

**ASSESSMENT OF ALTERNATIVE SOURCES OF ENERGY FOR MARINE
TRANSPORTATION IN NIGERIA**

BY

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**A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL, FEDERAL
UNIVERSITY OF TECHNOLOGY, OWERRI**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE
DEGREE OF MASTER OF SCIENCE (M.Sc.) IN MARITIME MANAGEMENT
TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI**

MARCH, 2024

CERTIFICATION

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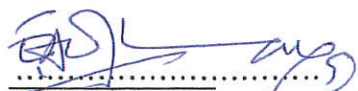
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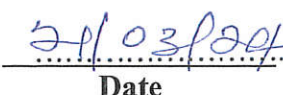
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DEDICATION

This piece of work is dedicated to God Almighty first who in His infinite mercies saw me through to the completion of my M.Sc. programme. And to my father, late Surveyor Bennett Ekeke Nwankwo, and every indigene of Ndoki land who may find pleasure to advance more than I have done in the study of Marine Technology.

ACKNOWLEDGEMENTS

My foremost thanks and unalloyed appreciation goes to God Almighty for his steadfastness and enablement in concluding this program.

I am most sincerely thankful and grateful to my supervisor Prof. C. Onyemechi for painstakingly ensuring a thorough supervision of the work and assisting in many ways other than academics, in ensuring the delivery of this project. I cannot thank him enough.

To the very many people who have been of great assistance in the course of my study, particularly my kind and ever encouraging Head of Department Dr. O.B.C. Ndikom, I am eternally most grateful. My special appreciation and acknowledgement also goes to you my erudite Professors whose magic hands impacted enormously on me during the period of my study; Professor K.U. Nnadi and Prof. G. C. Emeghara, not forgetting the ever kind Dr. D.E. Onwuegbuchunam.

My acknowledgements also goes to the many Lecturers who contributed in varied ways to the success of this program; Dr. I.C.Nze, Mr. T.C. Nwokedi, Mr. O.K. Okeke, my academic fathers, Professor Innocent Ogwude, Professor Pat Utomi, Professor Ibe, and other members of staff of the Department of Maritime Management Technology who were of immense assistance.

I cannot forget to acknowledge in a special way, the contributions of the Dean of SMAT, Professor O.T. Ebiringa and the Associate Dean of SMAT, the Dean PG School, Professor C.C. Ezeh and the Associate Dean of the PG school. I am indebted to you all.

My course mates who had one goal with me to achieve, Ebenezer Sorbari, Precious Njoku, Lawrence C. Christain, Omereife Joseph Emeka, Chinedum Emmanuel Afrogha Dickson Preye, Ndukwu Ibeabuchi, Nnaukwu Charles, and my bossom Nnamdi Anyanwu whose extra oil made our success simultaneously.

I must thank my mentors in the field of Maritime who stirred the hunger of maritime study in me. Mr. Stewarts Nnanta, Mr. Cliff. N. Nwagbara, Mr. Goodhope Chima Nwohu, Mr. Chris. Nkwonta, Staff of Global Maritime Academy, Delta State, Staff of ECOTES University, Benin Republic, Staff of Aquashield Oil and Marine services, Portharcourt, Captain Hezekiah Obaka. Captain Shaoloko Iraoya, Madam Chioma Omanake, Ms Oghenekevwhue Omukoro, Engr. Uche Goodhop Nna, Dr. Emmanuel Okechukwu Nna etc.

My sister, Doctor Nnenna Ekeke who saw a reason to support, Barrister Chiadikaobi Nwankwo, Dr. Emmanuel M. Nwankwo, Engr. Vincent Chidozie Nwagbara and all that impacted positively.

My in-laws who through prayers and support contributed to the success of this study. Elder Jerry U. Nwagwu, Mrs. Elizabeth Nwagwu, Miss. Perpetual C. Nwagwu and DSP (Rtd) John Nwamaghioha.

I must thank my mother, Deaconess Phoebe Enyinne Nwankwo, my sisters, Mrs. Blessing Uchechi Wamuo, Dr.(Mrs) Ozioma Nwogu, Ms Cherish Onyinye Ekeke, Late Ms Chinyere Glory Ekeke, Mrs. Olileanya Micheals, Mrs. Amarachi Elekwa, Ms. Chinonyerem Ekeke, Mr. Ikechi S. Ekeke, Mr. Uzodinma G. Ekeke and Mr. Obijuru Ekeke.

Lastly, my wife Mrs. Tina Ginkachi Ekeke who prepared and groomed me for this course and my three angels Phoebe Chienyemoke Ekeke, Bliss Chimdiya Ekeke, Olive Chizitere Ekeke, Increase Simi. Ozioma Ekeke, who were my co- students while on this study. My colleagues at AQUSHIELD Oil and Marine Services Limited and my entire class of MMT-M.Sc- 2019/2020, All Akirika Ndoki individuals of whom provided the encouragement, support and inspiration that made this project possible.

Thank you all.

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ABSTRACT

The study analyzed the alternative energy sources for marine transportation in Nigeria. The aim of the study was to assess the relative importance of identified economic sub-criteria that influence ship operators' preference of alternative energy sources for marine use, and to compare the scalability potentials of available alternative energy options for marine transportation in Nigeria, using identified scalability factors. The study used a survey method in which expert opinion of sampled population of ship-owners and operators on the comparative importance of the identified economic sub-criteria and the scalability factors was obtained. Questionnaire was used as the survey instrument, augmented with interview. The primary data generated from the survey was analyzed using the Analytical Hierarchical Process (AHP) tool, implemented by the use of an open AHP excel solver to determine the relative importance of the economic sub-criteria of alternative energy options for marine transportation in Nigeria. The Analysis of variance (ANOVA) method was also used to compare the scalability scores of the alternative energy options. It was found that; LNG alternative energy option has maintenance cost with relative importance score of 0.63 as the most important economic concern and consideration by ship-owners for its full implementation for marine transportation in Nigeria. Electric drive and advanced bio-fuel (HVO) alternative energy options, has capital cost with respective relative importance scores of 0.39 and 0.41 as the most important economic concerns of ship owners and operators rather than energy cost and maintenance cost. Ammonia, hydrogen gas and methanol alternative energy sources, have energy cost with respective relative importance scores of 0.34, 0.41 and 0.79 as the most important economic consideration by ship owners and operators in Nigeria. The result also indicates that based on the three scalability sub-criteria, LNG has a scalability ranking of 1 and highest mean scalability score. As a result, LNG is the alternative energy source with the most scalability potentials and maturity for implementation for marine use in Nigeria. This is seconded by electric drive with a maturity for scalability ranking of 2.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The use of fossil fuels particularly diesel oil and other high sulfur rich hydrocarbon types in Maritime operation and Shipping show significant impacts on the environment with such negative influences such climate change, emission related health challenges, biodiversity and environment degradation, among others. This remains the major reason why regulations have emerged in the global and regional economies to regulate and curtail the negative impacts of emission from diesel (fossil) use in ship internal combustion engines (ICE), particularly sulfur rich fuel types responsible for greenhouse gas (GHG), sulphur oxides (SO_x), nitrogen oxides (NO_x) and carbon dioxide (CO₂) emissions in order to limit the effects of the use of such fuel types. Thus the need for the development and use of alternate fuel types that could significantly limit emissions and impacts, and the associated environmental risk of spills of heavy fuel oil (HFO) and other marine oils.

The International Maritime Organization (IMO) imposed limits for sulfur oxides and carbon oxide related emissions in the global shipping industry. This has motivated ship owners to search for alternative energy sources in order to comply with the new limits while also maintaining operational competitiveness. Hansson, Mansson, Selma and Maria (2019) observes that the global annual total liquid fuel supply stands at about 4,000 Megatons (MT) per year and marine liquid fuels make about 300-400 (MT) proportion of this per year. Cargo ships use almost 90% of global marine fuels demand while tugs, fishing vessels, passenger boats, navy ships, and other ship types consume the balance 10%. Majority of ships in the global fleet today use diesel engines (ICE) employing marine diesel fuels of various grades with high levels of sulfur content,

as main propulsive energy sources. The harmful health effects of gas emissions from use of diesel fuels and associated environmental hazards necessitated domestic and international regulatory efforts aimed at reducing the impacts with most of the regulations holding the ships and ship owners responsible for any acts of violations. The implementation of the emission regulations over the years is seen to also put the ship owners into serious economic costs that hamper competitiveness at the end of the day.

1.2 Problem statement

Nigeria as a maritime nation and a member of the IMO has adopted for implementation many of the international regulations for ship-based pollution control particularly the international regulations for the prevention of pollution from ships as amended. The recent sulfur cap regulation which entered into force in 2019 providing regulations for the prevention of sulfur and nitrogen oxides gases etc. and the GHG emission regulations, more than ever before spurs the resolve of the ship owners, the global shipping industry, domestic shipping industry and ship operators to adopt, develop and use alternative energy sources for maritime operations and transportation. This is because it imposed very higher cost of treating the marine diesel fuel which is the dominant energy type currently in use in ship ICEs but rich in sulfur content before use while also exposing operators to risks of policing, fines, taxes occasioned by the implementation of numerous international and domestic environmental regulations. When compared with the freight rates prevailing in the shipping markets, the ship-owners and operators facing the risks of unprofitability so that the future competitiveness of shipping companies and ship operators will be influenced by the energy type in use for maritime operations and transport. The global maritime industry having already established the applicability of major alternative energy types such as LNG, Hydrogen gas, Methanol, LPG, Ammonia, advanced Biodiesel

(hydrogenated vegetable oil), and battery-electric energy in the marine industry as well their economics and environmental performances and global scalability, provides diversified options of alternative energy sources for various kinds of maritime operations and transportation. Thus depending on types of operations, ship-operated and ship-owner endowments, coastal states and/or regional endowments, adoption and investment decision for the development and use of alternative energy options may be made by comparing the performance parameters.

