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Ship-port interface: analysis of the cost-effectiveness of cold ironing at Mombasa Port

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WORLD MARITIME UNIVERSITY

Malmö, Sweden

SHIP-PORT INTERFACE: ANALYSIS OF THE COST-EFFECTIVENESS OF COLD IRONING AT MOMBASA PORT

By

RONALD SSALI

Uganda.

A Dissertation Submitted to World Maritime University in Partial
Fulfilment of the Requirements for the Award of the Degree Of

MASTER OF SCIENCE
In
MARITIME AFFAIRS,
(MARITIME ENERGY MANAGEMENT)

2018

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me. The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Signature: ………………………………

Date: 18th Sep 2018

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ABSTRACT

Title of Dissertation: **Ship-port interface: Analysis of the cost-effectiveness of cold ironing at Mombasa port**

Degree: **Master of Science**

The dissertation studied the cost-effectiveness of investing in cold ironing at the port of Mombasa as a measure to reduce the negative externalities exerted to the port communities during ship port interface. While at berth, ships generate noise and air emissions when auxiliary engines are run to produce the electricity needed to meet their hotelling services. This research focused on air pollutants generated from container ships at the port of Mombasa and did not assess the effectiveness of noise reduction resulting from the use of cold ironing. Specifically, the researcher intended to analyze the following; the port performance of Mombasa, the cost-effectiveness of the cold ironing system (terminal and ship retrofitting investments), and the emission reduction potential per berth per year. Quantitative data was collected from sources such as KPA, ENTEC and MTCC-Africa through interviews and comprehensive desk research. The data was analyzed using an excel model and through Monte Carlo simulations, several scenarios were analyzed taking into consideration the variations in the fuel price, interest rate and number of hours that ships stay connected at berth.

Additionally, a SWOT analysis was used to identify the strengths, weaknesses, threats and opportunities that may be explored to make cold ironing a cost-effective measure to reduce ship emissions. This was done with respect to the best practices from ports of Gothenburg, Oslo and Los Angeles. The study analyzed different scenarios comparing the benefits of using cold ironing over auxiliary engines and the findings indicate that the highest cost-effectiveness was realized in a combination where the Kenyan government exempted ships from paying tax on electricity consumed from shore and where the government adopted a policy requiring ships to use low Sulphur fuel oil (0.1% Sulphur). Numerous of recommendations are highlighted in the last chapter of this dissertation.

KEY WORDS: Ship-Port Interface, Cold Ironing, Ship emissions, Port of Mombasa

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AMP	Alternative Maritime Power
CAPEX	Capital Expenditure
CO_2	Carbon dioxide
CO	Carbon monoxide
CSI	Clean Shipping Index
DWT	Dead Weight Tonnage
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
ESI	Environmental Ship Index
ESPO	European Sea Ports Organization
EU	European Union
FAL	Convention on Facilitation of International Maritime Traffic
GHG	Greenhouse Gases
GMN	Global MTTC Network
HFO	Heavy Fuel Oil
HVSC	High Voltage Shore Connection
IAPH	International Association of Ports and Harbors
ICCT	International Council on Clean Transportation
ICD	Inland Container Depot
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organization
ISO	International Organization for Standardization
KPA	Kenya Ports Authority
LNG	Liquefied Natural Gas
LSFO	Low sulfur fuel oil

LVSC	Low Voltage Shore Connection
MARPOL	The International Convention for the Prevention of Pollution from Ships
MEPC	The Marine Environment Protection Committee
MTCC	Maritime Technologies Cooperation Centres
NoMEPorts	Noise Management in European Ports
NOx	Nitrogen Oxides
NPV	Net Present Value
NTB	Non-Tariff Barrier
OPS	Onshore Power Supply
PM	Particulate Matter
SEEMP	Ship Energy Efficiency Management Plan
SO_2	Sulphur dioxide
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	United States Dollar
WMO	World Meteorological Organization
WMU	World Maritime University

1.0 INTRODUCTION

1.1 Background

Over the last century, seaborne trade has continued to increase accounting for over 80 percent of the total global trade by volume, and future projections show a similar trend with globalization, deeper economic integration and deregulation of the shipping industry (UNCTAD, 2017). The growth in shipping has consequently led to an increasing share in the CO_2 emission from the industry estimated at 2.7 percent of total global CO_2 emission (Buhaug et al., 2009). The International Maritime Organization (IMO), as the responsible UN specialized agency to reduce the GHG emission from shipping, highlighted key strategies for improving energy efficiency through better operational, technical and logistics measures under its second GHG study. Also, IMO adopted an initial strategy for the reduction of GHG emission from ships during the MEPC 72 meeting, setting targets of 50 percent reduction in carbon emissions by 2050, with reference to the 2008 level (IMO, 2018a).

Ports are central hubs for the complex global maritime logistics network and are characterized by high energy demands and supply. The world's busiest ports have a throughput of over 30 million TEUs, and to handle this volume of containers efficiently without affecting the vessels' turnaround time, efficient cargo handling equipment and facilities must be in place (UNCTAD, 2017). However, port activities generate negative externalities that directly affect the surrounding communities. Ships and other equipment such as cargo handling devices, land-based locomotives, buildings, and harbor crafts are the significant sources of emissions in ports. This research focuses on the emissions from ships during their hoteling operations while at berth.

Ships burn bunker producing large amounts of CO_2, PM, NOx, SOx, unburned Hydrocarbons (HC) and CO (Homsombat, Yip, Yang, & Fu, 2013). The level of such emissions dramatically depends on the number of hours that ships spend in ports, the technology used, and operational efficiency (Bazari, 2016). To reduce the dwell time for ships in ports, IMO adopted mandatory requirements under the FAL convention for a single maritime window where electronic data on cargo, crew, and passenger shall be exchanged between public authorities (IMO, 2018b).

Emissions in ports are not globally regulated since IMO focuses on ship emissions, but the International organization for Standardization (ISO) developed standards such as ISO-50001 and ISO-14001 to help organizations adopt energy management and environmental management systems for continual improvement of energy efficiency (ISO, 2016). These standards can be integrated into existing port management practices to provide a consistent methodology for continual energy efficiency improvement. Port authorities implementing the ISO-50001 standards get logical approach on the usage of their existing energy consuming assets and guidance on measuring, documenting and reporting of energy improvement strategies like prioritizing new energy efficient technologies (Pinero, 2009).

The European Union has been active in the regulation of emissions from shipping adopting Directive 2005/33/EC on sulphur content in marine fuels. The directive set a 0.1 percent sulphur limit for fuel used by ships at berth in EU ports (Hämäläinen, 2015). The need for ports to conduct sustainable operations has been recognized globally. A survey conducted around EU seaports highlighted air quality, energy consumption, noise, water quality, waste management, port development, relationships with local community and climate change among their top environmental priorities (ESPO, 2017).

Cold ironing has been implemented in numerous ports such as Los Angeles, Antwerp, Genoa, Gothenburg, and Oslo, as a measure to reduce emissions and noise from ships. The concept of cold ironing (Onshore Power Supply) aims at providing ships with electrical power from the shore side to meet their hoteling demands while at berth, enabling them to shut off their auxiliary engines (Zis, North, Angeloudis, Ochieng, & Bell, 2014). The induced emissions from ships to shore operations depend on the electricity mix for the national grid supply.

However, cold ironing has not been adopted in most developing countries' ports, and emissions from port operations are causing health-related issues to the surrounding communities. IMO has been implementing the EU funded GMN project which is aimed at building capacity for developing states to improve energy efficiency in the maritime sector and mitigate the adverse effects of climate change. Hosting the MTCC-Africa, KPA adopted a Green Port Policy, and the port of Mombasa was used for the pilot project of Cold ironing for vessels berthing in the port to reduce emissions from the ships (MTCC-Africa, 2018).

1.2 Problem statement

Unlike European seaports, ports around Africa lack unified regional port regulations hence the responsibility falls to the national authorities to regulate the emissions with the port areas. The inefficiencies in the port operations lead to increased port time for ships due to delays, resulting into an increase in the amount of air emissions thereby exerting the negative externalities of shipping to the communities around the port of Mombasa. The level of technology used in the port of Mombasa is shifting towards the established green port initiatives, and cold ironing was proposed as a solution to reduce emissions for ships calling the port while at berth. However, the cost-effectiveness of the cold ironing pilot project for the use of onshore power supply for ships at berth remains to be assessed.

1.3 Research Objectives

The main objective of the research was to analyze the cost-effectiveness of the implementation of cold ironing at the port of Mombasa for both KPA and the ship operators as a measure to mitigate the negative environmental externalities from shipping towards the port communities.

Specifically, the research will be looking;

I. To analyze the port performance for container vessels at the port of Mombasa for which the cold ironing implementation is intended.
II. To analyze the cost-effectiveness of the cold ironing investment for KPA.
III. To analyze the financial implications of retrofitting cold ironing equipment for ships calling Mombasa port.
IV. To assess the emission reductions from ships berthing at the port of Mombasa.

1.4 Research Questions

To address the objectives of this research, the following questions must be answered.

I. How much are the number of calls and the dwell time for ships at Mombasa port?
II. Is onshore power supply a cost-effective option for shipping companies as compared to use of bunker during hoteling activities at berth?
III. What are the social and economic benefits of using cold ironing instead of fuel oil?

1.5 Research Limitations

The research focused on the performance of container vessels at Mombasa port whose energy demands while at berth are targeted to be met by cold ironing. The research did not address energy demands by other vessels calling the port other than container ships. The current emission factors for the total installed capacity of Kenya’s electricity mix needs to be researched and comparisons made with the ideal renewable energy scenario. Cold ironing is known to reduce noise from ships berthing in ports because auxiliary engines are shut off but this research does not assess the noise reduction potential from the adoption of cold ironing

1.6 Methods

The research uses quantitative data which obtained from primary and secondary sources. Primary data was collected using interviews with selected representatives from KPA and MTCC-Africa. Secondary data was gathered through extensive desk search for journal articles from Science Direct, Google Scholar, and official organization websites such as IMO, DNV-GL among others. Previous publications available in the WMU library both hard copy and soft copy were reviewed. The data collected was analyzed using a Microsoft Excel model and crystal ball software, allowing the researcher to simulate different scenarios during the cost-benefit analysis for the implementation of cold ironing at the port of Mombasa.

1.7 Research Outline

This dissertation consists of seven chapters organized as follows; Chapter one introduces the research topic, giving the background about cold ironing in ports, the problem statement, the research objectives and the limitation of the research. In chapter two, existing literature on cold ironing technology is reviewed, addressing the drivers for its implementation in ports. Chapter three explains the methods used to collect and analyze the data, describing the model used. Chapter four looks at the legislative framework governing ship emissions and the use of cold ironing in ports from the international, regional and national perspectives. Chapter five discusses ship port interface, focusing on cold ironing as cost effective measure to reduce air pollution from ships at berth. In addition, the chapter addresses the best practices from leading North American and European seaports. The findings of the research are presented under chapter six, highlighting the performance of Mombasa port, the emission reduction potential and the cost-effectiveness of using cold ironing at the port of Mombasa. The conclusion and recommendations follow in chapter seven. The model for computation of the cost-effectiveness of cold ironing and the emission reduction potential are attached as appendices. The approach used to conduct the research is illustrated in figure 1.1.

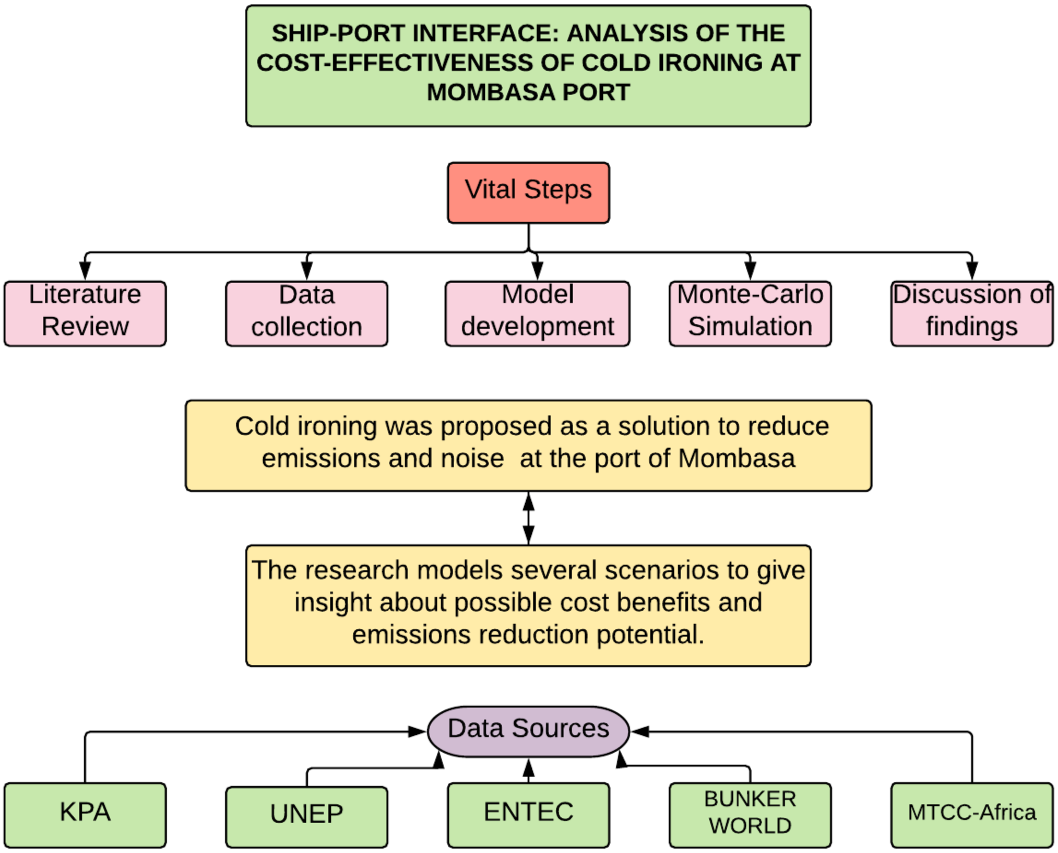

Figure 1.2: Flowchart showing the research approach taken to assess the cost-effectiveness of Cold ironing at Mombasa port, including the data sources. (Source: Author)

The approach taken aimed to address the research questions in order to achieve the specified objectives of the study. A discussion of the finding was made, and recommendations on the cost-effectiveness of Cold Ironing implementation at Mombasa port was made to KPA and the financial implications for retrofitting vessels were discussed to help ship owners make smart decisions during investments.

2.0 LITERATURE REVIEW

The volatility of fuel oil prices and the increased environmental and social impacts that shipping exerts on the surrounding communities have driven ship operators and port authorities to adopt sustainable operating practices. The interest in cold ironing, also known as Onshore Power Supply (OPS) or Alternative Maritime Power (AMP) has grown in major ports around the world, as an option to minimize the noise, air emissions, and operational expenses from running ship engines while at berth. With the advancements in technology, the electrical equipment and power demand for ships to run their hotelling activities have increased as the ship sizes get larger to maximize the economies of scale offered by shipping. This chapter will review previous studies conducted on the cost-effectiveness and externality benefits for the use of cold ironing in ports, which varies from ship to ship and port to port.

According to the International Association of Ports and Harbors (2010), emissions from ships originate from burning fuel oil in propulsion engines, auxiliary engines, auxiliary boilers, and VOC associated with bulk liquid cargo working losses. Therefore, reducing emissions from marine diesel engines is essential in improving air quality around port areas, but the regulation of such engines mainly focuses on the NOx emission and fuel standards. Ships in transit, maneuvering or at berth present unique challenges during the mitigation of emissions but this research focuses on the ship emission from the auxiliary engines while at berth. At-berth, the ship's main engines are shut off while the auxiliary engines are operated for hotelling services, but their loads vary from ship to ship depending on whether the ship self- discharges its cargo or not. The auxiliary boilers stay in operation to keep the main engines and fuel systems warm, in case the ship is directed to leave the port on short notice, and for use during offloading operations by steam-powered pumps (IMO, 2015).

While cold ironing will significantly reduce emissions from ships at berth, the precise percentage depends on the emission factors of the ship's auxiliary engines and the onshore power source. Annually, ships emit approximately 1.2 - 1.6 Tg of PM with aerodynamic diameters of 10μm (PM_{10}) or less, 5 - 6.9 Tg of NOx and 4.7 - 6.5 Tg of SOx (Corbett et al., 2007; Healy et al., 2009). Several studies have linked premature mortality to the exposure of populations to PM. The microscopic solids or liquid droplets in PM penetrate the human lungs causing inflammation and affecting the flow of oxygen to the blood. Cardiopulmonary and lung cancer, asthma, and a range of chronic illnesses are closely associated to $PM_{2.5}$ (Eide et al., 2013; Pope III et al., 2002; Zetterdahl, 2016). Although PM emission has not yet been regulated, the assumption is that PM emission reduces through improved engine efficiency, the use of low Sulphur fuels and after treatment using scrubbers.

