ASSESSMENT OF FUEL LOSS PREVENTION IN DISTRIBUTION TERMINALS

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November, 2023

DECLARATION

I Chifundo Tembo declare that this research project represents my work and it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

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Date 10th November 2023

DISSERTATION APPROVED BY:

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ABSTRACT

The issue of energy supply and management is critical to every nation's long-term development. In this effort, the prevention of fuel loss emerges as a significant priority, particularly for countries like Malawi which are attempting to maximize their energy resources and ensure efficient supply networks (MERA,2015).

The problem of fuel loss is not unique to Malawi, but it is particularly acute due to the country's reliance on imported fuel, limited storage capacity, and weak infrastructure.

The study focuses on identifying the types and causes of fuel losses, quantifying the amount of fuel lost, and developing a monitoring and tracking system to track fuel at every step in the distribution network.

This study also aims to develop and implement a fuel loss prevention model for oil and gas distribution terminals in Malawi. The model uses a combination of nucleonic level measurement, computer-controlled monitoring, and magnetic switches to set off alarms in the event of a fuel leak or theft. The system is designed to be easy to install and maintain and can be used in a variety of settings. The research will also give recommendations on the best practices for preventing or reducing fuel loss in distribution terminals.

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greater end. Above all, The Almighty God, through His love and grace, predestined my academic journey which today I cherish. Thanks.

DEDICATION

To the birth of my Breath; Andrew Tembo (Father) and Emma Gobah (Mother), my sisters and brothers not forgetting my friend.

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ACRONYMS/ABBREVIATIONS

MERA- Malawi Energy regulatory

NOCMA- Nation Oil Company of Malawi

VOC- Volatile organic compound

EPA – Environmental Protection Agence

OMC- Oil Marketing Company

SFR- Strategic Fuel Reserves

E&P- Malawi Petroleum Exploration and Production Law

LPG-Liquefied Petroleum Gas

NEP-Nation Energy Policy

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CHAPTER 1

1.0 INTRODUCTION

Energy supply has become a growing concern in Malawi and is essential for growth and development. Future economic growth is critically dependent on the long-term availability of energy from inexpensive, accessible, and ecologically acceptable sources. However, the government is confronted with major energy supply issues, such as expanding energy and electricity consumption; insufficient power generation capacities; and escalating oil import bills. Primary energy supplies of the country consist of hydropower, biomass, petroleum products, coal, and other renewable energy sources (John L Taulo et al., 2015). Malawi imports about 97% of its refined petroleum products (Gamula et al., 2014). The main petroleum products imported into Malawi are petrol, diesel, kerosene, and liquefied petroleum gas (LPG).

Malawi has experienced very acute fuel shortages since November 2009. This problem however exacerbated in 2011 when most service stations were dry for a good part of the year as noted by Cammack (2011:7) who states that in mid-2011 fuel supplies contracted to the point that diesel, petrol, and kerosene were unavailable for days, and when they arrived people had to queue for hours(Kampanje, 2012). The problem of fuel shortage has not been solved up to this day and fuel losses are adding to this problem.

According to the Malawi Energy Regulatory Authority (MERA), Malawi will lose an estimated 15% of its fuel imports (from 2020 to 2022). This translates to a loss of over 50 million litres of fuel per year, with the current average fuel pump price it is worth 100 billion kwacha. The problem of fuel loss needs urgent attention to minimize fuel losses

There is a need to investigate on the causes of fuel losses and how to prevent them.

1.1 Background

Malawi is a landlocked country in Southern Africa with a population of over 18 million people. The country has a limited energy supply, with only about 13% of the population having access to electricity.

The main sources of energy in Malawi are biomass (fuelwood, charcoal, and agricultural residues), hydro, and thermal (diesel)(John L Taulo et al., 2015). Biomass is Malawi's most dominant energy source, accounting for about 84% of the total energy consumption. It is used for cooking, heating, and lighting.

Hydropower is the second largest energy source, accounting for about 12% of the total energy consumption. Malawi has several hydroelectric dams, including the Nkula, Tedzani, and Kapichira dams. Thermal energy is the third largest energy source, accounting for about 4% of the total energy consumption. Malawi relies on imported diesel to generate thermal energy(John L. Taulo et al., 2015).

TABLE 1 ENERGY MIX, PROJECTIONS, AND TARGETS AS IN THE NATIONAL ENERGY POLICY

Energy source	2000 (Actual)	2008 (Actual)	2010	2020	2050
Biomass	93	88.5	75	50	30
Coal	1	2.3	4	6	6
Electricity	2.3	2.8	10	30	40
Liquid fuels	3.5	6	5.5	7	10
Nuclear	0	0	0	0	4
Renewable	0.2	0.4	5.5	7	10
TOTAL (%)	100	100	100	100	100

The issue of energy supply and management is critical to every nation's long-term development. In this effort, the prevention of fuel loss emerges as a significant priority, particularly for countries like Malawi which are attempting to maximize their energy resources and ensure efficient supply networks. Following a 2013/14 industry performance survey, consistently higher in-transit losses of over 0.6 % were recorded(Malawi MERA 2015). Fuel shortage is a serious problem that needs to be addressed urgently. The proposed solutions will require a coordinated effort from the government, the private sector, and civil society. The petroleum sector is an important part of the Malawian economy, and the government is committed to ensuring its sustainable development. However, some challenges still need to be addressed to make the sector more efficient and environmentally friendly.

1.2 Problem statement

Prevention of fuel loss in distribution terminals is a crucial issue in Malawi, considering the country's reliance on imported fuel, limited storage capacity, and weak infrastructure. Fuel losses occur at Malawi's fuel distribution terminals due to a variety of factors. Despite the studies done by MERA on calculating the fuel loss volume every year the public is still unaware of how important fuel loss studies are.

The problem of fuel loss needs urgent attention to minimize fuel losses. which leads to financial losses, which could cause an industry to close, lead to the loss of jobs, and cause economic instability. Due to this, it is crucial for Malawi's economic development and progress that fuel loss in distribution terminals is studied. Thus, there is a need for research to develop practical solutions to prevent fuel loss in distribution terminals and ensure efficient and sustainable fuel supply chain management in Malawi.

1.3 Study Objectives

I. Main objective

To mitigate the amount of fuel lost or unaccounted for in the distribution network.

II. Specific objectives

1. To determine the types and causes of fuel losses in the distribution network.
2. To quantify the amount of fuel lost due to each of these factors
3. To develop a monitoring and tracking system that will track fuel at every step in the distribution network, from the point of entry to the point of sale.

1.4 Research Questions

1. What are the various types of fuel losses in the distribution network, and what are their respective causes?

2. How much of the fuel is lost
3. How can monitoring and tracking systems be developed to track fuel at every level of the distribution network, from entry to sale?

1.5 significance of the study

Loss prevention is crucial in industries to ensure profitability and sustainability, according to Fennelly's Handbook of Loss Prevention and Crime Prevention. Fuel loss in distribution terminals results in financial losses, which could cause an industry to close, lead to the loss of jobs, and cause economic instability. Due to this, it is crucial for Malawi's economic development and progress that fuel loss in distribution terminals is studied. The paper by Deddy Hermawan, Y., & Kristanto emphasizes the problem of oil losses in the oil and gas business, which is a major concern globally. Leaks, evaporation, and theft are a few of the factors that might cause fuel loss.

The research on prevention of fuel loss in Malawian distribution terminals will assist in pinpointing the root cause of the problem and creating mitigation plans. The paper by Jurušs, M., and Seile explores the utilization of loss rates for petroleum products due to natural waste in customs operations. Fuel loss at distribution terminals can lead to erroneous data reporting, which can lead to poor fuel stock management and insufficient tax collection. As a result, the study of preventing fuel loss in distribution terminals in Malawi will aid in guaranteeing accurate data reporting, proper stock management, and higher revenue collection.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Distribution terminal

The distribution of petroleum products represents an important stage in the oil industry supply chain. It encompasses two major distribution paths in the chain: shipping of light products, such as gasoline and diesel, from refineries to distribution terminals; and shipping of heavy products to industrial customers and lube plants (Reis et al., 2017).