At present coastal states and regional capacities readiness to implement alternative energy usage in ships operating in their various maritime domains varies. For example, about 70% of coastal vessels and inland water ferries operating in Norway use LNG energy. In Nigeria however, there seem to exist no road map for establishing which alternative energy option is best for ships, ship owners and operators in the coastal and overall maritime domain of Nigeria. There is the seeming lack of empirical evidence on level of adoption and use of other energy types other than diesel fuel and almost total lack of vessels operating on alternative energy sources as basis for performance information for scaling-up use of alternative energy sources for maritime operations and transportation in Nigeria. Consequently, basic empirical information on Main current usages, availability and infrastructure on land, local production capacity and location which affects scalability of the above identified alternative energy technologies and use are lacking. As a result it is impossible make comparison between performances of the various energy sources for purposes of choice among the options and subsequently scaling-up the uses. Furthermore empirical information on accessibility to maintenance facility cum cost and capital acquisition cost which are known to influence the economics of alternative energy choice by ship operators in most coastal states is equally lacking as basis for comparing the maintenance of capital cost of

alternative energy sources in the Nigerian maritime industry. The study is thus cast to address the problems identified above.

1.3 Aim and Objectives of the study

The aim of the study is to assess the relative preference and hierarchy of choice and use of alternative energy sources for marine transportation in Nigeria based on scalability and economic parameters of the identified alternative energy types. The approach is to evaluate which of alternative energy type performs better in comparison to other energy options available for marine applications from the perspectives of economic and scalability parameters.

The specific objectives of the study are:

- (i) To assess the relative importance of energy cost, capital cost and ease of access to maintenance and cost, as economic sub-criteria influencing the preference and choice of alternative energy options for marine transportation in Nigeria.
- (ii) To rank the economic sub-criteria in the choice of alternative energy options for marine transportation in order of relative importance.
- (iii) To compare the scalability potentials of alternative energy sources based on the level of main current usages in Nigeria.
- (iv) To compare the maturity for scalability of marine alternative energy options in Nigeria based on the global production capacity.
- (v) To compare the maturity for scalability of alternative energy types for marine transportation based on availability and bunkering infrastructure on land.

- (vi) To develop a hierarchy of alternative energy sources for marine transportation in Nigeria based on scalability and economic parameters aforementioned.

1.4 Research Questions

- (i) What is the relative importance of energy cost, capital cost and ease of access to maintenance and cost, as economic sub-criteria influencing the preference and choice of alternative energy options for marine transportation in Nigeria?
- (ii) How can the economic sub-criteria in the choice of alternative energy options for marine transportation be ranked in order of relative importance?
- (iii) Is there a significant variation in the scalability potentials of alternative energy options for marine transportation in Nigeria, based on the level of main current usages?
- (iv) What is the difference in the level of maturity for scalability of marine alternative energy options in Nigeria based on the global production capacity?
- (v) Is there a significant difference in the maturity for scalability of alternative energy types for marine transportation based on level of availability and bunkering infrastructure on land?
- (vi) How can a hierarchy of alternative energy sources for marine use in Nigeria be developed based on the scalability and economic performances?

1.5 Hypotheses

- (i) The relative importance of energy cost, capital cost and ease of access to maintenance and cost, as economic sub-criteria influencing the preference and choice of alternative energy options for marine transportation in Nigeria is undefined.

- (ii) The order of ranks of the relative importance of economic sub-criteria in the choice of alternative energy options for marine transportation is undefined.
- (iii) There is no significant variation in the scalability potentials of alternative energy options for marine transportation in Nigeria, based on the level of main current usages.
- (iv) There is no significant difference in the level of maturity for scalability of marine alternative energy options in Nigeria based on the global production capacity.
- (v) There is no significant difference in the maturity for scalability of alternative energy types for marine transportation based on level of availability and bunkering infrastructure on land.
- (vi) The hierarchy of alternative energy sources for marine use in Nigeria be developed based on the scalability and economic performances is undefined.

1.6 Justification of the Study

There is presently a global concerted effort aimed at addressing the scourge of global warming and climate change, health risks and environmental hazards occasioned by the use of sulfur rich fossil fuels for propulsion and in industrial plants. Researches in alternatives energies sources aimed at developing more environmentally friendly energy options for marine navigation has gained traction over the years in the bid to limits emissions from ships and shipping operations. This study is an attempt to establish alternative energy options for use in marine transportation in Nigeria other than diesel, in order to limits the emissions from diesel powered ships which constitute the bulk of propulsive fuels for most ship operating in Nigeria.

The study is therefore justified by the fact that it will help in restoring the environment by limiting ship-based emissions and spills through the use of alternative energy sources for marine

transportation. It will be useful to the ship owners and operators as it will offers empirical evidences that will enable them to make economically justified investment in better alternative energy sources thereby eliminating the challenges policing, fuel taxes, fines, Sulfur and nitrogen oxides emissions imposed by environmental domestic and international environmental regulations while ensuring competitive and sustainable shipping operations. It will be useful to the shipyards, maritime equipment producers, and the local maritime industry for purposes of investment decisions for scaling-up the production and use of better alternative energy technologies for marine transportation.

The information from this research will be useful to the scholars who want to delve into researches in the area of alternatives energy sources for shipping and maritime operations as well as libraries. The study will also serve as basis for further research in this area.

1.7 Scope of the Study

It is important to state that among the four categories of parameters of applicability, economics, environmental performance and scalability which influences that development and transition to alternative energy types; Scalability and economic parameters were the major focus and scope of the research as the applicability and environmental performance of each of the identified alternative energy types have already be established at the global maritime industry level and they are not much influenced by factors particular and peculiar to coastal states and regional economies. However, scalability parameters and capital cost and maintenance cost/access economic parameters are known to be influenced by the peculiarities in coastal states and regional economies, thus the need to evaluate such parameters as it affects individual coastal states. This is the major motivation for the choice of scope as explained above.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Review

The concept of energy for marine transportation simply entails the motive power and the source of the propulsive force that propels the ship into movement whether generated in internal or external combustion engines. Since there exist various sources of energy for ship propulsion, all the available energy sources and types used for ship propulsion, form alternatives (ABS, 2019; DNV, 2018).

Some combination of energy types may equally occur while options exist for conversion of one energy type into another. Following the commercial, economic and competitiveness challenges facing the ship owners and operators in the maritime industry as a result of the emission regulations established by the IMO which rendered the use of diesel fossil fuel energy types cost prohibitive; the attention of the maritime industry is currently cast on other less emission prone alternative energy types for in marine transportation. In this section therefore, we will center our discussion on the basic concept of alternative energy types available for marine transportation and the other allied concept that influence choice of energy types for ship usage from the perspectives of the Nigeria maritime industry.

2.1.1 Concept of Alternative Energy Sources in Marine Transportation

Diesel fuel energy type over the years remained the dominant energy option for marine transportation in the global maritime industry. In recent times however, the use of diesel fossil fuel type in ship propulsion led to serious problems of climate change, health and the environment, hazards associated with CO_x and SO_x emissions as exhaust products of diesel combustion.

The use of diesel as main propulsive energy source in ships is marked every high energy performance index. It is also associated with low cost, high availability, commercial competitiveness, etc.. However, the environmental impacts and woes of its usage informed the serious search for alternative energy sources (Shaaban et al 2010; Thollander et al, 2007). This has led to the development of various renewable and non-renewable energy options for use in the maritime sector, thus the concept alternative energy types for maritime transportation’.

The concept of alternative energy types for maritime transportation therefore entails the development, adoption and use of other propulsive energy types and sources than diesel energy for purposes of ship propulsion. Since the main reason for the gradual phasing out of the use of diesel fossil fuel type is the associated pollution, emission and environmental change effects, such alternative energy type that must replace diesel fuel option must have capacities to overcome and/or perform better than diesel environmental. There exist many alternative energy options in the maritime industry. DNV (2018) provides prove that LNG, Hydrogen, Ammonia, Methanol, LPG, Advanced biodiesel, HVO, Electricity (in batteries) cum photovoltaic energy (solar/electrical energy in batteries) formed alternatives energy sources whose usage in maritime transportation is confirmed.

DNV (2018) argues that apart from diesel energy type, LNG remain the best performer; having well over 300 ships globally operated with LNG. The implication of this is that all the energy sources identified above including marine diesel form alternatives for marine transportation. As a result, the propulsive performances of the variously identified energy options, their availability, cost, scalability, environmental performances, cum capacity of the ship-owners to adopt and diffuse its usage is therefore the basis for choice of use among them.