Additionally, the SOx gases in the exhaust stream lead to the accumulation of various toxic organic chemicals, thereby creating additional PM and its associated health problems. The emission of SOx in the atmosphere also creates aerosols which impair visibility and contribute to the formation of acid rain (Wang & Corbett, 2007). Ships also emit NO_x during the burning of fuel in internal combustion engines at high temperatures. The NOx leads to the formation of acid rain, reduces visibility when combined with particles in the atmosphere and it contributes to global warming through the formation of ozone in the troposphere as it reacts in the presence of sunlight. Long periods of exposure to the ground level ozone formed by NOx causes respiratory system inflammation leading to choking, and reduced lung capacity. Recognizing the impact of SOx, the international community has tried to encourage the use of energy efficient technologies, marine renewable energy, and alternative fuels such as LNG within the maritime industry (Woodyard, 2010).

Besides air emissions, the operation of ships while in port occasionally results in disturbing noise to the surrounding communities. With the increased development and settlement around ports, it is essential to regulate the level of noise from ships while at berth. According to (Lloyd's Register, 2010), the primary sources of noise onboard ships at berth include;

I. Diesel generator exhaust: This is the predominant source of noise from ships while at berth. The diesel engine exhaust is usually located on top of the funnel, which is at heights above the surrounding landscape. This implies that the noise can propagate to great distances without being absorbed or reflected by the surrounding if the engines are not well attenuated with silencers.

II. Ventilation systems: The ventilation for the engine room, cargo holds, AC system, galley and others areas onboard a ship contributes to the level of noise coming from ships while at berth. Some manufacturers of fans used on ships indicate the sound power of their products to help in the choice of the right equipment for the various ships.

III. Secondary noise: Noise from ships at berth may also originate from secondary sources such as hydraulic pumps, cargo loading and unloading operations, winches, and reefers.

A study of 65 ships indicated that the sound power from ships increased with the increase in the deadweight tonnage (DWT) of the ships. This can be attributed to the use of high-speed diesel engines onboard smaller ships whose noise is easily attenuated using absorptive silencers (Witte, 2010). In addition to silencers, the noise from ships at berth can be eliminated using cold ironing where the generation of onboard power is stopped. The European Union has implemented some projects to address the level of noise in port areas such as the NoMEPorts (Noise Management in European ports) project. The

NoMEPorts project targeted the formulation of harmonized common approaches regarding port area noise mapping and management. A Good Practice Guide was made giving examples of best practice on noise management in ports (European Union, 2015).

While the implementation of cold ironing results in significant environmental benefits, port authorities and ship owners only get the interest in the technology if it presents economic benefits as well. The feasibility study for the use of the technology in various ports presented significant variances because different ports have different infrastructure needs for cold ironing installation. For instance, the capital cost of the cold ironing infrastructure at one berth in the port of Rotterdam was estimated at 4 million euros, which is approximately five times more than the estimated capital cost at the port of Gothenburg (Papoutsoglou, 2012).

On the vessel side, adopting cold ironing for new and existing vessels also includes high costs. IMO in collaboration with DNV-GL studied the cost-effectiveness of adopting cold ironing for several ships types depending on their gross tonnage (GT). The results indicated that the cost greatly depended on the plant design and the possibility of varying frequency and voltage between the ship and the shore side supply. The study estimated the cost of installing cold ironing on container ships to range between $50,000 and $750,000 depending on the vessel size (DNV-GL, 2016b). Hence the possibility of the investment paying back for retrofits depends on the number of years remaining on the ship's lifetime.

A study on the monetary and ecological benefits for using shore power at the port of Mombasa was conducted in 2012, showing possible net gains for the port authority but the researcher on did not analyze the cost implications the technology would have on the ship owners for making the necessary modifications to their vessels (Musyoka, 2013).

Another cost-effective analysis on the implementation of cold ironing was conducted for the Chinese port of Shenzhen and the results identified that ship owners preferred fuel switching to cold ironing technology, when it came to meeting the demands and limits from the regulations. The preference was because generating electricity using auxiliary engines while at berth was cheaper than using shore power. The Ministry of Transport of the People's Republic of China (MOT) as the responsible authority for drafting policies that govern Chinese ports encouraged the use of cold ironing technology under its twelfth 5-year energy saving and emission control plan (Zhang, 2016). Cold ironing was however very effective in reducing emission given China's current dominance in renewable energy.

To further emphasize the fact that the cost-effectiveness of cold ironing differs from one port to another due to several reasons, a feasibility study for the implementation of the technology at the cruise terminal in the port of Copenhagen projected the capital cost to be 36,866.548 Euros. However, the investment only made economic sense under the scenario that at least 60 percent of the vessels calling the port adopted cold ironing and if Copenhagen exempted these vessels from the payment of the local Danish environmental tax on the shore electricity supplied to the ships, as is the case in Germany and Sweden (Ballini, 2013).

This research will analyze the cost-effectiveness of the use cold ironing at the port of Mombasa for both the port authorities and ship owners, assess the emission reduction potential and scenarios under which the technology may be implemented for more benefits. The scenarios are explained under chapter six of this research paper.

3.0 METHODOLOGY

To achieve the objectives of the research, quantitative data was collected. The data was then analyzed using a Microsoft Excel model that allows simulating various scenarios that affect the cost-effectiveness of the investment in cold ironing. A detailed breakdown of the data collection methods used, the Monte Carlo model developed, and the data analysis is explained in the following sections of this chapter.

3.1 Data Collection

Information regarding the port performance for all kinds of cargo, the amount of container traffic, the vessel calls and average port days per ship, the ship waiting time and the container terminal berth occupancy were obtained from Kenya Ports Authority (KPA). Interviews were made with staff from the port authority that provided the relevant data used in this research. The performance data collected from KPA was from 2011 to 2017. The rest of the data used for the research, including the investment costs for the cold ironing was obtained through extensive desk research from various sources including MTCC-Africa, UNEP, ENTEC, Bunkerworld, and other online platforms referred to in this paper.

3.2 Description of the Monte Carlo Model

The model developed was intended to help decision-makers in KPA and ship owners to analyze the risk of investing in cold ironing technology (Appendix B). The uncertainty and variability in elements that affect the cost-effectiveness of cold ironing and the emission reduction potential such as, fluctuations in the interest rates, hours at connected at berth per ship, calls per ship per year, electricity prices, the fuel oil prices make it difficult to predict the future accurately. Therefore, a model was developed using Microsoft Excel and Oracle's Crystal Ball software to allow decision makers to make better decisions to be made under uncertainty. The model uses Monte Carlo simulation, a computerized mathematical technique that presents all the possible outcomes of the decisions made and the probabilities for these outcomes occurring so that people analyze the impact of risks.

As indicated in Appendix B, the model is divided into different parts, and the annual costs of both the cold ironing and the auxiliary diesel generator were calculated. The costs were presented on a whole project basis, expressed in USD. The annual cost was calculated using the Equation 1.

Annual cost = *IterminalAn* + *IshipsAn* + O&M + Fuel costs ……………. *Equation 1*

Where:

IterminalAn = Annualized investment costs for terminal

IshipsAn = Annualized investment costs for ships

O&M = Maintenance, expressed as saved maintenance in case of Cold Ironing

Fuel costs = Costs of the consumption of fuel or electricity

The total investment costs were calculated into annual costs (*IterminalAn* and *IshipsAn*), using an annuity calculation method, using an interest rate (9%) and depreciation period (ten years). The formula used to make the calculation is given in Equation 2.

$$P = \frac{r(PV)}{1-(1+r)^{-n}}$$ ……………………………………......……... *Equation 2*

Where; P= Annual Payments

PV = Present Value

r = Interest rate

N = number of years

The fuel consumption of the auxiliary engine was calculated from the Equation 3.

FC = P x LF x A x SFOC …………………………………………………. *Equation 3*

Where; FC=Fuel Consumption

P = Maximum Continuous Rating Power (kW)
LF = Load Factor
A = Activity (hours)
SFOC= specific Fuel Oil Capacity

However, the following assumptions were made during the development of the model in order to be able to calculate the cost-effectiveness of cold ironing investment;

I. The interest rate, which is the difference between market interest and inflation is 9.0%.
II. The cold ironing project has a 10-year project life.
III. The annual maintenance costs are calculated as 5 percent of the total investment costs. Various case studies confirm the validity of this approach.
IV. The maintenance cost per engine is 1.87 USD/h
V. The bunker price for Diesel and HFO is taken at the current rate from bunkerworld.

The developed model looks into the emission factors from the power sources for the Kenyan electricity generation mix and the emission factors for the auxiliary engines using Diesel and HFO. The emissions from the use of 2.7% Sulphur fuel and 0.1% Sulphur fuel, were both used to form a baseline for analyzing the benefits of ships using cold ironing (Entec, 2005). The cost-effectiveness calculations were computed using the Equation 4;

Cost Effectiveness (USD/ton) = Cost of measure/ Emission reduction ....Equation 4

3.3 Data Analysis

The researcher used Microsoft Excel sheets to analyze the performance of Mombasa port, the Net Present Value (NPV), the cost-effectiveness, the emission reduction potential and the sensitivity of the various inputs for the data collected.

Different scenarios were analyzed using Crystal Ball software to identify the most sensitive parameters to the output values of the model. A scenario where the Kenyan government exempts ships from paying the tax on the electricity consumed was assessed. A scenario where ships use 0.5% Sulphur MD (marine distillate) and 0.1% Sulphur LSFO instead of HFO was also assessed. Variations in the input values of interest rate, electricity price, and hours ships stay connected at berth were analyzed to determine their impact on the cost-effectiveness of the technology. Comparisons were made on the benefit for the use of cold ironing instead of auxiliary engines while ships are at berth.

The chosen approach in this research was aimed at answering the research questions of the study, consequently helping to achieve the research objectives. The findings of the study are presented and discussed in chapter six.

4.0 LEGISLATIVE FRAMEWORK

The control of the PM, SOx and NOx emissions from diesel engines was the primary focus for most national and international agencies but owing to the adverse effects of climate change, the reduction of GHG emission has intensified at national, regional and international level. Most regulations that exist were developed in response to catastrophic incidents but such times should no longer be the norm of the day, with the rapid advancements in technology and improvement in the accuracy of prediction models. The existing regulations, standards, and guidelines for emission reduction are reviewed below.

4.1 International Perspective

Detection and attribution studies indicate that human activities are the primary cause of the unambiguous global warming, evident by the continued increase in the global temperature, the rise in sea level, the decrease in sea-ice cover and the severe weather conditions (Stocker et al., 2013; WMO, 2017). Acknowledging that the catastrophic effects of climate change must be addressed jointly, countries signed the UNFCCC - Paris Agreement committing themselves to hold the increase in the global average temperature well below 2^0C above the pre-industrial levels (Comer, Roy, Mao, & Rutherford, 2017). These commitments complement the targets set out under the 2030 UN sustainable development goals, which are can only be realized with the implementation of national policies and strategies.

The International Maritime Organization (IMO) is responsible for the regulation of the shipping activities to ensure safety, security, environmental friendliness and uniformity across the industry. Additionally, IMO is responsible for controlling GHG emissions from the shipping industry as stipulated under the UNFCCC - Kyoto Protocol. During MEPC 72, the organization adopted the initial GHG reduction strategy setting out targets to reduce CO_2 emission from shipping by 50 percent by 2050 compared to 2008 (ICCT, 2018; IMO, 2018). The strategy, which will be revised in 2023, includes a list of short, mid and long-term measures that could be implemented to achieve the set emission targets, as indicated in table 4.1. Some of the proposed measures such as EEDI apply to only new vessels while other measures such as SEEMP and speed reduction can be applied to in-service vessels. The mid-term measures shall be applicable been 2023 and 2030 while the long-term measures will be applied from 2030 and beyond.

Table 4. 1: Candidate measures included in IMO’s initial GHG strategy.

Type	**Years**	**Measure**	**Target**	**Current status**
Short-term	2018-2023	New Energy Efficiency Design Index (EEDI) phases	New Vessels	10% in 2015 20% in 2020 30% in 2025
		Operational efficiency measures (e.g., SEEMP, operational efficiency standard)	In-service Vessels	SEEMP planning required
		Existing fleet improvement program	In-service Vessels	—
		Speed reduction	In-service Vessels	—
		Measures to address methane and VOC emissions	Engines and fugitive emissions	—

Mid-term	2023-2030	Alternative low-carbon and zero-carbon fuels implementation program	Fuels/new and in-service vessels	—
		Further operational efficiency measures (e.g., SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Market-based Measures (MBM)	In-service vessels/fuels	—
Long-term	2030+	Development and provision of zero-carbon or fossil-free fuels	Fuels/new and in-service	—

Note: Adapted from ICCT, 2018. *The international maritime organization’s initial greenhouse gas strategy*.

The strategy considers the reduction of methane and volatile organic compounds but does not address other pollutants such as nitrous oxide or black carbon. However, IMO's Pollution Prevention and Response (PPR) Subcommittee is considering formulating separate actions to regulate the emission of Black carbon from ships. The implementation of the proposed measures under the initial GHG strategy will emphasize the contribution of the shipping industry in meeting the Paris Agreement goal of limiting the increase in the global average temperature to well below 2°C.

Strict regulations have been developed to reduce the emission from ships. For instance, IMO adopted MARPOL Annex VI that addresses the prevention of air pollution from ships, explicitly targeting the reduction of SOx, NOx, PM, and Ozone Depleting Substances (ODS) emission. After reviewing the future availability of low Sulphur fuel oil, IMO’s MEPC re-emphasized that the global fuel Sulphur limit for all ships trading outside ECAs shall be 0.5 percent, starting 2020. This global Sulphur cap is a reduction from the current 3.5 percent Sulphur content limit in fuel oil for ships outside the ECAs (Koga, 2018). The improvement in the fuel quality is anticipated to reduce the health impacts extended from shipping to the people in coastal areas outside the ECAs. However, the economic implications on the ship operators for using low Sulphur fuel oil are expected to be significant. The price of low Sulphur fuels is approximately double the price of residual fuel that is commonly used by ships today (Bunker World, 2018). Four ECAs are identified under MARPOL, as indicated in figure 4.1. These include; the North American, the US Caribbean coasts, the Baltic Sea, and the North Sea.

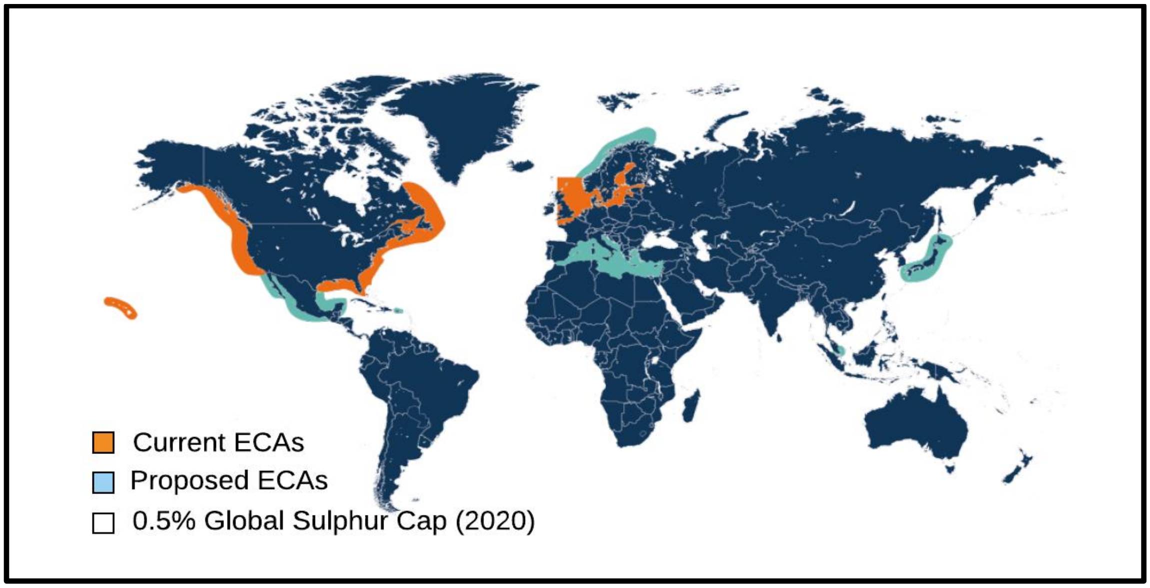

Figure 4.1: Emission Control Areas and the 2020 Sulphur cap (DNV-GL, 2016a).

The regulations under MARPOL require all ships trading within the ECAs to use fuel with a Sulphur content not higher than 0.1 percent (Fagerholt, Gausel, Rakke, & Psaraftis, 2015). Ship owners have to three main options to choose from when trying to comply with the Sulphur limits. Firstly, shipping companies may decide to use HFO together with scrubber installation, considering the uncertainty in the availability of complaint fuels. Secondly, the shipping companies may decide to switch to the complaint low Sulphur fuel, but the concern remains whether there will be enough de-sulphurised fuel so that ships do not have to rely on MGO and distillate blends. Thirdly, ship owners may opt for LNG as fuel given the fact that LNG bunkering infrastructure is developing at a fast pace. LNG eliminates SOx and PM, reduces NOx by up to 85 percent and possibly reduce CO_2 emission by up to 25 percent (DNV-GL, 2016).

The regulations on NOx emission from marine diesel engines under MARPOL requires the issuance of the Engine International Air Pollution Prevention (EIAPP) Certificate after conducting surveys per the NO_x Technical Code 2008. The NOx regulations apply to marine diesel engines with an output power over 130 kW, other than engines used for emergency purposes (Loov et al., 2014). Different Tiers of NOx control are used based on the date on which the ship was constructed, and the engine's rated speed is used to determine the actual limit value within any particular Tier. Tier I applies to marine diesel engines installed on ships constructed after 2000 but before 2011, Tier II applies to engines on ships constructed after 2011 outside the ECAs while Tier III applies to engines on ships constructed after 2011 but trading within the United States Caribbean Sea and the North American ECAs (Hansen et al., 2014). Tier III NOx limits can be achieved by the use of Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation (EGR) (Yaramenka, Winnes, Åström, & Fridell, 2017).

