil, release pollutants into the air, leading to poor air quality and adverse health effects. By transitioning to electric ships powered by clean energy sources like renewable electricity or fuel cells, the industry it improves air quality both on land and at sea, reducing harmful emissions such as sulfur oxides (Sox), nitrogen oxides (NOx), and particulate matter (PM).

The maritime industry's operations it had significant impacts on marine ecosystems, including pollution from spills, ballast water discharge and habitat destruction from ship grounding or anchor damage. Embracing sustainable maritime transportation practices, such as utilizing electrical ships with lower environmental risks, could help protect marine biodiversity and ecosystems.

The International Maritime Organization (IMO) has implemented regulations to reduce emissions, including the global sulfur cap for marine fuels and the Energy Efficiency Design Index (EEDI). By adopting sustainable practices, the industry can ensure compliance with these regulations, avoiding penalties and reputational risks. It a play vital role in transport over 90% of World which is the greatest determinant of the economy.

The maritime industry faces escalating environmental concerns and stringent regulations, prompting a shift from traditional oil-based fuels to alternative energy sources. Electric propulsion systems, particularly those powered by batteries, are recognized as key to achieving decarburization within this sector. Charging batteries from coastal power grids offers the potential for approximate zero emissions during vessel operation, but there is a lack of comprehensive environmental assessments considering the entire lifecycle of battery-powered ships.

While previous studies have emphasized emissions reductions during vessel operation, there remains a gap in understanding the environmental impact of different electricity production methods for charging onboard batteries. This gap poses a critical question: do battery-powered ships truly offer superior environmental benefits compared to diesel-powered vessels, or are there factors, such as emissions from electricity generation, that need careful consideration in Tanzania?

Given initiatives like the United Republic Of Tanzania Vice President's Office 2022-2032 National Environmental Plan, there is an urgent need to evaluate the environmental implications of battery-powered ships. Therefore, the overarching problem addressed by this spaper is to determine whether battery-powered ships provide unequivocal environmental advantages over diesel-powered counterparts, and to identify key factors influencing their environmental performance. Addressing this problem will guide decision-making processes in the maritime industry towards environmentally sustainable propulsion systems.

2.0 Review of the paper

Sustainable maritime transportation is a crucial aspect of reducing the environmental impact of the shipping industry Rodrigue, J.-P. (2020). In recent years, there has been growing interest in electric ships as a promising solution to address the environmental challenges associated with traditional fossil fuel-powered vessels. According to Smith (2022) While there is limited literature specifically focusing on electric ships, several studies have explored various aspects of sustainable maritime transportation and highlighted the environmental benefits of electrification.

Emphasize that electric propulsion systems not only reduce greenhouse gas emissions but also improve energy efficiency and reduce noise pollution, making them a viable alternative for achieving sustainable shipping practices. According to Liu et al. (2021). Here was a review of some key literature in this field.

2.1 Conceptual Definitions

"**Electric Ships:** Defined is a powered ship driven by electric motors, which are powered by either on-board battery packs, solar panel, wind turbine or generator(Age, 2012).A Review of Power System Design, Architectures, and Strategies" by Hult, M., &Bigum, M. (2019): This comprehensive review was article discussed the power system design, architectures, and strategies employed in electric ships. It provides an overview of electric propulsion technologies, energy storage systems, power management, and control strategies. The study highlights the environmental benefits of electric ships, including reduced emissions and improved energy efficiency.

Environment Impact of Electric and Hybrid Ships" by Parfaits, H. N., &Kontovas, C. A. (2018): This study was assessed the environmental impact of electric and hybrid ships compared to conventional vessels. It analyzes various aspects such as energy consumption, greenhouse gas emissions, and air pollution. The findings indicate that electric and hybrid ships have the potential to significantly reduce emissions and improve energy efficiency, particularly when powered by renewable energy sources.

Evaluate life cycle: it approximates the life time of modern ship is about 25-30 years. According to (Jamshed Alam Patwary, 2015) the life cycle series consist of acquire, commission, operate and dispose. Life cycle evaluation (LCE) study according to Riber, C., et al. (2019), analyzes the environmental impact of an electric passenger ship throughout its life cycle. It compares the environmental performance of the electric ship with conventional diesel-powered vessels. The LCE results demonstrate the significant potential of electric ships to reduce emissions and contribute to a more sustainable maritime industry.
Marine Environment : act as high productive zone that consist different kind of subsystem, such as coral reefs and sea grasses (Thushari & Senevirathna, 2020).

2.2 Types of Electric ships

Battery Electric Ships: These vessels rely on large-scale battery banks to store and provide electrical energy for propulsion and onboard systems. Battery technology has advanced significantly in recent years, improving energy density and allowing for longer operational ranges(EMSA, 2020). That kind of ship is equipped with large battery banks that store electrical energy. These batteries are typically charged while the ship is docked at port, using electricity from the grid or renewable energy sources like wind or solar power. When the ship is underway, the stored electrical energy is used to power electric motors that drive the ship's propellers.

These electric motors are highly efficient and can provide a smooth and quiet propulsion experience compared to traditional diesel engines. In addition to propulsion, the battery banks also provide power for various onboard systems such as lighting, heating, cooling, and navigation equipment. This ensures that the ship can operate all its essential functions without relying on fossil fuels. Advanced energy management systems monitor and control the distribution of electrical power throughout the ship. They optimize the use of stored energy, ensuring that the batteries are used efficiently and prolonging their operational life. Once the ship reaches its destination or a port with charging facilities, the batteries can be recharged. The charging process can be done relatively quickly depending on the port's infrastructure, and in some cases, the ship can be charged using renewable energy sources, further enhancing its sustainability.

Hybrid Electric Ships: Hybrid systems combine electric propulsion with a secondary power source, often a smaller conventional engine. The secondary source can be used to charge the batteries or provide additional power during peak demands, ensuring flexibility and extended range according to (Andersen & Rzadki, 2023). Hybrid electric ship: These vessels use a combination of batteries and other power sources, such as diesel engines or fuel cells. Batteries can be charged by the engines or through shore power. According to D. A., & Turnock, S. R. (2012). Hybrid electric ships are equipped with both large battery banks and conventional power sources like diesel engines or fuel cells. This setup allows for flexible and efficient energy use. The flexible hybrid solution allows the vessel to operate the engines at their optimal load by providing peak shaving which removes variable loads and also acts as spinning reserve. This reduces fuel consumption and associated emissions, increases engine maintenance intervals, and reduces noise levels when needed. According to Smith, T. (2022). Hybrid ships are equipped with both battery banks for electric propulsion and a secondary power source, typically a smaller conventional engine, which could be diesel or gas-powered. During normal operations, the ship primarily relies on the battery banks to power electric motors that drive the ship's propellers. This mode is particularly beneficial for low-speed operations, such as maneuvering in ports or navigating through environmentally sensitive areas, where emissions and noise need to be minimized. The conventional engine serves as a backup and supplementary power source. It can be used in several ways

Charging the Batteries: The engine can run to generate electricity and recharge the battery banks, either while the ship is underway or when there is excess capacity.

Peak Demand: During periods of high power demand, such as high-speed cruising or when additional thrust is needed, the engine can provide extra power to the electric motors, ensuring that the ship maintains optimal performance.

An advanced energy management system coordinates the operation of both power sources. It optimizes the use of stored electrical energy and the conventional engine to maximize efficiency and reduce emissions. The system decides when to use the battery banks, when to engage the conventional engine, and when to recharge the batteries. This hybrid setup offers significant flexibility. The ship can switch between electric and conventional power based on operational needs and environmental considerations. For example, it can operate in all-electric mode in emission-controlled areas and switch to hybrid mode for extended range during long voyages. According to Andersen & Rzadki (2023), this combination ensures flexibility and extended range, allowing hybrid electric ships to reduce their environmental impact while maintaining operational efficiency and reliability. In this system she hybrid electric ships, it use the conventional engine operates at its optimal load, and the battery system provides peak shaving by absorbing and supplying power during variable loads. This means the engine runs

more efficiently, avoiding fluctuations in power demand. The battery system also acts as a spinning reserve, ready to provide immediate power if needed, reducing the need for the engine to run continuously at high loads. By operating the engine at optimal loads and using batteries for peak demands and spinning reserve, hybrid ships significantly reduce fuel consumption and associated emissions. The engine runs more efficiently, leading to less frequent maintenance intervals and reduced wear and tear.
Fuel Cell Electric ships: These ships use hydrogen fuel cells to generate electricity, which is then used for propulsion and other onboard systems. Fuel cells produce zero emissions, making them an environmentally friendly option. According to Baldi, F., & Gabrielli, R. (2018).Fuel cells offer high energy efficiency and produce only water vapor as a byproduct, further reducing emissions. According to Larminie, J., & Dicks, A. (2018).

Fuel cells generate electricity through an electrochemical reaction, rather than combustion. Here's a simplified process of how they work: The protons pass through the proton exchange membrane (PEM) to the cathode side. The electrons, unable to pass through the membrane, flow through an external circuit, creating an electric current that can be used to do work (such as powering a motor). At the cathode, oxygen (O_2) from the air combines with the electrons (e^-) and the protons (H^+) to form water (H_2O). The only byproducts of this reaction are electricity, heat, and water vapor, making it a very clean energy source.

Full electric ship: These ships rely entirely on batteries for their propulsion and onboard power needs. They need to be charged at ports. According to Roy, B., & Rutherford, D. (2017). The terms are often interchangeable, but "full electric ship" might be used to more explicitly indicate the total reliance on batteries without any supplementary energy sources. Both types of ships share the same working principles of energy storage, propulsion, onboard system power supply, energy management, and recharging at ports.

Diesel-Electric ships: These ships have diesel engines that generate electricity, which is then used to power electric motors for propulsion. The diesel engines can operate at optimal efficiency, reducing fuel consumption and emissions. According to Papanikolaou, A. (2014). The ship is equipped with one or more diesel engines. Instead of being connected directly to the propellers, these engines drive generators that produce electrical power. The diesel engines drive generators, converting mechanical energy from the engines into electrical energy. This electricity is then used to power the ship's electric motors and other onboard systems. The electric motors, powered by the electricity generated by the diesel engines, drive the ship's propellers. This setup allows for precise control of the propulsion system and efficient power distribution. The electrical energy generated by the diesel engines also supplies power to various onboard systems, including lighting, heating, cooling, navigation, and communication equipment. This ensures that the ship can operate all its essential functions efficiently.

An advanced energy management system oversees the distribution of electrical power. It ensures that the diesel engines and generators operate at their optimal efficiency, adjusting the power output to match the ship's energy demands. diesel-electric ships use diesel engines to generate electricity, which is then used to power electric motors for propulsion. This configuration allows the diesel engines to operate at optimal efficiency, reducing fuel consumption and emissions while providing precise control over the ship's propulsion and power needs.

Gas Turbine-Electric ships: Similar to diesel-electric ships, but using gas turbines instead of diesel engines to generate electricity. Gas turbines can provide higher power output and are often used in high-speed vessels. According to (T. V., & Andersson, K. (2018) .The ship is equipped with one or more gas turbines. These turbines burn fuel, such as natural gas or marine diesel, to produce mechanical energy. The gas turbines operate at high efficiency, especially at higher power outputs, making them suitable for high-speed applications.

The mechanical energy produced by the gas turbines is used to drive generators, which convert the mechanical energy into electrical energy. This electricity is then used to power the ship's electric motors and other onboard systems. The electric motors, powered by the electricity generated by the gas turbines, drive the ship's propellers. These electric motors provide efficient and quiet propulsion, offering precise control and reducing the complexity associated with direct mechanical drive systems. The electrical energy generated by the gas turbines also supplies power to various onboard systems, including lighting, heating, cooling, navigation, and communication equipment. This ensures that the ship can operate all its essential functions efficiently on the generated electricity. An advanced energy management system continuously monitors and optimizes the use of generated electrical power. It ensures efficient distribution of power to both the propulsion system and the onboard systems, maximizing the operational efficiency and performance of the ship. One of the key advantages of gas turbine-electric systems is that gas turbines can operate at their most efficient point, regardless of the variable power demands for propulsion. This optimal operation reduces fuel consumption and emissions compared to conventional mechanical drive systems that must constantly adjust to changing power needs. Gas turbines are capable of generating high power output, making them ideal for high-speed vessels and applications where large amounts of power are needed quickly. This high power capability also allows for rapid acceleration and maneuverability. By operating gas turbines at their optimal efficiency and using the electrical energy generated for propulsion and other systems, gas turbine-electric ships can achieve reduced fuel consumption and lower emissions. The efficiency of gas turbines at high loads and their ability to use cleaner fuels contribute to the environmental benefits. Gas turbine-electric ships offer significant operational flexibility. The electric propulsion system provides precise control over the ship's speed and maneuverability. Additionally, gas turbines can be quickly started and stopped, allowing for dynamic power management and rapid response to changing operational conditions. In general gas turbine-electric ships use gas turbines to generate electricity, which is then used to power electric motors for propulsion and onboard systems. This configuration allows the turbines to operate at optimal efficiency, providing high power output while reducing fuel consumption and emissions. The system offers precise control and flexibility, making it suitable for high-speed and high-power applications (T. V., & Andersson, K., 2018)

Nuclear-Electric ships: These ships use nuclear reactors to generate electricity. The generated power is used to run electric propulsion systems. This type is primarily used in naval vessels, such as submarines and aircraft carriers, due to their long operational range without refueling. According Colton, R. P. (2012).

The ship is equipped with a nuclear reactor that serves as the primary power source. The reactor uses nuclear fission to generate heat. In this process, heavy atomic nuclei (such as uranium or plutonium) split into smaller parts, releasing a significant amount of energy. The nuclear fission reaction produces a substantial amount of heat. This heat is used to produce steam from water in a secondary loop. The steam is kept separate from the reactor core to prevent contamination. The steam generated from the reactor's heat drives steam turbines. These turbines convert thermal energy from the steam into mechanical energy. The mechanical energy from the steam turbines is used to drive electric generators. These generators convert mechanical energy into electrical energy, which is then distributed throughout the ship. The generated electricity powers electric motors that drive the ship's propellers. Electric propulsion systems offer precise control, high efficiency, and quieter operation compared to traditional mechanical propulsion systems. The electrical energy generated by the nuclear reactor also supplies power to various onboard systems, including lighting, heating, cooling, navigation, and communication equipment. This ensures that the ship can operate all its essential functions efficiently. An advanced energy management system oversees the distribution of electrical power generated by the nuclear reactor. It ensures efficient and balanced power usage between the propulsion system and onboard systems, optimizing overall performance. One of the significant advantages of nuclear-electric ships is their extended operational range.