Our concept of alternative energy sources for marine transportation encompasses all the above identified energy types for use in ship propulsion upon which we will set out to compare the performance and features of selected energy option for purposes of implementation and use in the Nigeria maritime sector. The multiplicity of alternative energy options requires the use of different ship propulsion systems and energy converters since differing energy types will follow differing energy pathways in delivering propulsive force to the engine. This has equally led to the development of alternative ship propulsion systems and dual or multi-fuel engines.

In summary, the study on alternative energy sources for marine transportation entails the analysis of the various identified energy types and performance-based comparison of the energy types for purposes of choice for use in marine transportation following the transmission from use of diesel energy to more environmentally friendly energy options.

2.1.2 Brief Description of Available Alternative Energy Sources for Marine Transportation

(i) LNG

LNG is a fossil energy type composed of methane (CH₄), being the fossil fuel with the lowest carbon content, LNG has natural endowment to reduce drastically CO₂ emissions. It is important however to note that methane has potential for greenhouse gas. This necessitates proactive drive to keep under control GHG emission when LNG is in put into marine usage.

Low- and high-pressure 2-stroke engines cum low-pressure 4-stroke engines are major engine technology types that employ LNG energy types (Ahmed et al 2014). These technologies are readily available today for marine use.

(ii) Hydrogen as Alternative Source of Energy for Marine Transport

ABS, (2018) notes that Hydrogen as a source of energy for marine transport offers the advantage of having the potential for zero emission particularly when produced from renewable sources. Hydrogen is produced from renewable sources on land. It however poses a very high

cost of production as a result of which bunkering infrastructure is not available in plentiful supply (DNV, 2018; ABS, 2018).

Currently, the main parent source of hydrogen produced for marine use today is natural gas and this trend of production from natural gas is believed to continue until transition to renewable energy sources is fully actualized (ABS, 2018). In addition to high cost of production, hydrogen is only currently applied in short sea shipping over short distances as a result of applicability challenges associated with its use for marine transport.

Safety and flammability concerns are also paramount with the use of hydrogen. There is no doubt however, that the applicability of hydrogen as alternative fuel for marine transportation in ship has been established over the years in the global maritime industry.

(iii) Ammonia as Alternative Source of Energy For Marine Use

The application of ammonia as a source of alternative energy for ship production has also been established. Currently, ammonia for ship production is produced from fossil energy sources though potentials exist for ammonia production from renewable energy sources in which case it will be a carbon free source of energy though with capacity for GHG emission. Ammonia has high density and has proved capable of being used deep sea offshore operations. The lack of bunkering infrastructure however has led to very high cost and a barrier to full adoption and use of ammonia competitive alternative energy source for marine operations. Since ammonia is toxic, safety is therefore a concern with its use and considerations must be made mitigate the safety risks posed by its use for marine transportation (Zhou et al 2010).

(iv) Methanol

Methanol as an alternative fuel for marine use is produced from both fossil fuel sources and renewable sources. When produced from fossil fuel sources, the environmental performance is

low due to emissions; but from renewable sources, it performs better environmentally. It has the advantage of being employed in existing energy conversion technologies and as a result imposes low capital acquisition cost. Lack of bunkering facilities currently affects its adoption rate for marine transportation.

(v) LPG

LPG is an alternative energy source for marine transport produced from fossil fuel (natural gas) sources similar to LNG. Similar to LNG, the energy cost is low and the capital cost associated with the use of LPG is also low. It however has a medium maturity level with poor environmental performance. The lack of infrastructure for bunkering of LPG limits its adoption for use in marine transportation.

(vi) HVO

HVO is a biodiesel fuel produced from treatment of diesel with hydrogen-treated vegetable oil and referred to usually as a drop-in fuel as a result of its direct substitution for diesel of other petroleum based fuel types. It is expensive following the lack of bunkering infrastructure which has limited production capacity. Scalability is therefore a concern with HVO.

(vii) Fully Electric (Batteries)

Electricity as alternative sources of energy for marine transportation is produced in electric batteries and cells for storage of electric renewable electric charges/energy. Electric energy sources offers the advantage of zero emission as a result of it performs creditably well from the perspective of environmental friendliness. It has low energy density and as such is not widely applied in all marine operations and systems. It can serve for short inland water operations of short distance shipping. Electrical Multiple fuel pathways also exist that use converters and fuel

cells to convert the chemical energy content of the fuel types into electrical energy via electrochemical reactions similar to energy conversion processes in battery cells

2.1.2 Concept of Energy Pathways

An energy pathway is the term used to describe the processes and channels of decomposing various alternative energy sources and types into energy carriers and its subsequent transmission for the propulsion of the ship.

ABS, (2018) notes that though the use of aforementioned alternative energy options can ensure reduced emissions of pollutants; factors such as availability, applicability, physical and chemical characteristics, safety, scalability, cost, etc inhibit their commercial use currently when compared with diesel fossil fuel types. The decision to use a particular alternative energy types for marine transport will thus depend on the ability of that the alternative energy type to satisfy adequately the needs of the industry based on the identified factors. The decision to employ other energy types other diesel must also be complemented with the provision onboard ship of primary sources (feedstock), energy carriers (fuels), propulsion systems and/or energy converters as the decomposition of the fuel energy option of choice into energy needed for propulsion most times follow energy conversion pathways. It is important to note the energy conversion pathway of each alternative energy type influences propulsion technology and equipment type as well as cost of adoption and use (ABS, 2018). See figure 2.1 below for energy conversion pathways from various energy sources to mechanical energy for marine transportation.

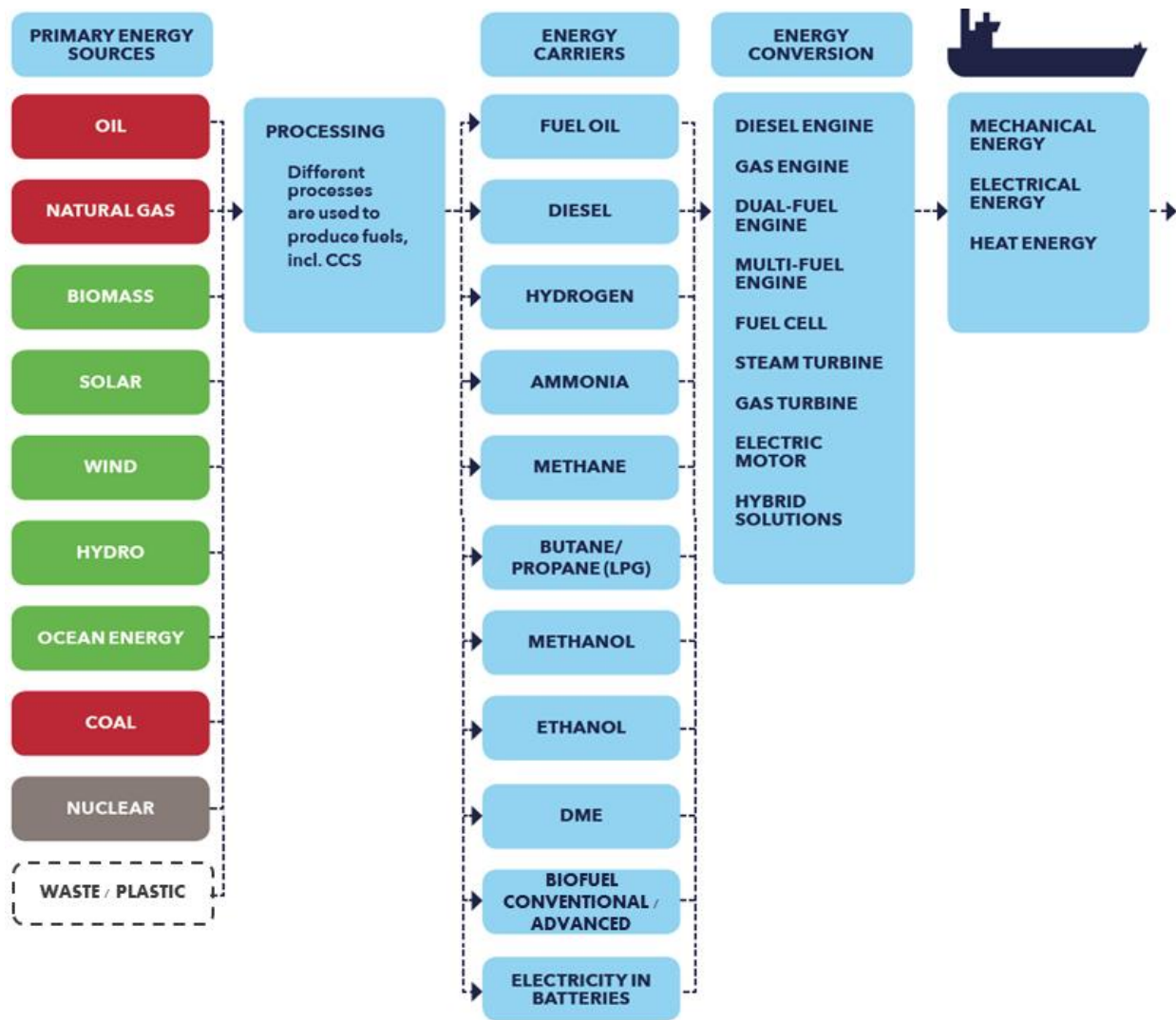


Figure 2.1: Energy Conversion Pathways
 Source: Adapted from DNV (2018).