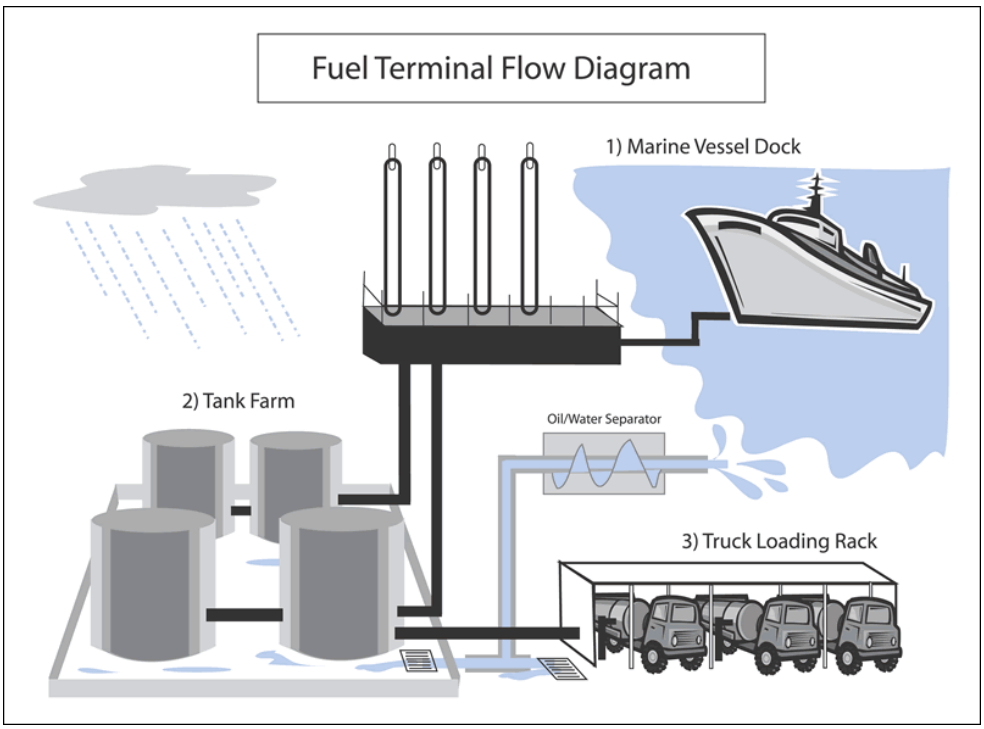


FIGURE 1 DISTRIBUTION TERMINAL

According to Yinghua, S., Gang, W., & Zhongwei, L. (2020), a distribution terminal is a logistics facility that serves as a point of intersection between a distribution system's transportation and storage networks. It is responsible for receiving goods from upstream suppliers, storing them, and shipping them out to downstream customers. Distribution terminals play a vital role in the global supply chain.

They help to ensure that goods are transported from manufacturers to customers in a timely and cost-effective manner. Distribution terminals also play an important role in reducing inventory costs and improving customer satisfaction (Yinghua et al., 2020).

Some of the key functions of a distribution terminal:

1. Receiving: Distribution terminals receive goods from manufacturers and other suppliers.
2. Storage: Distribution terminals store goods until they are ready to be shipped to customers.
3. Order picking: Distribution terminals pick and pack orders for customers.
4. Shipping: Distribution terminals ship orders to customers using a variety of transportation modes, such as trucks, trains, and airplanes.

Rushton, Alan., Croucher, P., & Baker, P. (n.d.). The handbook of logistics and distribution management classified the distribution terminal into:

a. Break-bulk terminals: These terminals handle large shipments of goods that need to be broken down into smaller loads for distribution to individual retailers or customers. Break-bulk terminals are typically located near ports or rail yards, and they often have extensive storage and handling facilities.
b. Consolidation terminals: These terminals combine smaller shipments from different suppliers into larger loads for more efficient transportation. Consolidation terminals are often located in major metropolitan areas, and they typically have a high volume of throughput.
c. Cross-docking terminals: These terminals receive and ship goods without storing them. Cross-docking terminals are typically used for fast-moving goods, such as fresh produce or pharmaceuticals.
d. Distribution centers: These terminals store and distribute goods to retailers and customers. Distribution centers are typically located in central locations to minimize transportation costs.

e. Fulfillment centers: These terminals process and ship orders to customers. Fulfillment centers are typically located near major population centers to ensure fast delivery times.

2.2. Malawi petroleum sector

In the Energy policy document, the government of Malawi recognized the two main parts of this sector which are the upstream and the downstream. Upstream covers aspects of exploration of oil and gas, production and refinement of crude oil, ethanol, and other fuels.

Downstream encompasses supply logistics and marketing of liquid fuel products and gas (Gamula et al., 2014a).The Petroleum (Exploration and Production) Act (Cap 61:02) (the 'E&P Act') and the Liquid Fuels and Gas (Production and Supply) Act (Cap 50:03) (the 'Production and Supply Act') govern oil and gas exploration and production in Malawi (Laws and Regulations Governing Petroleum Activity in Malawi, 2016).

The E&P Act mainly deals with the exploration and production of petroleum within Malawi whereas the Production and Supply Act mostly deals with extraction, conversion, importation, blending, transportation, storage, distribution, wholesale and retail sale of liquid fuels and gas within Malawi (Laws and Regulations Governing Petroleum Activity in Malawi, 2016).

Malawi's Petroleum sector is heavily reliant on imported petroleum products. Malawi has no refineries for petroleum products because it has been proven to be uneconomical due to the small national market.

Malawi therefore imports about 97% of its refined petroleum products; the balance is contributed by locally-produced ethanol which is sold directly to the oil companies for blending with petrol on a maximum 20:80 ratio of ethanol-petrol(Gamula et al., 2014).

The main petroleum products imported into Malawi are petrol, diesel, kerosene, and liquefied petroleum gas (LPG).

The petroleum sector is dominated by two companies, the National Oil Company of Malawi (NOCMA) and Petroleum Importers Limited (PIL). NOCMA was established when the Government of Malawi adopted the National Energy Policy (NEP) in 2003 (GoM, 2018).

Its main objective is to ensure the security of the fuel supply in Malawi. NOCMA imports 55% of the total volume of fuel being imported in Malawi. Some of the suppliers that NOCMA uses are VITOL and Trafigura through the port of Beira, Augusta in Dar-es-salaam, Oryx, and Sahara Energy (GoM, 2018).

Petroleum Importers Limited (PIL) is a privately owned consortium. Following the recommendation of the Malawi government. The International Monetary Fund and the World Bank ensured the security of supply after the collapse of the state-owned Petroleum Control Commission when it was formed. PIL imports 45% of the total volume of fuel imported in Malawi. Some of the suppliers that PIL uses are Glenco Energy UK and Petromoc through the port of Beira (MERA, 2013).

The petroleum sector is a major contributor to the Malawian economy, providing employment for thousands of people and generating significant revenue for the government.

The sector is facing several challenges, including high import costs, unreliable supply, and environmental pollution. In 2011, petroleum products accounted for 40% of Malawi's import bill. The country's fuel imports are largely financed by foreign exchange earnings from tobacco, tea, and sugar exports. However, these exports have been declining in recent years, due to several factors, including the global financial crisis and the fall in commodity prices (Kampanje, 2012).

The fuel shortage in Malawi is a complex issue with several contributing factors. These include:

1. The decline in foreign exchange earnings from exports
2. The high cost of fuel imports
3. The inefficient use of fuel
4. The lack of investment in energy infrastructure
5. The smuggling of fuel across the border

2.3. Malawi distribution terminal

Malawi solely relies on imported fuel mainly from Beira, Dar es Salaam and Nacala. Of the three sources, Beira is the main source providing over 70% liquid fuels to Malawi. The Malawi Energy Policy (2003) prescribed the 50%, 30%, and 20% route shares among Beira, Dar es Salaam, and Nacala respectively to ensure the security of supply at all times and that petroleum products land at the least cost(The Malawi Government Gazette, 2018).

However, the route mix has not been attainable over the years due to structural limitations coupled with weak enforcement mechanisms which poses a threat to the security of supply. The main mode of transportation is by road as over 90% of petroleum products are sourced from Beira and Dar es Salaam ports with the balance being transported by rail through Nacala(The Malawi Government Gazette, 2018).

The country's importation licensing regime allows for multiple importers which includes importation companies, Oil Marketing companies, and individual bulk users who have their storage depots.

Oil marketing companies that have importation licenses complement their imports with supplies from Oil Importing Companies. Currently, the country has a total stock holding capacity of 85.123 million litres distributed among Oil Marketing Companies, ethanol-producing companies, and individual bulk users. The stockholding capacity is expected to be boosted by 60 million liters upon full commissioning of the government-owned

Strategic Fuel Reserves (SFRs) which will be managed by the National Oil Company of Malawi(The Malawi Government Gazette, 2018).

The Oil Marketing Companies distribute their products through retail stations which are spread across the country. The distribution network therefore comprises importers, transporters, oil marketing companies, and retailers, and through the synergies of the industry players, the country enjoys an uninterrupted flow of petroleum products (The Malawi Government Gazette, 2018).