Nuclear reactors can operate for long periods without refueling, allowing ships to undertake prolonged missions and reducing the need for frequent stops for fuel. Nuclear-electric ships are equipped with multiple safety systems to ensure the safe operation of the nuclear reactor. These include radiation shielding, emergency shutdown systems, and redundant cooling systems to prevent overheating. While nuclear reactors do not emit greenhouse gases during operation, they require careful handling of nuclear fuel and waste. The lack of emissions makes them environmentally friendly in terms of operational pollution, but there are significant considerations regarding the lifecycle management of nuclear materials. In general nuclear-electric ships use nuclear reactors to generate heat, which is converted into electrical energy through steam turbines and generators. This electricity powers electric propulsion systems and onboard equipment. The use of nuclear power provides these ships with a long operational range and high efficiency, making them particularly suitable for naval vessels that require extended mission capabilities by Colton, (2013)

Solar Electric ship: These vessels use solar panels to generate electricity, which is stored in batteries and used for propulsion. They are often used for small recreational boats and research vessels. According toYamamoto, K. (2017). The ship is equipped with an array of solar panels, typically installed on the deck or other exposed surfaces. These panels capture sunlight and convert it into electrical energy through the photovoltaic effect. The solar panels generate direct current (DC) electricity when exposed to sunlight. The efficiency of this conversion process depends on the quality of the solar panels and the amount of sunlight available. The generated electricity is stored in onboard batteries. These batteries can store large amounts of energy and provide a stable power supply even when the sunlight is not available, such as during nighttime or cloudy conditions. The stored electrical energy in the batteries is used to power electric motors that drive the ship's propellers. These electric motors offer efficient, quiet, and environmentally friendly propulsion. In addition to propulsion, the electricity stored in the batteries powers various onboard systems, including lighting, heating, cooling, navigation, and communication equipment. This ensures that the ship can operate all its essential functions on solar-generated power. An advanced energy management system monitors and optimizes the use of stored energy. It ensures efficient distribution of power between the propulsion system and other onboard systems, maximizing the operational efficiency and range of the ship. To maximize energy generation, the ship may be equipped with solar tracking systems that adjust the angle of the solar panels to follow the sun's movement. This ensures the panels capture the maximum amount of sunlight throughout the day.

Solar electric ships produce zero emissions during operation, making them an environmentally friendly option. They rely on renewable energy and do not require fossil fuels, significantly reducing their carbon footprint. Due to the current limitations of solar panel efficiency and energy storage capacity, solar electric ships are typically used for small recreational boats, research vessels, and other applications where long operational ranges and high speeds are not critical. They are ideal for operations in sunny regions and for tasks that benefit from silent and clean propulsion. In general solar electric ships use solar panels to generate electricity, which is stored in batteries and used for propulsion and onboard systems. This setup provides a sustainable and environmentally friendly option for maritime transportation, particularly suited for small boats and research vessels that can take advantage of solar power according to Yamamoto, K. (2017)

Wind -assisted electric ship: These ships combine wind power (using sails or kites) with electric propulsion systems. Wind energy can reduce the load on the electric propulsion system, increasing overall efficiency. According to Stansby, P., & Wood, R. (2014). The ship is equipped with sails, kites, or other wind-catching devices designed to harness wind energy. This wind power can be directly used to assist with the ship’s propulsion. When there is sufficient wind, the sails or kites generate thrust by capturing the wind's energy. This thrust helps propel the ship forward, reducing the load on the electric propulsion system. The ship can use various types of sails, such as traditional fabric sails, rigid sails, or kites, each optimized for different wind conditions and vessel types. The ship also has electric motors powered by stored electrical energy from batteries or other onboard energy sources. These motors drive the ship's propellers and provide propulsion when wind power is insufficient or to complement the wind power.

The ship may have batteries or other energy storage systems that store electricity generated from renewable sources (e.g., solar panels) or from shore power when docked. This stored energy is used to power the electric motors and onboard systems. The ship can operate in a hybrid mode, where both wind and electric propulsion systems work together. The energy management system adjusts the power output of the electric motors based on the available wind power, optimizing the use of both energy sources. An advanced energy management system monitors the ship's energy usage and controls the distribution of power between the electric propulsion system and the onboard systems. It ensures that the wind power is effectively utilized to reduce the load on the electric motors, thereby increasing overall efficiency and reducing fuel consumption. The wind-assisted electric ship can adjust its sails or kites to optimize wind capture depending on wind conditions. When there is ample wind, the electric propulsion system's load is reduced, conserving stored energy. When wind conditions are poor, the electric motors provide the necessary propulsion. By utilizing wind energy, the ship reduces its reliance on stored electrical energy and potentially fossil fuels, leading to lower emissions and a smaller carbon footprint. This makes wind-assisted electric ships an environmentally friendly option for maritime transportation. The combination of wind and electric propulsion increases the ship's overall efficiency and range. The reduced load on the electric motors means that the ship can travel longer distances without needing to recharge the batteries as frequently. In general wind-assisted electric ships use sails or kites to harness wind energy, which helps propel the ship and reduce the load on the electric propulsion system. This hybrid approach optimizes energy use, increases efficiency, and reduces emissions, making it a sustainable solution for maritime transportation (Stansby, P., & Wood, R., 2014).

2.3 The Factors Affecting the Electric Ships Developments Research

Several factors impact the development of electric ships:

i. Battery Technology: Advances in battery storage capacity, weight, and safety are crucial for extending electric ships' range and efficiency.
ii. Charging Infrastructure: The availability and accessibility of charging stations or infrastructure for electric ships influence their feasibility and practicality.
iii. Regulations and Standards: Legal frameworks, international regulations, and industry standards play a significant role in shaping the design, operation, and safety of electric ships.
iv. Cost and Investment: The cost of electric propulsion systems and infrastructure, as well as investments in research and development, impacts the pace of adoption and innovation.
v. Environmental Concerns: The drive towards reducing carbon emissions and environmental impact is a significant motivator for the development of electric ships.
vi. Performance and Efficiency: Improvements in electric propulsion efficiency, power generation, and overall ship performance are critical for their widespread adoption.
vii. Infrastructure Challenges: Adaptation of ports, maintenance facilities, and integration of electric systems within existing maritime infrastructure pose challenges to electric ship development.
viii. Public Perception and Acceptance: Public acceptance and perception of electric ships, along with their safety and reliability, influence market adoption and support for further development

2.4 Research Gap of the Paper

Many literatures revealed that electric ship has substantial impact on reduction of emission gases on shipping industry. According to (Hawkins et al., 2013) EVs powered by the present European electricity mix offers 10% to 24% decrease in global warming potential (GWP) relative to conventional diesel or gasoline vehicles assuming lifetimes of 150,000 km. This compares diesel engine with electrical engine.

Another study also compared the performance of a ship with either diesel electric hybrid propulsion or conventional propulsion system(Jeong et al., 2018).

Research on electric ships is continuously evolving, but several gaps persist in understanding their full impacts. Comprehensive studies are needed to evaluate the complete lifecycle environmental impact of electric ships, including manufacturing, operation, and disposal. Addressing these research gaps is crucial for the widespread adoption of electric ships, contributing to a more sustainable and efficient maritime industry. Therefore, the evaluation of the impacts of operating of electric ship on marine environment in this research were addressed the above gaps.

3.0 Methodology

This section of the paper tries to were describe in detail methodologies used in accomplishment of the previous study including the research approach, research design, the population of the study, sample size and sampling techniques, data collection, and data analysis. This part was explained on how this study was conducted and structured looking on the design, on how data was collected analyzed.

3.1 Research Approach

A case study-based on the integration of Life Cycle Assessment (LCA) process with laboratory experimental simulation was proposed and physical observation

3.2 Research Design

The research design in the context of electric ships typically was refers to the blueprint or systematic plan outlining how investigations or studies will be conducted to explore, analyze, or develop elements related to electric propulsion, energy storage, power management, or other aspects of electric ship technology. In this paper, the researcher employed comparative study design whereby electric vehicle was used as a case study to enable the researcher to solicit in-depth information from various issues related to impact of operating of electrical ship on marine environment compare with convectional ship.

3.3 Research Area

Studying shipping transport, specifically focusing on the Kigamboni-Magogoni ferry in Dar es Salaam, carries significant importance

3.4 Material/Instrument

Materials used for the study were; Fuel tank sight level, Engine Manual book, log book, Fuel Inventory Management System, Engine Control and Monitoring Panel and power measurement unit, sample probe, and heat sample line, and for the modeling battery propulsion system the following was used as a battery, Inverter, AC-DC Converter, motor drive (Induction Motor), voltmeter and propeller

3.5 Data Collection

3.5.1 Fuel Consumption

Data was collected from the user sample ferry. Manual recordkeeping on each voyage was recorded and compared with an onboard fuel monitoring system that tracks various parameters including fuel consumption. 10 voyages each day were recorded in one month at different loads and speeds and the average was computed. Fuel consumption was calculated by using the following formula.

$$\text{Fuel Consumption}=\frac{\text{Fuel flow rate}\times\text{Operating Hours}}{\text{Distance travelled}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

$$\text{Fuel Consumption}=\ \text{Previous Level(F2)}-\text{Current Fuel Level(F1)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots2$$

$$\bar{x}=\frac{\text{Tota fuel consumption per hour(TFh)}}{\text{Trip}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

3.5.2 Emission Measure

When fuel is burned, its components react with oxygen from the air, resulting in the formation of various emissions. The chemical composition of the fuel determines the types and amounts of emissions produced. Different fuels emit varying levels of carbon monoxide (CO) carbon dioxide (CO2), nitrogen oxides (NOx), sulfur oxides (SOx), Particulate matter (PM10) and other pollutants upon combustion. In general, a 'clean' fuel with minimal contaminants and a high combustion temperature produces the 'cleanest' emissions

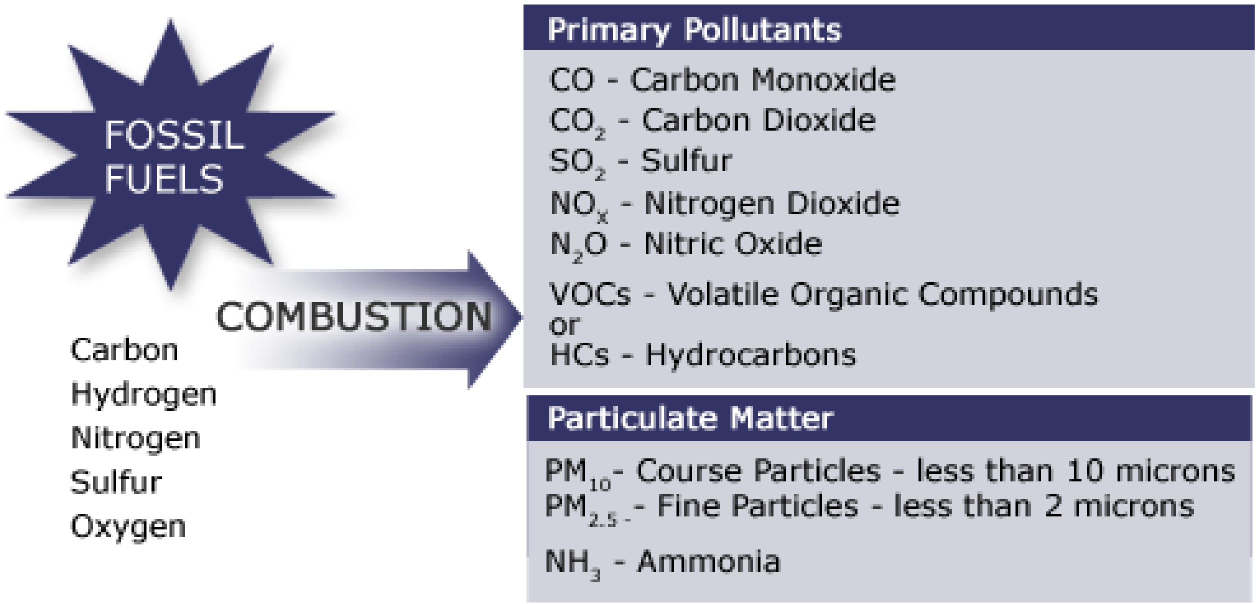


Figure 2: When fossil fuels are burned, a variety of pollutants are produced. Some of these, known as primary pollutants, make up the majority of the emissions

Experimental tests were conducted to measure the emission on the engine and battery model system. Three vessels from Magogoni station were used as samples for engine tests on various operations and conditions. A typical diesel engine has an emission factor of O.2 kilograms of nitrogen oxides (NOx)) and 0.03 kilograms of carbon monoxide (CO) per liter of diesel fuel consumed (Fan, 2017; Valverde et al., 2019). The IMO emission factor was used to calculate the analytical. where CO=0.03kg/l, CO_2 =2.7kg/l, NOx = 0.2 kg/l, SOx = 0.05 kg/l ,CO (Carbon Monoxide) = 0.0325 kg/L,CO2 (Carbon Dioxide) = This value can vary, but a typical estimate is approximately 2.68 kg/L, NOx (Nitrogen Oxides) = 0.2 kg/L ,SOx (Sulfur Oxides) =This value can vary significantly based on the sulfur content of the diesel fuel. A typical estimate is approximately 0.002 kg/L for ultra-low sulfur diesel and PM10 (Particular Matter) = 0.0003 to 0.001 kg/L.To present the emission factors of various pollutants for a diesel engine, expressed in kilograms per liter (kg/L) of diesel fuel consumed (Fan, 2017; Valverde et al., 2019).

$$Emmission = fuel\ consumption \times Emission\ factor \div 1000 \ldots\ldots 4$$

$$Emmission = 0.001 \times fuel\ consumption \times Emission\ factor \ldots\ldots 5$$

$$Etotal = C \times \sum_{i=1}^{n} (Emmision \times Consumption \times Hours) \ldots\ldots 6$$

$$Emz = C \times \sum_{i=1}^{1} (Emmision(mz) \times Consumption(mz) \times Hours(mz)) \ldots\ldots 7$$

$$Emn = C \times \sum_{i=1}^{1} (Emmision(mn) \times Consumption(mn) \times Hours(mn)) \ldots\ldots 8$$

$$Egn = C \times \sum_{i=1}^{1} (Emmision(gn) \times Consumption(gn) \times Hours(gn)) \ldots\ldots 9$$

$$\text{Deviation CO2}(\%) = \left(\frac{Actal\ CO2 - IMO\ CO2}{IMO\ CO2}\right) \times 100 \ldots\ldots 10$$

$$\text{Deviation NOx}(\%) = \left(\frac{\text{Actal NOx} - \text{IMO NOx}}{\text{IMO NOx}}\right) \times 100 \ldots\ldots 11$$

Where

C- The constant factor C (0.001)
Et-Total emission
H- Hours operating in hours
Cy- Consumption in Hours
N –Number of engine operating
Ey-Emission Factors
CO_2 =2.7kg/l, 5.95248 pound /liter
CO= 0.0325 kg/L
NO_x= 0.2 kg/l.,0.2 kg/liter * 2.20462 pounds/kg ≈ 0.440924 pounds/liter
SO_x =0.05 kg/l.0.05 kg/liter * 2.20462 pounds/kg ≈ 0.110231 Pounds/liter
PM10= 0.0003 to 0.001 kg/L.