At the international level, IMO has continued to regulate emissions from ships but the challenge that remains in the control of emissions and their externalities to the people living in port areas is the absence of international regulations to control emissions from ports and the ineffective implementation of the international regulatory requirements. However, regional efforts and initiatives to protect the environment, especially from the EU have been steps ahead of the IMO programmes.

4.2 Africa vs. EU Perspective.

At a regional level, both the European Union (EU) and African Union (AU) have adopted several regulations to enhance the protection of the environment against emissions from shipping activities. These regulations are always in line with the international legal frameworks to which the member states are a signatory. A comparison of the environmental protection legal framework on shipping activities within the EU and the AU is outlined in table 4.2.

Table 4. 2: Summary of the legal framework on emissions from the EU and AU.

Regions	**Key Legal Frameworks on ship emissions**
European Union	Directive 2012/33/EU - on the Sulphur content of marine fuels
	Directive 2014/94/EU - on the deployment of alternative fuels infrastructure
	Directive 2008/50/EU - on ambient air quality and cleaner air
African Union	Africa's Integrated Maritime (AIM) Strategy - 2050
	Revised African Maritime Transport Charter

Note: Adapted from EU and AU regulations summary lists (Author, 2018).

Unlike the EU that has several regulations and directives to control the emissions from the shipping industry, the African Union has limited unified laws to ensure clean shipping activities within the region. For instance, the EU passed the Sulphur directive 2012/33/EU limiting the maximum Sulphur content in fuels used by ships at berth in EU ports to 0.1 percent (DNV-GL, 2016). The directive exempts ships staying at berth for a period less than 2 hours and ships that use cold ironing while at berth.

In addition to the Sulphur directive, the EU passed the directive 2014/94/EU on the deployment of alternative fuel infrastructure where cold ironing was highlighted as a measure to reduce air emission and noise from both inland and ocean-going vessels, within European seaports. The directive requires EU Member States to assess the need for cold ironing for vessels in maritime and inland ports and address the technology in their national policy frameworks. The EU also set standards limiting the concentration levels of SOx, NOx, and PM under the Air Quality Directive 2008/50/EU (IMO, 2015). Also, the EU is using differentiated environmental charges as another way of reducing the environmental footprint from shipping activities (EU, 2017).

On the other hand, the AU developed the 2050 Africa's Integrated Maritime (AIM) Strategy which envisions to address the protection of populations from the negative externalities of maritime transport. However, the implementation of the strategy remains the responsibility of the member states, which are failing to do so, owing to the lack of expertise and resources (Egede, 2016; Walker, 2017). The other relevant regional maritime treaty is the Revised African Maritime Transport Charter, but it does not highlight out any measures to be taken by the member states on emission control from ships trading within the region. Among the objectives of the charter includes; the promotion of bilateral and multilateral cooperation among member states maritime administrations, the promotion of funding into research and innovations by national institutions regarding the development of maritime transport and port operations, and the promotion of maritime education and training in the education systems of the member states. Since most African states are party to the IMO, the regulation of shipping activities in their jurisdiction is mainly made through the ratified international conventions. However, the member states' ability to implement the policies relies on the availability of resources and capacity.

4.3 Kenyan policies overview

Kenya has ratified several IMO conventions to protect the environment from the negative externalities of shipping. The state is party to the Convention on Facilitation of International Maritime Traffic (FAL) which aims to reduce the delays in maritime transport including the dwell time in ports. Since the dwell time impacts the amount of emissions, the effective implementation of the FAL convention reduces the amount of PM, NOx and SOx emission from the ships by reducing the berthing time. Besides, Kenya is party to the International Convention for the Prevention of Pollution from Ships

(MARPOL) Annex VI which targets to reduce air pollution from ships (IMO, 2018c). According to article 2 (6) of the Kenyan Constitution, all international conventions signed automatically become legally binding (Maraga, 2012).

Domestically, Kenya’s National Environment Management Authority (NEMA) implements the Air Quality Regulations under the Environmental Management and Coordination Act, which sets emission limits from controlled and non-controlled facilities including thermal and geothermal power plants (NEMA, 2014). Also, the authority set regulations on noise and excessive vibration from machinery or other equipment including pumps, fans, air-conditioning apparatus or similar mechanical devices. Such regulations apply to port areas, and the Minister of Environment and Mineral Resources has the power to designate any place as a controlled area in cases where the emissions are likely to exceed the required (GoK, 2009).

The Kenya Ports Authority implements a Green Port Policy where it targets to improve and attain the highest environmental performance standards for the benefit of the Mombasa Port Community and all other areas under its stewardship. Cold ironing was identified as one of the measures to improve energy efficiency from ships calling the port of Mombasa under IMO's GSM project (MTCC-Africa, 2018).

With environmental protection regulations becoming more stringent, many alternative measures have been explored to reduce the emission footprint from shipping and the related negative social externalities. The high investment cost for cold ironing makes it a less favorable option for many ship owners and port authorities except in cases where the regulations require so. Also, the emission reduction potential for the use of the technology highly depends on the energy mix of the shore electricity supplied, but a reduction in NOx, SOx and PM will be achieved even with shore electricity supplied from coal power plants. Incentives are a good way of persuading ship owners to adopt cold ironing as it helps them lower the operational cost during the lifetime of their vessels.

5.0 SHIP PORT INTERFACE

The maritime industry is complicated due to the numerous stakeholders involved in the movement of goods across the seas. The smooth and complementary interface between the different stakeholders is essential in improving safety, security, and efficiency within shipping. This is however usually not the case as different stakeholders have different and contradicting interests and goals. Ship port interface is vital in the maritime industry, and the stakeholders aim to minimize the time ships spend in ports as it is associated with higher operational costs, reduced safety, and security.

During ship port interface, air emissions are given off causing harmful effects to the areas surrounding ports. The emissions from ships are associated with the operation of propulsion engines, auxiliary engines, boilers and VOC working losses (IMO, 2015). During transit, emissions are mainly from the propulsion engines operating at high loads as ships are in open waters. During maneuvering, the ships are operating with the harbor, either approaching or leaving their berths with their propulsion engines operating at low loads. While at berth, ship emissions are mainly from auxiliary engines and boilers since the main engines are shut off (IAPH, 2010). Several measures have been developed to reduce these emissions while ships are operating under different modes, including the use of cleaner fuels, abatement technologies, just in time and cold ironing (Bazari, 2016). The cost-effectiveness of cold ironing technology will be addressed by this research, and in this chapter, the technology will be introduced and the selected ports implementing the technology reviewed.

5.1 Cold Ironing Technology

The term "Cold Ironing" originated from the times where coal-fired ships staying in port for long periods would stop their iron steam engines, allowing them to go cold since they did not need motive power (Papoutsoglou, 2012). Cold ironing allows ships to shut off their auxiliary engines and utilize the onshore supply of electricity, which is usually from the national grids or the installed power stations in ports. The world's first cold ironing facility by ABB was installed at the port of Gothenburg in 2000. Since then, numerous ports around the world adopted the technology, but the main concern was the standardization of the cold ironing systems so that ships could be able to use the services at multiple ports without the requirement to change their onboard installations (ABB, 2009; DNV-GL, 2017).

The International Organization for Standardization (ISO), the Institute of Electrical and Electronics Engineers (IEEE) and International Electrotechnical Commission (IEC) came together to develop standardized, safe and effective ways for vessels to use both high voltage and low voltage shore connection. Consequently, the IEC/ISO/IEEE 8005-1:2012 standard for HVSC, covering power requirements exceeding 1000 kVA and IEEE/PAS 80005-3:2014 standard for LVSC, covering power requirements below 1000 kVA were developed (Sciberras, Zahawi, Atkinson, Juandó, & Sarasquete, 2016). The standards set specifications for the design, installation, and testing of the cold ironing systems and components. The typical layout of the cold ironing facility, components, and ship side connection is illustrated in figure 5.1.

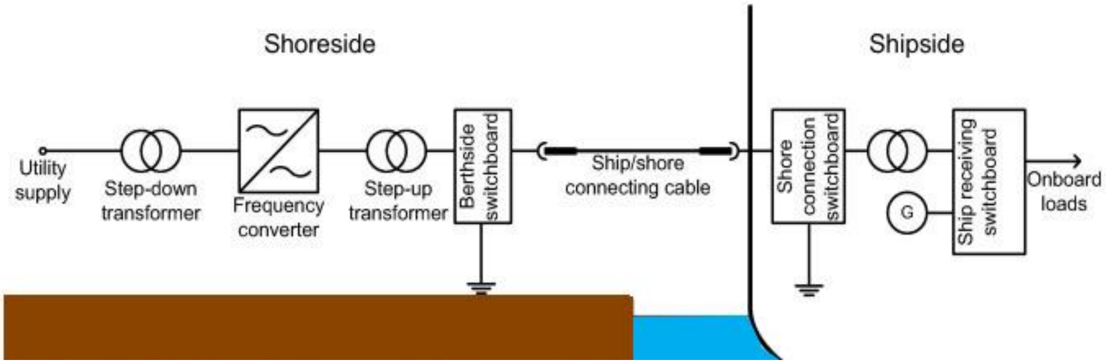

Figure 5.1: Reproduced from the overview of a Typical Cold Ironing System (Sciberras, Zahawi, & Atkinson, 2015).

Some of the challenges of using Cold Ironing include the fact that electric power from shore side is not adopted for use onboard ships hence various systems and components have to be installed or retrofitted on existing ships. A substation is needed to convert the frequency and voltage of the grid electricity to those required onboard ships. A frequency converter needs to be installed to convert the 50 Hz Kenyan grid standard frequency to the 60 Hz onboard ship frequency requirements. Because of the space limitations at berth, container ships are required to have an onboard cable reel. The onboard installations include a medium voltage connection switchgear, grounding connections, and a step-down transformer.

5.2 Implementation of Cold Ironing: Best Practices

Cold ironing has been implemented in several ports around the world, especially in Europe and North America. A non-exhaustive list of the ports using cold ironing technology, the geographical location of the ports, the voltage and frequency needed are indicated in Appendix A. However, this research only reviewed the use of cold ironing technology at the selected ports of Los Angeles, Oslo and Gothenburg, to give insights about the practices taken to ensure that cold ironing is sustainable and cost-effective in these ports. The strategies used in these ports to ensure the sustainability of the technology were analyzed to form a benchmark for the implementation of the technology in the port of Mombasa.

5.2.1 Port of Los Angeles

The Port of Los Angeles (PoLA) invested in cold ironing or Alternative Maritime Power (AMP) as a measure to reduce emissions from container ships during berth. This was an initiative under the “No Net Emission Increase programme (NNEI)” at the port of Los Angeles by the LA municipal authority. In 2004, the Port of Los Angeles became the first port in the world to install Cold Ironing for container vessels at its West Basin Container Terminal. In the same year, the Port welcomed NYK’s NYK Atlas, the world’s first container ship built with cold ironing specifications in mind. In addition, the Port of Los Angeles actively participated in the development of IEC/ISO/IEEE 80005-1:2012 international standard on Utility connections in port, describing high voltage shore connection (HVSC) systems, both on board the ship and onshore (PoLA, 2018).

As of 2018, the Port of Los Angeles has 75 AMP vaults, the most in amongst all global ports. The development of such facilities was driven by the California Air Resources Board (CARB) which adopted a regulation to reduce emissions from marine diesel auxiliary engines on container, reefer and cruise ships at-berth. The regulation requires ships to shut off their auxiliary diesel engines while at-berth and instead use grid-based power, for at least 50 percent of the annual vessel visits (Papoutsoglou, 2012). The Port is dedicated to refining cold ironing technology, and through a collaboration with Cavotec SA, considerations were made to supply shore power solutions for all ship types using a versatile "AMP Mobile" system (PoLA, 2012).

The Port of Los Angeles was the first port in North America to reward ships for going green under the Environmental Ship Index (ESI) Program. During the first six months, shipping lines calling at the Port earned USD 162,500 for sending their cleanest vessels to the Port (PoLA, 2016). Through such incentives, the adoption of cold ironing technology in the maritime industry can be significantly accelerated.

5.2.2 Port of Oslo

Oslo faced challenges of air pollution and the respective health effects on the residents. This was majorly a problem during winter when people would resort to the burning of wood, driving with studded tires and the increased emission of NOx from the cold car engines (Kukkonen et al., 2005). To mitigate these challenges, the use of diesel cars was prohibited, and incentives have been given to electric car users. The port of Oslo handles the most general cargo in Norway; therefore, the port receives considerably large traffic of vessels which a direct correlation with the emissions. The port of Oslo was the first Norwegian port to provide cold ironing to the vessels trading within Norway (DNV-GL, 2017).

Norwegian companies have always been the leaders in technology advancements and innovations. The cruise ferry line, Color Line, was the first company to adopt cold ironing technology on its vessels that called the port of Oslo. The port of Oslo, DNV GL, Cavotec, and ABB collaborated under the “ReCharge” project to develop a methodology that helps authorities identify where it would make the most environmental and economic sense to install cold ironing facilities. The methodology is based on AIS data and ship technical data, and it can also be used to identify ships and routes suitable for battery propulsion (DNV-GL, 2017).

The installation of cold ironing facilities at the port of Oslo is also driven by the anticipated advancements in vessel design technologies that shall see battery-hybrid and fully battery powered vessels penetrate the maritime industry. For instance, DNV GL initiated a concept for a zero emission, unmanned container ship named "ReVolt." The ReVolt serves as a vision for the potential of future container ships technology. The ship is intended to serve as a motivation for shipyards, equipment manufacturers and ship owners to invest in technologies like cold ironing. It is estimated that the ReVolt could save up to USD 34 million with reduced operational and maintenance costs for its expected 30-year lifetime (DNV-GL, 2015). Therefore, with the traffic levels at the Port of Oslo and anticipation for the development of more battery-powered vessels, cold ironing will not only be used as a substitute for auxiliary engines while vessels are at berth, but it shall also be used for charging the batteries of such vessels.

5.2.3 The Port of Gothenburg

The port of Gothenburg enormously contributes to the economic performance of Sweden. While the port focuses on its growth, it has ensured that the growth is sustainable and the port surroundings are not negatively affected by the shipping activities. Therefore, the port has ventured in numerous environmental protection initiatives over the years. The port of Gothenburg has tremendous experience in the use of cold ironing technology. The port invested in low voltage shore connection systems as early as 1989, to supply 3 RoPax vessels with electricity while at berth (IAPH, 2018). In 2000, ABB installed the first high voltage shore connection system at the port to supply power to cargo vessels. This installation came from a collaboration between the port of Gothenburg, Stora Enso and Wagenborg (ABB, 2010). Other cold ironing facilities were installed in the port in 2006 by Stena lines to supply its ships.

The port of Gothenburg has numerous financial incentives to encourage ship owners to invest in cold ironing technology. For instance, there are no charges on the power provided to the ships and the tax on onshore power in Sweden has significantly reduced, currently being 0.5 Ore/kWh (Port of Gothenburg, 2018). The port offers discounts on port charges to ships that have good environmental performance, including ships using cold ironing. The environmental discounts are issued to vessels that have registered either under the Environmental Shipping Index (ESI) or the Clean Shipping Index (CSI). These indexes form a basis for the calculation of the discounts offered for example, ships that have at least 4 stars according the CSI and those that have at least 30 points according to the ESI, earn a 10 percent environmental discount on the port charges depending on their gross tonnage (Port of Gothenburg, 2017).

From the review of the use of cold ironing in European, American and Asian ports, it should be noted that the cost-effectiveness of the projects varies from port to port and also the governments have to offer some incentives to allow ship owners to adopt the technology.

5.3 The benefits and challenges of the use of cold ironing

For port authorities and ship owners, the installation of shore-based cold ironing facilities is generally driven by the environmental regulations from the municipal or national level. However, with the competition between different ports and shipping lines, the sustainability of their operations has moved up the priority list for most ports and companies and cold ironing is implemented to improve their market value. A SWOT analysis was used to assess the strengths, weaknesses, threats, and opportunities of using cold ironing for port authorities and ship owners, as indicated in table 5.1. Lessons can be drawn from this critical review and used for the case of Mombasa port.

Table 5. 1: A SWOT analysis for the use of cold ironing from shore and ship perspectives.