The Malawi Energy Regulatory Authority (MERA) is responsible for regulating the importation and sale of petroleum products in Malawi. MERA sets the maximum retail prices for petroleum products and issues licenses to importers and retailers(Laws and Regulations Governing Petroleum Activity in Malawi, 2016).

To purchase petroleum products, oil marketing companies (OMCs) in Malawi must first obtain a license from MERA. Once they have a license, OMCs can purchase petroleum products from NOCMA, commercial importers, or foreign refineries. OMCs are then responsible for transporting and distributing the petroleum products to their retail outlets(The Malawi Government Gazette, 2018).

The importation of petroleum products into Malawi is a complex and expensive process. The cost of petroleum products in Malawi is influenced by several factors, including the international price of crude oil, the exchange rate of the Malawi kwacha, transportation, handling costs, distribution costs, and profit margin.

2.4. Factors Contributing to Fuel Loss in Distribution Terminals

Oil is one of the world's most important raw materials. It has been the world's leading source of energy since the mid-1950s. The oil industry is one of the most important components of the world economy and has a significant impact on the development of other industries(Lisitsa et al., 2019).

The transportation and marketing of petroleum liquids involve many distinct operations, each of which represents a potential source of evaporation loss.

Crude oil is transported from production operations to a refinery by tankers, barges, rail tank cars, tank trucks, and pipelines(Petroleum Industry, 2011).

According to Petroleum Industry Transportation and Marketing of Petroleum Liquids 2011 Evaporative emissions from the transportation and marketing of petroleum liquids may be considered, by storage equipment and mode of transportation used, in four categories:

1. **Rail tank cars, tank trucks, and marine vessels: loading, transit, and ballasting losses.**

Loading losses are the primary source of evaporative emissions from rail tank cars, tank trucks, and marine vessel operations. Loading losses occur as organic vapors in "empty" cargo tanks are displace into the atmosphere by the liquid being loaded into the tanks(Eiip, 2001). Ballasting losses are associated with the unloading of petroleum liquids at marine terminals and refinery loading docks from vessels that do not have segregated ballast tanks. Ballasting emissions occur as vapor-laden air in the empty cargo tank is displaced to the atmosphere by ballast water being pumped into the tank(petroleum industry, 2011).

Transit loss is the expulsion of vapor from a vessel compartment through vapor contraction and expansion, which are the result of changes in temperature and barometric pressure(Eiip, 2001).

2. **Service stations: bulk fuel drop losses and underground tank breathing losses.**

Another major source of evaporative emissions is filling underground gasoline storage tanks at service stations. Emissions are generated when gasoline vapors in the underground storage tank are displaced to the atmosphere by the gasoline being loaded into the tank(Petroleum Industry, 2011).

3. **Motor vehicle tanks: refueling losses.**

Service station vehicle refueling activity also produces evaporative emissions. Vehicle refueling emissions come from vapors displaced from the automobile tank by dispensed gasoline and from spillage(petroleum industry, 2011).

4. **Large storage tanks: breathing, working, and standing storage losses.**

Breathing is the process in which stock vapors are expelled from an enclosed volume that is in communication with the stock liquid surface and is due to either a vapor temperature increase, evaporation from the stock liquid surface, or a barometric pressure decrease(Laverman et al., 1991).

Standing losses are due to the evaporation of stored products occurring without varying the level of the liquid in the tank(Gwangwava et al., 2018). working storage, stock does flow into or out of the storage tank(Eiip, 2001).

According to Denizhan and Görmez's (2018) case study on loss prevention in fuel terminal operations in Turkey, various factors lead to fuel loss in distribution terminals. These elements are divided into three categories: operational factors, equipment factors, and human factors.

1) Operational Factors: Operational factors include the procedures and practices that are followed in the fuel terminal such as Overfilling: Overfilling of storage tanks during loading can lead to spillage and subsequent loss of fuel. Incorrect measurement: Inaccurate measurements of the volume of fuel loaded or unloaded can result in fuel loss.

   Inadequate maintenance: Inadequate maintenance of the terminal's infrastructure and equipment can lead to leaks and spills. Inefficient processes: Inefficient processes, such as long waiting times for trucks, can lead to increased idling and fuel loss from engine idling(Denizhan & Görmez, 2018a).
2) Equipment Factors: Equipment factors refer to the physical equipment used in fuel terminal operations. The following equipment factors can contribute to fuel loss: Leakages: Leakages in storage tanks, pipes, or valves can lead to fuel loss.

Inaccurate gauges: Inaccurate gauges used for measuring the level of fuel in storage tanks can result in overfilling or underfilling.

Inadequate sealing: Inadequate sealing of tanks, pipes, or valves can lead to fuel loss. Old and worn-out equipment: Old and worn-out equipment can be prone to leaks and failures, resulting in fuel loss(Denizhan & Görmez, 2018).

3) Human Factors: Human factors refer to the actions and behaviors of the personnel involved in fuel terminal operations. The following human factors can contribute to fuel loss: Lack of training: Personnel who are not properly trained in fuel terminal operations may not follow proper procedures, leading to fuel loss.

   Negligence: Negligent actions by personnel, such as leaving valves open or not checking equipment properly, can lead to fuel loss.

   Lack of supervision: Lack of supervision of personnel can result in non-compliance with safety procedures and fuel loss. Theft: Fuel theft by personnel can result in significant fuel loss(Denizhan & Görmez, 2018).

2.5. The amount of fuel lost due to each of these factors

The amount of fuel lost due to operational, equipment, and human factors can vary depending on several factors, such as the type of fuel, the storage and transportation equipment used, and the operating procedures followed. According to a study by the U.S. Department of Energy, fuel losses due to operational, equipment, and human factors can range from 0.2% to 1.0% of total fuel consumption. This means that the United States could lose up to 1 billion gallons of fuel per year due to these factors. Another study, conducted by the European Commission, found that fuel losses due to operational, equipment, and human factors can range from 0.5% to 2.0% of total fuel consumption in the European Union.

This means that the European Union could lose up to 10 billion litres of fuel per year due to these factors. The amount of fuel lost due to each of these factors. Rail tank cars, tank trucks, and marine vessels: loading, transit, and ballasting losses. Service stations: bulk fuel

drop losses and underground tank breathing losses. Motor vehicle tanks: refueling losses. Large storage tanks: breathing, working, and standing storage losses.

For example, products of lower viscosity (e.g., heavy fuel oil) stick to the walls of the tank or pipe and cause a loss of volume. These insignificant losses are irretrievable.

Concerning those insignificant losses, it is impossible to identify the exact mass of the loss and the reason for the loss. The law in the Netherlands does not establish a standard rate for irretrievable loss. Rates for loss that are being applied in the Netherlands are mainly based on practical observations. In practice 0.2−0.3% are the most common rates of loss applied. 0.3% rate of loss for petroleum products is considered to be a standard rate in business deals (Belastingdienst, 2013)

TABLE 2 UNCONTROLLED VOC EMISSION FACTORS FOR PETROLEUM-CARRYING MARINE VESSELS (EPA, 1996)

Petroleum Liquid	Ship/Ocean Vessel Loading (Pounds VOC per 1,000 gallons Transferred)	Barge Loading (Pounds VOC per 1,000 gallons Transferred)	Ballasting (Pounds VOC per 1,000 gallons Ballasted)	Transit (Pounds VOC per week per 1,000 gallons Transported)
Crude Oil	0.61	1	1.1b	1.3
Gasoline	1.8b	3.4b	0.8b	2.7b
Jet Naphtha/Other	0.5	1.2	NA	0.7
Distillate Oil/Kerosene	0.005	0.012	NA	0.005
Residual Oil	4 x 10-5	9 x 10-5	NA	3 x 10-5