3.5.3 Evaluate the Impact of electricity compared with conventional ship

Life cycle assessment was conducted from production, transport, usage and disposal for marine diesel oil, and battery system. The find result finally was compared to consider the ship emission type, two impacts majors proposed: Global warming Potential (GWP) indicated by CO_2, and Acidification Potential which is indicated by SO_2. The data obtain from specific objectives number one and two will be used as input for life cycle assessment.

3.6 Data Analysis

1 Quantitative Data analysis

The collected data were analyzed using both statistical and thematic analysis techniques
Statistical tools, such as SPSS, MAT LAB and excel, were employed to analyze survey data. Descriptive statistics were used to summarize the data, while inferential statistics helped in identifying significant patterns and relationships

2 Qualitative Data Analysis

Thematic analysis was conducted on interview transcripts and observational notes. This involved coding the data to identify recurring themes and patterns related to the environmental impact of electric ships

3.6.1 Scenario analysis

The scenario analysis was proposed to define the parameters for comparing the battery and diesel systems, taking into account the specific characteristics of the case ship and its operational protocols.

To facilitate this, a four-stroke diesel engine (DOOSAN engine MD196TI/320HP), (DEUTZ engine BF6M1015/270HP) and Generator (BOUDON 100KVA, PERKING 60KVA, PERKING 75KVA), identical to the one installed on the case ship, was installed in a laboratory. Test runs were conducted to measure engine emissions, aligning with the actual operational profile of the ship.

Concurrently, the battery system was virtually modeled, and its accuracy was validated through PSIM simulation. It's essential to note that the simulation aimed to provide insights into the appropriate modeling of battery systems for the 40Tanzania ferry vessels, rather than serving as direct input for the Life Cycle Assessment (LCA). Since the battery system produces no emissions, the simulation results were not directly incorporated into the LCA.

3.6.2 Life Cycle Assessment Analysis

The second phase of the proposed approach aimed to assess the comprehensive environmental impact of a battery-powered ship in comparison to a conventional diesel mechanical vessel. Aligning with established standards, the LCA process followed the guidelines outlined in ISO Standards [27], comprising four main steps: goal and scope definition, lifecycle inventory analysis (LCI), lifecycle impact assessment (LCIA), and interpretation.

3.6.2.1 Goal and Scope

The primary objective of this LCA research was to analyze the life cycle of energy pathways, encompassing production, transport, and use stages (refer to Figure 8). The scope of the analysis deliberately excluded battery or diesel engine products, as previous LCA studies have demonstrated minimal environmental impacts associated with their manufacturing, installation, and recycling processes.

3.6.2.2 Lifecycle Inventory Analysis (LCI)

Figure 7 provides an overview of the LCA process adopted in this study. Following the identification of activities at each life stage in the Goal and Scope phase, the LCI step involved estimating the type and quantity of emissions associated with each activity. This comprehensive analysis encompassed numerous unit processes along the supply chain, ranging from energy production to onboard utilization.

4.0 Findings of the study

4.1 Modeling of Propulsion System

Modeling the battery propulsion system for optimal power module selection involves a comprehensive analysis of various factors, including ship characteristics, route, sailing destination, and charging infrastructure. By systematically evaluating these parameters, engineers can determine the most suitable battery setup to enhance the vessel's efficiency and performance compared to traditional diesel propulsion.

Factors such as the ship's size, weight, design, and intended usage are crucial in selecting the appropriate battery system. Additionally, considerations like the sailing route, duration, and frequency of stops play a significant role in determining the energy requirements and charging strategies. For instance, a vessel navigating shorter routes with frequent stops might benefit from a different battery configuration compared to one traversing longer distances with fewer breaks. Alternative energy and diesel engine model are show in the figure below.

Figure 4.1: Electric Power Propulsion System

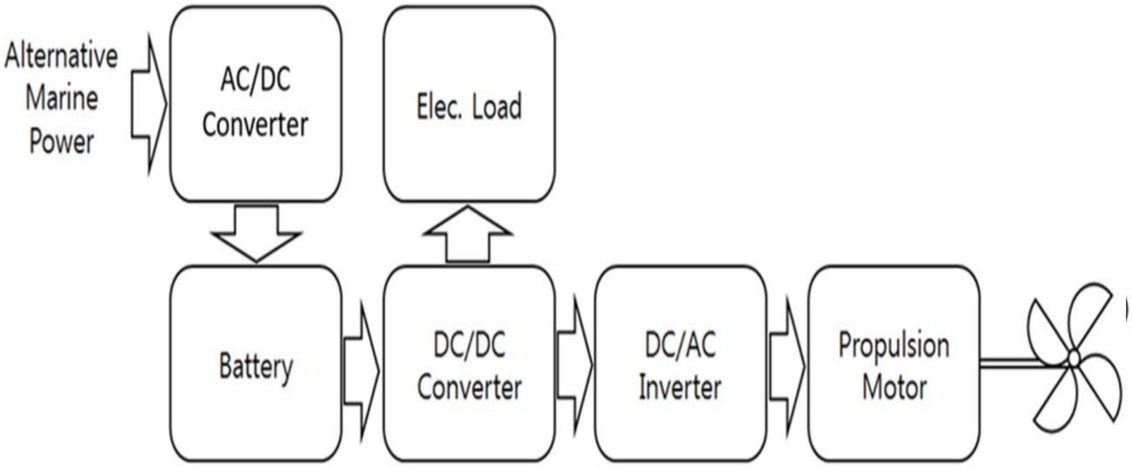
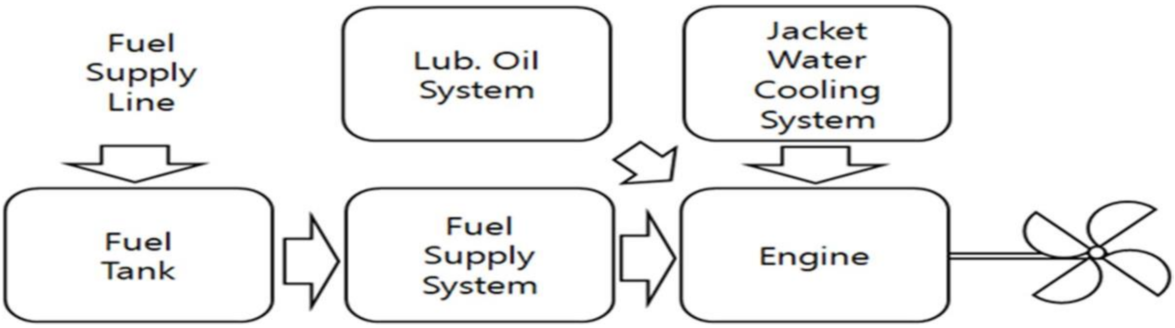


Figure 4.2: Fossil (Diseal) Power Propulsion System



4.2 Fuel Consumption Measurement

The table shows the fuel consumption of two vessels, MV. Kazi, MV. Kigamboni and Generator. The average fuel consumption was estimated at 170 liter, 110 liter and 40 liter respectively for Two vessels and the generator and consumption per unit output were at Mv Kazi 1,489,200 liter per year, 963,600 liter per year, and 350,400 liter per year respectively.

Figure 5.0: Mv Kazi dash board for RPM and Engine running Hours Parameters, Doosan Engine Control and Monitoring Panel" or "Doosan Engine Management System."

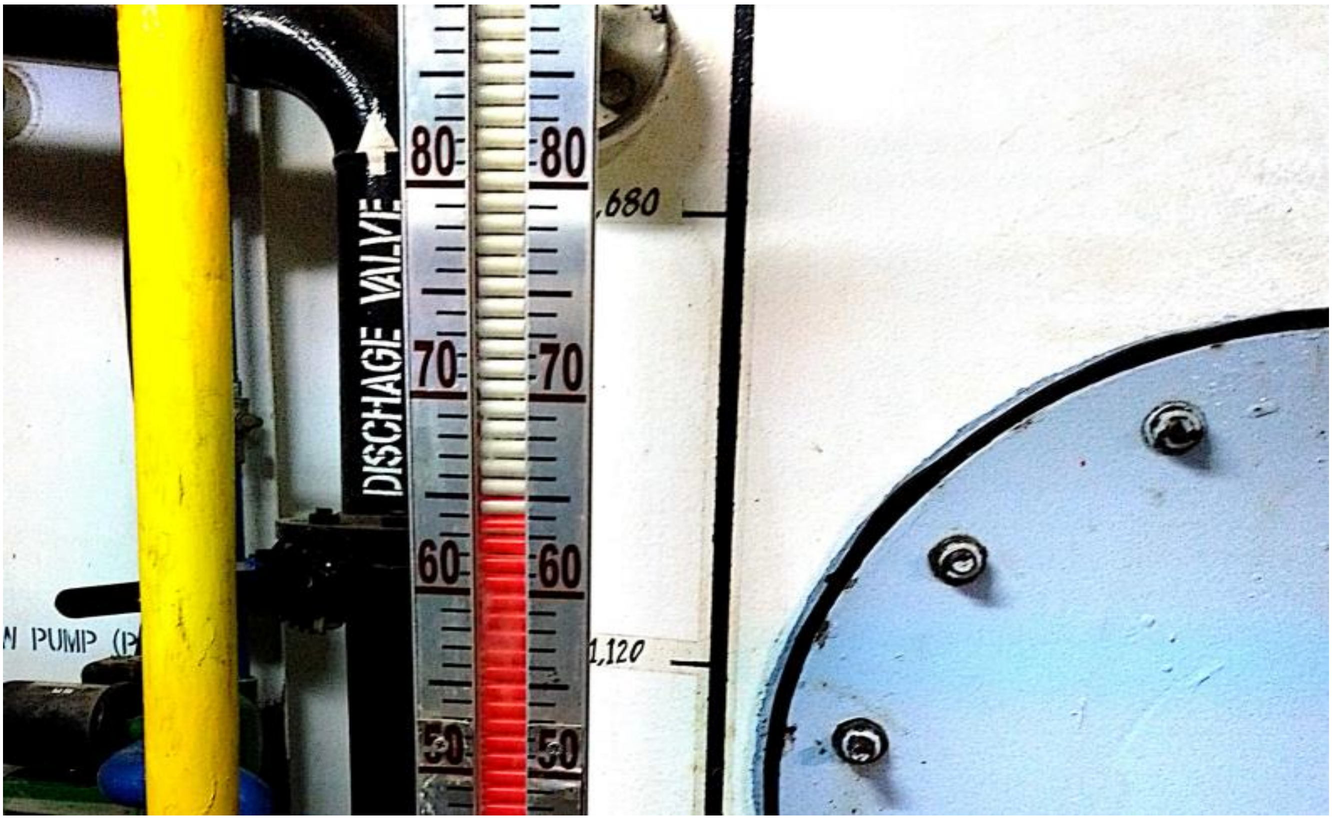


Figure 5.1 fuel level tanks for manual (fuel level sight glass) Indicator.

FUELING SOLUTIONS

Alarm LEAK,SUDDEN LOSS

27-05-2024 15:24:17

DAY TANK 1		
Product Vol	898.6	lt
Prod.level	517.76	mm
TC Volume	877.9	lt
Ullage	146.4	lt
Water	42.2	lt
Temperature	35.4	°C

Alarm SUDDEN LOSS

27-05-2024 15:24:18

DAY TANK 2		
Product Vol	894.9	lt
Prod.level	514.39	mm
TC Volume	880.0	lt
Ullage	150.1	lt
Water	40.8	lt
Temperature	35.5	°C

Alarm SUDDEN LOSS

27-05-2024 15:24:18

DAY TANK 3		
Product Vol	825.4	lt
Prod.level	452.34	mm
TC Volume	812.5	lt
Ullage	219.6	lt
Water	40.8	lt
Temperature	34.3	°C

Status Ok

27-05-2024 15:24:18

DAY TANK 4		
Product Vol	877.3	lt
Prod.level	498.59	mm
TC Volume	864.7	lt
Ullage	167.7	lt
Water	39.7	lt
Temperature	32.8	°C

Figure 5.2: Appears to be a monitoring display for the fuel levels in four different storage tanks.

Fuel Tank Monitoring System or Fuel Inventory Management System. This name reflects the system's purpose of monitoring and managing the status and contents of fuel tanks. Alarm leak, sudden loss: Indicates that the system has detected a sudden loss of fuel, possibly due to a leak. Product Vol (Volume): The total volume of fuel present in the tank, measured in liters (lt).Prod. Level (Product Level): The height of the fuel in the tank, measured in millimeters (mm).TC Volume: Temperature Compensated Volume, which is the volume of the fuel adjusted for temperature, measured in liters (lt). This ensures accurate measurements regardless of temperature fluctuations. Ullage: The empty space in the tank above the fuel, measured in liters (lt). This indicates how much more fuel the tank can hold before it is full. Water**:** The volume of water present in the tank, measured in liters (lt). Water can accumulate due to condensation and needs to be monitored. Temperature: The current temperature inside the tank, measured in degrees Celsius (°C).

Alarm sudden loss**:** Indicates an alarm for a sudden drop in fuel volume, which could signal a leak or other issues. Status Ok: Indicates that the tank is functioning normally and there are no alarms.