Strength	**Weaknesses**
■ Effectively reduces air emissions of PM, SOx, and NOx depending on the energy mix of the shore power supply. ■ Reduces noise pollution from ships while at berth. ■ Reduces operational costs by reducing the auxiliary engine	■ Compatibility issues for ships that installed cold ironing systems before ISO standards were adopted in 2012. ■ High capital investments for port authorities to install shore facilities. ■ High capital investments for ship owners hence retrofitting certain

maintenance frequency. ■ Can be used for charged battery-hybrid and fully electric vessels while they are at berth. ■ Improved health benefits for the ship crew and populations near the ports. ■ Availability of international standards for HVSC and LVSC systems (PoLA, 2018).	vessels may not make financial sense. ■ Most container ships use 60 Hz frequency hence there is a need for conversion from the 50 Hz on the Kenyan grid (Sciberras, Zahawi, & Atkinson, 2015). ■ Cold ironing only reduces emissions for ships at berth, and not during ship maneuvering or transit.
Opportunities	**Threats**
■ The volatility of the price for fuel oil likely to increase operational costs so cold ironing can be alternative ■ Rapid advancements in technology likely to increase the number of battery-powered vessels which can use shore power for charging ■ Incentives are given for vessels with high environmental performance and using cold ironing, under the differentiated port charges, e.g., at EU ports (EU, 2017). ■ Possibility for benching marking from several ports implementing cold ironing	■ There are financial and technical risks for retrofitting vessels with cold ironing systems. ■ Economically risky to invest in shore-side cold ironing facilities since their payback period is usually long term. ■ Electricity produced from Auxiliary Engines is usually cheaper than shore-side electricity (Zhang, 2016). ■ High voltage handling poses safety challenges to the crew. ■ Cold ironing only available in a few ports.

Note: Adopted from the literature and best practices used in this research (Author, 2018)

From the above analysis, the objective for port authorities should be to maximize their strengths in order to take advantage of the opportunities of using cold ironing. Using cold ironing not only presents social benefits through the reduction of emissions and noise, but may also economic benefits to the ship owners in cases where incentives are given by the ports (Arduino, Carrillo, & Ferrari, 2011). With the availability of ISO standards on HVSC and LVSC systems, ports can adapt these to ensure that ships trading all over the world can utilize the technology without having to face challenges for variations in the equipment needed to receive shore power onboard ships. The rapid advancement in technology can also be used to improve the highlighted strengths for using the technology.

On the negative side, the use of cold ironing presents several threats and weaknesses, which can be minimized by exploring the available opportunities from the external environment to reduce the operational costs when using cold ironing instead of producing power using auxiliary engines. The anticipated growth in the use of battery-hybrid or fully battery powered ships is likely to increase the demand for shore power as these could be used to charge such systems while ships are at berth. The analysis of the external environment to identify the threats and opportunities for cold ironing was approached by from a political, economic, social, technological, environmental and legal aspect using PESTEL. The issues highlighted under the SWOT can be benchmarked with for the case of Mombasa port.

6.0 CASE STUDY: COLD IRONING AT MOMBASA PORT

6.1 Overview of Mombasa Port

The port of Mombasa is one of Africa's oldest harbors, dating back as early as the 18th century. Located along the Kenyan coastline, the port serves a vast hinterland of nearly 250 million people from Uganda, Kenya, Tanzania, Burundi, Rwanda, Northern Eastern Democratic, South Sudan, Republic of Congo and Somalia. The port of Mombasa is managed by Kenya Ports Authority (KPA), a state corporation whose goal is to facilitate and improve maritime trade through the provision of competitive services. The port has two container terminals namely, the Mombasa container terminal and the Kipevu container terminal, and it has registered significant growth in traffic volumes over the last decade, with the annual cargo throughput increasing by 6.9% and the container traffic growing by 9.3% (KPA, 2015). Figure 6.1 gives an overview of the port of Mombasa indicating the road connection to the fenced port area, the berths, and installed beacons & buoys.

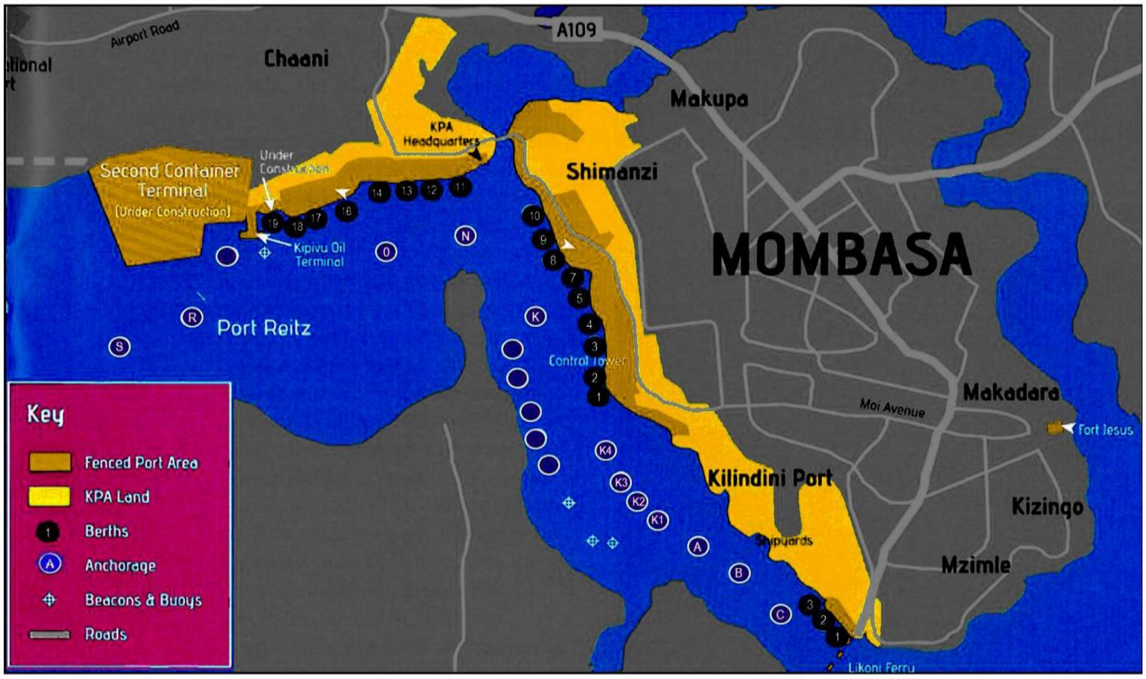

Figure 6.1: Reprinted from the overview of the port of Mombasa, KPA.

In 2015, the port of Mombasa rolled out a comprehensive green port policy and implementation plan in efforts to reduce the negative externalities associated with port operations. The policy recommends the reduction of air emissions through the adoption of renewable energy and the provision of shore power to ships calling the port, among others (Kalmar, 2016). The researcher collected data from KPA to analyze the performance of container traffic at the port of Mombasa, for which the cold ironing is targeted.

6.2 Mombasa port performance.

The cargo throughput, vessel traffic performance, the amount of port time by ship type and the percentage berth occupancy at the Mombasa container terminal were analyzed. The performance of the port partly justifies the need for cold ironing since the amount of emissions greatly depend on the number of ships calling the port. Cold ironing is intended for container ships, so the researcher intended to assess the amount of containerized cargo through the port. Another critical factor that contributes to the amount of ship emissions while in port is the efficiency of the port operations. High port efficiency reduces the amount of time ships stay in port, reducing the ships' operating costs and emissions as less fuel is burnt. The researcher analyzed the average port time for the different ship types, and the findings are presenting in the following sections.

6.2.1 Cargo Throughput

The volume of cargo discharged and loaded at the port of Mombasa includes containerized cargo, dry bulk, liquid bulk, and conventional cargo. Figure 6.2 illustrates the cargo throughput in thousands of Deadweight tonnage (DWT) at the port of Mombasa for the various categories of cargo between the period of 2010 and 2017. Over the period, the total cargo handled at the port in each of the years has continued to grow, which is attributed to numerous reasons such as the port's dedicated efforts to improving efficiency of the operations during ship port interface, and the economic integration of the East African community that advocated for the removal of non-tariff barriers (NTBs) in the region.

Conventional cargo accounted for the smallest proportion of the total volumes handled, at 1.3 million tons in 2010 and 2.2 million tons in 2017, while containerized cargo has the highest Deadweight tonnage for each of the years analyzed, accounting for over 11 million tons in 2017. The amount of liquid bulk handled at the port slightly increased over the years, from 6.3 million tons in 2010 to 8.4 million tons in 2017, while the amount of dry bulk doubled over the period increasing from 3.9 million tons in 2010 to 8.1 million tons in 2017.

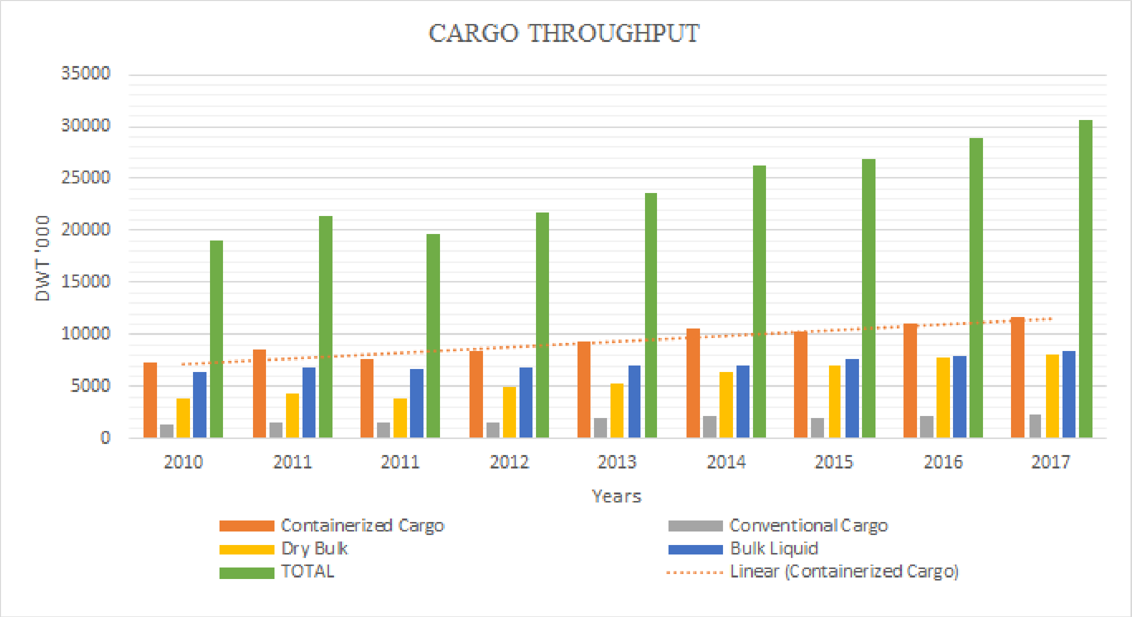

Figure 6. 2: Cargo throughput at the port of Mombasa (Author, 2018).

The linear trendline for containerized cargo indicates a positive gradient and if business goes as usual, the volume handled at the port is expected to continue increasing. As indicated in figure 6.2, the total volume of goods handled at the port continued to grow each year, and this resulted in congestion in the port yard space. To mitigate the above issue, a Standard Gauge Railway (SGR) was developed to facilitate the transportation of cargo from the port to the inland container depot (ICD) in Nairobi. Maersk line recently started running a full block freight train along the line to facilitate trade through the port (KPA, 2018).

6.2.2 Vessel performance

To understand the vessel traffic at the port of Mombasa, the researcher analyzed the 2015 vessel performance data collected from the Kenya Ports Authority. The findings are presented in figure 6.3, illustrating the monthly number of ships that called the port of Mombasa during 2015, and the TEUs handled during that period. The linear trendline for the number of ships registered indicates a positive slope, with 20 ships in January and over

25 hips between June and December. The peak number of ships registered happened in June and October with 31 vessels.

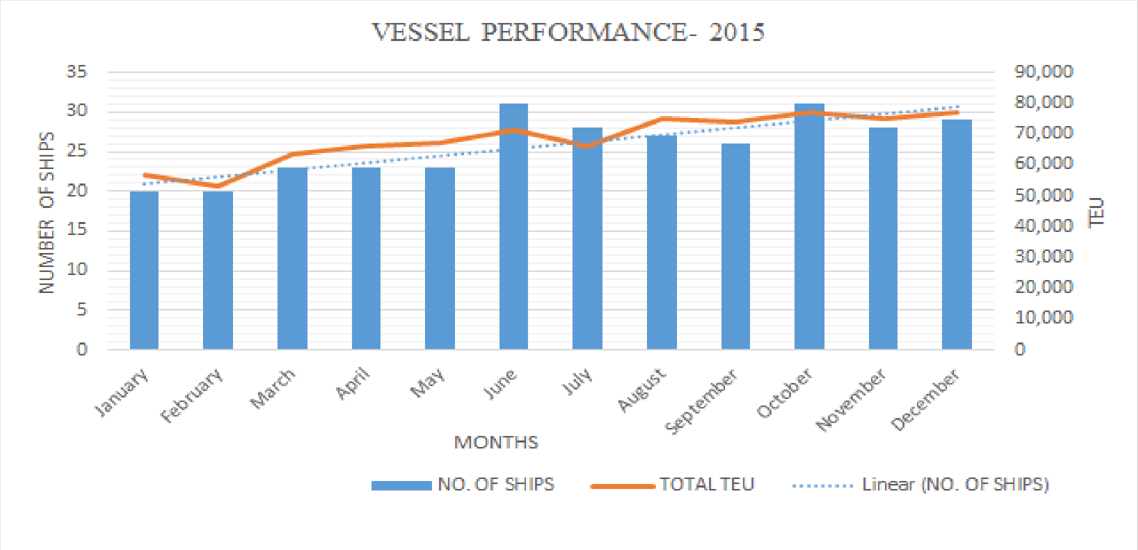

Figure 6. 3: Vessel Performance at the port of Mombasa (Author, 2018).

The relationship between the number of ships and the total TEU represents a positive correlation, as indicated in figure 6.3. The monthly total TEU registered at the port fluctuated according to the number of ships. For instance, 53,003 TEUs were registered in February, a month where the lowest number of ships was registered, and 76,867 were registered in October, a month with the highest number of ships. While the researcher found out that the total of TEUs recorded at the port of Mombasa was influenced the number of ships that were received, the amount of TEU could also depend on the difference in the size of ships that call the port in the different periods.

6.2.3 Vessel calls and port time

The researcher assessed the relationship between the number of ships and the average time spent in the port of Mombasa. Since the amount of emissions from ships partly depends on the amount of time they spend in the port, the researcher found it prudent to understand how much time container ships for which cold ironing implementation is intended, stayed in port. Figure 6.4 illustrates the number of ships and the average time the different types of ships spent in the port of Mombasa in 2015. The vessels that called the port included barges, bulk carriers, car carriers, container ships, fishing vessels, general cargo vessels, passenger ships, RoRo vessels, tankers, tugs, yachts, naval ships, among others.

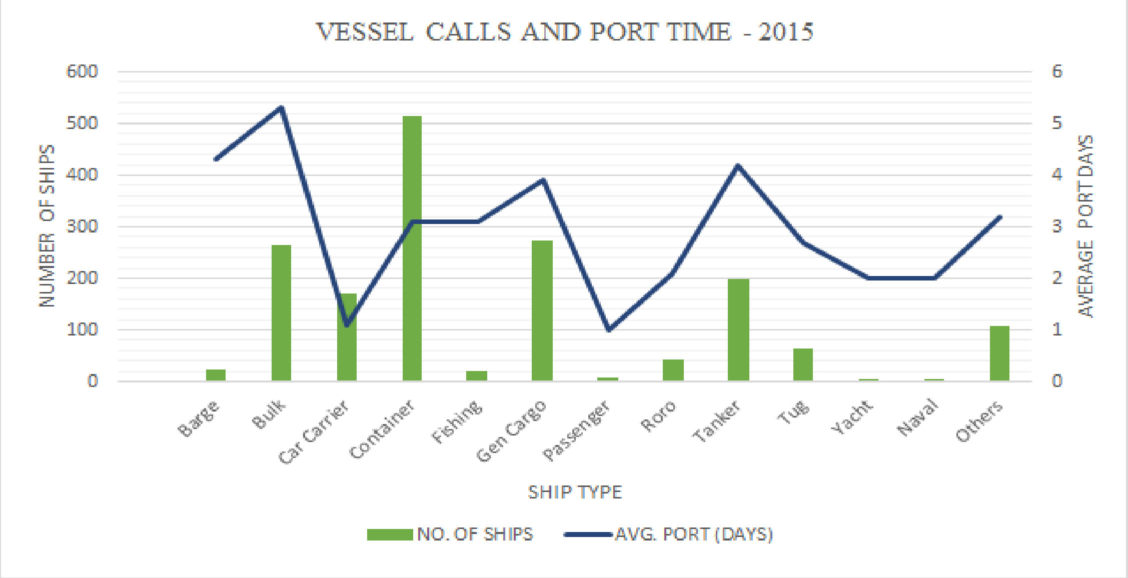

Figure 6. 4: Vessel calls and time that ships spent at the port of Mombasa (Author, 2018).

The fewest number of ships that visited the port in 2015 by ship type included yachts, naval ships, and passenger ships, registered as 3, 4 and 8 respectively. 514 container ships were the highest number of ships registered at the port, followed by general cargo vessels at 274 and bulk carriers at 264. On the other hand, the average amount of time spent in the port of Mombasa by the different vessels was topped by bulk carriers, barges, and tankers, at 5.3, 4.3 and 4.2 days respectively. Passenger ships and car carriers spent the shortest time (1 day) in the port while container ships spent 3.1 days in the port of Mombasa on average. This amount of time was used in the model to analyze the operational costs of using cold ironing and ships’ auxiliary engines.

6.2.4 Mombasa container terminal berth occupancy

With cold ironing being proposed at the container terminal, the researcher analyzed the monthly berth occupancy between 2011 and 2017, according to data collected from KPA and presented in Figure 6.5. The lowest percentages were recorded in June, September and October 2012 that were all below 60 percent while the years 2011, 2014, 2016 and 2017 had over 80 percent berth occupancy in all the months.