CHAPTER 3

3.0 STUDY AREA

3.1 Geographical Location

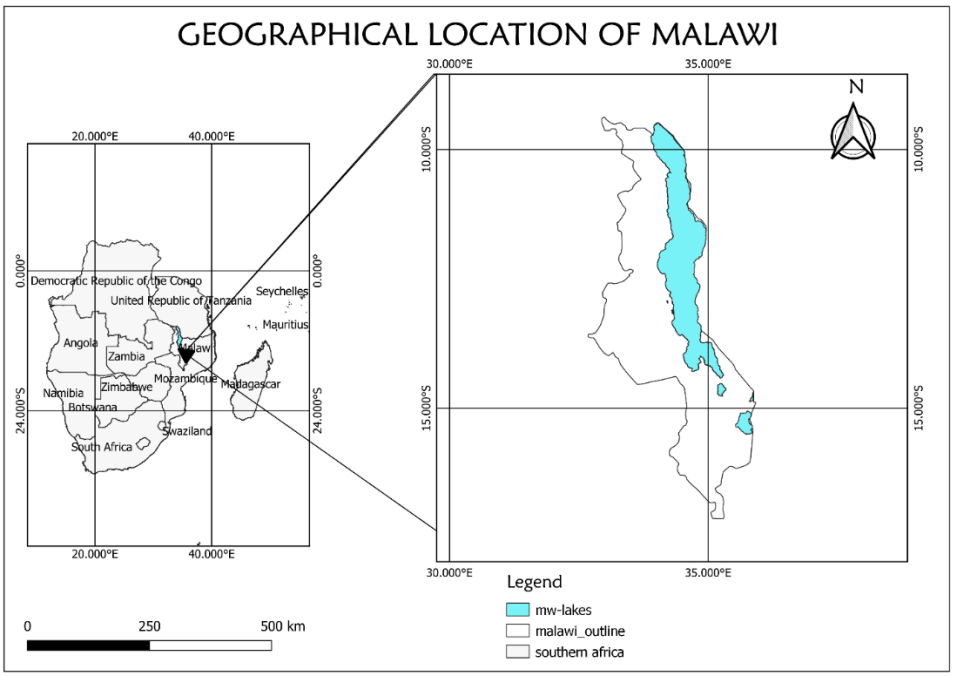


FIGURE 2 GEOGRAPHICAL LOCATION

Malawi is part of the sub-Sahara of Africa and is a landlocked country located in the southeastern part of the continent. Composed of 45,747 square miles Malawi is bordered in the north and east by Tanzania, to the east, south, and southwest by Mozambique, and to the west by the nation of Zambia. Much of the land surface of Malawi is a large plateau that is between 914.4 to 1219.2 meters above sea level. Elevations rise over about 2500 meters in the Nyika Plateau, Zomba Mountain approximately 2087 meters and 3002 meters in Mulanje Mountain. The Shire highlands in the south are the lowest area in the country with elevations extending from 609.6 to 914.4 meters.

The Malawi Rift which is located at the southern end of the western area of the East African Rift between 9^0 and 14^0S is a prominent example of immature rifting hence making the rift system dynamic and two-thirds of it is covered by Lake Malawi (Grijalva, et al., 2018).

CHAPTER 4

4.0. METHODOLOGY

4.1 Introduction

The research methodology of this study will use a qualitative approach using a case study research design. The case study will concentrate on a specific oil and gas corporation and its distribution terminals. To collect data for the study, both qualitative and quantitative methodologies will be used. The information will be gathered through document analysis and semi-structured interviews with key stakeholders in the oil and gas business.

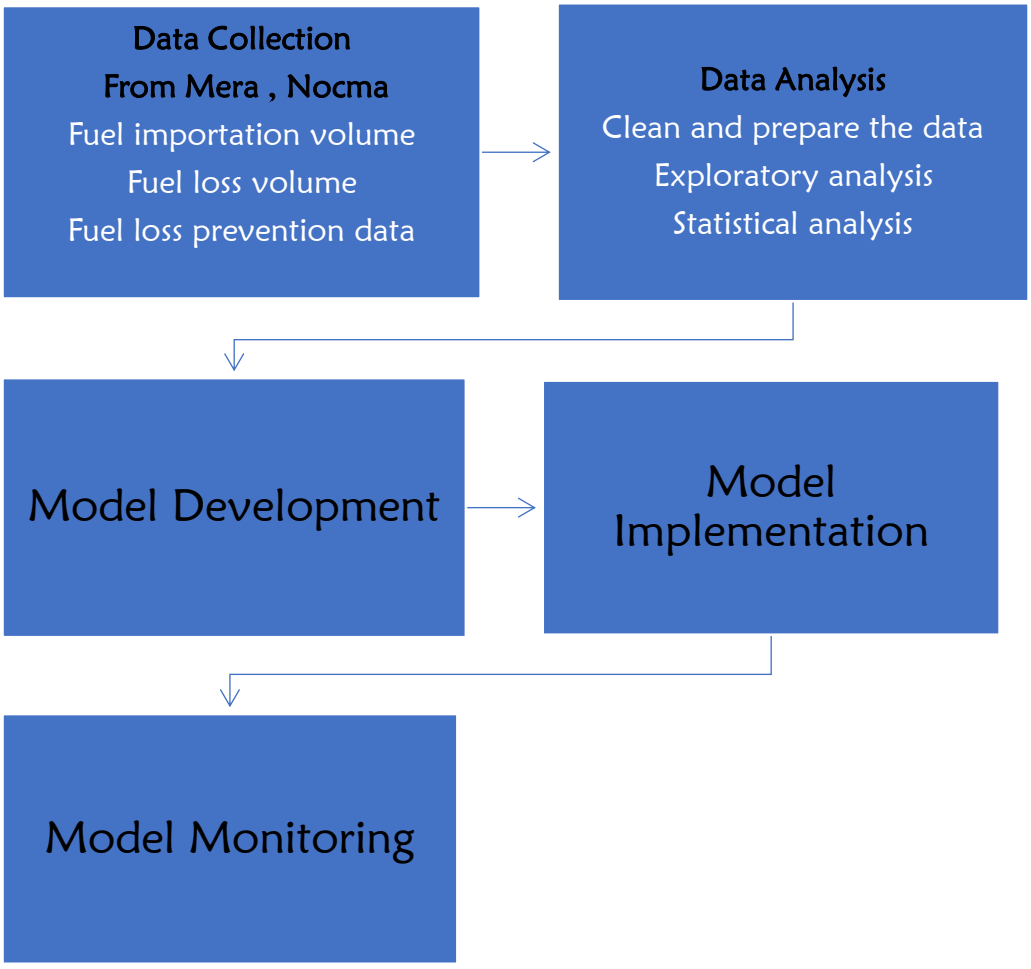


FIGURE 3 RESEARCH DESIGN

4.2 Data collection

The project required quantitative and qualitative data. The data on the common causes of fuel loss, fuel loss volumes, and Fuel consumption data was outsourced from National Oil Company of Malawi (NOCMA) and Malawi energy regulatory authority through interviewing the managers of MERA and NOCMA.

Some of the information was obtained through Observations and document analysis. Site visits to the distribution terminals were conducted to observe fuel loss prevention practices. On document analysis relevant company documents and reports on fuel loss volumes, fuel consumption and fuel prevention strategies will be analyzed to provide context and additional information.

Fuel loss volume: Data on fuel loss volume was collected from a variety of sources, including fuel importers, distributors, and retailers Like PIL, NOCMA, MOUNT MERU, and SIMSO. The data was collected for one year and was disaggregated by fuel type.

Fuel importation volume: Data on fuel importation volume was collected from the Malawi Energy Regulatory Authority (MERA). The data was collected for five years and was disaggregated by fuel type and country of origin.

Fuel prevention measures: Data on fuel prevention measures were collected through interviews with government officials, industry representatives, and civil society organizations. The data was collected to identify the most common fuel prevention measures in use in Malawi and to assess their effectiveness.

4.3. Analysis of data

A mixed-method approach will be used to analyze the data that has been obtained. To find themes and patterns in the qualitative data, content analysis will be used to examine it. To find patterns and links in the quantitative data, statistical approaches will be applied to the analysis.

4.3.1. Data Cleaning and Preparation

The following steps were taken to clean and prepare the data:

Remove outliers. Outliers are data points that are significantly different from the rest of the data. They can be caused by errors in data collection or entry. Outliers were removed from the data using a variety of methods, including imputation and deletion.

Some of the information collected from MERA was incomplete which would have made the data processing very hard. This type of data was removed through the process of deletion.

Handle missing values. Missing values are data points that are missing. They can be caused by a variety of factors, such as equipment failure or human error. Missing values were handled using a variety of methods, including imputation and deletion.

The information below was handled using the deletion

Column	Column	Column	Column
PETRODA		Energem	
Petrol	Diesel	Petrol	Diesel
245.00			
392.00			
180.00			
		923.00	669.00
		608	1,933.00

TABLE 3 MISSING DATA

Transform variables. Some variables were transformed to make them more suitable for analysis. For example, fuel loss volume was transformed into a percentage of total fuel consumption.

4.3.2. Exploratory Data Analysis

Exploratory data analysis (EDA) is a process of exploring and understanding data. It is used to identify patterns, trends, and relationships in the data. The following EDA techniques were used to explore the data on fuel loss, fuel importation, and fuel prevention:

Bivariate analysis: Bivariate analysis is the analysis of two variables at a time. It was used to identify relationships between variables, such as the relationship between fuel loss volume and fuel type.