The figure appears to be a monitoring display for the fuel levels in four different storage tanks, labeled as Day Tank 1, Day Tank 2, Day Tank 3, and Day Tank 4. Each tank's information is displayed in a structured format, including volume, product level, temperature, and alarms indicating the status of each tank. In the given statement, the key used to identify fuel consumption is the product volume. This metric indicates the amount of fuel currently in the tank in liters, and by comparing the product volume over time, one can determine the amount

]

of fuel consumed. In this time I obtained data through the 10 number of Ferry trips and current fuel level obtained from figure 5.2 with operating time
T1=Tank number 1 for Engine number 1
T2=Tank number 2 for Engine number 2
T3=Tank number 3 for Engine number 3
T4=Tank number 4 for Engine number 4
F2= Previous Level
F1=Current Fuel Level
TFh =Total Fuel For hours
F1/T1=Current Fuel level for tank number 1 in liters
F1/T2=Current Fuel level for tank number 2 in liters
F1/T3=Current Fuel level for tank number 3 in liters
F1/T4=Current Fuel level for tank number 4 in lts
T 1=F2-F1, T2=F2-F1,T3=F2-F1,T4=F2-F1...……………………………………………9
TFh= T1+T2+T3+T4……………………………………………………………10
1TRIP = Approximate 1HR………………………………………………………11

Fuel consumption data collection for every trip or hour of vessel engine DOOSAN MD196TI/320HP

TRIPS	T1	T2	T3	T4	F1/TI	F1/T2	F1/T3	F1/T4	TFh
					F2/T1	F2/T2	F2/T3	F2/T4	
1	41.3	45.2	40.1	44	898.6	894.9	825.4	877.3	**170.6**
					939.9	940.1	865.5	921.3	
2	38.4	41.5	38.1	39.3	860.2	853.4	787.3	838	**157.3**
					898.6	894.9	825.4	877.3	
3	40.2	42.1	39.5	41.1	820	811.3	747.8	796.9	**162.9**
					860.2	853.4	787.3	838	
4	39.6	41.3	40.2	42	780.4	770	707.6	754.9	**163.1**
					820	811.3	747.8	796.9	
5	40.3	43.2	40.6	39.7	740.1	726.8	667	715.2	**163.8**
					780.4	770	707.6	754.9	
6	41.2	39.8	40.4	41.4	698.9	687	626.6	673.8	**162.8**
					740.1	726.8	667	715.2	
7	40.2	40.6	39.6	40.5	658.7	646.4	587	633.3	**160.9**
					698.9	687	626.6	673.8	
8	41.1	42.3	40.8	42.1	617.6	604.1	546.2	591.2	**166.3**
					658.7	646.4	587	633.3	
9	39.9	43.2	41.3	42.1	577.7	560.9	504.9	549.1	**166.5**
					617.6	604.1	546.2	591.2	
10	41.2	40.5	39.8	40.6	536.5	520.4	465.1	508.5	**162.1**
					577.7	560.9	504.9	549.1	
	403.4	**419.7**	**400.4**	**412.8**	**1636.3**				**1636.3**

Table 5: Consumption data collection for every trip of vessel engine DOOSAN MD196TI/320HP

Total fuel consumption for 10 trip or 10hrs is **1636.3** for Mv Kazi

Average fuel consumption are obtained by

$$\overline{\mathrm{x}} = \frac{\text{Tota fuel consumption per hour(TFh)}}{\text{Tip}}$$

$$\overline{\mathrm{x}} = \frac{1636.3}{10}$$

163.63 liters per hour

To construct a graph showing the fuel consumption of Tank 1, Tank 2, Tank 3, and Tank 4 against 10 trips, we can use the data provided.

First, we organize the data obtained from Tank reading against Trips for M KAZI, MD196TI /320HP

Trip	Tank 1	Tank 2	Tank 3	Tank 4
1	41.3	45.2	40.1	44
2	38.4	41.5	38.1	39.3
3	40.2	42.1	39.5	41.1
4	39.6	41.3	40.2	42
5	40.3	43.2	40.6	39.7
6	41.2	39.8	40.4	41.4
7	40.2	40.6	39.6	40.5
8	41.1	42.3	40.8	42.1
9	39.9	43.2	41.3	42.1
10	41.2	40.5	39.8	40.6

Table 5.1: Represent data for every tank and fuel consumption with trips for Mv Kazi (2023)

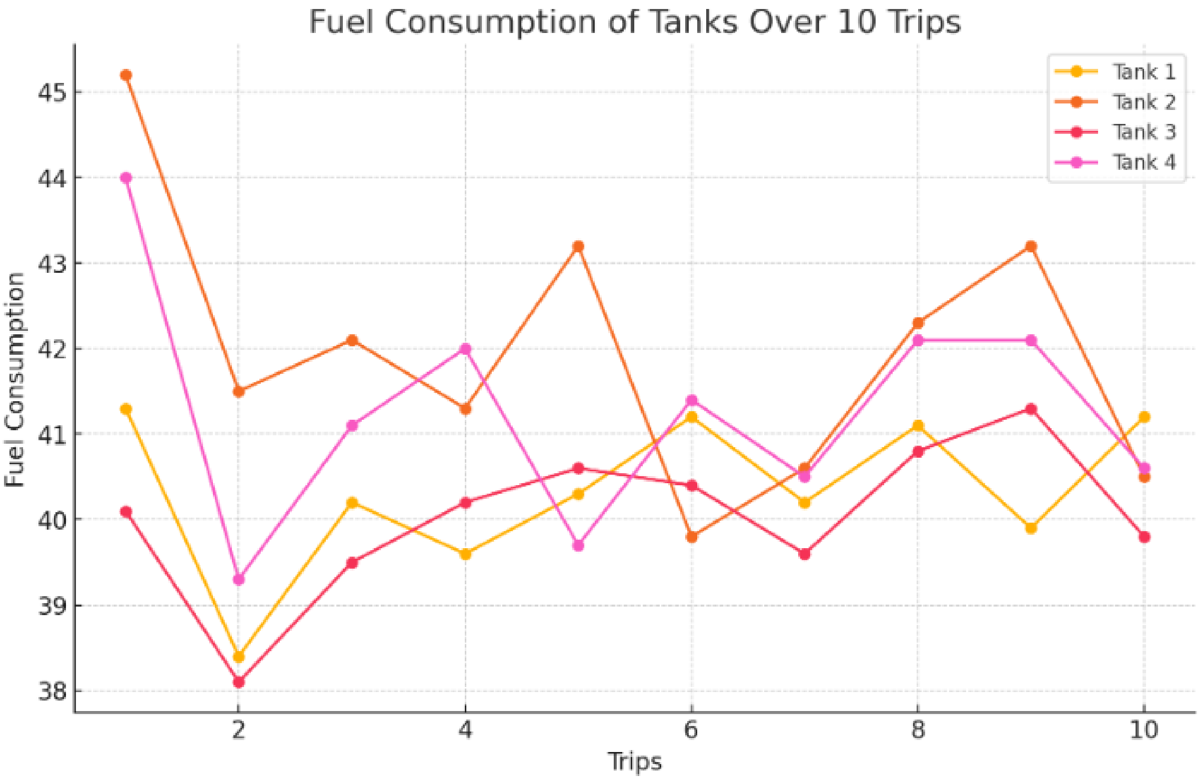


*Figure 5.3: The graph showing the fuel consumption of each tank over 10 trips***.**

Each line represents the fuel consumption of one tank, and the x-axis represents the trips. This visualization helps to compare the fuel consumption patterns across different tanks for each trip

The graph shows the fuel consumption of four different tanks (Tank 1, Tank 2, Tank 3, and Tank 4) over 10 trips. Here's a breakdown of the key observations and possible explanations: Tank 1 (Orange Line) for fuel consumption of Engine number 1 MD196TI /320HP, range 38 to 41 units of Fuel per trip or hour.

General Tank 1 has lowest points of consumption compare of tank 2 and tank 4 it about 403.4 liters per 10 trips or 10hrs or 40.03 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 41.3 units on trip 1.Is observed that are stable for fluctuation range about 3unit.Tank 2 (Yellow Line) for fuel consumption of Engine number 2 MD196TI /320HP, range 39.8 to 45 units of Fuel per trip or hour.

General Tank 2 has moderate points of consumption compare of other tank, it about 419.7 liters per 10 trips or 10hrs or 41.97 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 45.2 units on trip 1.Is observed that are unstable for fluctuation range is about 5unit.**Tank 3 (Red Line**) for fuel consumption of Engine number 3 MD196TI /320HP, range 38.1 to 41.3 units of Fuel per trip or hour.

General Tank 2 has lowest points of consumption compare of other tank, it about 400.4 liters per 10 trips or 10hrs or 40.04 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 45.2 units on trip 1.Is observed that are unstable for fluctuation range is about 3unit.**Tank 4 (Pink Line):** for fuel consumption of Engine number 4 MD196TI /320HP, range 39.3 to 44 units of Fuel per trip or hour.

General Tank 4 has lowest points of consumption compare of tank 4, it about 412.8 liters per 10 trips or 10hrs or 41.28 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 44 units on trip 1.Is observed that are unstable for fluctuation range is about 5unit

Fuel consumption data collection for every trip of vessel engine DEUTZ BF6M1015/270HP

TRIP S	**T1**	**T2**	**T3**	**T4**	**F1/TI**	**F1/T2**	**F1/T3**	**F1/T4**	**TFh**
					F2/T1	**F2/T2**	**F2/T3**	**F2/T4**	
1	22.6	26.3	21.4	25.3	175.4	169.7	171.6	169.7	**95.6**
					198	196	193	195	
2	24.4	25.1	23.5	22.9	151	144.6	148.1	146.8	**95.9**
					175.4	169.7	171.6	169.7	
3	24.5	27.0	26.2	28.1	126.5	117.6	121.9	118.7	**105.8**
					151	144.6	148.1	146.8	
4	27.3	25.4	26.5	27.3	98.7	92.2	95.4	91.4	**106.5**
					126.5	117.6	121.9	118.7	
5	25.2	27.3	25.4	28.0	73.5	64.9	70	63.4	**105.9**
					98.7	92.2	95.4	91.4	
6	24.3	24.7	26.6	28.3	49.2	40.2	43.4	35.1	**103.9**
					73.5	64.9	70	63.4	
7	26.0	25.4	26.5	27.0	23.2	14.8	16.9	8.1	**104.9**
					49.2	40.2	43.4	35.1	
8	25.3	24.7	25.4	26.5	171.7	170.3	172.6	169.5	**101.9**
					197	**195**	**198**	**196**	
9	27.1	23.6	26.3	25.2	144.6	146.7	146.3	144.3	**102.2**
					171.7	170.3	172.6	169.5	
10	26.6	23.9	25.6	26.2	118	122.8	120.7	118.1	**102.3**
					144.6	146.7	146.3	144.3	
	253.3	**253.4**	**253.4**	**264.8**	**1024.9**				**1024. 9**

Table 5.2: Fuel consumption data collection for every trip of vessel engine DEUTZ BF6M1015/270HP (2023)

Total fuel Consumption **1024.9 per 10** trip or 10hrs

Average fuel consumption are obtained by

$$\bar{x} = \frac{\text{Tota fuel consumption per hour(TFh)}}{\text{Tip}}$$

$$\bar{x} = \frac{1024.9}{10}$$

$$\bar{x}\mathbf{=102.49\ liters\ per\ hour}$$

I was organize the data obtained from Tank reading against Trips for Mv Kigamboni BF6M1015/270HP

Trip	Tank 1	Tank 2	Tank 3	Tank 4
1	22.6	26.3	21.4	25.3
2	24.4	25.1	23.5	22.9
3	24.5	27.0	26.2	28.1
4	27.3	25.4	26.5	27.3
5	25.2	27.3	25.4	28.0
6	24.3	24.7	26.6	28.3
7	26.0	25.4	26.5	27.0
8	25.3	24.7	25.4	26.5
9	27.1	23.6	26.3	25.2
10	26.6	23.9	25.6	26.2

Table 5.3: obtained from Tank reading against Trips for Mv Kigamboni BF6M1015/270HP

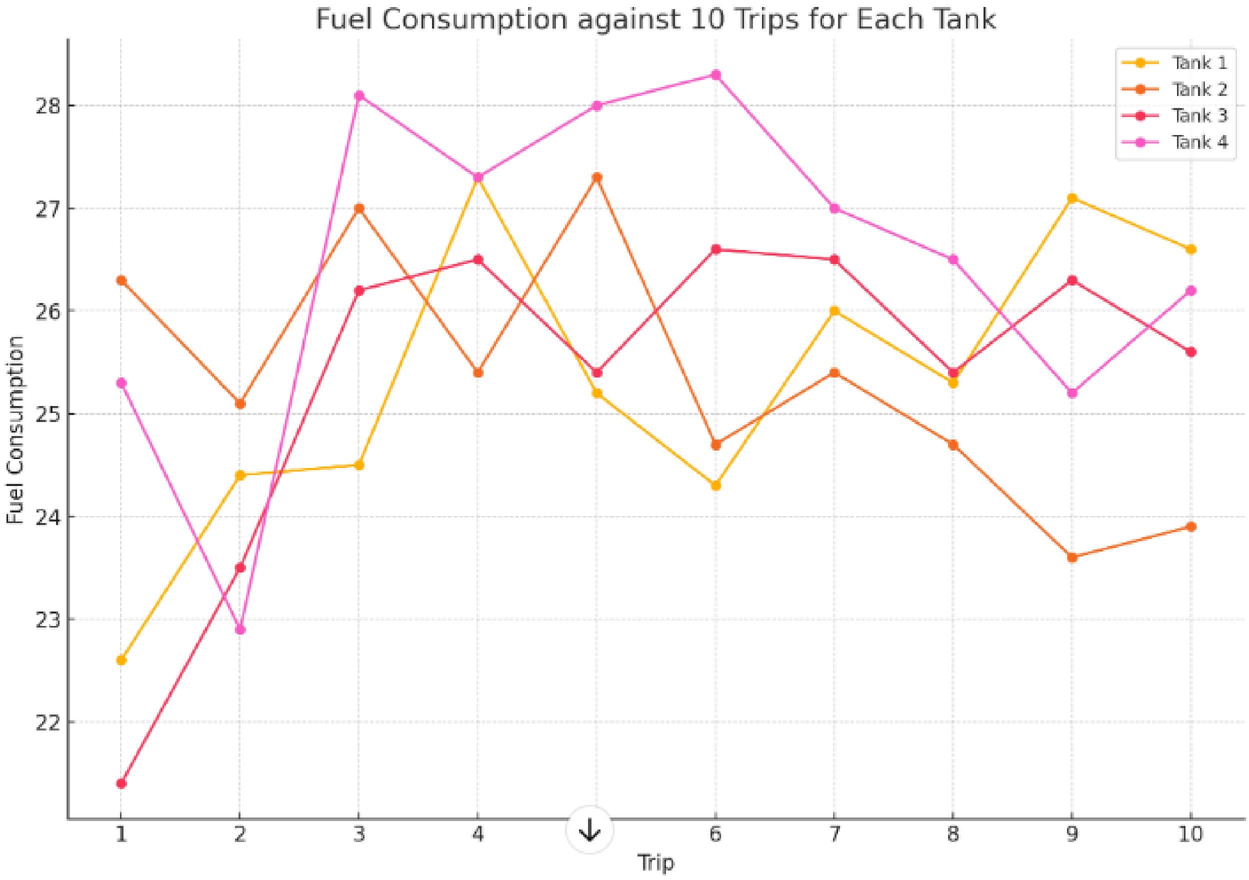


Figure 5.4: The graph showing the fuel consumption for each of the four tanks across 10 trips or 10hrs. Each tank's consumption is plotted with distinct markers and a legend for easy identification.