2.1.3 Concept of Economic Factors that Influence Alternative Energy Choice for Marine Transport

These include financial elements and considerations which influences the cost of implementing the use of alternative energy options for marine transportation purposes. Since the cost/economic implications of the implementation of each alternative energy option will influence the commercial and operational competitiveness of the given company; economic feasibility is thus a major feature for consideration in the adoption, development and use of alternative energy types.

Gross and Kong (2013) and DNV (2018) identified three economic parameters influencing the economy of the ship owners in consideration of alternative energy use to include:

(i) Energy costs

This has to do with the cost of energy acquisition for operating the ship usually expressed as USD/MWh (Dollars per megawatts fired hour per day) shaft output. Comparison of cost for different ship types is possible since energy consumption rates and power output vary for different ship and carrier types.

(ii) Capital costs

Capital costs include the additional cost of converter for various alternative fuel types and energy pathways, energy storage system and process system. This is necessary since the each alternative energy types require a specific related engine technology type and convert systems as well as storage systems to be operated in ships. The acquisition of these puts a capital cost of the ship-owners.

(iii) Ease of access to Maintenance and Cost

Since each alternative energy type is applied in operating specific engine and ship propulsion technology types, the availability and ease of accessing maintenance for each energy pathway technology types and the cost of maintenance associated with each technology type form an economic decision variable affects the adoption and use of alternative energy types and which the Nigeria shipping industry and ship owners must address in the transition to more environmental friendly energy options.

2.1.4 Concept of Scalability of Alternative Energy Options

Scalability as a concept is the measure of the possibility and/or level of use and maturity of various alternative energy technology types as basis scaling-up and/or implementing the massive use of use of the technology and energy type. Therefore an alternative energy type for marine

transport purposes must have the features of being scaled-up and produced for mass usage. This will promote accessibility to the energy type and the technology option it offers. As aforementioned, the various alternative energy types and pathways offer differing possibilities of scalability (maturing and scale-up), influenced by factors such as: current usage, availability and infrastructure on land, global production location etc. Thus we view scalability of alternative energy types as depending on the identified factors discussed below and scalability assessment can be carried out from the perspectives of those identified factors.

(i) Main current usages

This measures the existing/present level of application and use of specific alternative energy types for ship operations in the global maritime industry and/or a given regional economy or coastal state such as Nigeria. The scale of current usage is an indication of level of adoption and acceptance and influences rate of further scaling-up for mass usage in a given economy. A technology option that is totally absent and lacking in an economic is indicative of the non-maturity of its use within the economy and may further indicate the absolute lack of supportive infrastructure to drive the use and scaling-up of the concerned alternative energy type.

(ii) Availability and infrastructure on land

Availability measures the sufficiency in supply for uptake by ships of alternative energy types in the energy market. The unavailability and/or limited supply of specific energy types for uptake by ships will hamper operations of the industry and affect productivity. Furthermore, availability entails also the presence of supportive infrastructure for each alternative energy type as the lack of such infrastructure may hamper access to energy and scalability.

(iii) Global production capacity and locations

This measure is the determination of production locations and capacity of alternative fuel types and the analysis of the energy supply chain. Local production in adequate capacity offers a regional or costal state competitive advantage in the energy market. However, the alternative energy industry is known to span the entire globe, with production in Asia, North and South America, Europe, Africa and the Middle East. For battery-electrical systems, investment is required in major seaports such that ships are charged at ports as need arises.

2.2 Theoretical Framework

In this section, the theoretical support for the adoption and use of alternative energy sources for marine transportation were examined. Some of the major theories examined include: expectancy theory, prospect theory, system approach theory, diffusion of innovation theory and behavioral change models. These were aimed at providing logical explanations to support evidences of the transition from diesel energy sources to more environmentally friendly alternative energy sources in marine transportation.

2.2.1 Diffusion of Innovation Theory (DOIT)

The social science theory of Diffusion of Innovation (DOI) was developed in 1962 by E.M. Rogers. It was aimed at explaining how over time, new products, ideas and technological innovation gain wide acceptance, spread and diffuses through a sample population of interest, e.g., Nigeria. The diffusion leads to the adoption of the new innovation within the system, industry and/or nation. Thus the innovation, new technology or products becomes the greater choice for use among the population than the old product. The key to adoption is that the person must perceive the idea, behavior, or product as new or innovative. It is through this that diffusion

is possible. The diffusion of innovation theory is of the view that adoption of novel ideas, products and/or technology in a social system follows a process and does not occur simultaneously among all members of a target population.

Thus different types of adopters group have been identified with each group having similar characteristic traits that influences how quick they are about adoption and use of new technology and products. These include:

1. **Innovators** – Innovators form first group of people in a target population to try the use of a new product and or technology and share the characteristics of willingness to take risks.
2. **Early Adopters** – The second group of people who represent the second stage of adoption and diffusion of new products and technologies is the early adopters. Early adopters share the characteristics of having leadership traits and enjoying leadership roles enabling them to always embrace opportunities for change.
3. **Early Majority** – Early majority group live above average in the adoption of new ideas technologies and products. At this stage, evidence of the successful performance of the new technology and/or product is the major motivational and convincing factor that influences the decision of the early majority to embrace novel products and technologies.
4. **Late Majority** – These portions of the target population are known with having traits to position them to be skeptical about adoption of new technology. Thus, they try the implementation of the new technology after it has been successfully applied by the majority with the target population.
5. **Laggards** - These last group of people in the hierarchy of diffusion of innovation are conservatives and may not adopt the innovation except public pressure (e.g. government

policy), fear (fear of loss of income, fear of nonperformance in a competitive market setting, loss of customers, etc), statistics of successful application by other members of the population is used to induce them to adopt the innovation. See figure2 below for a pictograph presentation of the diffusion of innovation in a social group.

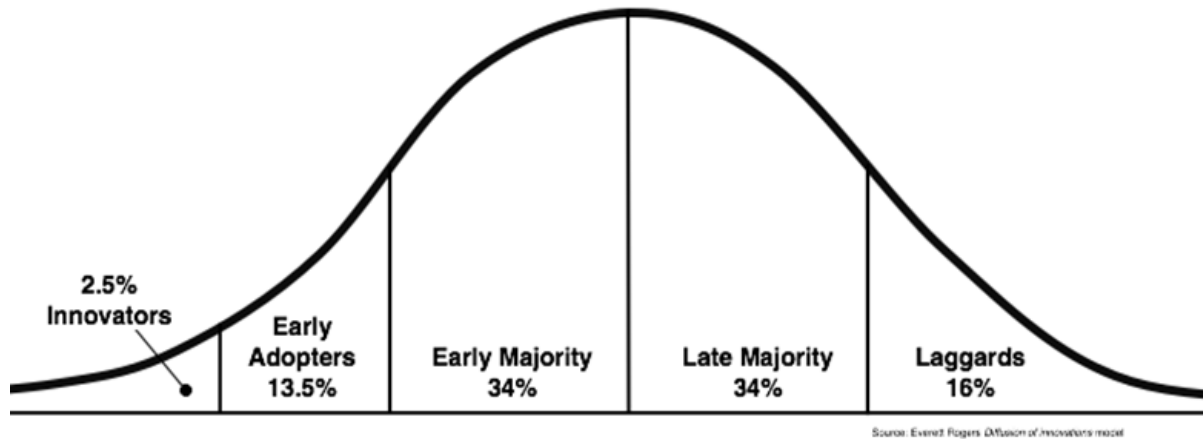


Figure2.2: DOI process by social groups

Source: Adapted from: <http://blog.leanmonitor.com/early-adopters-allies-launching-product>

The DOI theory notes that in view of the classification of adopter of innovation, the adoption of an innovation by an individual of industry follows various stages which include:

- (i) Be aware of the need for an innovation (awareness of a change and/or innovation.
- (ii) Decision to either reject or adopt the innovation.
- (iii) Trial use of the new product and/or trail application of the change (test-running the innovation)
- (iv) The continued use of the innovation. The continued use of the innovation guarantees its diffusion among the social group.

The DOI theory can be used to explain and accelerate the adoption of use of alternation energy sources for marine transportation following the energy transition from the use of heavy fossil fuel energy options in ships. The regulatory intervention of the IMO promoting the use of more

environmentally friendly fuel types other than heavy diesel oil has already led to the development of many alternative energy options for the shipping industry as already itemized. The adoption, use and diffusion of these alternative energy options among ship owners in the Nigeria maritime industry will surely be influenced by the availability and accessibility to each cum satisfactory and successful performance of each fuel source type. This cannot be automatic and as a result, will follow the processes identified in and explained in the theory of DOI. Change follows a process; therefore the change to use of energy options other than heavy diesel oil in the Nigerian maritime transport sector can be viewed and implemented from the options offered in the DOI.

2.2.2 Public Interest Theory of Regulation (PITR)

The opinion expressed by the PITR is that rules and regulations are offshoots and products of the need to protect the public from harmful impacts (Newbery, 2000). Such harmful impacts as it concerns the use of energy include pollution effects, green-house effects/global warming, injuries and health hazards associated with use of high emission fossil fuel types, etc. In the view of the PITR, without public regulation, firms and organization have no way to provide enough incentive to account for the costs of externalities they subject the public to bear for the use of environmentally harmful energy types. Thus according to the public interest theory of regulation, government is a benevolent welfare maximizer that balances the costs and benefits associated with regulations (Lyon and Haitao 2010; Crew 1999; Gilbert and Kahn 1996; Balanchandra, 2012).