4.3.3. Statistical Analysis

Statistical analysis is the use of statistical methods to analyze data. The following statistical analyses were performed on the data on fuel loss, fuel importation, and fuel money value:

Correlation analysis: Correlation analysis is used to measure the strength and direction of the relationship between two variables. It was used to measure the relationship between fuel loss volume and fuel type, fuel loss volume and region, and fuel loss volume and fuel prevention measures.

Regression analysis: Regression analysis is used to predict the value of one variable based on the values of other variables. It was used to develop a model to predict fuel loss volume based on fuel type, region

4.4. Model Development

This fuel loss prevention model uses a combination of nucleonic level measurement, computer-controlled monitoring, and magnetic switches to set off alarms in the event of a fuel leak or theft. The system is designed to be easy to install and maintain and can be used in a variety of settings, including fuel storage tanks, fuel trucks, and generators.

Components

- Nucleonic Level sensor

This sensor measures the level of fuel in the tank and sends the data to the computer controller. The nucleonic point or continuous, non-contact, level method measures the signal strength of a radioactive (gamma) source beamed across a vessel.

It is generally independent of fluid properties such as pressure and temperature, although variations in density may cause inaccuracy. Typical measurement range is 0.24–3.36 m. Point-level measurement can be achieved by mounting a nuclear source and detector/switch on diagonally opposite sides of a vessel. This method has been applied successfully on difficult applications such as measuring levels in flash vessels and distillation column reboilers under all temperature and pressure conditions and in detecting liquid interfaces on three-phase separators(Edwards & Otterson, 2014).

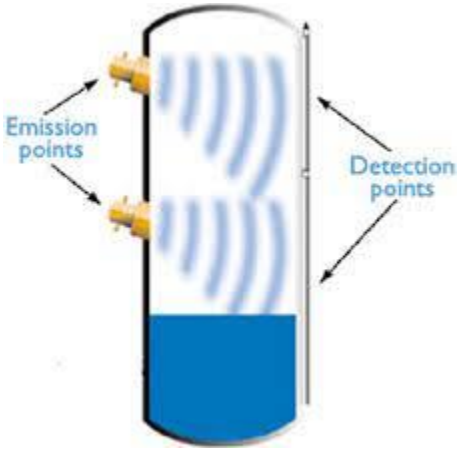


FIGURE 4 NUCLEONIC LEVEL MEASUREMENT

- **Computer controller:**

in a computer control system, sensors are used to collect data and then input to the computer. There are many kinds of sensors, e.g., thermal sensors, pressure sensors, light sensors, etc. (Technological Studies, 2022).This device monitors the level data from the sensor and sets off alarms if the fuel level drops below a certain threshold.

- **Magnetic switches:**

Magnetic activated level switches for controlling liquid levels in most industrial applications. When they have been installed at the point of operation,

they work as on/off switches and are used for fully automatic management of tanks (including pressurized ones) allowing operations such as starting/stopping of pumps, opening /closing of solenoid valves, and activation of alarm systems. One or more instruments can be used, depending on the number of operations points necessary These switches are placed around the tank and set off alarms if they are triggered by magnets(Riels, 2015).

- Alarms: The alarms can be audible, visual, or both.

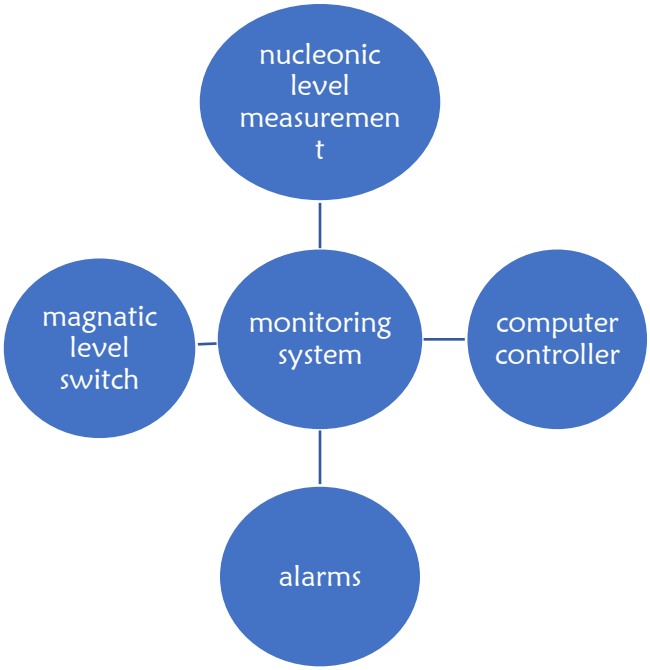


FIGURE 5 FUEL LOSS PREVENTION MODEL

Operation

The fuel loss prevention model works as follows:

1. The level sensor measures the level of fuel in the tank and sends the data to the computer controller.
2. The computer controller monitors the level of data from the sensor.
3. If the fuel level drops below a certain threshold, the computer controller sets off the alarms.
4. The magnetic switches are placed around the tank and set off alarms if they are triggered by magnets.

5. If a fuel leak or theft occurs, the magnetic switches will be triggered and the alarms will go off.

Benefits

The fuel loss prevention model has several benefits, including:

- It is effective in preventing fuel leaks and theft.
- It is easy to install and maintain.
- It can be used in a variety of settings.
- It is relatively inexpensive to implement.

4.5 Model Implementation

To implement the fuel loss prevention model, follow these steps:

1. Install the level sensor in the fuel tank.
2. Connect the level sensor to the computer controller.
3. Install the magnetic switches around the fuel tank.
4. Connect the magnetic switches to the computer controller.
5. Configure the computer controller to set off the alarms at the desired fuel level and/or if a magnetic switch is triggered.
6. Test the system to make sure that it is working properly.

4.6 model monitoring

is the process of continuously observing and evaluating the performance of a fuel loss prevention model to ensure that it is working as expected and that it is still effective in preventing fuel loss. Fuel loss prevention systems are typically complex and involve multiple components. As a result, there are many potential points of failure that could lead to fuel loss. Model monitoring can help to identify these potential failures early on, so that they can be addressed before they cause significant fuel loss.

CHAPTER 5

5.0 Results

5.1 The following were found to be the major causes of fuel loss in Malawi

A. Evaporation

Evaporation is the process by which a liquid change into a gas. In the case of fuel, evaporation occurs when volatile organic compounds (VOCs) in the fuel escape into the atmosphere. VOCs are compounds that contain carbon and hydrogen, and they are easily vaporized at normal temperatures and pressures. The amount of fuel lost due to evaporation annually in Malawi is about 1%.

Another factor that contributes to evaporation is fuel quality

Evaporation losses are usually considered from the quantitative point of view and the fact that poor-quality fuel causes negative changes in engine condition which is not always taken into account. Because of these losses, the boiling point and density of petrol rise and such important parameter of petrol quality as an octane number is reduced, which increases petrol consumption in engine operation and its malfunction(Chernyak et al., 2010).

Evaporation can be a significant problem for fuel storage tanks.

Tanks that are not properly sealed or that are not vented to the atmosphere can allow large amounts of fuel to evaporate. In addition, tanks that are exposed to high temperatures, such as those that are located in direct sunlight, can also experience significant evaporation losses.

B. Equipment failure

equipment failure in Malawi accounts for about 8% of all losses. It is one of the major causes of fuel loss in Malawi.

Equipment leaks

Equipment leaks are another major cause of fuel loss. Leaks can occur from a variety of sources, including tanks, pipes, valves, and pumps. Leaks can be caused by several factors, including aging equipment, improper maintenance, and accidental damage.

Small leaks can go unnoticed for a long time, and they can result in significant fuel losses over time. Larger leaks can be more obvious, but they can also be more dangerous. Leaking fuel can pose a fire hazard and can also contaminate the environment.

Failure of transport equipment

In the petroleum industry, failure of transport equipment can have serious consequences, including oil spills, environmental damage, and economic losses. Transport equipment is used to move petroleum products from one location to another.

Measurement equipment failure

The petroleum industry relies heavily on measurement equipment to ensure the safe and efficient storage and transportation of petroleum products. However, measurement equipment failure can occur due to various factors, such as the Instrument used for measurement like dip stick and float level measurement equipment are more prone to errors.

Wrong interpretations and volume calculation tools like dip stick require calculations like interpolation which one can easily miscalculate and interpret wrongly hence giving wrong results which can show fuel loss or fuel gain (MERA,2023).it can also be caused by the tank calibration charts which might be giving errors in conversions.

C. Theft

Theft can occur at any point in the distribution process, from the refinery to the retail outlet. Fuel theft can be a major problem for businesses that store and transport large quantities of fuel. Thieves may target fuel tanks, pipelines, or even delivery trucks. In some cases, thieves may work with employees of the fuel company to steal fuel. Theft is a significant cause of fuel loss, accounting for approximately 2% of all losses.