Tank 1 (Orange Line) for fuel consumption of Engine number 1 (BF6M1015/270HP), range 22 to 27 units of Fuel per trip or hour.

General Tank 1 has lowest points of consumption it about 253.3 liters per 10 trips or 10hrs or 25.33 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 27.3 units on trip 4. Is observed that are stable for fluctuation range. Tank 2 (Red Line) for fuel consumption of Engine number 2 (BF6M1015/270HP), range 23 to 27 units of Fuel per trip or hour. Generally Tank 2 shows more stable fluctuations compared to other tanks it about 253.4 per 10 trips or 25.34 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 27.3 units on trip 5.

Is observed that are stable for fluctuation range. Tank 3(Pink Line) for fuel consumption of Engine number 3 (BF6M1015/270HP), range 21 to 26 units of Fuel per trip or hour. Generally Tank 3 shows the same stable fluctuations like tank 2 compared to other tanks it about 253.4 per 10 trips or 25.34 liters per hour. Its consumption remains relatively stable with some fluctuations, peaking at 26.6 units on trip 6.Is observed that are stable for fluctuation range. At the same fuel consumption on tank 2.Tank4(Magenta line) for fuel consumption of Engine number 4 (BF6M1015/270HP), range 22 to 28 units of Fuel per trip or hour.

General Tank 4 shows the unstable fluctuations compared to other tanks it about 264.8 per 10 trips or 26.48 liters per hour. Tank 4 generally consumes more fuel, and Tank 1 and Tank 3 are more prone to larger fluctuations. Its consumption remains relatively stable with some fluctuations, peaking at 28.3 units on trip 6.Is observed that are stable for fluctuation range and high fuel consumption than other tank due to High RPM setting, Poor performance of engine or High load operation.

Overall Observations

All tanks show some level of fluctuation in fuel consumption across the trips. Tank 4 consistently shows higher fuel consumption compared to others is about 264.8 per 10 trips or 26.48 liters per hour, frequently reaching 28. Tank 1 and Tank 3 have the lowest points of fuel consumption is about 253.4 per 10 trips or 25.34 liters per hour, around 22-23. Tank 2 shows more stable fluctuations compared to other tanks due to range of 4 and total fuel consumption of Mv Kigamboni is 102.49 liters per hour.

Data obtained from Tank reading against Trips for Generators

TRIPS	TANK 1 100KVA	TANK2 60KVA	TANK3 75KVA	F1/TI	F1/T2	F1/T3	**TFh**
				F2/T1	F2/T2	F2/T3	
1	16	**9**	**11**	817	89	86	**36**
				831	98	97	
2	14	10	10	803	79	76	**34**
				817	89	86	
3	15	9	9	788	70	67	**33**
				803	79	76	
4	13	12	11	775	58	56	**36**
				788	70	67	
5	14	11	12	761	47	44	**37**
				775	58	56	
6	15	8.5	11	746	38.5	33	**34.5**
				761	47	44	
7	16	9	11	730	29.5	22	**36**
				746	38.5	33	
8	14	10.5	10	716	19	12	**34.5**

				730	29.5	22	
9	17	11	12	699	69	68	**40**
				716	80	80	
10	15	10	11	684	59	57	**36**
				699	69	68	
	149	**100**	**108**	**357**			**357**

Table 5.3 Obtained from Tank reading of generator of Mv Kigamboni ,Mv Kazi and office service generator

Total fuel consumption for 10 trip or 10hrs is **357 liters**

Average fuel consumption are obtained by

$$\bar{x} = \frac{\text{Tota fuel consumption per hour(TFh)}}{\text{Trip}}$$

$$\bar{x} = \frac{357}{10}$$

35.7 liters per hour

Data for fuel consumption of generators (Mv Kazi,Mv Kigamboni and Offices

TRIPS	TANK 1 (BOUDON 100KVA)	TANK 2(PERKING 60KVA)	TANK 3 (PERKING 75KVA)
1	16	9	11
2	14	10	10
3	15	9	9
4	13	12	11
5	14	11	12
6	15	8.5	11
7	16	9	11
8	14	10.5	10
9	17	11	12
10	15	10	11
TOTAL	**149**	**100**	**108**

Table 5.3.1 Obtained from Tank reading of generator of Mv Kigamboni ,Mv Kazi and office service generator

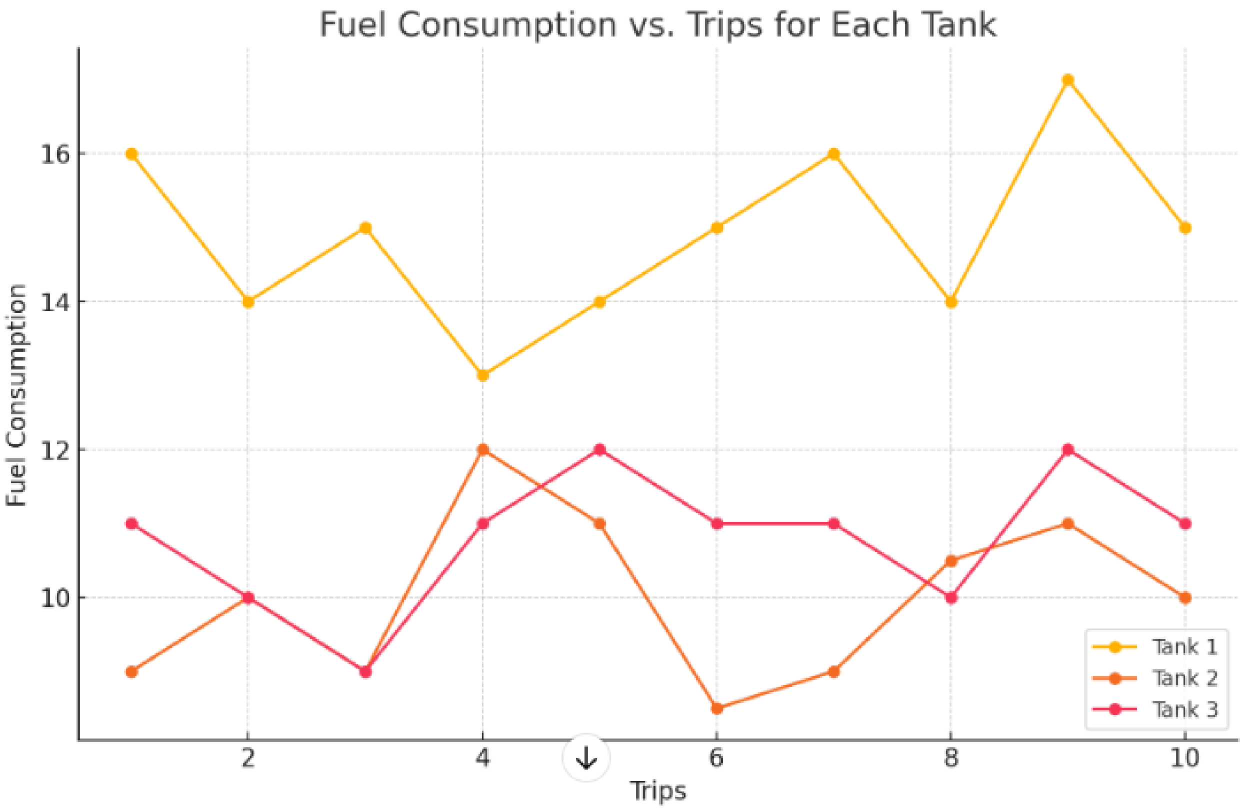


Figure 5.5 The graph showing the fuel consumption for each of the three tanks across 10 trips or 10hrs. Each tank's consumption is plotted with distinct markers and a legend for easy identification (2023) Each line represents one of the tanks, with markers indicating the data points for each trip.

The graph shows the fuel consumption of three generators (represented by Tank 1, Tank 2, and Tank 3) over ten trips. Here's a detailed analysis of the fuel consumption patterns for each tank, explaining which tank consumes the most fuel and which consumes the least.

Analysis of Fuel Consumption for Generators

Tank 1 for fuel consumption of generator number 1 (BOUDON 100KVA), range 13 to 17 units of Fuel per trip or hour**.** Generally shows higher fuel consumption compared to the other two tanks .Its consumption remains relatively stable with some fluctuations, peaking at 17 units on trip 9. Total fuel consumption 149 per 10hrs or equal to 14.9 liters per hour. Here was observed Tank 1 is consistently the highest consumer of fuel among the three, likely indicating a generator with higher power output.

Tank 2 for fuel consumption of generator number 2 (PERKING 60 KVA), range 8.5 to 12 units of fuel per trip. Tank 2 shows the lowest fuel consumption overall. There is a noticeable dip to 8.5 units on trip 6 and peaks at 12 units on trip 4.Total fuel consumption 100 per 10 trips or 10 hours or equal to 10 liters per hour. Here was observed Tank 2 is the lowest consumer of fuel, which could suggest a more fuel-efficient generator due to low power output that is used less intensively compared to the others.

Tank 3 for fuel consumption of generator number 3 (PERKING 75 KVA), range 9 to 12 units of fuel per trip. Tank 3 shows moderate fuel consumption, generally higher than Tank 2 but lower than Tank 1. Its consumption is fairly stable, with small fluctuations. Total fuel consumption 108 per 10 trips or 10 hours or equal to 10.8 liter per hour. Here was observed Tank 3 has moderate fuel consumption, indicating a balance between power output and efficiency. Tank 3 has moderate fuel consumption, indicating a balance between power output and efficiency. Tank 2 is the most fuel-efficient, consuming the least amount of fuel, which might be due to higher efficiency or less intensive use.

Tank 3 sits in between, showing moderate fuel consumption. Understanding these patterns can help in optimizing fuel usage and improving the efficiency of the generators. In general observation for fuel consumption reasons for variation due to power output requirement, Generators with higher power outputs typically consume more fuel. Tank 1 might be powering more equipment or running at a higher load. Differences in fuel efficiency between generators can result in varying fuel consumption. Tank 2's lower fuel usage suggests it might be a more efficient generator or have low load in operation. From the graph of figure 5.5, it seen that Tank 1 is the highest consumer of fuel, likely due to higher power output or lower efficiency. Tank 2 is the most fuel-efficient, consuming the least amount of fuel, which might be due to higher efficiency or less intensive use. Tank 3 sits in between, showing moderate fuel consumption. Understanding these patterns can help in optimizing fuel usage and improving the efficiency of the generators.

4.3 Emission Measurement

Both was vessel produce emission during operational while there no emission was assumed when battery as renewable source of energy were used.

Table 6.1: Emission Measurement. Equipment and Emission factors Data from Equipment at Magogoni ferry (march2023)

EQUIPMENT TYPE	AMOUNT	SOURCES OF POWER	CONSUMPTION PER HOUR (L)	Emission factor per kg/ 1,000 liters of fuel burned per hour				
				CO2	**CO**	**NO x**	**SO2**	**PM10**
Mvkazi	1280hp (955kw)	Diesel	170	0.46	0.005	0.034	0.009	0.0002
Mvkigamboni	1080hp (807kw)	Diesel	110	0.30	0.003	0.02	0.006	0.0001
Generator	315hp (235kw)	Diesel	40	0.11	0.001	0.01	0.002	0.00004
Total/hr			**320**	**0.87**	**0.009**	**0.064**	**0.017**	**0.00034**
day			**7680**	**20.88**	**0.22**	**1.54**	**0.41**	**0.0082**
month			**230400**	**626.4**	**6.6**	**46.2**	**12.3**	**0.25**
year			**276480**	**7516.8**	**79.2**	**554.4**	**137.6**	**3**
10years			**2764800**	**75168**	**792**	**5544**	**1376**	**3**

Table 6 show fuel and emission for equipment year obtained from 2023

A. Results From Comprehensive Fuel and emission per 10 years Analysis

Equipment	Fuel Consumption (L/10yrs)	CO2 Emission Factor (kg/10yrs)	CO Emission Factor (kg/10yrs)	NOx Emission Factor (kg/10yrs)	SO2 Emission Factor (kg/10yrs)	PM10 Emission Factor (kg/10yrs)
Mv Kazi	14,892,000	6,851.52	74.46	506.328	134.028	2.9784
Mvkigamboni	9,636,000	2,890.8	28.908	192.72	57.816	0.9636
Generators	3,504,000	385.44	3.504	35.04	0.7008	0.14016
TOTAL	**28,032,000**	**10,127.76**	**106.872**	**734.088**	**192.5448**	**4.08216**

Table 6.1 show fuel and emission for 10 year obtained from 2023 up 2033

Fuel consumption is the amount of fuel used by a piece of equipment over a specific period. In a data obtained, fuel consumption is given in liters per hour (L/hr) and extrapolated over various time periods (day, month, year, 10 years). In MV KAZI with engine Doosan MD196TI /320HP has consume 14,892,000L/10 years as fuel ,Mv kigamboni with engine Deutz BF6M1015/270HP has consumes 9,636,000 litter of fuel consumption per 10 years and generators has consumes 3,504,000 litter of fuel consumption per 10 years. Emission emitted from Mv Kazi are 6,851.52 Kilogram of CO2 per 10 years, 74.46 Kilograms of CO per 10 years, 506.328 Kilograms of NOx per 10 years, 134.028 Kilograms of SO2 per 10 years, 2.9784 Kilogram of PM10 per 10 years. Mv Kigamboni emission emitted 2,890.8 Kilograms of CO2 per 10 years, 28.908 Kilograms of CO per 10 years, 192.72 Kilograms of NOx per 10 years, 57.816 Kilograms of SO2 per 10 years, 0.9636 Kilograms of PM10 per 10 years. Generator emission emitted 385.44 Kilograms of CO2 per 10 years, 3.504 Kilograms of CO per 10 years, 35.04 Kilograms of NOx per 10 years, 0.7008 Kilograms of SO2 per 10 years, 0.14016 Kilograms of PM10 per 10 years.