It is important to note that the regulation of the use of heavy fossil fuel sources of energy for marine transportation by the IMO in favour of alternative energy sources are to maximize environmental benefits from the use of alternative energy sources. This is quite in line with the

provisions of the PITER. Following from there, the choice of alternative energy type from among the more environmentally friendly energy options, its adoption, use and diffusion will also be influenced by the level of beneficial performance other than environmental performance offered by the choice energy option over and above other available alternatives (Mullins, 2016; Haris, 2007). Thus, the choice of alternative energy sources for marine transportation and the transition from heavy diesel oil can be explained from the perspectives of the public interest theory of regulation.

2.2.3 Expectancy Theory

This another behavioral theory based on human motivation. According to Mullins (2016) the expectancy theory was developed by Victor Vroom in 1964 as a theory of motivation that determines how individual needs, wants, desires, and/or expectancy drive individuals to seek opportunities for better performance and to perform better. In the views of Mullins (2016), the view expressed by Victor Vroom in the expectancy theory is that individuals are influenced to act in response to intrinsic motivation that their expectation will be met by their actions.

The expectations in this case represent the target outcomes of behavior and/or action. If individual choice of behavior is premised on the expectation of most favorable outcome as expressed by the expectancy theory, it therefore follows the behavior of a group of individual at the industry level with regards to choice of technology and /or energy type will undoubtedly be premised on the most favorable performance outcome (environmental, cost, accessibility, availability, scalability, etc) that the technology and/or energy type will offer. The rational qualities of individuals enables them to tend to choose between alternative action plans based on perceived satisfactory outcomes derivable (Borkowski, 2011; Neivid et al, 2012).

The implication is that comparison of cost and benefits of alternative choices remain the basis for individual's motivation to adopt preferred action plans and behaviors. In the case of choice between alternative sources in the energy transition process, the comparison of economic cost and benefits, scalability potentials, environmental performance, applicability, etc offered by alternate energy sources, remain the dominant motivations for the choice among alternative energy sources for use in marine transportation. The energy options that maximize desired performance metrics will be ranked higher and better and preferred for adoption and use over energy options that maximize pain and/or minimize desired performance metrics.

2.2.4 Prospect Theory (PT)

PT is also a behavioral theory. Lewis (2008) notes that it was first proposed by Daniel Kahneman and Amos Tversky in 1992 as the way of choice between probable alternatives that involves uncertainty with known outcomes. Harris (2007) notes that following prospect theory, decisions are based on the probable value of losses and gains rather than on the final outcome; and that these losses and gains on which decisions are based are assessed using some heuristics. Nevid et al (2012) describes heuristics as mental shortcuts used to focus on one aspect of a problem while ignoring the remaining parts of the problem. While Lewis (2008) and Harris (2007) agree that the use of heuristic rules work in some situations; they argue that it cannot sufficiently replace rational choice, probability models, logic and empirical decision models for decision making.

Heuristics can only serve best for intuitive judgments there is inadequacy of information on the subject matter. Thus the prospect theory suggests that the potential benefits from policies and programmes should be the basis for choice decisions in favor of such policies and that where limited information is available for purposes of decision, heuristics offers alternative as basis for

decision. In the case of choice between alternative energy sources for marine transportation, the lack and/or inadequacy of data on the performance prospects with regards to the earlier identified factors (economic, scalability, applicability, environmental) of the various alternative energy types inhibits the adoption of empirical models for decision purposes. Yet, the performance prospects can be envisaged and determined by the use of heuristics so that comparison can be made between the energy types to enable the adoption, use and diffusion of the preferred energy option in the Nigeria marine transportation sector (Heutel, 2017; Augsburg, 2009).

From the theoretical reviews, it is obvious that a host of factors can influence and be used to explain the choice of alternative energy types in the marine transportation and shipping sector. The theories thus offer varying perspectives that can explain and be considered in implementing the transition to more environmentally friendly energy sources in the shipping and marine transport sector in Nigeria.

2.3 Empirical Review

In this section, we discussed elaborately on available literature in alternative energy resources for marine transportation with a view to identify the major literature gaps which the study aimed to providing empirical information on, to bridge the knowledge gap. The empirical review is also organized in sub-heading for clarity of information and ease of understanding. The empirical review centered majorly of the criteria for choice of alternative energy sources for marine use and the major influencing factors of applicability, environmental performance, economic and scalability which reflects the objectives of the study.

2.3.1 Empirical Review of Energy Efficiency Barriers and Policies in the Maritime and the Influence of Energy Efficiency in Choice of Alternative Source of Energy in Shipping

The European Energy Agency (EEA, 2017) views energy efficiency as the generation of more energy output from the use of less quantity of energy and a corresponding less emission of CO₂ and greenhouse gases. i.e., when there is limited emission and energy output is more than energy input ($E_o > E_i$); where E_o and E_i respectively stand for energy output and energy input. By implication, an energy source that delivers higher output of power with a smaller input of fuel will offer a better alternative energy source than those that deliver less power than input fuel; that ensures that emissions from ship operations is minimized. This is because, energy efficient fuels perform better in terms of propulsive efficiency by delivery greater propulsive energy to the engines for conversion into mechanical energy while at the same time offering less costly option of acquisition of the input fuel and good performance from environmental perspectives. While an operator may employ higher quantity of non-energy efficient fuel in order to achieve a given energy output target; less quantity of energy efficient fuel sources may achieve the same target energy output at minimized externalities cost (pollution cost).

Energy efficiency viewed from the perspective of having less emission and pollution from the use of a higher quantity of energy/fuel was the central motivation for the development of series of emission regulations by the IMO and the recourse to alternate energy sources for marine transportation. In which case, we opine that the efficient energy sources should be environmentally efficient. Shaaban and Petianin (2010), note that there exists single strategy for achieving energy efficiency for various countries. The study emphasized the importance of setting ambitious goals as energy efficiency targets by individual Countries; devising and

implementation of national strategies cum institutional frameworks and policies to actualize the energy efficiency targets (EEA, 2017).

According to Chai & Yeo (2012) implementing energy efficiency policies and regulations may require a decision on which alternative energy source(s) offers the best option so that economic incentives, voluntary agreements, monitoring and evaluation of performance, information instruments support by data on successful use, capacity building may be adopted and used as action plan jointly with regulations, to actualized the target energy efficiency need. Many factors are known to be driving the energy efficiency needs of the maritime industry. These same factors are responsible drivers of the need for the development of alternative energy sources for marine transportation since each alternative energy types and/or sources offer efficiency levels different from all the other competitor sources.

Thollander et al (2007) notes that National vulnerability to energy supply, increasing energy prices and the associated cost, environmental pollution associated with energy use, regulatory and economic factors remain the major drivers of energy efficiency in the global maritime industry. Most importantly, the IMO emission regulations in recent times is known to be the fore-front driver of energy efficiency thus catalyzing the current drive for and search for more energy efficient alternative sources of energy for marine transportation in the shipping industry (IMO, 2015).

2.3.1.1 Energy Efficiency Measures (EEM)

To ensure the alternative fuel sources for marine transport are environmentally efficient; maritime stakeholders including national coastal administrations, the IMO, Regional blocks, etc developed measures aimed at curtailing emissions and pollutants from ships. The IMO for example developed regulatory measures such as the Energy Efficiency Design Index (EEDI),

Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Operational Index (EEOI), with the aim of adopting the regulations as avenues to aid in the fight against global warming and climate change; since the shipping industry is believed to contribute significantly to the gaseous emissions responsible for these environmental woes. While the EEDI is mandatory for new ships except for ships such as Ro-Ro car carriers and passenger vessels with hybrid propulsion systems and electric drives cum turbines, the SEEMP is compulsory for all existing vessels with special emphasis on bulkers.

These regulations took effect from 2013 and by 2025, all maritime jurisdictions and vessels are proposed to be compliant with all emission regulations including the GHG control measures (IMO, 2015). The EEOI is a voluntary regulatory measure aimed at helping ship operators to achieve the objective of reducing emission and improving energy efficiency for which the EEDI and SEEMP were developed (IMO 2015).

The EEDI is essentially a measure of efficiency of ships in transportation; such that maximum is cargo carried with minimal fuel consumption. Hence minimal CO₂ emissions will give a vessel a good index. CO₂ reduction level measured in grams of CO₂ per ton mile traveled was first set at 10% from which it must be reduced to lower limits every five years in line with technological advancement (IMO, 2015). SEEMP was established as an operational measure for existing ships as a mechanism that enables improvement of energy efficiency of existing ships cost effectively. The EEOI is the tool/technology employed by shipping companies and ship operators in the implementation of the SEEMP to promote energy efficiency in shipping fleet operations (IMO, 2015).

2.3.1.2 Energy efficiency Gap and Barriers.

Energy efficiency gaps represent deviation from energy efficiency set points and targets and are indications that a given alternative energy source lack capacity to meet energy efficiency target levels. When that happens, the operator is left with the option of finding alternative energy sources that can bridge the energy efficiency gap created by a poor performance energy type. Sorrel (2000) observed that energy efficiency gaps are created by barriers to energy efficiency while barriers to energy efficiency are factors that block and hinder actual commitment to implementation of investment in cost-effective energy technology and measures that are all-round energy efficient. Thus, following the presence and prevalence of barriers, energy efficiency gap exists (Thollander, et al 2007).