D. Spillage

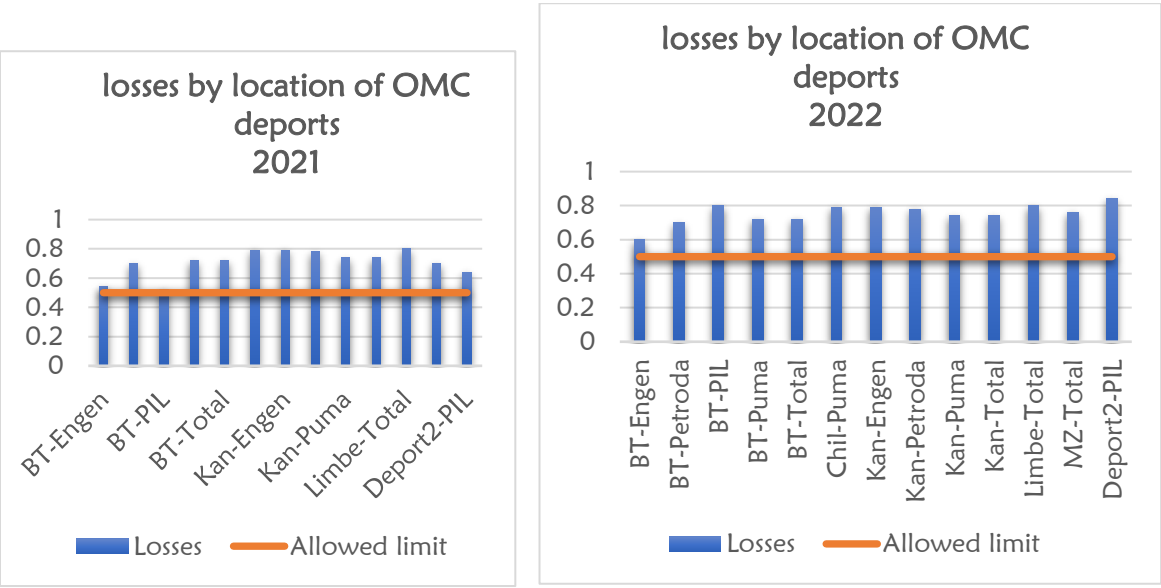
Spillage is a less common cause of fuel loss, accounting for approximately 3% of all losses. Spillage can occur during loading, unloading, and transport operations. Spills can be caused by several factors, including human error, equipment malfunctions, and accidents. Spills can be expensive to clean up and can also contaminate the environment.

E. Temperature

Petroleum expands when heated and contracts when cooled. This thermal expansion is important for the storage and transportation of petroleum products, as it can lead to changes in volume and pressure. This causes the volume of fuel to decrease from time to time, Malawi experiences fuel loss due to the change in temperature due to its different loses about 1% of its fuel to temperature losses.

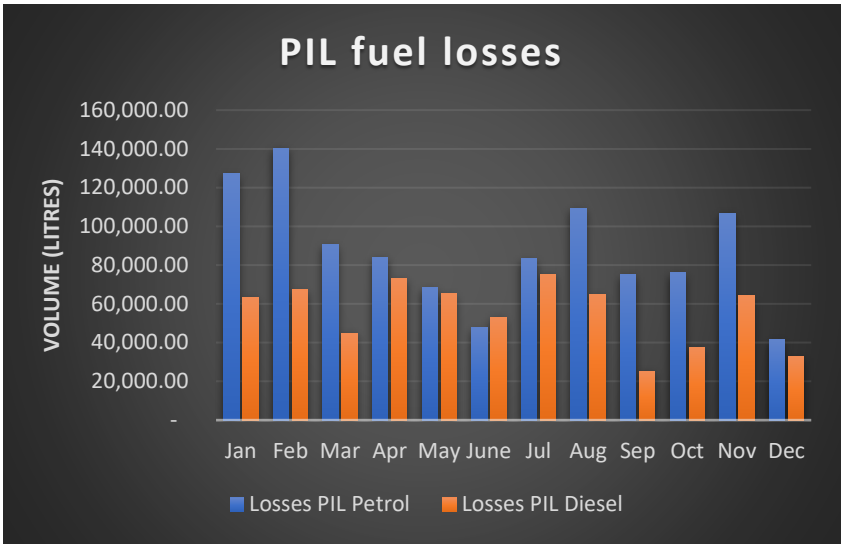
5.2 The quantity of fuel lost annually

Fuel losses



As you can see, the losses have increased for all locations between 2021 and 2022. The location with the lowest losses in 2013 was BT-PIL, with losses of 0.52% which is below the allowed limit of losses. The location with the highest losses in 2022 was deport2-PIL, with losses of 0.84% which is higher than the allowed limit meaning that the fuel losses have increased with time.

Figure 6 Fuel loss petrol vs diesel



During the research it was discovered that as the volume of fuel increased fuel loss also increased hence there are more losses in months where more fuel was purchased that's why January and February have the highest petrol loss. In all the month petrol has a higher volume than diesel due to its nature of being more volatile and a higher calorific value than diesel. The graphs below verify the information.