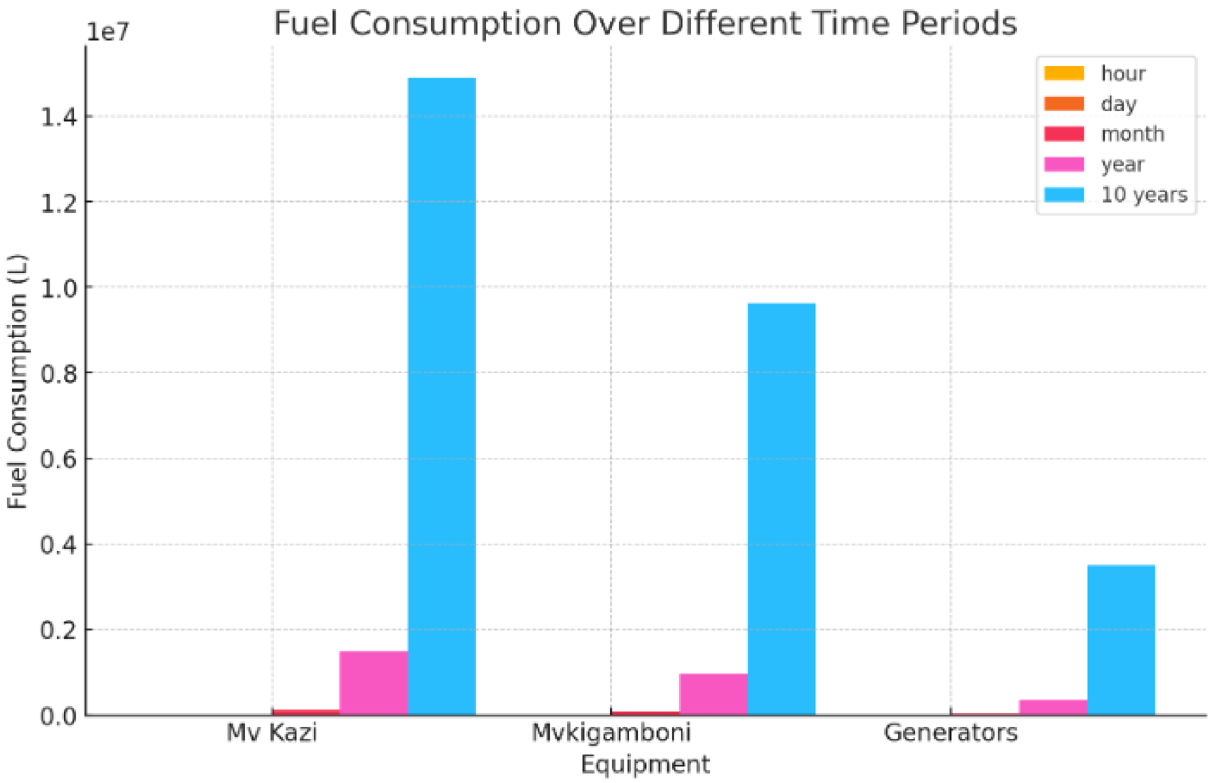


Figure 6: Show fuel with different time of period after 10 years

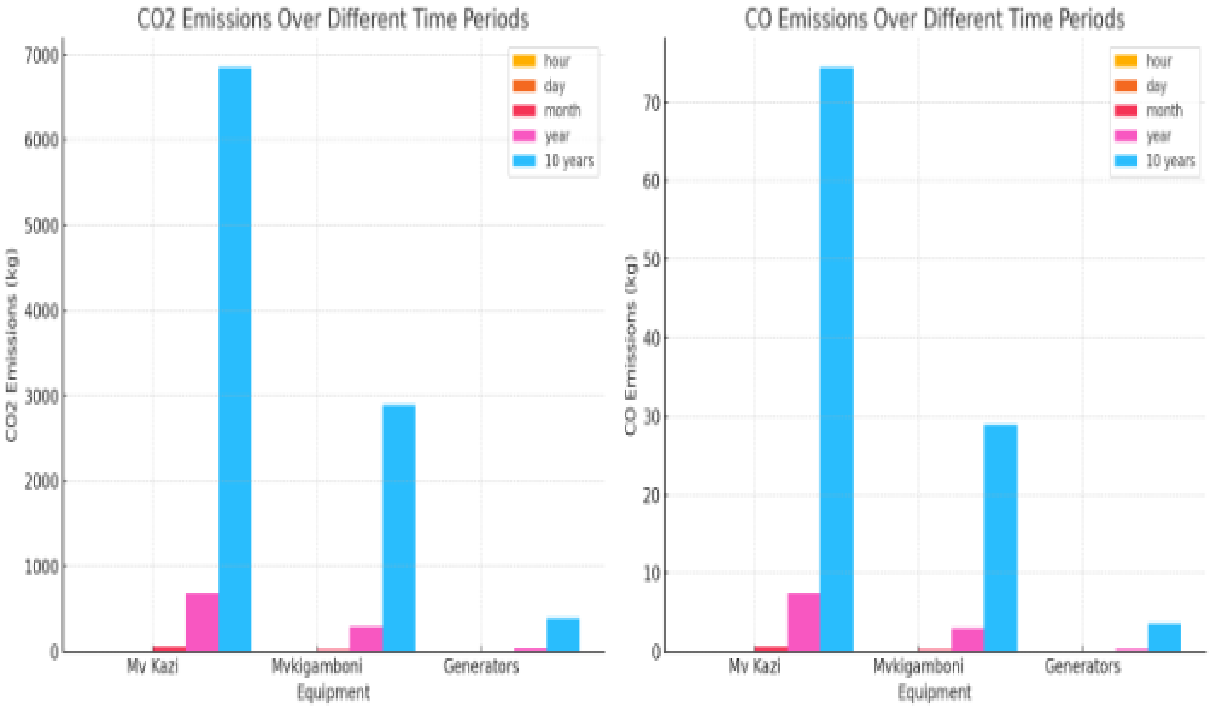


Figure 6.1: Show emission of CO2 and CO equipment with different time for 10 years

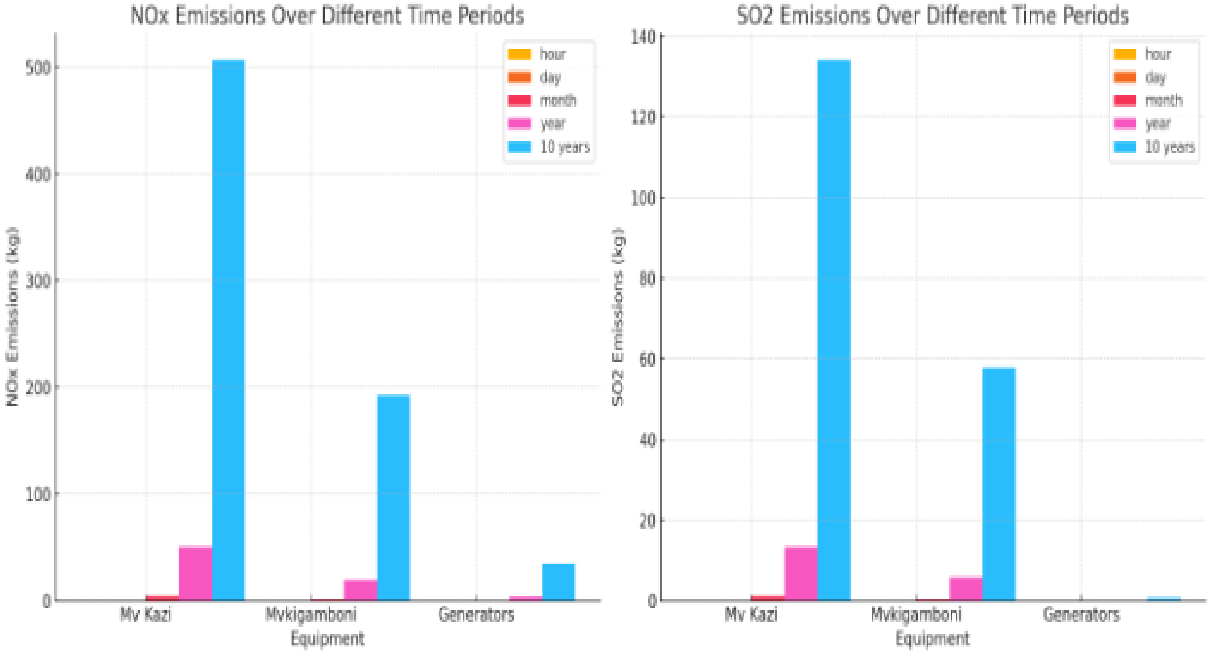


Figure 6.2: Show emission of NOx and SOx of equipment with different time after 10 years

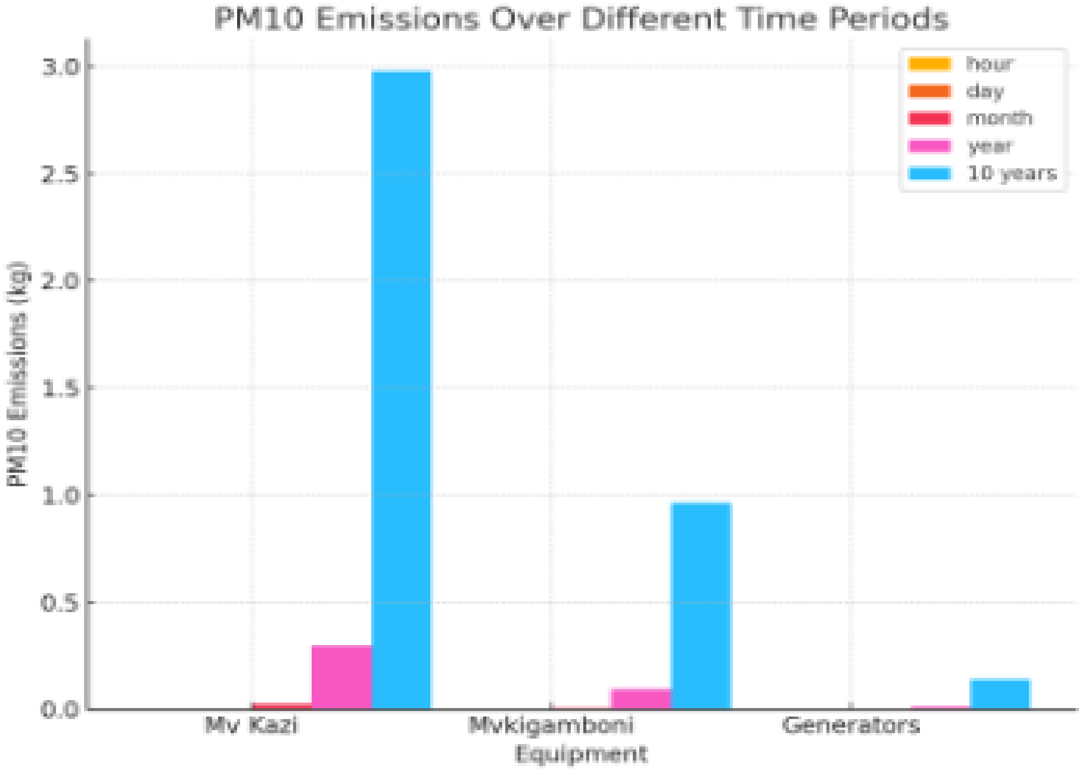


Figure 6.3: Show emission of PM10 of equipment with different time after 10 years

Compare Fuel consumption and emission

Table 6 compares fuel consumption and emissions during daily operation, with emissions assumed to be zero when the batteries are in use. Interestingly, deviations between actual emission measurements and analytical calculations using IMO emission factors were observed. According to these factors, the CO2 emission factor is 2.7 kg per 1 liter of fuel,CO is 0.0325 kg per 1Litter, SOx is 0.05 kg per liter NOx emission factor is 0.02 kg per 1 liter of fuel and PM10 is 0.0003 to 0.001 kg/L. IMO CO2 is 3.21 kg per kg of fuel and IMO NOx is 0.0875 kg per kg of fuel IMO CO1.1 kg, IMO SO2: 0.9 kg and IMO PM10 is 0.7 kg,. A-B route for MV. KIGAMBONI and A'-B' route for MV. KAZI and A"-B" for Generators from Magogoni to Kigamboni.The analytical calculations tended to overestimate emission levels, with particularly notable discrepancies in Nitrogen Oxide(NOx) emissions, Carbon dioxide (CO2) emission, Carbon monoxide (CO) emission, Sulfur Oxide (SO2) emission and Particular Matters(PM10) emission which were sometimes calculated to be 9.7 times higher than the actual measurements. The purpose of the analytical calculations was to identify deviations from actual measurements, which were then used in the life cycle inventory (LCI) analysis.

$$Emission = Base\ Emission \times \frac{fuel\ Consumption}{110} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

$$Emission = Fuel\ consumptionBase\ Emission \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

$$Deviation\% = \frac{(Actual - IMO)}{IMO} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

Route	**Fuel Consumption (kg)**	**CO2 (kg)**	**CO(kg)**	**NOx(kg)**	**SO2(kg)**	**PM10(kg)**	**IMO CO2 (kg)**	**IMO CO(kg)**	**IMO NOx (kg)**	**IMO SO2 (kg)**	**IMO PM10 (kg)**	**Deviation CO2 (%)**	**Deviation CO (%)**	**Deviation NOx (%)**	**Deviation SO2 (%)**	**Deviation PM10 (%)**	**Battery Electricity Consumption (kWh)**
A-B (MV Kigamboni)	**110**	279.40	0.9	2.20	0.7	0.5	353.10	1.1	9.625	0.9	0.7	1134.35%	-18.18%	968.96%	-22.22%	-28.57%	66.67
B'-A' (MV	**170**	431.80	1.39	3.40	1.08	0.77	545.70	1.70	14.875	1.39	1.08	324.55%	18.18%	156.95%	-22.22	-28.57%	103.03