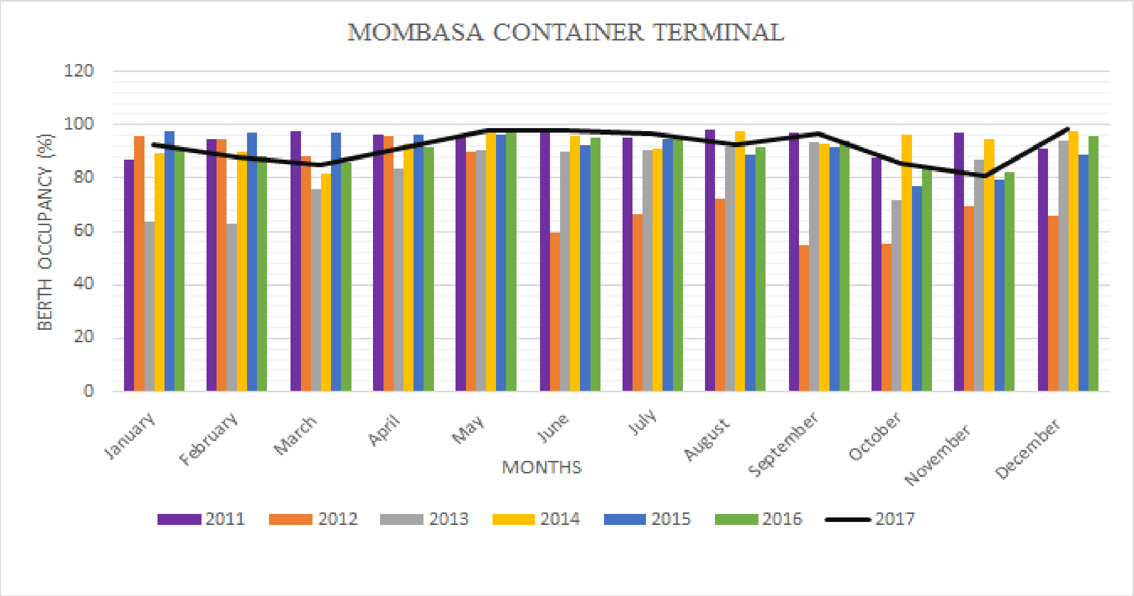

Figure 6. 5: Berth occupancy at Mombasa container terminal (Author, 2018).

From the analysis of the performance of Mombasa port, containerized cargo constituted the highest volume of the total cargo handled between the period of 2011 and 2017, and container ships called the port the most times in 2015 compared to any other ship type. With this understanding about the container ships performance, the researcher attempted to assess the cost-effectiveness of using cold ironing technology and the emission reduction potential. This information was incorporated into the model developed for calculating and answering the questions of the study.

6.3 Kenya’s energy sector overview

Kenya’s energy sector can be categorized according to the energy sources, with biomass accounting for 69 percent, petroleum for 22 percent and electricity for 9 percent (Kiplagat, Wang, & Li, 2011). The country's overdependence on biomass is attributed to the poor rural electrification where people in rural areas use wood fuel and charcoal to meet their energy needs. All the petroleum used in Kenya is imported although oil deposits were discovered in the northwestern part of the country.

Kenya’s power sector is one of the most developed in sub-Saharan Africa, attributed to its open market to independent power producers (IPPs) since the mid-1990s. KenGen limited is the largest power generator, but there exists approximately nine other IPPs. Kenya has 2.4 GW installed electricity capacity and imports additional electricity from Uganda and Ethiopia (Global legal insights, 2018). Figure 6.6 shows Kenya’s installed electricity capacity by source, where hydro accounts for 36 percent, geothermal for 28 percent, thermal for 31 percent and other renewables accounting for 5 percent (USAID, 2018).

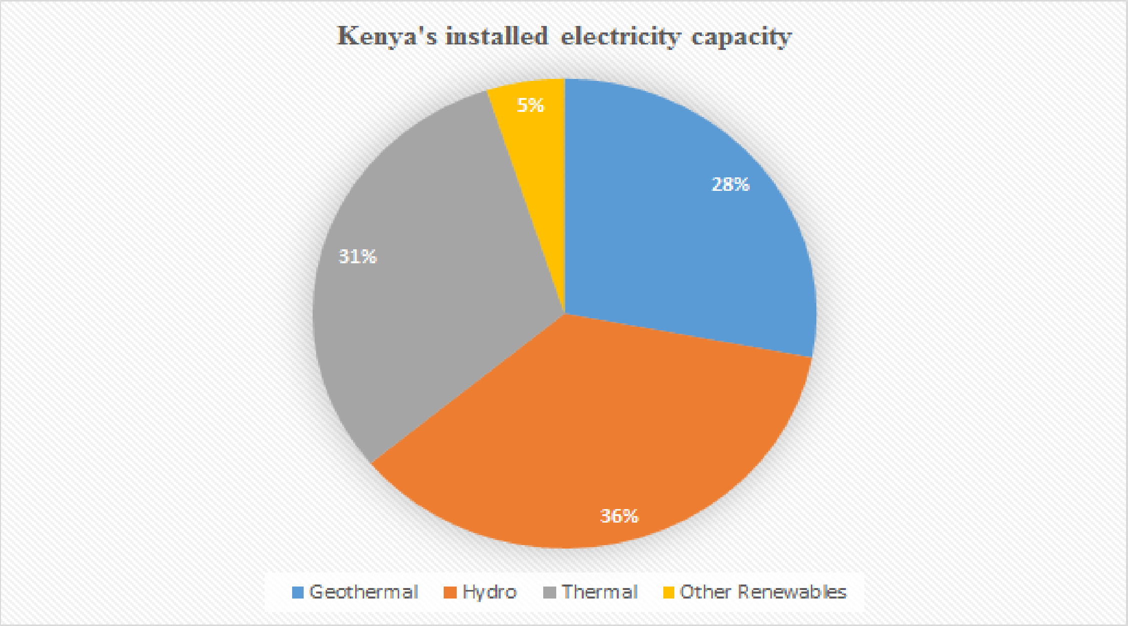

Figure 6. 6: Adopted from Kenya’s installed electricity capacity, USAID (Author, 2018).

Since Kenya's electricity dramatically depends on hydro, the country experiences frequent power outages due to the unpredictable weather conditions. The power demand in Kenya is increasing at a faster rate than the supply. The cost of electricity in Kenya is however quite high, at 0.15 USD/kWh, as compared to other countries like South Africa where 1 kWh costs 0.04 USD (Global legal insights, 2018). The growth of Kenya's power sector is affected by several factors including, inadequate access to finances, limited distribution infrastructure, land risks, and slow procurement procedures, among others.

The port of Mombasa was prone to unplanned power outages, forcing the port authority to upgrade from the 11KV bus to the 132 KV. However, this did not completely solve the problem hence the port should consider increasing the capacity of power generated on site. Moreover, with the planned port expansions, the demand for power will increase.

The researcher intended to define the emission factors for generation of power depending on Kenya's mix. The emission factors were used in the comparison of the benefits of using cold ironing over burning fuel in auxiliary engines to produce power while ships are at berth. Although 69 percent of the electricity mixture used in Kenya comes from renewable sources, air emissions are given off during the production of thermal electricity from power plants.

6.4 Cost analysis for the use of cold ironing at Mombasa

The cost of using cold ironing at a port widely varies from port to port, depending on the existing infrastructure near the port including the electricity substations or whether there exists infrastructure to allow retrofitting of the technology at the terminal. The CAPEX and OPEX on cold ironing components for the terminal were obtained from the proposed quotations by MTCC-Africa. The researcher used an interest rate from the Central Bank of Kenya of 9 percent to calculate the annualized costs of investing in the cold ironing components to be incurred by KPA over a 10-year depreciation period.

The cost of supplying high voltage electricity to Mombasa port and then to the berth used by container ships depended on the distance from the nearest high voltage supply and the need for a 16 kVA transformer to step down the voltage. The estimated cost for supplying Mombasa port with a 7 MVA high voltage electricity connection was taken as USD 621,185. Additionally, Kenya's electricity has a frequency of 50 Hz yet approximately 90 percent of the container ships need 60 Hz electricity to run onboard equipment. The cost of buying and installation of a frequency converter needed was estimated at USD 408,656. To supply the high voltage electricity from the terminal to the berth at an estimated distance of 750 meters, the cost of cable installation was taken as USD 115,500, bringing the total CAPEX to USD 1,145,341. Reference should be made to appendix B for a summary of the costs discussed above. The researcher amortized the costs to get the annual CAPEX.

On the other hand, the total annual OPEX included the maintenance of the components for cold ironing, taken as 5 percent of the total CAPEX (Entec, 2005). This annual cost equaled to USD 57,267. However, the total annual cost was calculated with consideration of the possible variations in the interest rate and the annual maintenance cost of the cold ironing equipment. The researcher used Monte Carlo simulations with 100,000 trails to find the mean value for the cold ironing cold ironing as indicated in figure 6.7.

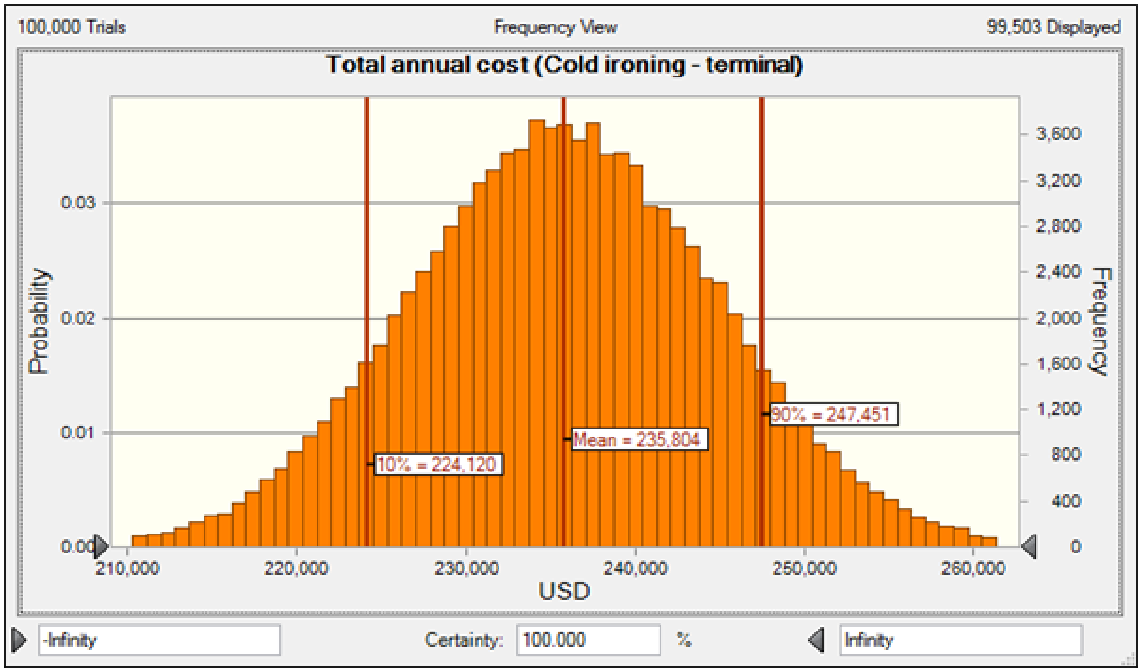

Figure 6. 7: Total annual cost for installing cold ironing at the container terminal (Author, 2018).

The mean total annual cost after 100,000 trails was USD 235,804. A look at the percentiles displayed in figure 6.7 shows that there is a 90 percent chance of the total annual cost for installing cold ironing in the terminal, being USD 247,451 and a 10 percent chance that the total annual cost will be equal or less than USD 224,120. The researcher analyzed the input factors that cause the variations in the forecasted total cost through a sensitivity chart, and the findings are displayed in figure 6.8.

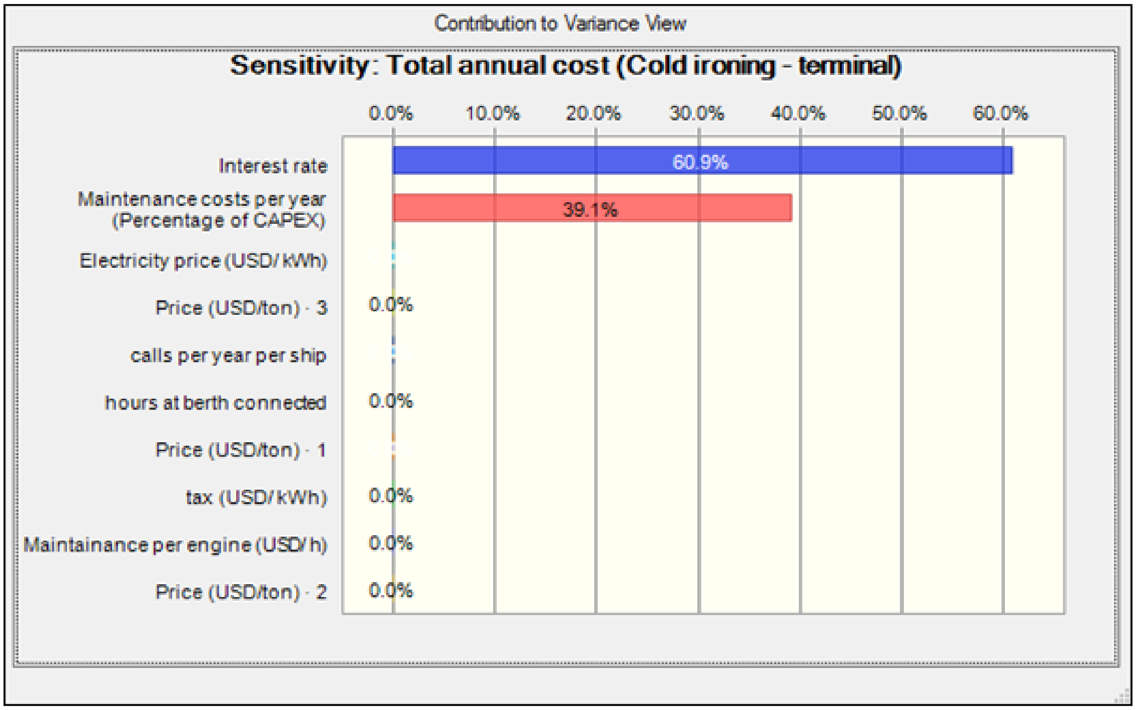

Figure 6. 8: Sensitivity chart on the total annual cost for installing cold ironing (Author, 2018).

It is indicated that the total annual cost for installation of cold ironing at the container terminal in Mombasa port dramatically depends on the variations in the interest with a 60.9 percent positive correlation. Also, the variations in the percentage of the total CAPEX for cold ironing that determines the annual maintenance cost has a 39.1 percent sensitivity value and a positive correlation impact on the total annual cost.

The researcher went ahead and analyzed the Net Present value for investing in the cold ironing by the Kenya Ports Authority (KPA). The NPV was calculated over a period of 10 years for which the project's depreciation time is estimated. The calculation only considered the initial investment cost in the equipment and the annual operation expenditures to compute the NPV. Figure 6.9 shows the NPV for cold ironing investment at the Mombasa container terminal.

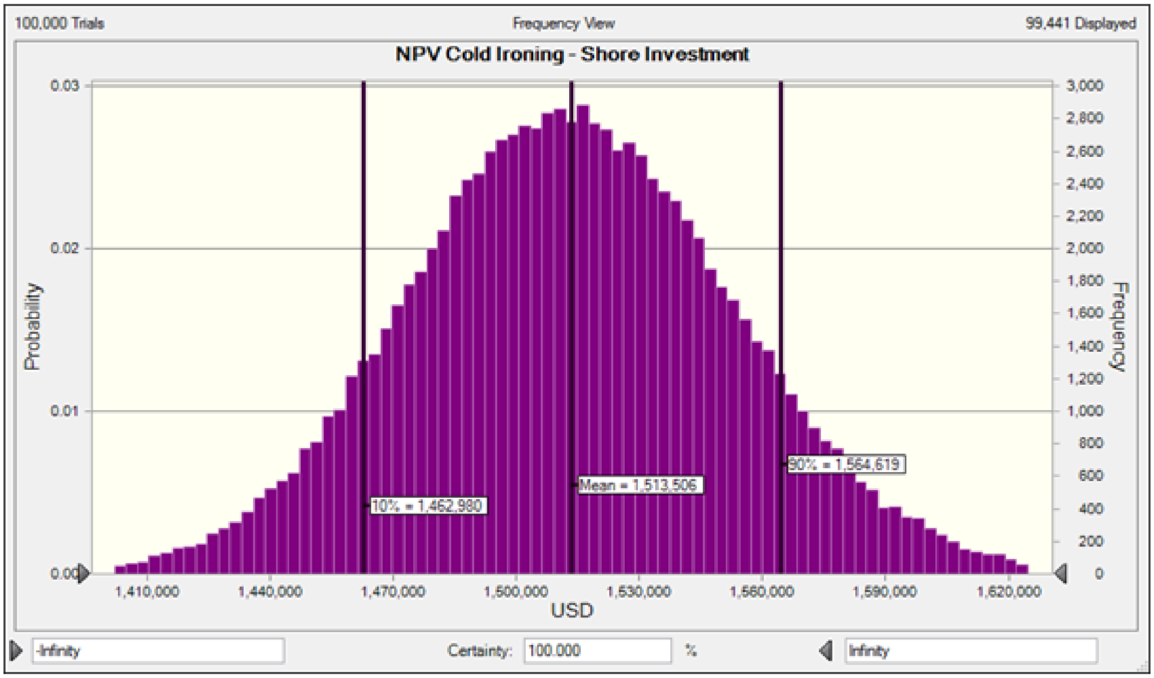

Figure 6. 9: NPV for cold ironing investment at the Mombasa container terminal (Author, 2018).