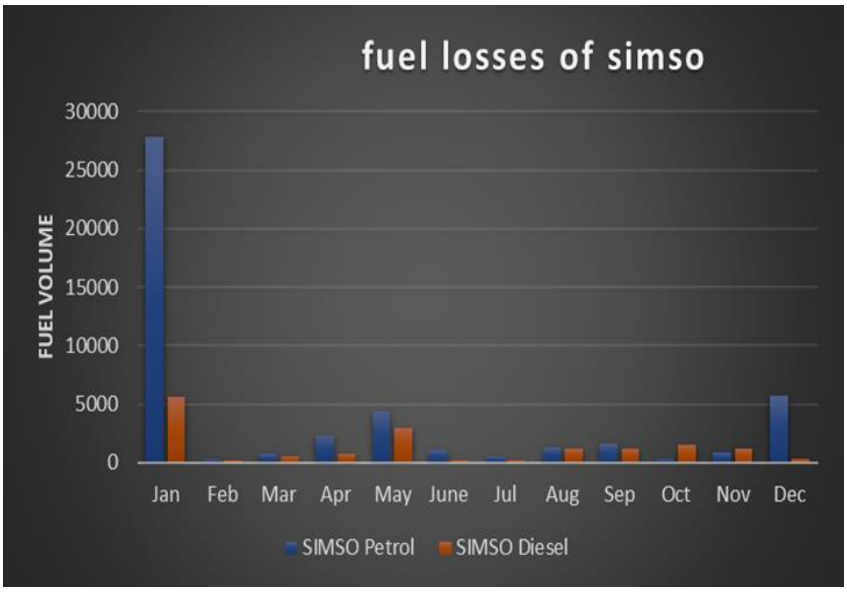


Figure 7 Fuel loss petrol vs diesel simso

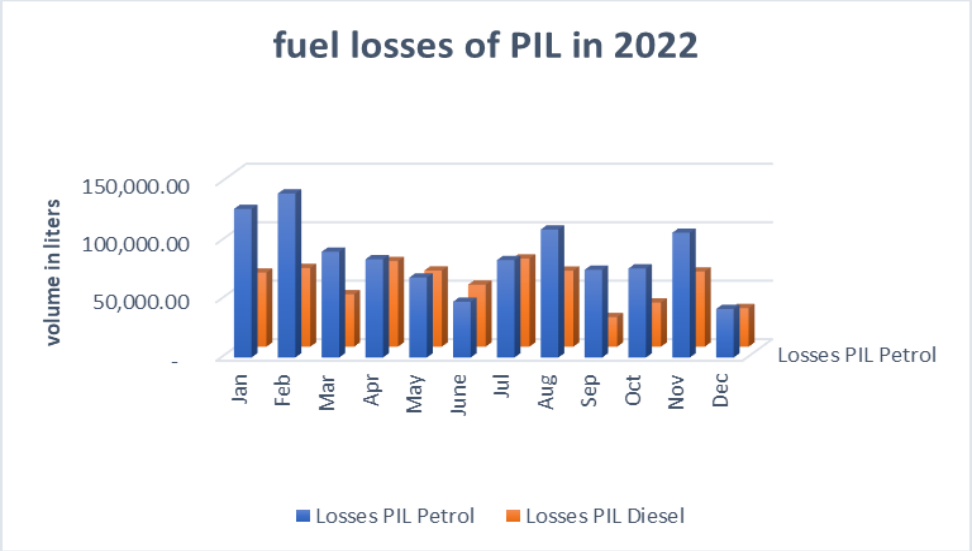


Figure 8 Fuel loss petrol vs diesel PIL

5.3 correlation of fuel loss volume and each type of fuel

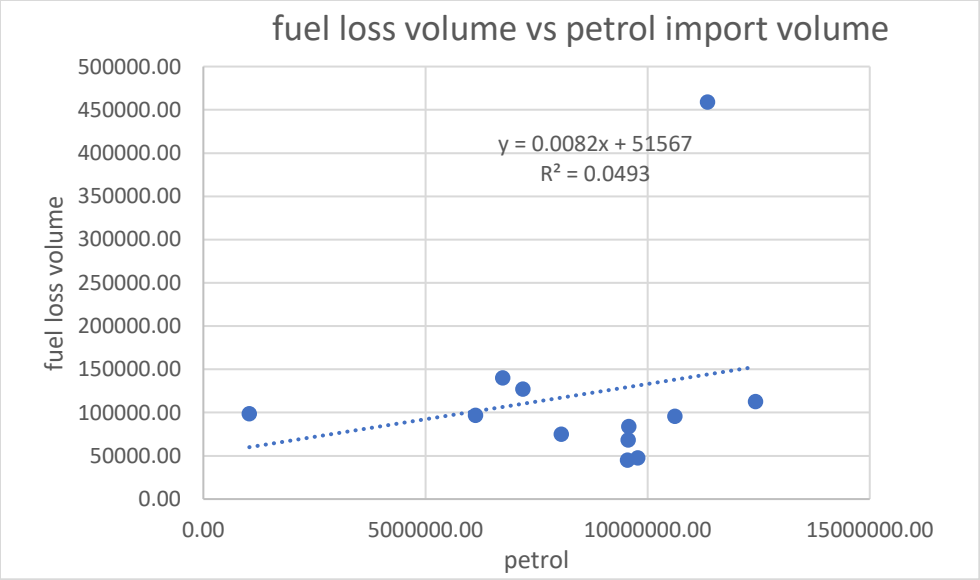


Figure 9 correlation between fuel loss and petrol

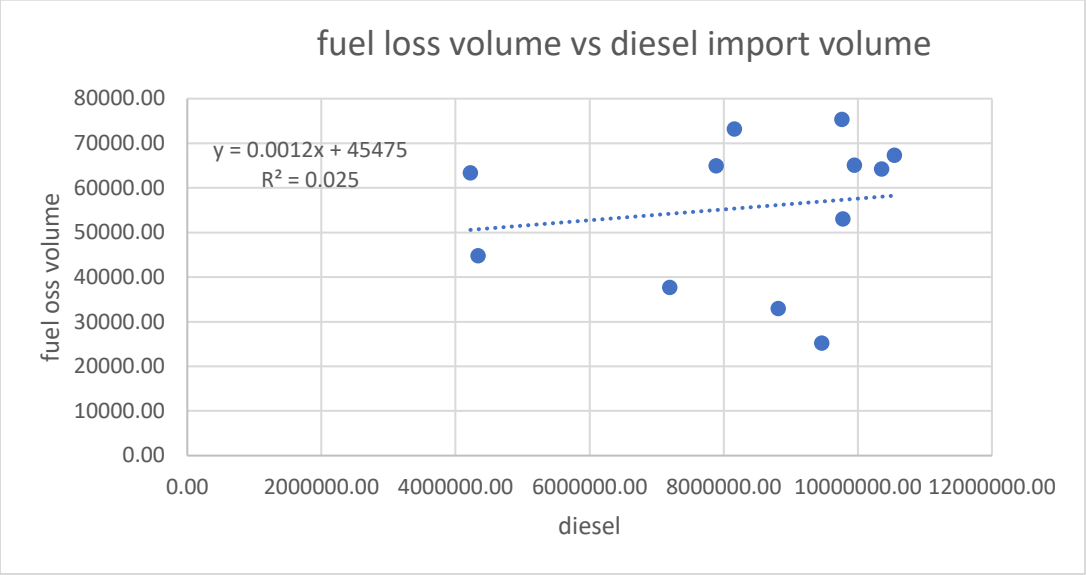


Figure 10 correlation between fuel loss and diesel

Both figure 9 and 10 showed a positive relationship, this means that as the volume of fuel type increases, so does the volume of fuel lost. Because the trend line is linear, the relationship between the two variables is proportionate. The R2 values are 0.0493 and 0.025 respectively, indicating a poor relationship. This indicates that the variables have a poor relationship and that other factors may be influencing fuel loss volume.

CHAPTER 6

6.0 Conclusion and Recommendations

6.1. Conclusion

Fuel losses in distribution terminals can be costly for terminal operators. Terminal operators can identify the variables associated with fuel losses and develop methods to mitigate those losses by conducting a data analysis of fuel losses. Malawi still needs to perform more research on fuel loss because, according to estimates, it costs the Malawian economy between 20 and 100 billion kwacha each year.

petroleum loss prevention at distribution terminals is crucial in the petroleum industry. This is due to the fact that it includes tactics for recognizing and minimizing fuel loss from storage tanks, pipelines, and other equipment. Engineering controls, operational procedures, and maintenance programs can all be used to prevent accidents.

Three approaches are Combined to prevent fuel loss in distribution terminals. The first strategy is to undertake a thorough risk assessment in order to identify probable sources of fuel loss. The second option is to use engineering controls to reduce fuel loss, such as leak detection and repair systems. To reduce the danger of fuel loss, the third strategy is to establish and implement operational procedures and maintenance plans.

The study shows that the potential for fuel loss in distribution terminals can be significantly reduced through a combination of prevention strategies. The presence of engineering controls, operational procedures, and maintenance programs can reduce the risk of fuel loss from occurring. The suggested system for fuel loss prevention was not tested this is one of the limitations of the project so it is very had to tell if the developed system will work better than the current system.

Finally, the implementation of maintenance programs can help to ensure that equipment is in good working order and that potential sources of fuel loss are identified and repaired before they can cause significant losses. Based on the results of the study, it is clear that the prevention of fuel loss in distribution terminals is essential for the protection of the environment and the financial health of the fuel industry. By implementing a combination

of prevention strategies, fuel companies can significantly reduce the risk of fuel loss and protect their profits.

6.2 Recommendations

According to the results and existing literature, the following have been suggested for potential research directions. By using the following method fuel loss can be prevented in the distribution terminals.

a. **According to** (farm storage and Handling of petroleum products, 2017) **the following steps reduce fuel evaporation losses**:

Paint the tank with reflective paint (silver or white) and reduce evaporation losses by up to 40 percent compared to a dark-colored tank.

Use a pressure-ventilated cap to reduce evaporation losses by 50 percent. This type of cap restricts direct venting of tank fumes until a slight pressure has built up in the tank. Having a painted and pressure-vented tank has a 75 percent evaporation loss reduction compared to a dark-coloured tank.

Locate a painted and pressure-vented tank in the shade to further reduce evaporation losses by over 40 percent. A shelter with a roof also helps reduce weathering of hoses and valves Do not fill the tank to more than 90 percent of its capacity; this practice reduces pressure in the tank, and thus, evaporative or spill losses. (See table 5)

Source: Farm Storage and Handling of Petroleum Products, Farm Mechanization Factsheet No. 210.510-1, Resource Management Branch, British Columbia Ministry of Agriculture and Lands.

b. Monitoring for Fuel Losses

To avoid spills and catch leaks, it is recommended that fuel tanks be monitored at least every 2 weeks. The best way to determine if there is a leak is through a visual inspection when walking around the tank, looking for rust spots, stains on the ground, or cracks, breaks, or bends in the hose.

Another way to determine if fuel losses are occurring is to maintain inventory records. An example of a fuel inventory control sheet is included in Figure 6.3. If the tank is equipped

with a meter, an ongoing inventory record, kept for a minimum of two years or as long as the life of the tank, should be updated when fuel is used and added to the tank. The expected volume is compared to the actual volume. This amount is obtained from fuel dipping, which measures the amount of fuel in a tank with a dipstick or tape. Do not dip tanks immediately after fuel delivery; allow time for fuel agitation to subside(Farm Storage and Handling of Petroleum Products, 2017).

c. Secondary Containment

As a safety precaution, secondary containment that contains 110 percent of the maximum volume of the storage tank is recommended. Installing a double-walled tank or using a diking system can accomplish this goal.

Double-walled tanks provide excellent protection against leaks and also provide thermal insulation, reducing extreme changes in fuel temperature. Each double-walled tank has a space between two walls that will contain 10 percent more volume than the storage capacity of the tank.

d. Train operators on fuel loss prevention

Operators should be trained on fuel loss prevention procedures. This includes training on how to properly load and unload tanker trucks, how to identify and report leaks, and how to minimize evaporation.

e. Use of Hybrid Tank Gauges (HIMS)

This is the most recent evolution of tank measurement methods and appears to be capable of achieving the greatest accuracy of all present methods because it utilises the most robust elements of existing level measurement technology(Braddock & Chambers, 2011).