Kazi)																	
B'-A' (MV Kazi)	**170**	431.80	1.39	3.40	1.08	0.77	545.70	1.70	14.875	1.39	1.08	324.55%	-18.18%	156.95%	-22.22%	-28.57%	103.03
B-A (MV Kigamboni)	**111**	282.94	0.91	2.22	0.11	0.505	356.31	1.11	9.7125	0.91	0.71	1148.03%	-18.18%	966.79%	-22.22%	-28.57%	66.67
A"-B" Generator	**40**	101.60	0.33	0.80	0.25	0.182	128.40	0.40	3.50	0.28	0.25	307.90%	-18.18%	133.33%	-22.22%	-28.57%	24.24
One Voyage	**601**	**1525.54**	**4.92**	**12.02**	**3.83**	**2.74**	**1895.43**	**5.97**	**51.505**	**3.95**	**2.74**	**126.45%**	**-18.18%**	**185.20%**	**-22.22%**	**-28.57%**	**364.24**

Table 7: Show fuel, emission and deviation for 10 year obtained from 2023 up 2033

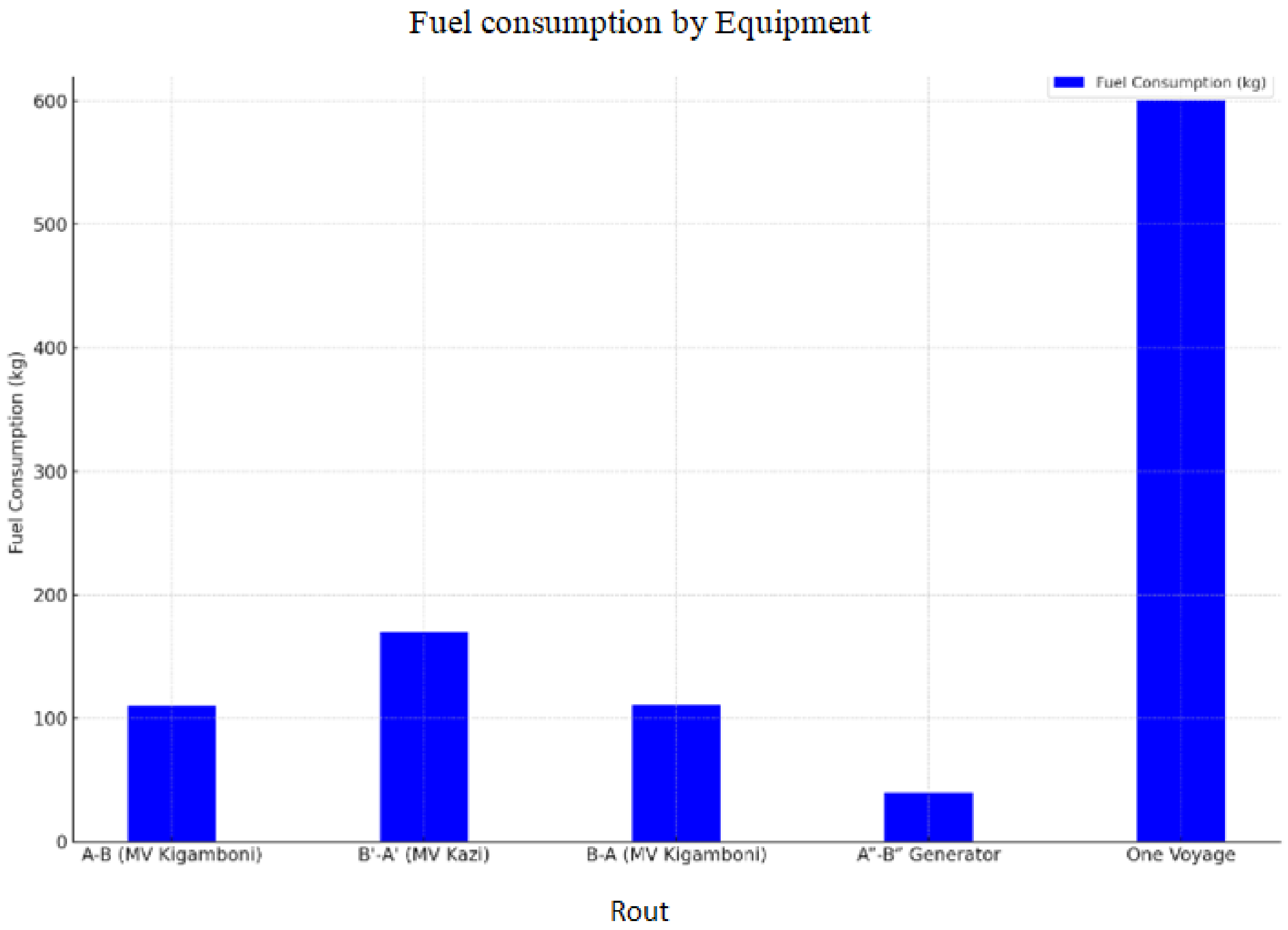


Figure 7: Show fuel consumption for route of equipment with different time per trip (2023)

Fuel Consumption by Equipment" provides a visual representation of fuel consumption (measured in kilograms) across different routes and equipment types. The bars in the chart represent the amount of fuel consumed by various equipment types**, Routes/Equipment: A-B (MV Kigamboni)** this bar shows the amount of fuel consumed by the MV Kigamboni vessel on a specific route from point A to point B. The fuel consumption is approximately 100 kg. **B'-A' (MV Kazi)** bar represents the fuel consumption of the MV Kazi vessel on a route from point B' to A'. The fuel consumption here is higher than that of MV Kigamboni, at around 200 kg. **B-A (MV Kigamboni)** ,This bar again refers to the MV Kigamboni vessel but on a different route (B-A), showing slightly lower fuel consumption compared to its A-B route. A"-B" (Generator) is represents the fuel consumption of a generator used between points A" and B". The fuel consumption here is much lower, indicating that generators consume less fuel compared to vessels. **One Voyage** is bar shows the total fuel consumption for a single voyage. The fuel consumption is the highest in this category, indicating that the voyage involves significant energy use. Here was seen that the concept of fuel with Equipment as **Fuel Consumption** is the amount of fuel used by each equipment or for each route is critical for assessing operational efficiency, environmental impact, and cost management.

Equipment Performance for Different equipment, such as vessels or generators, have varying levels of fuel efficiency, as reflected in the chart. For instance, vessels like MV Kigamboni and

MV Kazi consume significantly more fuel compared to the generator, which may be due to differences in size, power requirements, and operational tasks. **Operational Considerations** for chart highlights the importance of route planning and equipment selection to minimize fuel consumption and emissions. By comparing fuel consumption across different equipment and routes, stakeholders can make informed decisions to optimize energy use In summary, this chart serves as a tool for analyzing and comparing the fuel efficiency of different equipment types and routes, which is essential for operational planning and environmental management.

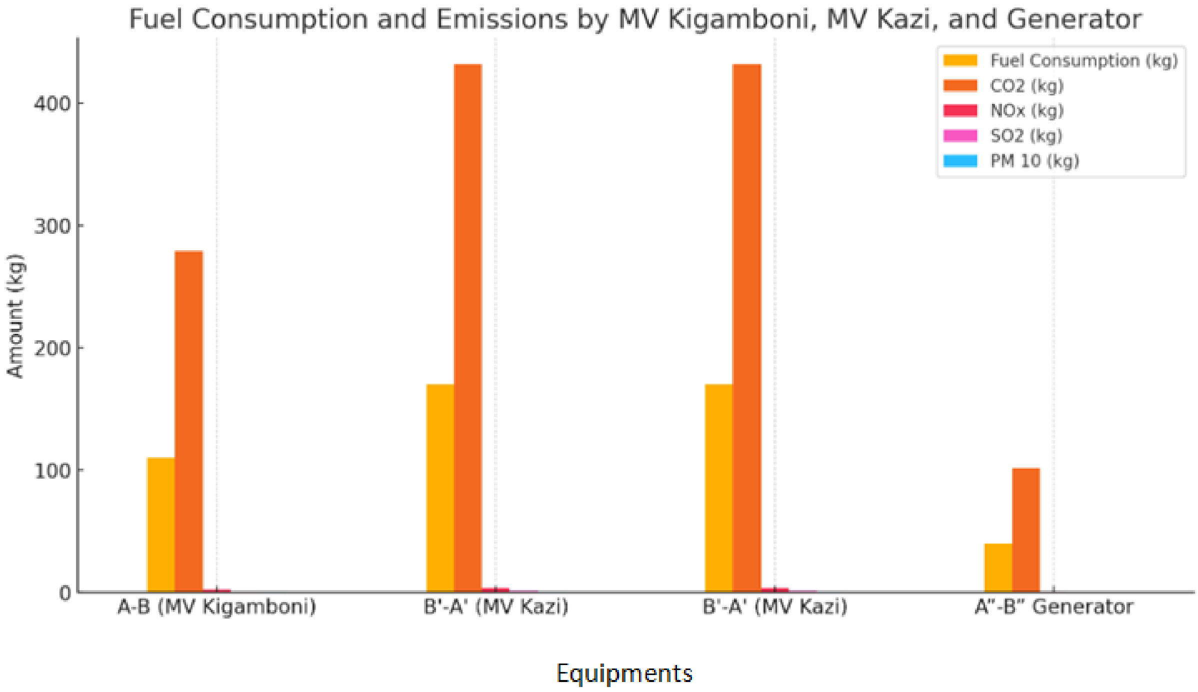


Figure 7.1: Show fuel consumption for route of equipment with different time trip day (2023)

Fuel Consumption and Emissions by Route (MV Kigamboni and MV Kazi)" compares the fuel consumption (in kilograms) and emissions (CO2 and NOx, also in kilograms) for different routes and vessels. Chart that compares the fuel consumption and emissions (CO2, NOx, SO2, and PM 10) for MV Kigamboni, MV Kazi, and the generator on the specified routes. The chart highlights the relative amounts of each pollutant across these different operations.MV Kazi (B'-A') shows higher emissions and fuel consumption compared to MV Kigamboni and the generator.MV Kigamboni (A-B) has lower values for all categories except for the generator.The generator (A”-B”) has the lowest fuel consumption and emissions, reflecting its smaller operational impact.This visual comparison helps to understand the environmental impact of each route and the vessels/generator involved.

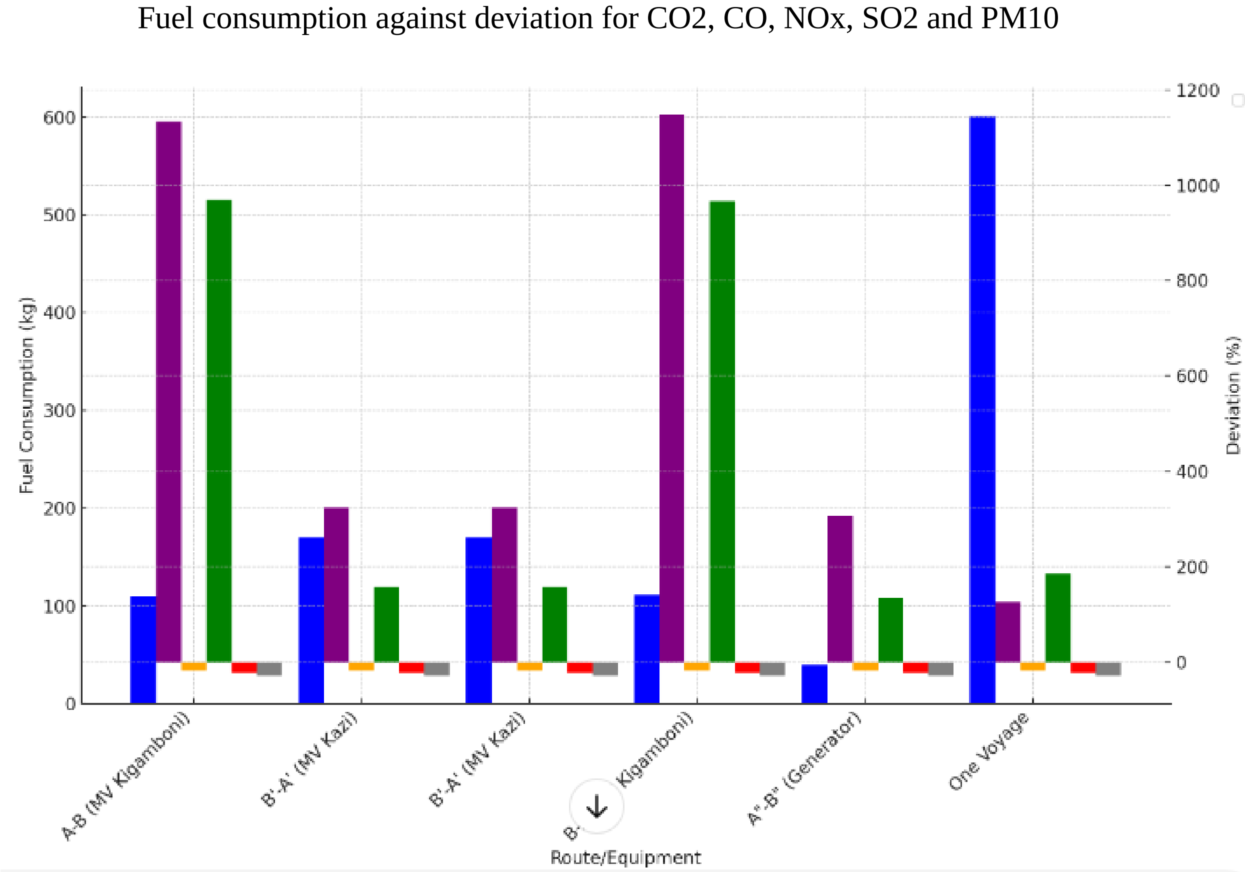


Figure 7.3: Show fuel consumption for route of equipment with different time and emission per day

Fuel consumption versus deviation for CO2, CO, NOx, SO2, and PM10 by route and equipment but also assigns a distinct color for each type of fuel or equipment. Here's the approach Fuel Consumption (kg) was denoted by Brue color .The bars will represent the fuel consumption for each route per equipment. Deviations (%) Different color-coded bars will be used to show the deviations of CO2, CO, NOx, SO2, and PM10. Color assignments are CO2 Deviation is Purple, CO Deviation is Orange, NOx Deviation is Blue SO2 Deviation is Green, PM10 Deviation is Red Each bar will be color-coded according to the deviation represented.