The forecasted mean NPV is USD 1,513,506, and since the calculation only considered cash outflows, the port would need to have net present cash inflows greater or equal to the mean NPV highlighted in figure 6.9 in order for the project to be acceptable. Annualizing the NPV for 10 years would give the required annual cash inflows to be equal or greater than USD 235,834 in order to make the project worth investing in.

Since the sensitivity analysis revealed that the cost of investing in cold ironing at the container terminal greatly depends on the interest rate, the Kenya Ports Authority could consider acquiring the funds at a lower rate, close to that used for inter-bank transactions which is presently at 5.79 percent. The researcher assumes that KPA will not add a premium to the cost of the electricity in order to recover the investment costs in the cold ironing infrastructure hence the payback period for the investment was not evaluated.

6.5 Cost analysis for retrofitting a container ship to use cold ironing.

The investment cost for retrofitting a container ship to use cold ironing was analyzed using baseline specifications from MS Kota Gabung, which calls Mombasa port approximately six times a year. Most container ships require an onboard transformer to convert the 16 kV from the proposed station at the Mombasa port to the 400 V used by onboard equipment. The cost for installation of the required onboard transformer is USD 191,320. The cost for installation of the required low voltage cables for a distance of 125 meters is valued at USD 4,375 while the respective onboard cable reel required to minimize the handling of high voltage cables for safety reasons costs USD 177,800. The total CAPEX for retrofitting the ship equaled to USD 373,495. A summary of the cost calculations is attached as appendix B.

The operational costs for ships using cold ironing depend on a number of input variables including, the price of electricity taken at 0.15 USD/kWh, the amount of tax imposed on the electricity consumption, currently at 0.018 USD/kWh in Kenya, the number of calls for the shipper year, the amount of time ships stay connected at berth, which on average is 3 days (72 hours) for container ships at the port of Mombasa (figure 6.4), and the estimated saved maintenance per engine, due to reducing the running time for the auxiliary engines.

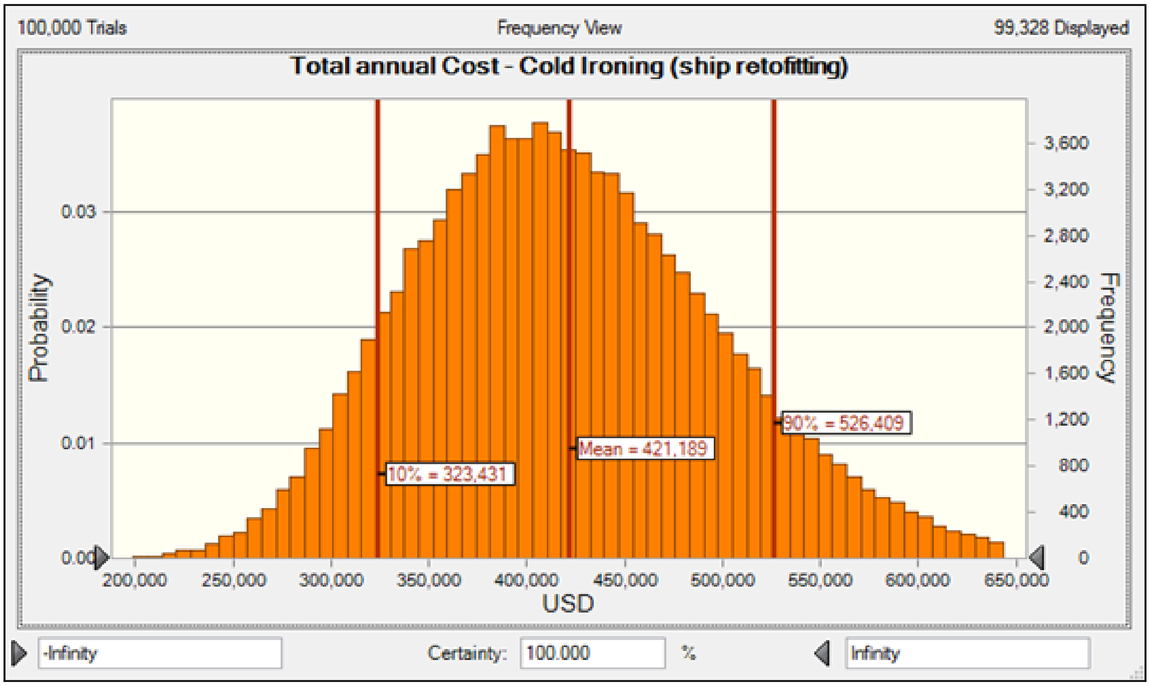

Figure 6. 10: Total annual cost for retrofitting a ship to use cold ironing (Author, 2018).

The findings in figure 6.10 were after 100,000 trails during the Monte Carlo simulations, with the mean total annual cost for retrofitting the ship being USD 421,189. There is a 90 percent chance of the forecasted total annual cost being equal or less than USD 526,409. Additionally, the researcher considered the fact that the proposed cold ironing will be able to serve 3 container ships at one berth hence the annualized OPEX included all the variables mentioned. The sensitivity of various inputs towards the variance in the total annual cost for retrofitting a container ship are illustrated in figure 6.11.

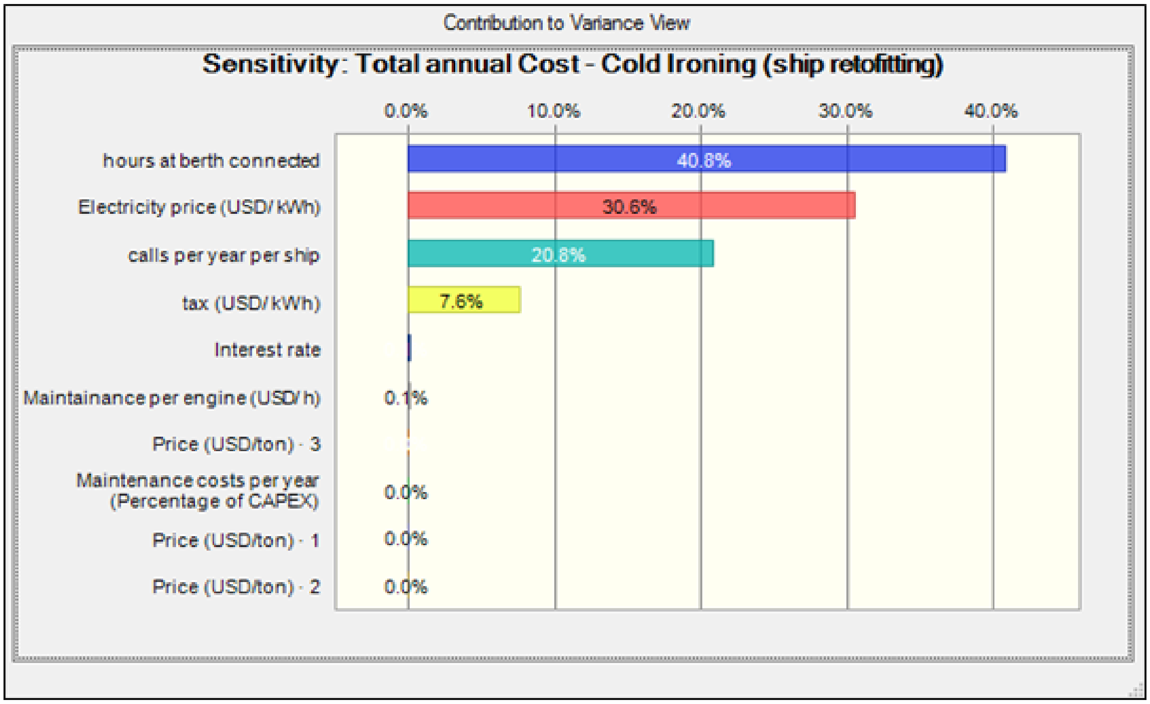

Figure 6. 11: Total annual cost for retrofitting a ship with cold ironing (Author, 2018).

The input with the most contribution to the variance in forecasted total cost value for ship retrofitting is the number of hours a ship stays connected at berth, with a 40.8 percent positive correlation impact on the result. This followed by the price of the electricity, the number of calls per ship per year, the tax and the interest rate at 30.6%, 20.8%, 7.6% and 0.13% respectively. The amount of time ships spend in the port depends on the efficiency of the port operation hence Mombasa port needs to cut down the average port time for ships to lower the ships' operational costs.

The researcher computed the NPV for retrofitting a container ship using the baseline information of MS Kota Gabung which has a remaining lifetime of 25 years, with the assumption that the ship was designed to last 30 years. The cash outflows were used in the computation and with variations in several inputs contributing to the CAPEX and OPEX, Monte Carlo simulations were run to determine the mean NPV as illustrated in figure 6.12.

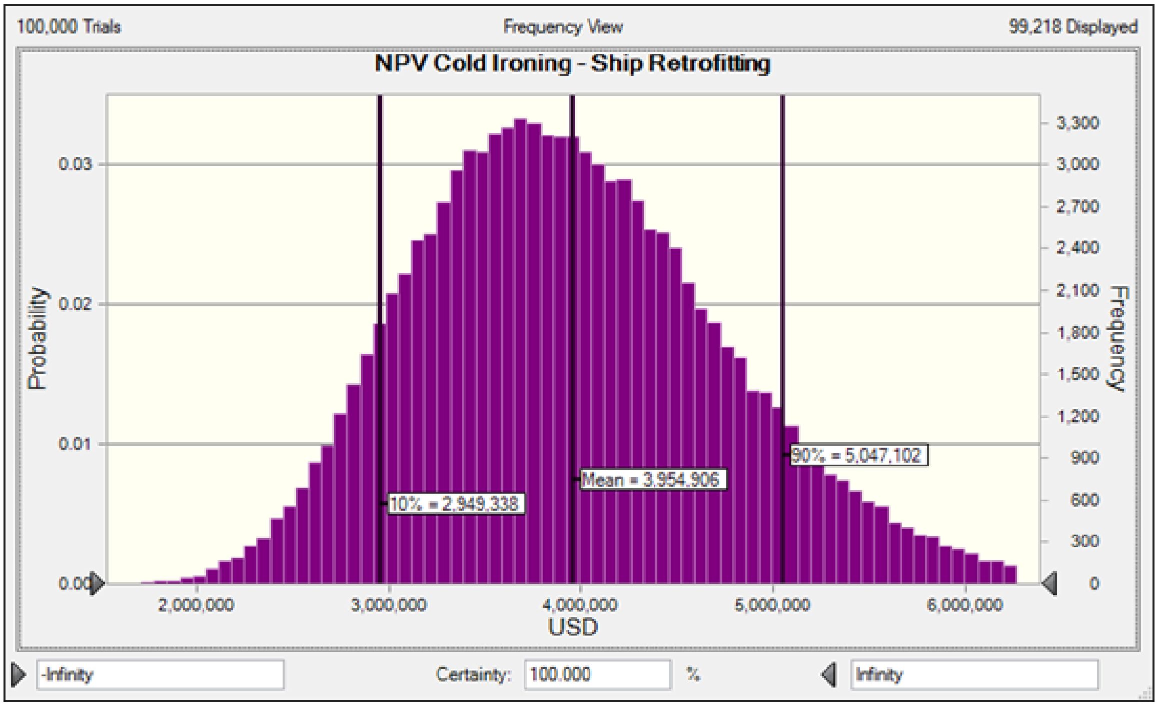

Figure 6. 12: NPV for retrofitting a ship with cold ironing (Author, 2018).

After 100,000 trials, the mean NPV obtained was USD 3,954,904 while the simulation indicated that there is a 90 percent chance for the NPV to be equal or less than USD 5,047,102. Figure 6.13 shows that the variance in the NPV was significantly impacted by the number of hours that ships stayed at berth, the electricity price, the number of calls per ship per year, the interest rate and the tax imposed on consumption of electricity in proportions of 36.9%, 27.7%, 18.9%, -9.5%, and 6.9% respectively. The interest rate has a negative correlation against the forecasted NPV as clearly illustrated in figure 6.13. Since the researcher only considered cash outflows in the computation of the NPV, its ideal that the inputs with a positive correlation be reduced to reduce the payback period for the investment.

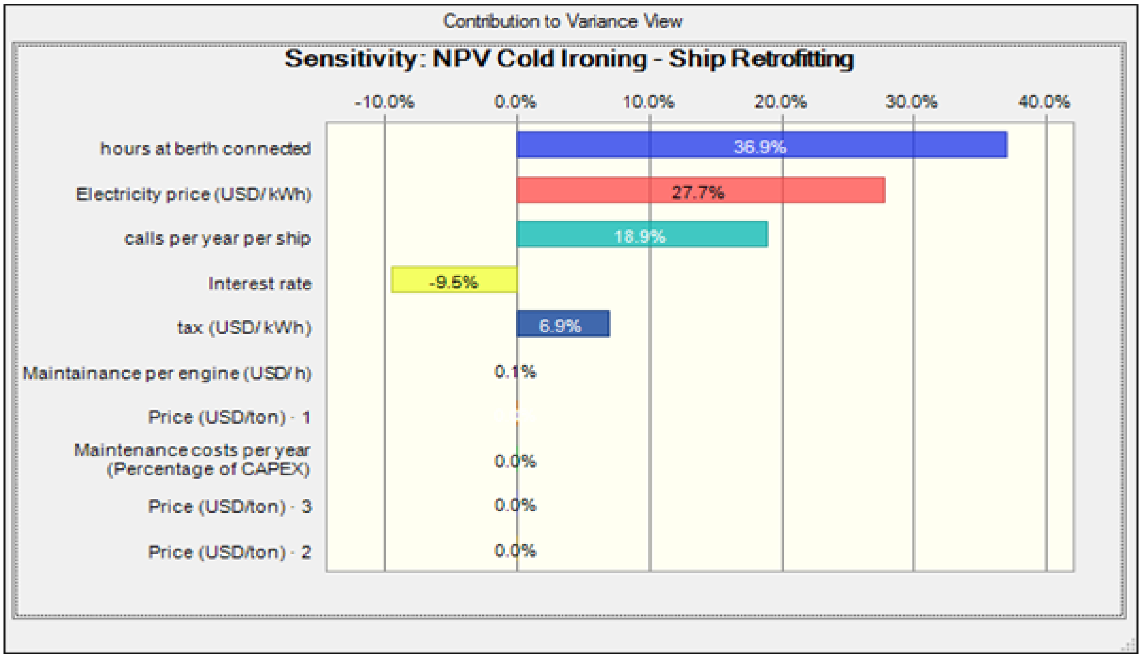

Figure 6. 13: Sensitivity chart for NPV of retrofitting a ship with cold ironing (Author, 2018).

The correlation between the forecasted NPV and the various input variables is further illustrated in figure 6.14, that shows the scatter chart of each input. The correlation coefficient for the relationship between the annual maintenance costs and the forecasted NPV for ship retrofitting is 0.0031 with a positive line of fit. This is the case for the relationship between the hours that ships stay connected at berth and the total number of calls they make per year, with the NPV as they both have positive correlation coefficients of 0.5859 and 0.4187 respectively. On the other hand, the interest rate has a negative correlation coefficient of -0.2963 against the NPV.

The total cost of the cold ironing system was obtained for use in the calculation of the cost-effectiveness of the technology, since a converted berth and ship cannot reduce emissions on their own hence they have to be assessed together The researcher also explored the cost benefit of using cold ironing over auxiliary engines to provide power to ships at berth. The findings of the comparison are presented and discussed in the following sections of this chapter.