Therefore, to ensure efficiency in the use of alternative energy sources, the appropriate strategy is to seek out and identify barriers to the efficient performance of the preferred energy sources. These barriers may take the form of economic performance barriers, applicability barrier, environmental performance barriers, and scalability barriers, among others. The identification of what constitute the barrier enables the operator to employ appropriate technology options to deal with and/or remove the barriers in order to improve the energy efficiency of the alternative type.

By implication, the alternative energy sources that face less economic, environmental applicability, scalability, etc., barrier effects will emerge as the most energy efficient option for marine transportation (Brown 2001). Studies by Balachandra (2006) and Kounetas et al (2010) identified financial barriers, information and production risks as examples of major barriers to energy efficiency,

2.3.2 Decisions on Alternative Energy Preferences

Tholander et al (2007) carried out an empirical study on the political and economic factors that drive state governments to adopt particular alternative energy (renewable energy) source. According to Thollanda et al (2007), it is a general belief that states with comparative advantage in the production of a given alternative energy source over others, will naturally desire to choose the alternative energy sources that offers her comparative advantage in production as a way of creating jobs and generating employment, earning revenue from energy exports, among other advantages. However, the findings of the study were contrary as local environmental conditions and factors known to influence alternative energy choices, adoption and preferences (Thollanda et al, 2007). This is in agreement with the current trend in the marine transportation sector where the IMO emission regulations have greatly influenced energy preferences in most coastal states.

Zhou et al (2010) notes that with the shipping and maritime sector contributing about 3% of emission that pollute the environment, alternative energy preferences and policies for the shipping industry must aim to address the issues of environmental sustainability and climate change more than profit maximization concerns. This is because while the local community may not benefit directly from the excess profits of the ship operators and owning companies; the harm to the environment occasioned by emissions is an externalities effect which is suffered by all members of the public. Ahmed et al (2014) argued that alternative energy preferences by state actors must guarantee positive change beyond the profit and economic competitiveness motive of the actors, to enhancing public welfare and good. Public welfare in this context encompasses the environment healthiness achieved by limiting pollution (Oates, 2001; Rabe, 2004; Ahmed et al 2014).

From the foregoing, it is obvious that economic factors, possibility of successful usage (applicability) and, environmental factors play major roles in alternative energy preference decisions by states and other stakeholders.

Hanssonab, Manssonc and Selam (2019) used a multi-criteria decision approach to analyze the prospects of marine alternative energy sources for Swedish maritime industry stakeholders. In the first instant, the study identified the need for alternative fuel sources for marine operations arising from the need to reduce environmental and climate impacts of shipping, in the short and long run (Hanssonab, Manssonc and Selam, 2019). Seven alternative fuel sources which include:

- (i) LNG
- (ii) Liquefied biogas (LBG)
- (iii) Methanol from natural gas
- (iv) Renewable methanol
- (v) Hydrogen for fuel cell, from natural gas or electrolysis based on renewable electricity, and;
- (vi) HVO.

The performance of the identified alternative marine fuel sources were compared against that of the HVO, diesel, as benchmark based on ten performance criteria which include Economic, Environmental, Technical and social criteria among others. The analytic hierarchy process was used to analyze panel data collected from a section of maritime industry stakeholders in Sweden. The study established that ship owners, engine manufacturers and fuel producers place more importance on economic criteria, particularly fuel price. Government authorities however prioritize environmental criteria, particularly GHG emissions. While ship-owners and engine

manufacturers ranked LNG most preferable followed by Heavy fuel oil (HFO), fossil methanol, and LBG HVO; government authorities ranked hydrogen most preferable followed renewable methanol, and HVO (Hanssonab, et al 2019) .

The findings of the study shows an obvious disparity in the preference of alternative energy sources for marine use by the public regulatory agencies in the maritime domain on one hand, and the ship-owners, builders, fuel producers and operators on the other hand. It also provides further evidence that applicability, economic, environmental and scalability and social factors to a greater extent influence alternative energy preferences of stakeholders in the maritime industry.

Studies by the American Bureau of shipping (ABS, 2019) on pathways to sustainable shipping in which the ABS sought to set course to find low carbon alternative fuel sources for marine transportation; established the applicability of LPG, LNG, hydrogen, ammonia, electric drives, HVO, methanol, LBG, as main alternative energy sources verified for marine industry use.

ABS (2019) emphasized the need for further research to develop the potentials of each identified alternative energy type. The study shows diesel (heavy fuel oil) from fossil still holds the greatest performance index in terms of applicability (energy index, technological maturity, flammability and toxicity), economic (energy cost, capital cost, ease of access to maintenance cost), and scalability (main current usages, availability and manufacture on land, global production capacity and locations). It is however lacking in environmental performance in which it is the least preferable.

The above situation has made it difficult for ship-owners and operators to shows perfect willingness to the adopt easily the advocacy for transition from use of heavy fuel oil to more environmentally friendly options, while governments and administrative authorities

champion the drive and transition to alternative fuel sources (ABS, 2019). The policy implication is that the most preferable alternative energy for adoption by Nigeria operators for example must have capacity to balance the need of the ship-operators, ship-owners, engine manufacturers, fuel producers and the public need for zero emission.

Det Norst Veritas (2018) compared alternative marine fuels with a view to providing empirical evidence on the performance of each identified fuel type when compared among them and with heavy diesel fossil fuel. The study used all the alternative energy sources identified in ABS (2019) with the exclusion of diesel. It determined the applicability of each alternative energy type based on energy density; and provided that LNG provide better performance than other energy source options. Asserting that the energy density of a fuel determines its applicability potentials for ship types and ship operations; DNV (2018) found that given its low volumetric and gravimetric densities, battery-electric systems cannot efficiently propel deep-sea operation. It also notes that LNG has around 40 % lower volumetric energy density than diesel, and roughly the same as LPG. For purposes of storage, LNG has about 1/3 the volumetric energy density as diesel. Liquid hydrogen, ammonia and methanol have even lower volumetric energy density – around 40-50 % of LNG. See figure below for a comparison of energy densities of various energy sources for marine transportation.

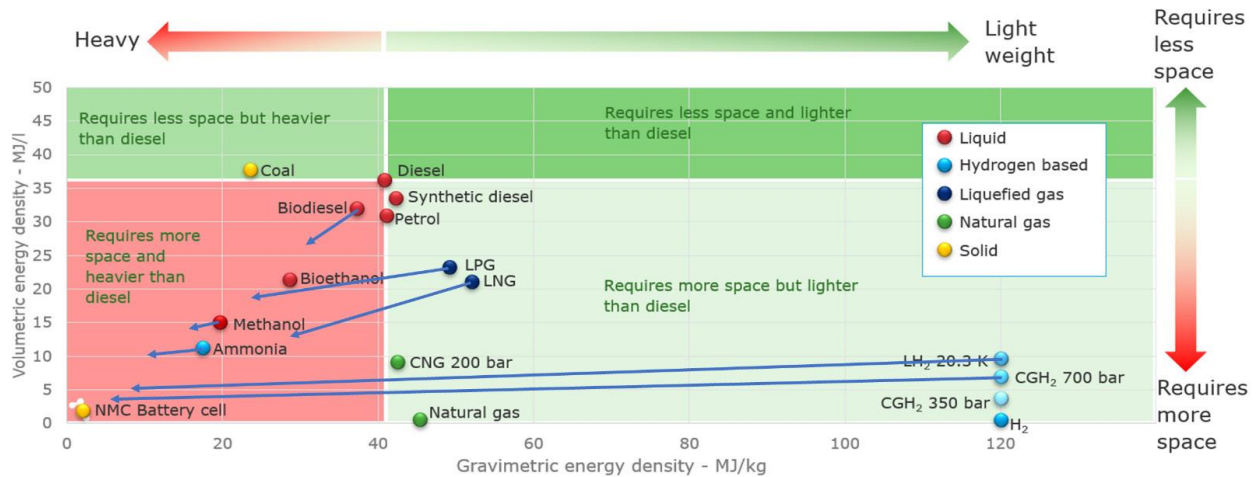


Figure 2.3: Comparing Energy Densities of Alternative marine Fuel Sources
 Source: Adapted from Det Norsk veritas, (2018).

In terms of energy cost, DNV (2018) determined that LNG, methanol and LPG offer more competitive costs than other options while HVO proves to be the most significantly expensive. According to ABS (2019), Hydrogen and ammonia also expensive with are marked with significant price uncertainties. Distribution and supply cost of hydrogen and ammonia hold the potential of increasing the cost of usage, given the nature of the hydrogen and ammonia value chain. See figure below for the comparison of the energy costs of alternative energy sources for marine use.