4.5 Life Cycle Assessment Inventory (LCAI)

During life cycle impact assessment (LCIA), the emissions and their quantities derived from life cycle inventory (LCI) analysis contribute to various environmental impact potentials. In the maritime sector, four primary impact categories are typically considered due to ship emissions: Global warming potential (GWP) and Acidification potential (AP). These categories provide a framework for evaluating the environmental impacts of marine vessels and guide efforts to mitigate their effects. See figure 8 Battery vs Diesel

Figure 8.1 compares the LCIA results of the two options, illustrating a clear superiority of the battery system over the diesel option in terms of environmental footprints. The analysis results validate the initial hypothesis, showing that the use of a battery system significantly outperforms the diesel option across all environmental impact categories. Specifically, over the ship's life, the battery system results in approximately 1.6 × 10^7 kg CO2 equivalent (GWP), and 2.17 × 10^5 kg SO2 equivalent (AP).

Figure 8: Battery vs Diesel

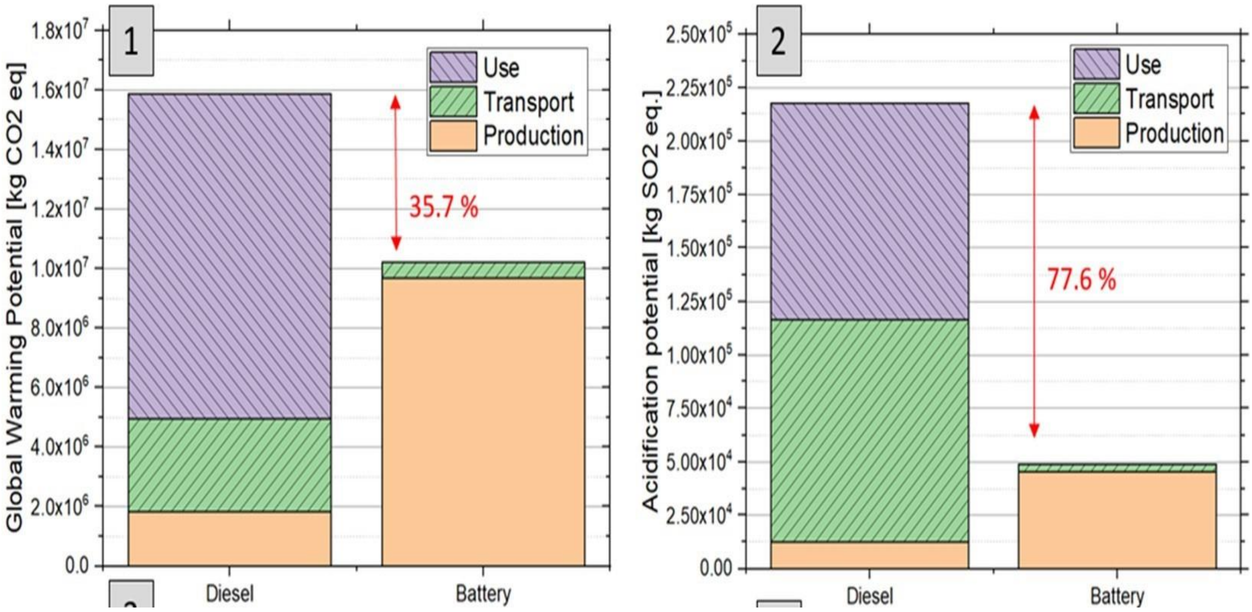


Figure 8 show diesel and batteries with emission of CO2 and SO2 effect

The diagram was provided compares the environmental impact of diesel and battery technologies in terms of two key environmental indicators. Global Warming Potential (GWP) measured in kg CO2 equivalent, and Acidification Potential (AP) measured in kg SO2 equivalent. These indicators are divided into three lifecycle stages**: Production, Transport,** and **Use.** Global Warming Potential (GWP) in case of diesel is higher overall, with a significant contribution coming from the **Use** phase, which dominates the impact due to the CO2 emissions generated during the combustion of diesel fuel. In case of **Battery**, the GWP is lower by 35.7% compared to diesel. However, the **Production** phase contributes more to the GWP for batteries, indicating that manufacturing and resource extraction processes for batteries are more CO2-intensive than for diesel. The **Use** phase, however, is much lower for batteries, highlighting their cleaner operational emissions.

Acidification Potential (AP**)** the AP for diesel is also higher, with the **Use** phase again being the major contributor. This phase includes the emission of sulfur oxides (SOx), which contribute to acid rain and environmental degradation. **Battery** was the AP for batteries is 77.6% lower than for diesel. The impact from the **Use** phase is minimal, reflecting the lower emissions during operation. However, like GWP, the **Production** phase is more significant for batteries, but still much lower compared to diesel's overall AP .Environmental Implications the Diesel engines have a higher environmental impact during the **Use** phase due to the continuous emission of greenhouse gases (GHGs) and pollutants like SO2, contributing significantly to global warming and acidification. While the production of batteries is more resource and energy-intensive, leading to higher initial CO2 and SO2 emissions, the **Use** phase is much cleaner, resulting in a lower overall impact. This suggests that, from a lifecycle perspective, battery technology is more environmentally friendly than diesel, especially in reducing operational emissions. The diagram emphasizes the environmental benefits of transitioning from diesel to battery technology, particularly in reducing GHG emissions and acidification potential during the operational life of vehicles or machinery. However, it also highlights the need for cleaner production methods for batteries to further minimize their overall environmental impact.

4.5.2 Ship Subject to Tanzania Policy

The Tanzania government's policy to convert conventional ships into eco-friendly vessels presents an opportunity to investigate the actual environmental benefits. A scenario was developed where 3 ships would be converted into fully battery-powered ships each year, spanning a 10-year period to replace all 3 existing ships with battery propulsion. The national electricity grid was assumed to maintain its energy share from 2023.

Comparing to diesel-only operation, Figure 8.1 illustrates the Life Cycle Assessment (LCA) results. They suggest that over the ten-year period, greenhouse gas emissions (GWP) could be reduced by 5.27 × 10^7 kg CO2 equivalent. Additionally, other local pollutants like acidification potential (AP), eutrophication potential (EP), and photochemical ozone creation potential (POCP) could be reduced by approximately 1.57 × 10^6 kg SO2 equivalent, (see Figure 8.1) Except for GWP, all other environmental impact potentials were reduced by more than half.

Moreover, if the battery conversion policy extends beyond the initial 3 vessels over the following years, it is anticipated that a 50% reduction in environmental impacts can be achieved before 2050.

Figure 8.1: Ship Subject to Tanzania Policy

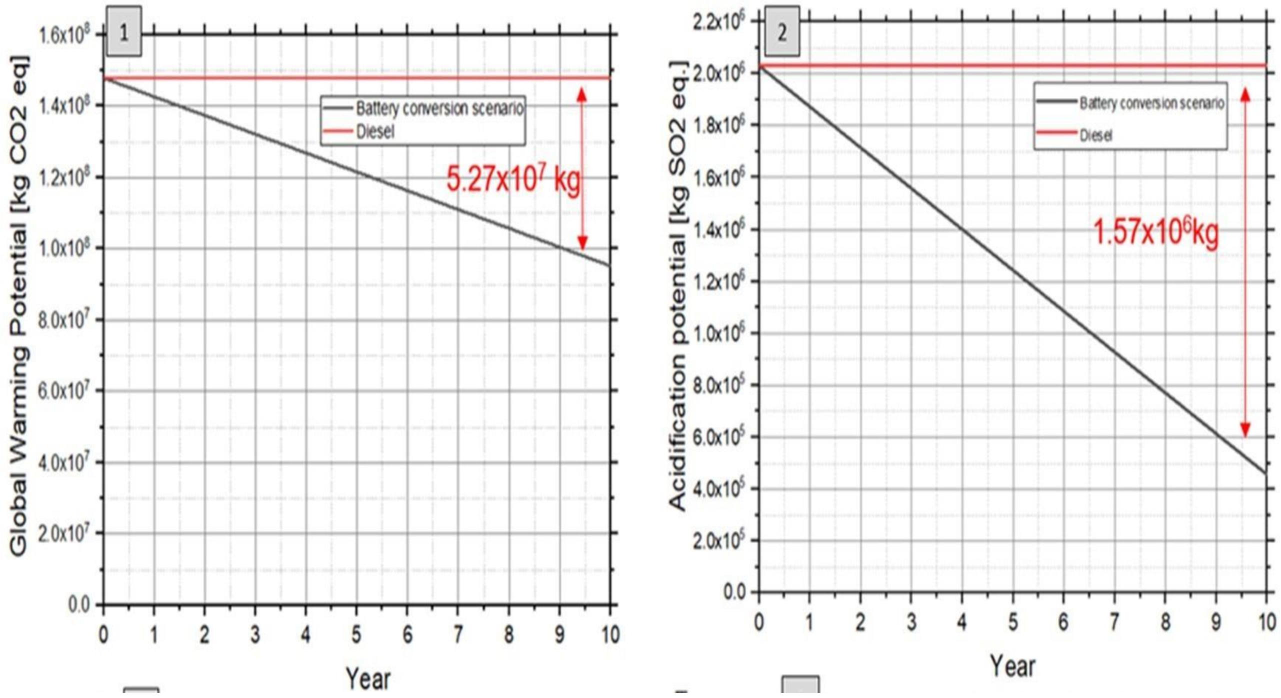


Figure 8.1 shows compares the ***Global Warming Potential (GWP)*** *and* ***Acidification Potential (AP)*** *after 10-years*

The diagram you provided comparison for **Global Warming Potential (GWP)** and **Acidification Potential (AP)** over a 10-year period between two scenarios, a **Battery Conversion Scenario** and **Diesel.** The graph shows a significant difference between the environmental impacts of these two energy sources over time. **Global Warming Potential (GWP) Diesel,** the red line represents the GWP associated with diesel, which remains constant over the 10 years. This indicates a continuous emission of greenhouse gases (GHGs) such as CO2 due to the combustion of diesel fuel. **Battery Conversion Scenario** The black line indicates the GWP for the battery scenario, which decreases over time. This suggests that transitioning to battery-powered systems results in a reduction of GHG emissions over time, amounting to a total reduction of **5.27 x 10^7 kg CO2 equivalent** after 10 years.

Acidification Potential (AP) Diesel, the red line for diesel shows a constant AP over time, indicating ongoing emissions of acidifying gases such as sulfur oxides (SOx) from diesel combustion. **Battery Conversion Scenario**: The black line represents the AP for the battery scenario, which decreases over time, leading to a total reduction of **1.57 x 10^6 kg SO2 equivalent** after 10 years.

Environmental Policy Context in Tanzania

Tanzania, like many other countries, is working towards reducing its environmental impact, especially in terms of GHG emissions and air pollutants. The country has various policies and frameworks in place aimed at mitigating climate change and promoting sustainable development. The key points of relevance include, **National Environmental Management Act (2004).** This Act provides a legal framework for sustainable management of the environment in Tanzania, including reducing air pollution and minimizing GHG emissions**,** **National Climate Change Strategy (2012).** Tanzania's strategy emphasizes the need to reduce GHG emissions in all sectors, including transport and energy, to combat climate change**.** **Renewable Energy Policy**, Tanzania is encouraging the adoption of renewable energy sources and technologies, such as solar and winds to reduce reliance on fossil fuels like diesel.

Relevance of Tanzanian Environmental Policy

GWP and Climate Change Mitigation: The significant reduction in GWP shown in the battery conversion scenario aligns with Tanzania's goal to lower GHG emissions. The diagram supports the transition from diesel to battery-powered systems as an effective way to achieve this. **AP and Air Quality Improvement:** The decrease in acidification potential also aligns with Tanzania's objectives to reduce air pollution, particularly in urban areas where diesel engines are commonly used. Reducing SOx emissions would help improve air quality and reduce the incidence of acid rain, which can damage ecosystems and infrastructure. That effectively illustrates the long-term environmental benefits of transitioning from diesel to battery technology, supporting Tanzania's policies aimed at reducing GHG emissions and improving air quality. By adopting battery-powered systems, Tanzania could significantly decrease its environmental impact, contributing to both global and local sustainability goals.

4.6 Discussion

While state-of-the-art battery technologies for ships can indeed lower emissions and ensure compliance with international and regional standards, it's important to acknowledge that battery operation doesn't equate to zero emissions when considering the entire lifecycle of a vessel.

This study has underscored the need to take a holistic view of environmental impacts when assessing battery-powered ships. By conducting a comprehensive Life Cycle Assessment (LCA), this research provides valuable insights into the realistic environmental effects of such vessels, which can inform future maritime policies.

To support the development and adoption of battery-powered ships, several critical questions need addressing:

Can renewable energy sources generate sufficient electricity to charge ship batteries effectively?

Is there awareness that adopting new technology might merely shift emissions from the operational stage to other lifecycle stages, such as construction, transportation, or recycling?

Given Tanzania significant air pollution challenges, this study demonstrates that using batteries can lead to substantial reductions not only in greenhouse gas emissions but also in local pollutants. It serves as a pioneering investigation, offering essential guidance for the planned conversion of 10 vessels, potentially paving the way for more environmentally sustainable practices in the maritime industry.

5.0 Conclusion of the Paper

The paper concludes the research findings as follows:

1. The study showcased the advantages of utilizing battery-driven propulsion, leading to significant reductions in environmental impact compared to conventional diesel-mechanical propulsion. Specifically, there was a decrease of 35.7% in Global Warming Potential (GWP), 77.6% in Acidification Potential (AP), However, it was observed that battery applications currently fall short of achieving the 50% GWP reduction target under Tanzania current electricity mix.

2. Key technological and operational factors influencing emissions throughout the 'Well to Propeller' process were identified. This includes emissions associated not only with onboard use but also with fuel and electricity production, as well as fuel transport based on locations and energy sources.

3. The study suggested that current practices for maritime environmental assessment may have been misaligned regarding cleaner shipping. It proposed corrective guidance, emphasizing the effectiveness of Life Cycle Assessment (LCA) and advocating for its standardization to ensure consistent and integrated use.

4. The proposed LCA approach is expected to contribute significantly to standardizing maritime LCA models. It offers a framework for evaluating effective fuels to meet the International Maritime Organization's (IMO) 2050 target, considering the lifecycle intensity of greenhouse gases (GHG)/carbon and local pollutants.

5. Significant discrepancies between measured and analytically calculated marine engine emissions were identified, suggesting that marine LCAs should rely on measured data for accuracy and reliability.

6.0 Recommendations

The paper recommends for further studies should be done at kigamboni Magogoni-Ferry in Dar es Salaam in order to reveals issues which were not addressed in this paper.

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