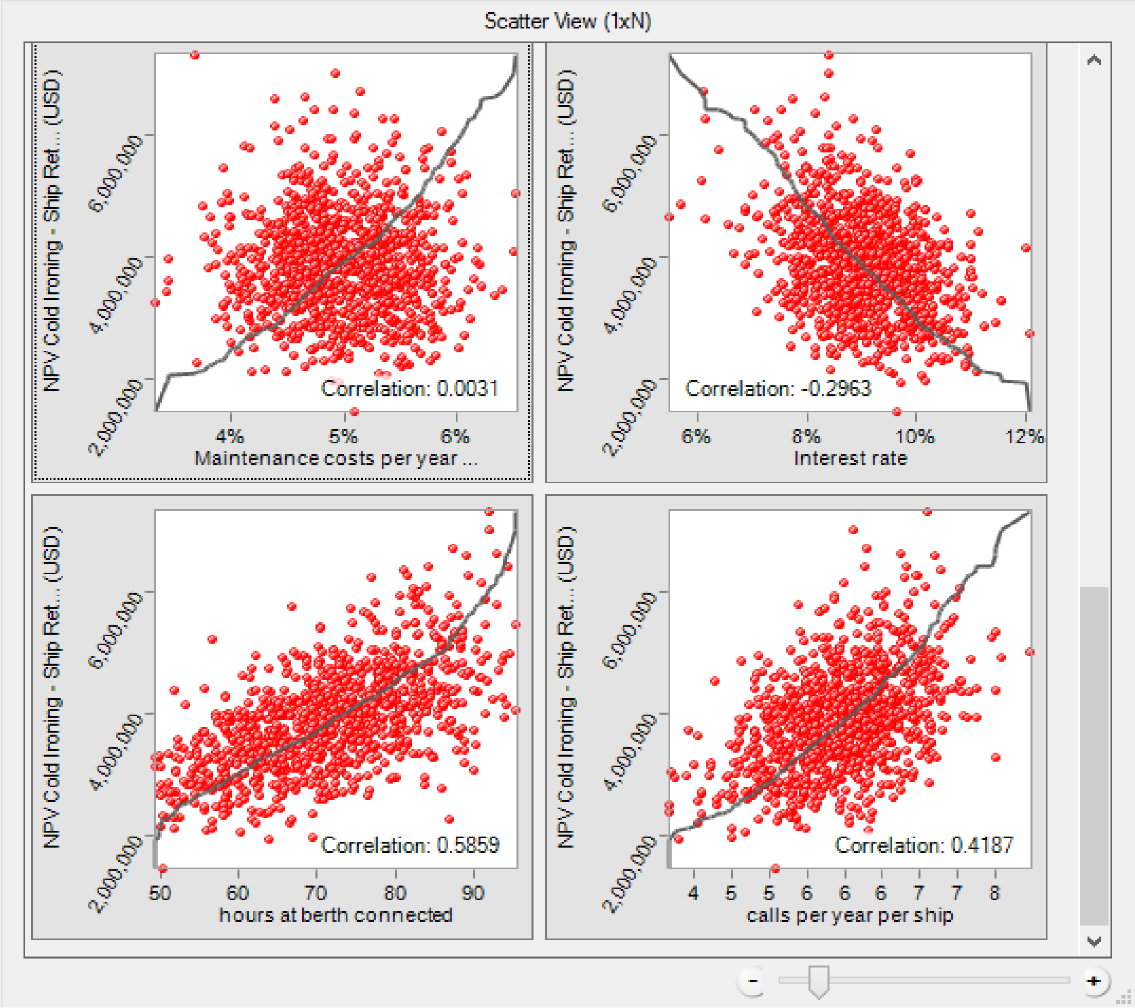

Figure 6. 14: Scatter chart on the NPV for retrofitting a ship with cold ironing (Author, 2018).

6.6 Cost-effectiveness of using cold ironing technology at Mombasa port.

The researcher’s primary objective was to assess the cost-effectiveness of investing in cold ironing technology at the port of Mombasa. Such an assessment has to be on the combined converted berth and ships system since neither ships nor the berth can reduce emission on their own. Hence the researcher computed the total annual costs for the cold ironing system and the amount of emissions reduced from using the technology, as indicated in Appendix B. The cost-effectiveness was then computed as a ratio of the total cost to the tons of emissions reduced.

6.6.1 The total cost of the cold ironing system

The total annual cost of investing in the cold ironing technology at the terminal and for three unique ships was computed, and the results are illustrated in figure 6.15.

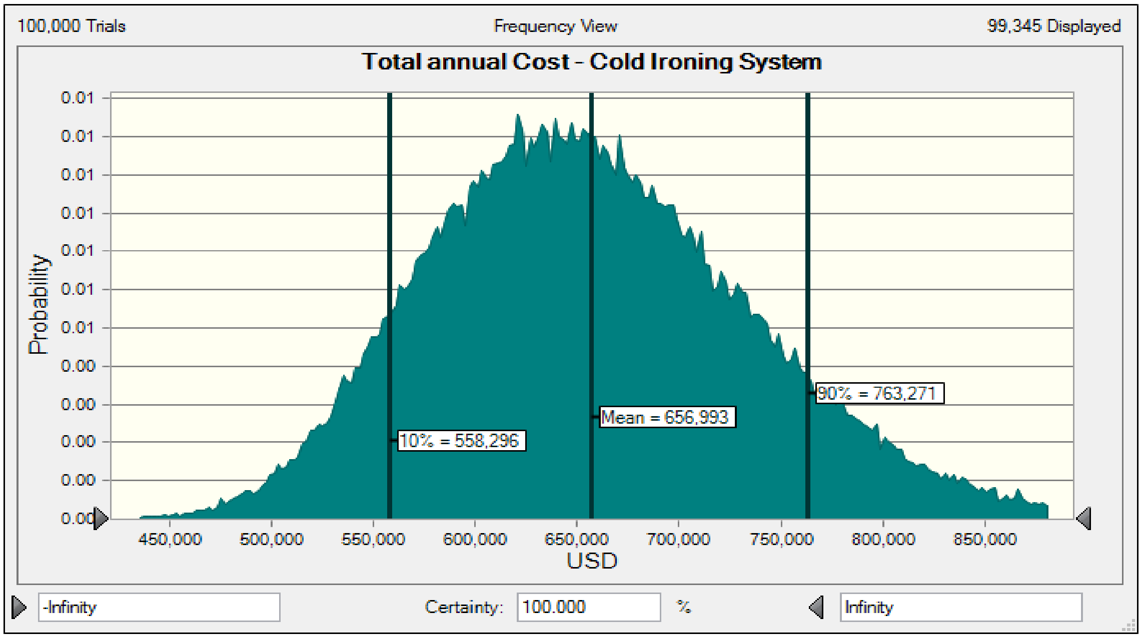

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Figure 6. 15: Total annual cost for the cold ironing system (Author, 2018).

After 100,000 trails using Oracle’s crystal ball software, the mean total annual cost for the cold ironing system was USD 656,993. According to the percentiles in figure 6.15, there is a 10 percent chance that the total annual cost is equal or less than USD 558,296 and a 90 percent chance that the total annual cost is USD 763,271. However, for purposes of calculation of the cost-effectiveness of the cold ironing technology, only the mean values were used. The variance in the total annual cost of the cold ironing system is due to changes in several inputs, as indicated in figure 6.16. The forecasted total annual cost is significantly affected by the number of hours that ships stay connected at berth, contributing to 40 percent of the changes in the output value. The sensitivity of the total annual cost of the cold ironing system is also affected by the price of electricity, the number of calls that the ships make per year and the tax charged on the consumption of the electricity.

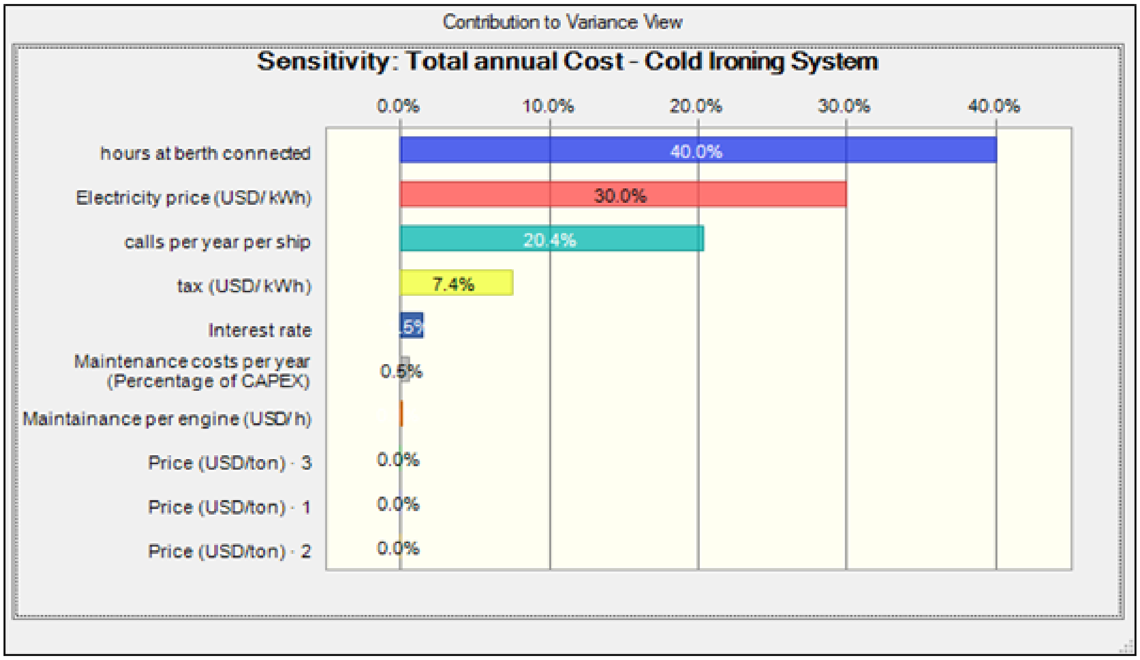

Figure 6. 16: Sensitivity chart on the total annual cost of the cold ironing system (Author, 2018).

6.6.2 Emission reduction per berth from the use of cold ironing

The researcher computed the emission reductions per berth by comparing the amount of emissions from using auxiliary engines with the emissions from the electricity source. Starting 1st January 2012, the global Sulphur limit in marine fuels was reduced to 3.5 percent for vessels operating outside the set Emission Control Areas (ECAs). For purposes of this study, it was assumed that the average Sulphur content in marine fuel used by ships while at berth is 2.7 percent. This was used as a baseline for comparison of the emission reductions per berth, but the percentage reduction in the emissions highly depends on the emission factors for the shore side electricity supplied to the vessels. The amount of emissions produced when using auxiliary engines per berth per year was obtained through Monte Carlo simulations with 100,000 trials since input factors such as the number of hours that ships stay connected at berth and the number of calls per ship per year may vary. The results for the tons of pollutants emitted are illustrated in figure 6.17 for fuel oil with 2.7% Sulphur content.

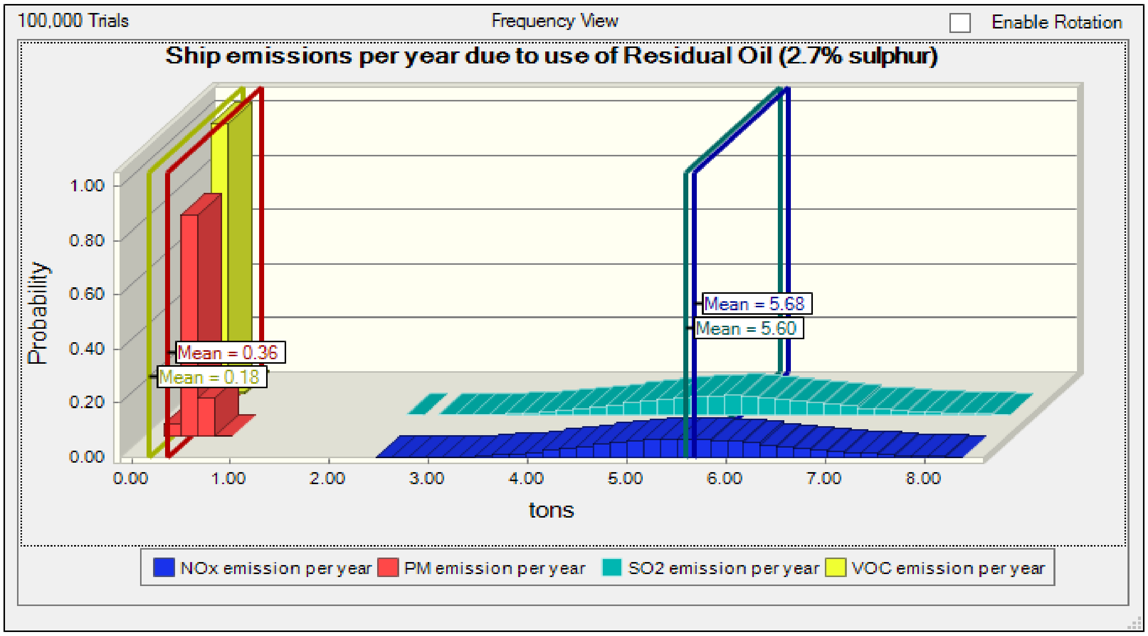

Figure 6. 17: Overlay chart showing the amount of emissions per year (Author, 2018).

The amount of emissions (tons) of NOx, PM, SO_2, and VOC are indicated in the overlay chart - figure 6.17, with mean values of 5.68 tons, 0.36 tons, 5.60 tons, and 0.18 tons respectively. These values were compared to the total emissions from the supply of electricity in Kenya. For purposes of this study, the considered the ideal situation where all the electricity supplied to ships at berth in Mombasa comes from renewable sources. No emission factors have been studied on the current power generation in Kenya. Therefore, with renewable energy, which dominates the Kenyan electricity mixture, the study computed the emission reduction potential for the scenario where Kenya has fully implemented its green port policy and electricity supplied in the port is renewable. The emission factors from renewable energy production are zero, and the reduction in the total annual emissions per berth are shown in table 6.1.

Since the emission factors for the generation of renewable energy are zero, the assumed ideal scenario provides 100 percent reduction efficiency for all the NOs, SO_2, VOC and PM. This is the social benefit of using cold ironing instead of auxiliary engines that depend only on fossil fuels. These benefits translate to a reduction in health cases for the people staying in port areas.

Table 6. 1: Emissions reduced per berth (tons/year/berth) for using cold ironing instead of auxiliary engines with 2.7 Sulphur residual oil.

Emissions	**NOx**	**SO_2**	**VOC**	**PM**
Total Emission from using Residual oil (2.7% Sulphur)- tons	5.6758	5.5984	0.1821	0.3641
Total Emission from using Cold ironing (100% renewable)	0.00	0.00	0.00	0.00
Emission Reduced	5.6758	5.5984	0.1821	0.3641
Reduction efficiency (%)	100	100	100	100

Source: (Author, 2018)

6.6.3 Computation of the cost-effectiveness of using cold ironing system

With findings of the total cost of the cold ironing system (terminal and ships) and the amount of emissions reduced from the use of auxiliary engines with residual oil of 2.7% Sulphur content, the researcher computed the cost-effectiveness (USD/ton of pollutant), and the results are summarized in table 6.2. The mean value for the total annual cost was used in the calculations.

Table 6. 2: Cost-effectiveness of investing in cold ironing system at Mombasa port.

Total annual cost of cold ironing system - (USD 656,993)				
Emissions per berth/year	**NOx**	**SO_2**	**VOC**	**PM**
Total Emission from using Residual oil (2.7% Sulphur)	5.6758	5.5984	0.1821	0.3641
Total Emission from using Cold ironing (100% renewable)	0.00	0.00	0.00	0.00
Emission Reduction (tons)	5.6758	5.5984	0.1821	0.3641
Cost-effectiveness (USD/ton of pollutant)	115,754	117,354	3,608,621	1,804,310

Source: (Author, 2018)

6.7 Scenarios to improve the cost-effectiveness of cold ironing

To clearly understand the gap that may have ship owners prefer generating power with auxiliary engines while at berth instead of investing in cold ironing technology, the researcher made a comparison of the total annual OPEX for using the several alternatives including the use of 0.5% and 0.1% Sulphur content fuel which is likely to become mandatory in the near future. According to MARPOL Annex VI regulation 14, the global Sulphur limit for marine fuels shall be 0.5% starting from 1st January 2020. This requirement will also affect the fuel used by ships while at berth in the port of Mombasa, so the researcher explored the impact it would have on the cost-effectiveness of cold ironing. The researcher also explored the possibility of having of the Kenyan legislation add requirements for vessels calling their ports to use fuel oil with Sulphur limit of 0.1% to enhance the protection of the local communities from the negative externalities of shipping, as is the case for European seaports. The findings from the Monte Carlo simulations of alternatives are summarized in table 6.3, showing a comparison between the total annual OPEX and emissions for ships using cold ironing against ships using the different fuel oil. Mean values for the OPEX and total emissions per berth per year were used in table 6.3.

Table 6. 3: Cost-effectiveness of investing in cold ironing system at Mombasa port.

	Technology/Fuel oil used			
	Cold ironing (ship retrofitting)	Residual oil (2.7% Sulphur)	Marine distillate (0.5% Sulphur)	LSFO (0.1% Sulphur)
OPEX (USD)	362,867	209,583	309,556	314,123
NOx	0.00	5.68	5.42	5.37
SO_2	0.00	5.60	1.04	0.21
VOC	0.00	0.18	0.18	0.18
PM	0.00	0.36	0.17	0.14

Source: (Author, 2018)

The OPEX for ships that would use cold ironing instead of burning fuel in auxiliary engines while at berth is highest at a total annual value of USD 362,867. This price is greatly affected by the price of electricity and the amount of time that ships spend at berth. Therefore, the researcher explored scenarios that would reduce the OPEX for using cold ironing to make it economically attractive for ship owners. Additionally, it can be seen from table 6.3 that cold ironing presents the best environmental benefits with the ideal situation of renewable energy generation having zero emissions. The use of fossil fuel generates air emissions whose amounts depend on the Sulphur content in the fuel. Low Sulphur marine gas oil with 0.1% content presents the lowest tons per pollutant of NOx, SO_2, VOC, and PM, in comparison with the 0.5% Sulphur marine distillate and the 2.7% Sulphur residual oil. However, the fuel price for the LSFO is higher than the other two fuel alternatives making the OPEX for generating power with auxiliary engines higher than when the heavy fuel oil is used. Therefore, for port authorities and ship owners, there is a tradeoff on how to balance the economic and social benefits of using cold ironing over auxiliary engines.