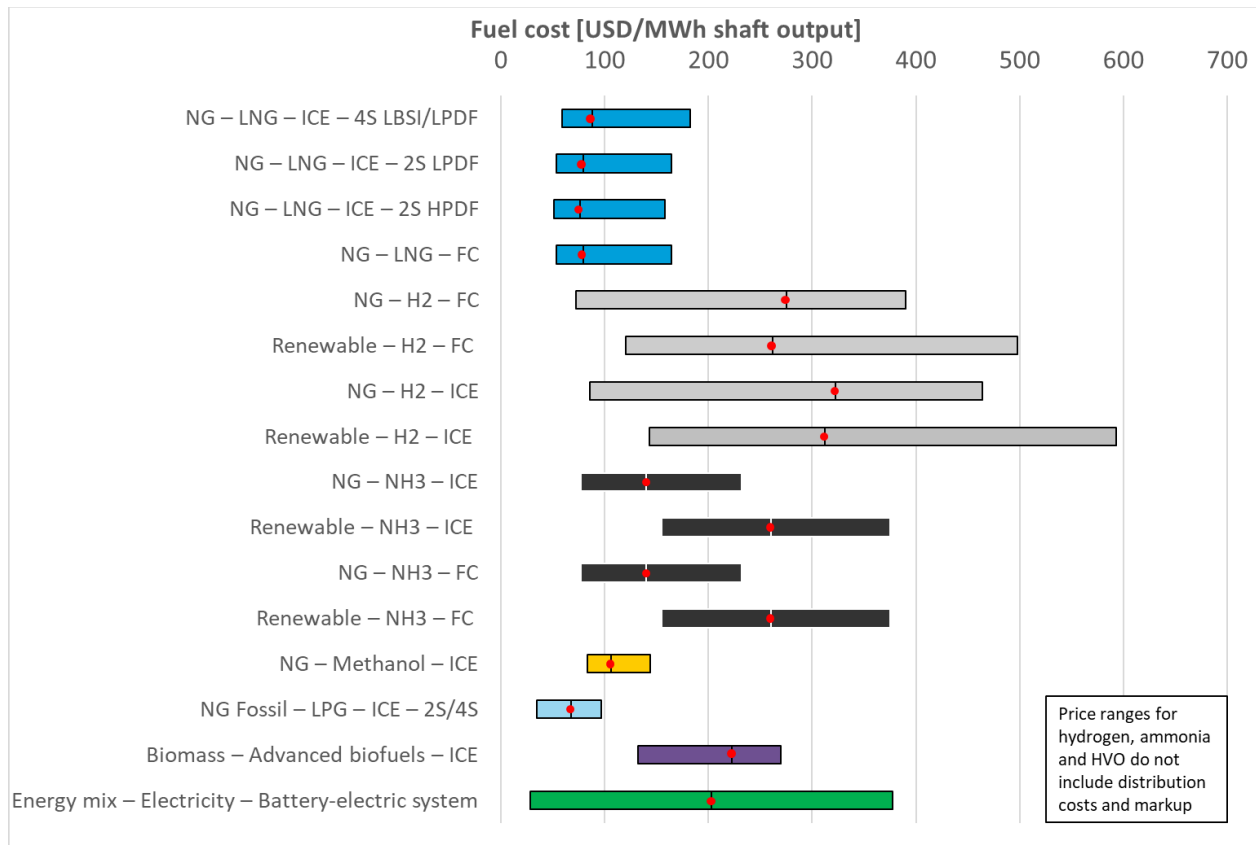


Figure 2.4: Energy cost for the alternative energy pathways, considering energy content and system efficiency (USD/MWh shaft output)

Source: DNV (2018)

In summary, evidences from empirical literature provide information that LNG, Hydrogen gas, Methanol, LPG, Ammonia, advanced Biodiesel (hydrogenated vegetable oil), and battery-electric energy options have applicability in the marine transport and shipping industry. The economic viability of each energy sources cum the environmental performances was also established. The preference of high energy density with low cost energy sources by ship-owners and operators as well the preference of coastal authority administrations for environmentally high performance energy types were also established in the empirical literature. The reviews further show many policies and programs have been developed at local, national and international levels aimed at improving efficient alternative energy sources for use in marine transportation.

2.4 Literature Gap

From the empirical literature, various studies have revealed the applicability of all the identified alternative energy sources used in this study for purposes of marine transportation and shipping. At the global level, studies by Det Norsk veritas (DNV, 2018), American Bureau of Shipping (ABS, 2019) already established the economic, applicability and environmental performances of each alternative energy type. While the work of Hansson, Mansson and Selam, (2019) established the preference of Swedish maritime stakeholders (ship-owners, operators, fuel producers and engine manufacturers) for LNG energy type based on a multi-criteria assessment that includes applicability, economic, environmental and scalability performances of each alternative energy type; the Thomas and Haitao (2010) established the preference of renewable energy sources by public authorities and States the United States of America.

Viewed from local context perspective with Nigeria in focus, literature gaps are identified such that the economic viability and implications of transition to alternative energy types remain inadequately addressed and there is seeming lack of empirical evidence and knowledge on the economic viability of the alternative marine fuel options. This knowledge is important because the competitiveness and commercial viability of indigenous shipping organizations (ship-owners, companies and operators) will depend on to a large extent on the economic implications of the alternative energy type adopted for use and/or implementation. Secondly, empirical information on the scalability potentials of the available alternative marine energy sources in the domestic maritime sector in Nigeria is seemingly unavailable.

The scalability potential and/or possibility is a very important data in view of the need to guarantee access mass to adopted alternative fuel sources and technologies by all stakeholders in the maritime transport sector in Nigeria. The current study is cast to bridge the above identified

literature gaps by providing empirical evidences on the economic and scalability criteria for decisions on preference and choice of alternative marine transportation energy sources.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

In this section, the methods and procedures that were employed in dealing with the research questions in order to realize the objectives of the study were discussed. Research methodology is a way and process used in carrying out a research including theoretical and philosophical assumption upon which the research is based and the implications of these for the method or methods adopted. The researcher employed the use of comparative statistics and analytical hierarchy models comprising major analysis of variance, paired-sample t-test to compare the alternative energy preferences of the sampled population and establish hierarchy of alternative energy preferences for marine transportation in Nigeria based on economic and scalability criteria.

3.1 Description of the Study Area

The study area of the research is the Nigeria maritime transport sub-sector with particular focus on the alternative energy preferences of ship-owners and operators in the sector as well as the Nigeria maritime administration and safety agency as coastal authority. The major locations of these operators in Nigeria include Lagos, Port-Harcourt, Warri, Calabar, Eket in Akwa-ibom state. Therefore the study area of the research is the Nigeria maritime industry with focus on the energy needs of ship-owners for shipping operations in the sector.

3.2 Research Design

The study is designed to assess the viability of adoption and use of alternative energy sources for marine transportation in Nigeria based on scalability and economic criteria of the identified

alternative energy types. Adopting a qualitative research design approach, survey questionnaire was administered to the sampled population of ship-owners, ship-operators and maritime regulatory authorities. The aim of the survey is to gather data on the opinion, preference and rating of the economic and scalability performance of each identified alternative energy source by the sampled proportion of maritime stakeholders industry in Nigeria. Having earlier identified the objectives and research questions to be addressed by the study, comparison of alternative energy types will be carried out using the data obtained while a hierarchy of alternative energy preferences by maritime industry stakeholders in Nigeria will be developed.

3.3 Sources of Data

This research relied entirely upon primary sources of data for the study. Primary data constitute of data originally generated from primary means such as questionnaires, surveys, interview, field observations, etc. The data used for the study was sourced from primary sources; since the study is a qualitative study that sought to rate the economic and scalability performance of alternative energy sources for marine transportation for purposes of decision on alternative energy preferences by industry stakeholders.

3.4 Instruments for Data Collection

Survey was used as main the main instrument for data collection. The survey will be carried out by using questionnaire calibrated to elicit responses from maritime operators, regulators and ship owners on their perceived economic and scalability conditions of identified alternative energy types. The question will elicit responses from the sampled population on capital acquisition cost and maintenance cost of each alternative energy technology as major criteria for economic

consideration. It will also elicit responses from the sampled population on the main current usages, availability cum infrastructure, and production capacity cum location as major criteria for determining the scalability of alternative energy sources and technology types in Nigeria. To carry out the survey, questionnaire method was thus used as the instrument of data collection and questions were structured in line with the objectives of the study and randomly administered to the sampled population.

3.5 Population of the Study

The study population consists of the sample of population drawn from the Nigeria ship-owners association and ship deck and engine room operators drawn from the Nigeria maritime/dock workers Union. Sample was also drawn from the Nigeria maritime administration and safety agency as the apex maritime regulatory agency in Nigeria.

3.5.1 Sampling Techniques

The study adopted purposive random (non-probability) sampling method. This is most appropriate for the research due to specialized and highly professional nature of it requiring that only individuals involved in actual operations of the ship either as deck or engine room professionals or ship-owners with direct industry contact and professional knowledge will have in-depth knowledge on the issue of energy transition in the maritime industry and as to make useful contributions for decisions on alternative energy preferences. Thus, the research questionnaire will purposively be administered to randomly selected members of the industry stakeholders comprising of the ship-owners, ship-operators, and regulators. To determine the appropriate sample size for large (infinite) population and uncertain number of population,

judgment was made about the confidence level and the maximum error allowance. The equation below was applied. The sample size for population of the study to be interviewed is determined by using:

$$n = Z^2/4E^2$$

where; n = Sample size; Z = Z score at 95 percent level of confidence = 1.96

E = Maximum acceptable error = 0.05

Thus we have:

$$N = 1.96^2/4(0.05)^2$$

n = 324 maritime industry stakeholders.