This can be viewed as an "emerging technology" of the tank-gauging world. Hybrid systems are also known as Hybrid Inventory Measurement Systems (HIMS). At the time of writing this technology was still evolving. It stands out from conventional methods because it can measure level by conventional automatic tank gauging (ATG), volume by pressure sensor, and density just like current HTG. Hybrids, however, utilise level measurement

equipment and a “smart” pressure transmitter, and a temperature measurement device, which allows the volume to be calculated more accurately than can be achieved using HTG. 10.

6.3 Limitations of study

Whenever assessing fuel loss, data from numerous sources, such as tank gauging records, inventory management systems, and leak detection systems, are frequently used. The quality and completeness of this data might vary greatly, making precise estimations of fuel loss challenging. During this research some of the data was absent resulting in an under- or overestimation of fuel loss.

The research had difficulties in pinpointing the precise reasons of fuel loss. Fuel loss occured as a result of a variety of events. It was very hard to Determine the proportionate importance of each component because some of the the causes where not further researched. It will be difficult to establish focused mitigation solutions without unambiguous attribution.

Mitigation methods' cost-effectiveness: Putting preventative measures in place

Fuel loss can be expensive, both in terms of capital expenditure and continuous maintenance. It is critical to thoroughly assess the cost-effectiveness of various mitigating solutions, taking into account predicted fuel savings and potential return on investment.

Proper personnel training and supervision can help to reduce human error and increase fuel loss prevention. However, maintaining continuous training and awareness over time might be difficult.

Technological progress: new technologies, such as improved metering systems, real-time monitoring systems, and artificial intelligence-based analytics, can help identify, quantify, and prevent fuel loss more effectively. However, adoption of these technologies can be difficult and can limited by cost, compatibility with existing infrastructure, and the need for specialized expertise.

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APPENDICES

Appendix A fuel losses from MERA

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9
	Losses							
	PIL		NOCMA		Mount Meru		SIMSO	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
Jan	127,075.00	63,385.77			117,773	25,104	27854	5632
Feb	140,252.00	67,341.52			55,119.00	29,654.00	309.00	230.00
Mar	90,428.00	44,820.82			79,675.00	14,315.00	756.00	564.00
Apr	84,065.00	73,187.00			56,876.00	10,628.00	800.00	780.00
May	68,415.00	65,123.00			59,874.00	17,862.00	4,366.00	3,009.00
June	47,707.00	53,044.00			25,296.00	13,703.00	1,111.00	169.00
Jul	83,327.00	75,390.00			6369.781	**7,000.00**	567	252
Aug	109,494.00	64,994.00			30,000.00	**907.00**	1278	1200
Sep	75,028.00	25,259.00			7,065.00	813.00	1,602.00	1,175.00
Oct	76,149.00	37,708.00			4,578.00	3,685.00	355.00	1,504.00
Nov	106,701.00	64,282.00			6,775.00	1,842.00	887.00	1,172.00
Dec	41,549.00	32,963.00			5,774.00	435.00	5684	345

TABLE 4 FUEL LOSSES

Appendix B

Fuel losses in 2021

OMC Deport	Losses	Allowed limit
BT-Engen	0.54	0.5
BT-Petroda	0.7	0.5
BT-PIL	0.52	0.5
BT-Puma	0.72	0.5
BT-Total	0.72	0.5
Chil-Puma	0.79	0.5
Kan-Engen	0.79	0.5
Kan-Petroda	0.78	0.5
Kan-Puma	0.74	0.5
Kan-Total	0.74	0.5
Limbe-Total	0.8	0.5
MZ-Total	0.7	0.5
Deport2-PIL	0.64	0.5

Appendix C

Fuel losses in 2022

OMC Deport	Losses	Allowed limit
BT-Engen	0.6	0.5
BT-Petroda	0.7	0.5
BT-PIL	0.8	0.5
BT-Puma	0.72	0.5
BT-Total	0.72	0.5
Chil-Puma	0.79	0.5
Kan-Engen	0.79	0.5
Kan-Petroda	0.78	0.5
Kan-Puma	0.74	0.5
Kan-Total	0.74	0.5
Limbe-Total	0.8	0.5
MZ-Total	0.76	0.5
Deport2-PIL	0.84	0.5

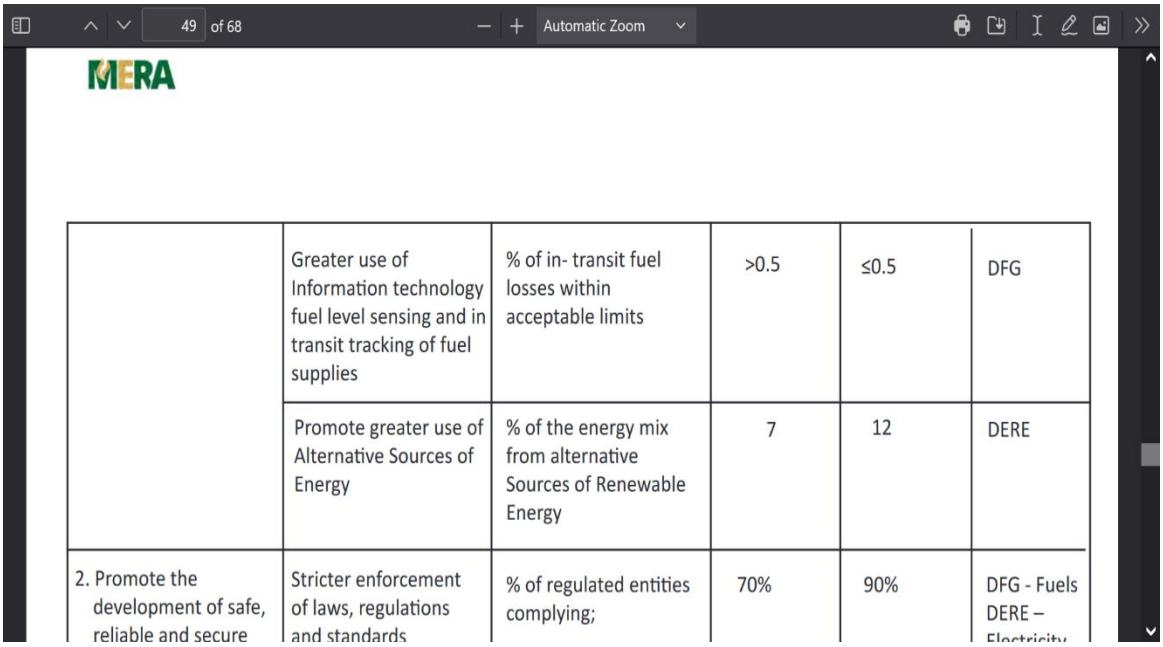
Appendix D

Table 5 Evaporative Losses from A 1,200 Litre (265 Gallons) Aboveground Gasoline Storage Tank.

TANK CONDITIONS	EVAPORATION LOST (Litres)	EVAPORATION LOST (Gallons)	% OF FULL
Dark tank in the sun	38	8.4	3.2
White tank in the sun	23	5.1	1.9
Dark tank in the sun with pressure vent cap	21	4.6	1.8
White tank in sun with pressure vent cap	9	2	0.8
Dark tank in shade	9	2	0.8
White tank in shade with pressure vent cap	5	1.1	0.4
Underground tank	< 4	< 1	0.3
Double-walled aboveground tank	Losses similar to an underground tank		

Appendix D

Allowed limit by MERA



	Greater use of Information technology fuel level sensing and in transit tracking of fuel supplies	% of in- transit fuel losses within acceptable limits	>0.5	≤0.5	DFG
	Promote greater use of Alternative Sources of Energy	% of the energy mix from alternative Sources of Renewable Energy	7	12	DERE
2. Promote the development of safe, reliable and secure	Stricter enforcement of laws, regulations and standards	% of regulated entities complying;	70%	90%	DFG - Fuels DERE – Electricity

Appendix E

Sample questions

What are the most common causes of fuel loss in Malawi?

How much of the fuel is lost annually?

What are the costs of fuel loss and how do they affect Malawi's economy?

How does MERA monitor fuel loss?

What are the current procedures in place to prevent fuel loss and how effective are they?

What data does MERA collect on fuel loss?

What are MERA's plans to reduce fuel loss in the future?

What is the fuel importation volume and fuel loss volume from 2020 to 2022