6.7.1 The 2020 global Sulphur cap and tax exemption on electricity

The fact that marine fuel used by ships shall need to have a Sulphur content of not more than 0.5% by 1st January 2020 presents challenges and opportunities for several maritime stakeholders. The biggest concern about the entry into force of the regulation was whether there would be enough fuel with that Sulphur content to be used by the global fleet in all parts of the world. On the other hand, this presents opportunities for fuel companies to distill the HFO and improve its value. This move is targeted to reduce the amount of emissions from ships and make the maritime industry a low carbon industry. The researcher ran simulations using this scenario, where the Kenyan government exempts the tax charged on consumption of electricity used by ships and the period starting from 2020 when the global Sulphur cap will be effective.

The study found that the total annual OPEX for ships using cold ironing under the tax exemption reduced to USD 323,209 while the OPEX for using auxiliary engines to generate electricity increased to USD 309,556. The gap between the operation expenditures reduced, and this presents a better scenario for ship owners to adopt the technology. This scenario also produced higher cost-effectiveness than when 2.7% Sulphur residual oil was used in auxiliary engines. However, a comparison of the tax exemption scenario with the possible use of 0.1% Sulphur fuel oil presented more economical and social value. The findings from the two scenarios for the combination of tax exemption with marine distillate, and combination of the tax exemption with LSFO regulations are presented in table 6.4.

Table 6. 4: Scenario analysis for the cost effectiveness of cold ironing.

Scenario 1: Tax Exemption and Marine distillate (0.5% sulphur)				
Emissions	**NOx**	**SO2**	**VOC**	**PM**
Total annual cost of cold ironing system (USD) - with Tax Exemption	617,142			
Total Emission from using MD (0.5% sulphur)	5.4177	1.0385	0.1821	0.1716
Total Emission from using Cold ironing (100% renewable)	0.00	0.00	0.00	0.00
Emission Reduction (tons)	5.4177	1.0385	0.1821	0.1716
Cost effectiveness (USD/ton of pollutant)	113,911	594,289	3,389,734	3,597,269
Scenario 2: Tax Exemption and LSFO (0.1% sulphur)				
Emissions	**NOx**	**SO2**	**VOC**	**PM**
Total annual cost of cold ironing system (USD)	617,142			
Total Emission from using LSFO (0.1% sulphur)	5.3708	0.2094	0.1821	0.1365
Total Emission from using Cold ironing (100% renewable)	0.00	0.00	0.00	0.00
Emission Reduction (tons)	5.3708	0.2094	0.1821	0.1365
Cost effectiveness (USD/ton of pollutant)	114,906	2,947,595	3,389,734	4,519,645

Source: (Author, 2018)

The cost effectiveness for investing in cold ironing will be higher in 2020 when ships will be using marine distillate of a maximum 0.5% Sulphur content compared to the baseline values used of 2.7% Sulphur content currently used by ships on average. As seen from table 6.4, the cost effectiveness of the cold ironing is highest in the second scenario where the Kenyan exempted vessels from paying tax on electricity and adopted regulations requiring ships to use a maximum 0.1% Sulphur content fuel oil.

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Cold ironing has been implemented for several years in most European seaports and a few Asian ports but the technology is yet to be adopted by any African port. However, with the increased awareness of the environmental and social impacts of port operations, and the drive to integrate corporate social responsibility within the shipping industry, the uptake of cold ironing was identified as one of the measures to partly address the some of the negative externalities of shipping around the Mombasa port community.

The main objective of the study was to assess the cost-effectiveness of cold ironing at the port of Mombasa. From the findings of the study, it is evident that the cost of the cold ironing system greatly depended on the amount of time ships stayed at berth. Currently the average port time for container ships at Mombasa port was 3.1 days which is quite high compared to the time spent by ships in other ports. This delay can be attributed to the inefficient port operations and gaps during ship port interface. The OPEX for ship owners also depended on the cost of electricity which for Kenya is at 0.15 USD/kWh, a price considered to be high when compared to other regions and countries such as South Africa. When cold ironing was compared with the alternative of the use of auxiliary engines with residual oil at 2.7% Sulphur content, there was a gap in the OPEX, economically favoring the use of fuel oil, and that gap became higher considering scenarios where all ships will be required to use 0.5% Sulphur fuel oil from 2020 under the MARPOL convention, and under a scenario where the Kenyan government adopted a policy making it mandatory for ships to use 0.1% LSFO while at berth. Additionally, the researcher identified that operational costs for the ship owners increased by margins from the OPEX incurred during ship onboard generation of electricity using auxiliary engines, in circumstances where a premium is charged on the supply of onshore electricity to recover the CAPEX for the terminal infrastructure.

The interest rate for which investment expenditure depreciates is at 9 percent, a value which had a high impact on the total cost of the cold ironing system. The variations in the annual maintenance costs of the technology also affected the total cost of the cold ironing system and such variations depend on the level of training and competence that the crew and shore staff have. The highest cost-effectiveness was realized with a scenario combination where the Kenyan government exempted ships from paying tax on the consumption of electricity and regulations requiring ships to use LSFO were adopted.

From the SWOT analysis of the implementation of cold ironing in leading ports in Europe, North America and Asia, the researcher identified that the social benefits of cold ironing depended on the emission factors for the on shore electricity supply mix. Therefore, the realization of environmental benefits at the port of Mombasa therefore depended on Kenya’s energy mix. However, there has not been quantified emission factors for the installed power in Kenya hence with the ideal renewable energy scenario, the emissions would be completely reduced. The use of incentives such as discounts from the environmental ship index has encouraged ship owners to take up low carbon technologies.

7.2 Recommendations

From the study of the current state of Mombasa port performance, the investment cost for terminal cold ironing infrastructure, the investment cost for retrofitting container ships to receive shore electricity, the cost-effectiveness of cold ironing as a system and the benchmarking from the leading ports in Europe, North America and Asia regarding the adoption of cold ironing, the researcher recommends the following;

I. There is need for improved efficiency at the port of Mombasa so that ships don’t spend too much time at berth. This can be achieved through improved ship port interface where a single window system is implemented effectively. KPA should encourage effective yard utilization so that there is less congestion in the container terminal. Virtual arrival should be encouraged so that ships come into port when berths are available to reduce the anchorage time. Automation of operational activities should be fully explored to improve efficiency with in the port.

II. To ensure that maximums benefits of using cold ironing are realized, KPA should consider generating electricity used for port activities and ship hoteling services at the port. After the adoption of a green port policy, the port authority needs to explore the feasibility of generating renewable energy at the port, as is the case for Egypt’s Damietta port that is implementing a green power project aimed at producing all the port’s energy demands through renewable energy.

III. Considering the fact using cold ironing at the port of Mombasa would exert higher operational costs than generating electricity with the ships auxiliary engines, KPA should not charge a premium on the cost of electricity sold to the ships to encourage them adopt the technology.

IV. There is need for financial incentives to be awarded to ship owners for the use of low carbon technologies. A study should be carried out on the possible adoption of systems that allow ships to have discounts on berthing fees for the use of cold ironing. For instance, this is the case in Europe where they have the clean shipping index (CSI) and the environmental ship index (ESI).

V. Acknowledging that the finality for most shipping companies is to maximize profits, there is need for regulations to be adopted and enforced regarding environmental protection, as these measures may not be accepted openly because of their financial implications. The EU adopted Directive 2014/94/EU on the deployment of alternative fuels infrastructure, that encourages the use of technologies like cold ironing. The Kenyan legislation should be updated to include requirements for ships to receive cold ironing or other cleaner alternatives.

VI. Bearing in mind that the global Sulphur cap requiring ships to use fuel oils with a maximum of 0.5 % Sulphur content will be effective from 1st January 2020, the operational costs for ships are anticipated to increase therefore, cold ironing can be a good alternative source of power for ships in scenarios where the Kenyan authorities can exempt the payment of VAT on the electricity supplied to the ships. The tax exemption would lower the cost of electricity, subsequently lowering the OPEX for the ship operation with cold ironing.

VII. Ship owners should be positive towards the uptake of low carbon technologies like cold ironing, therefore ships calling the port of Mombasa should be made aware that consumers are becoming aware of the environmental impacts from shipping and that they are willing to reward companies that are practicing corporate social responsibility in their business activities. Hence adopting low carbon technologies may present economic benefits to ship owners with increased business opportunities.

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APPENDIX A
NON-EXHAUSTIVE LIST OF PORTS IMPLEMENTING COLD IRONING

PORT	COUNTRY	HIGH VOLTAGE	LOW VOLTAGES	FREQUENCY
Antwerp	Belgium	6.6 kV	400 V	50 Hz/60 Hz
Goteborg	Sweden	6.6 kV/10 kV	400 V	50 Hz
Helsingborg	Sweden		400 V/440 V	50 Hz
Stockholm	Sweden		400 V/690 V	50 Hz
Piteå	Sweden	6 kV		50 Hz
Kemi	Finland	6.6 kV	400 V	50 Hz
Oulu	Finland	6.6 kV	400 V	50 Hz
Kotka	Finland	6.6 kV	400 V	50 Hz
Lübeck	Germany	6.6 kV	400 V	50 Hz
Zeebrugge	Belgium	6.6kV	400 V	50 Hz
Los Angeles	U.S.A	6.6 kV/11 kV		60 Hz
Long Beach	U.S.A	6.6 kV	480 V	60 Hz
San Francisco	U.S.A	6.6 kV/11 kV		60 Hz
San Diego	U.S.A	6.6 kV/11 kV		60 Hz
Seattle	U.S.A	6.6 kV/11 kV		60 Hz
Juneau	U.S.A	6.6 kV/11 kV		60 Hz
Pittsburg	U.S.A		440 V	60 Hz
Vancouver	Canada			60 Hz
Oslo	Norway	6.6kv		50Hz
Rotterdam	Netherlands	6.6kv		50Hz
Copenhagen	Denmark		400 V	50 Hz
Helsinki	Finland		400 V	50 Hz
Genoa	Italy		400 V	50 Hz
Rotterdam	Netherlands		400 V	50 Hz

APPENDIX B

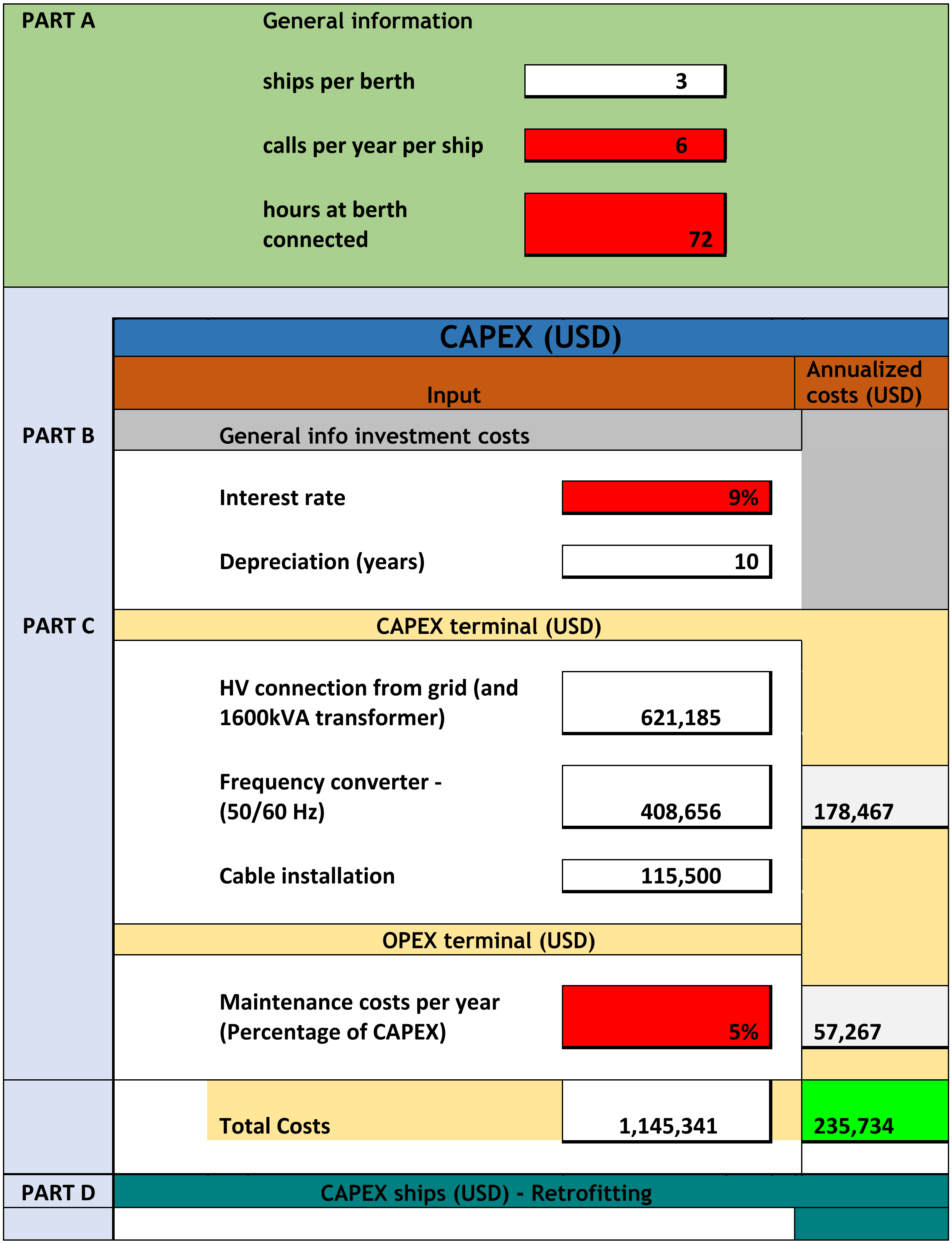
DESCRIPTION OF THE EXCEL CALCULATION AND CRYSTAL BALL'S MONTE CARLO SIMULATIONS MODEL.

PART A	This part provides the general information about the number of ships per berth, the number of calls per year per ship and the amount of time ships stay connected at berth. This information is used in the calculation of the OPEX for ships using cold ironing
PART B	This part gives information on the interest rate used for calculation of the annualized CAPEX and the depreciation in years.
PART C	The breakdown of the CAPEX and OPEX for the terminal cold ironing equipment is given. The maintenance cost is considered under the OPEX. The total cost is amortized.
PART D	The CAPEX for retrofitting container ships is broken down under this part. The total cost is annualized
PART E	This part breaks down the OPEX for a ship using cold ironing and the OPEX for a ship using auxiliary engines to produce electricity needed for hotelling services. The saved maintenance for ships using cold ironing is considered as a negative in the summation of OPEX
PART F	This part includes the total annualized costs for the cold ironing system and that for using auxiliary engines, and the total amount of NOx, SO_2, VOC and PM generated from using cold ironing vs using auxiliary engines
PART G	The CAPEX for using auxiliary engines while at berth is not considered as these are operated during maneuvering and at sea.
PART H	The emission factors for the ideal renewable energy and for the fuel oils of 2.7%, 0.5% and 0.1% are given.

Note;

I. Cells filled with "Red" represent assumptions for the input variables in the spreadsheet model, defined by choosing a specific probability distribution type.

II. Cells filled with "Green" represent output variables of interest (defined forecasts).



PART A	General information		
	ships per berth	3	
	calls per year per ship	6	
	hours at berth connected	72	
	CAPEX (USD)		
	Input		Annualized costs (USD)
PART B	General info investment costs		
	Interest rate	9%	
	Depreciation (years)	10	
PART C	CAPEX terminal (USD)		
	HV connection from grid (and 1600kVA transformer)	621,185	
	Frequency converter - (50/60 Hz)	408,656	178,467
	Cable installation	115,500	
	OPEX terminal (USD)		
	Maintenance costs per year (Percentage of CAPEX)	5%	57,267
	Total Costs	1,145,341	235,734
PART D	CAPEX ships (USD) - Retrofitting		

PART E	On-board transformer including installation	191,320	
	cabling installation	4,375	58,198
	Cable reel system	177,800	
	Total CAPEX	373,495	
	OPEX - Ship using Cold ironing (USD)		
	Input		Yearly costs (USD)
	Electricity costs		
	Electricity price (USD/ kWh)	0.15	
	tax (USD/ kWh)	0.02	370,138
	Consumption (kW)	1,700	
	Saved maintenance		
	Maintenance per engine (USD/ h)	-1.87	-7,271
PART F	number of engines	3	
	Total Costs		421,065
	TOTAL COSTS- Cold Ironing System (USD)		656,799
	POLLUTION		
	Input		
	Electricity source	Kenya (Renewable energy)	

Pollutants	Emissions (ton)
NOx	**0.00**
SO2	**0.00**
VOC	**0.00**
PM	**0.00**

AUXILIARY ENGINES

PART G

CAPEX (USD)	Yearly costs (USD)
Input terminal	
General info investment costs	
no investments ☐	

OPEX using Auxiliary Engines (USD)	
Input terminal	Yearly costs (USD)
Fuel costs	

Fuel Price (USD/ton)	**MD (0.5% Sulphur)**	680.0
	Consumption (ton/h)	0.4

TOTAL COSTS Auxiliary Engines (USD)	**309,506**

PART H

	Hydro/geothermal/wind/solar	
NOx (g/kWh)	0.00	11.90
SO2 (g/kWh)	0.00	2.28
VOC (g/kWh)	0.00	0.40
PM (g/kWh)	0.00	0.38