Thus the number of questionnaires that need to be administered and responses collected from industry stakeholders is 324 questionnaire responses. This sample size was used for objectives 3 to 5.

For objective 1, since our interest is to determine the relative importance/preference of the economic criteria and sub-criteria for alternative energy options for marine transportation in Nigeria, it implies that we will make a more professional analytical tool which requires that only individuals with adequate sound knowledge of the implementation of the tool will be sampled.

For correct implementation of the Analytical Hierarchical process (AHP) therefore,

the study population was narrowed to consists of the sample of population drawn from the Nigeria ship-owners association and ship deck and engine room operators with the requisite knowledge drawn from the AQUASHED Maritime services, AP molar Nigeria Limited, Sea trucks, Smith Lamnaco and the Nigeria maritime/dock workers Union. The sampling technique employed was purposive random sampling technique in which a total of 20 professional ship

owners and ship operators were sampled. Two professionals were drawn from each ship owning company. This is to ensure that the standard for implementing the AHP which requires the opinion of only experts (professionals) in the sector with core understanding and knowledge in the area is not violated. The ratings of the professional were averaged and streamlined for the implementation of the AHP.

3.5.2 Testing Reliability of the Instrument

Reliability assesses repeatability and consistency of the responses to the survey instrument. For example, a response to survey instrument and/or measurement is said to be reliable if it produces the same output or almost the same result when repeated under the same or similar conditions. Testing for reliability is important as it refers to the consistency across the parts of a measuring instrument. To measure the reliability and internal consistency of the survey instrument, we used the Cronbach Alpha coefficient.

It will be determined after administering the survey instrument once to overcome the problems associated with testing over multiple time periods. Reliability is will thus be determined using the split-half reliability index and the Cronbach Alpha index. The split half estimate will be done by dividing up the test into two parts first half of the items/second half of the items), administering the two forms to the same group of individuals in the population and correlating the responses. The coefficient alpha is the mean (average) of all possible split half estimates while the existence of differences between the two would be used to assess reliability.

To estimate coefficient alpha (a), we use:

$$a = \frac{n}{(n-1)[1-\text{SumVar}(Y)/\text{Var}(X)]} \dots$$

Where n = Number of items

Sum $\text{Var}(Y)$ = Sum of item variances

$\text{Var}(X)$ = Composite variance.

Since many respondents, about 300 raters will be indicating their preference for alternative energy sources for marine transportation based on performance of each fuel type, Correlating the responses of the respondents for each alternative energy type enables us to measure the reliability of the responses. Correlation coefficient between 0.70 and above is high as acceptable as reliable.

3.6 Method of Data Analysis

3.6.1 AHP

AHP is a method for organizing and analyzing complex decisions, using mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined further since then. It contains three parts: the ultimate goal or problem to be solved, all of the possible solutions, called alternatives, and the criteria to be employed in making judgment and/or preferences from the alternatives. AHP provides a rational framework for a needed decision by quantifying its criteria and alternative options, and for relating those elements to the overall goal. In using the AHP, criteria and sub-criteria are compared to determine order of relative importance, two at a time, through pair-wise comparisons. AHP converts these evaluations into numbers, which can be compared to all of the possible criteria, making it possible for a choice to be made among the criteria based on their relative ranking.

The central goal of the overall study is to make choice of the alternative energy options for marine use in Nigeria based on three identified criteria of level of economic implications for the maritime industry operators (economy), environmental performance and scalability performance.

The economic performance is identified to be influenced by energy cost, capital cost, and ease of maintenance and cost as sub-criteria of the economy parameter. This seminar is therefore limited to determine the order of relative importance of the economic sub-criteria in decision for each of the identified alternative energy options for implementation in marine transportation in Nigeria, using AHP. The structure of the problem and goal is as shown figure3.1 below.

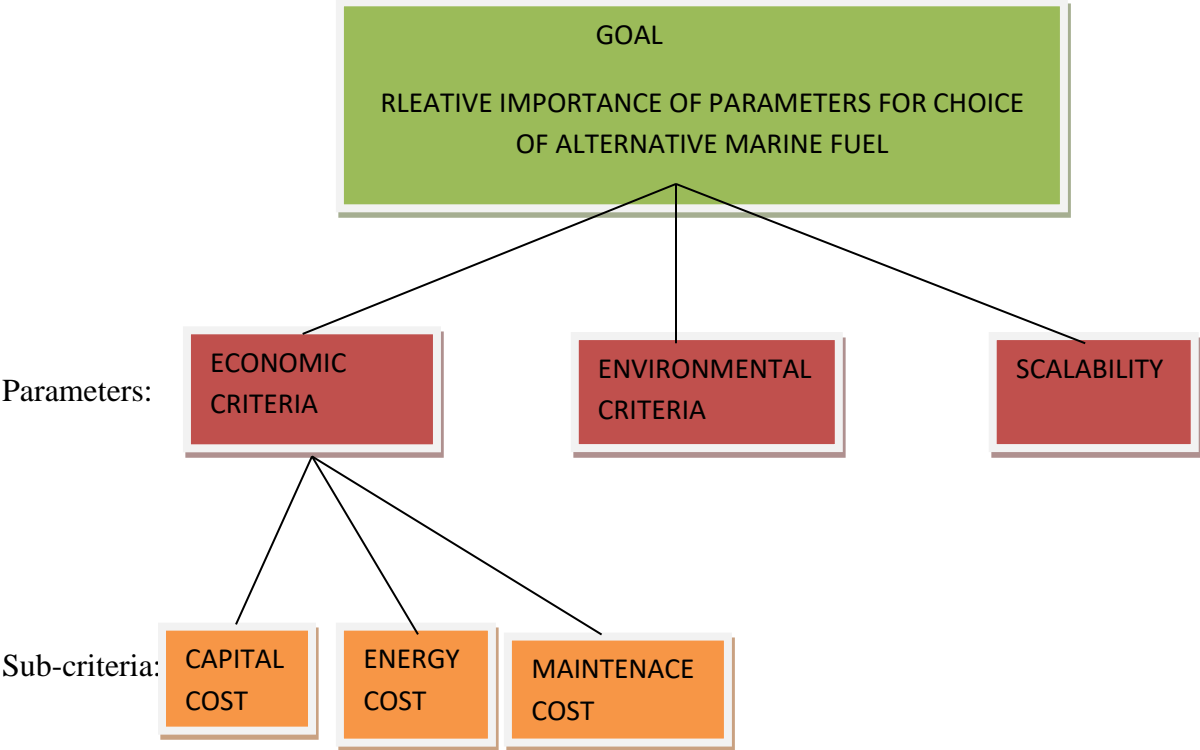


Figure3.1: representation of the AHP Parameters.

3.6.2 Analysis of Variance (ANOVA)

The ANOVA is a statistical tool for comparing and determining the existence of differences between more than two groups of variables. ANOVA can be employed to analyze survey data and to achieve objectives 4 to 6. By employing the one way ANOVA method of analysis, we determined the significance of the differences in respondents rating of the scalability performances of alternative energy sources. The scalability of the alternative energy sources will be compared based on three criteria of current main usages, availability cum infrastructure on land, and production capacity cum locations, by the use of ANOVA.

With K sample groups (where K = 7 = number of alternative energy sources for marine transport) and n- samples (n= number of respondents from which data was collected), we assign a general data element as X_{ij} where j = group number from 1 to k, i = data item number from 1 to n in each group.

We calculated the overall sample mean across all groups by adding all the data values from every group and dividing by the total number of values. We called this "grand mean" X^{\wedge} calculated as:

$$X^{\wedge} = \frac{\sum_{j=1}^k \sum_{i=1}^n X_{ji}}{Kn} \text{-----(3.1)}$$

Also each individual alternative energy source has a mean defined simply as the sample mean of respondents rating of the group j .

$$\text{Mean}X_j = \frac{1}{n} \sum_{i=1}^x X_{ji}$$

The variation between groups (alternative energy groups) SS_b which represents the sum of the squares is calculated as:

$$SS_b = n \sum_{j=1}^k \left(\text{Mean}X_j - \bar{X} \right)^2$$

Total variation within the groups SS_w which is the sum of squares across all groups is given as:

$$SS_w = \sum_{j=1}^k \sum_{i=1}^n \left(\text{Mean}X_j - \bar{X} \right)^2$$

We convert the values of SS_b and SS_w into variances by dividing with the respective degrees of freedom ($K-1$) and $(n-1)$. Note that the variation between groups (SS_B), the number of degrees of freedom is one less than the number of groups, or $k - 1$. Also for the variation within groups (SS_w), the number of degrees of freedom is the product of the number of groups and one less than the number of sample values-mathematically, $k(n - 1)$. If we use S^2_b to denote the variance (technically, the "mean square") between groups and S^2_w the variance (or "mean square") within groups. Then;

$$S^2_b = \frac{n \sum_{j=1}^k \left(\text{Mean}X_j - \bar{X} \right)^2}{(K - 1)} \text{-----(3.2)}$$

And;

$$S^2_w = \frac{\sum_{j=1}^n \left(\text{Mean}X_{ji} - \hat{X} \right)^2}{K(n - 1)} \text{-----} (3.3)$$

The F-test (F-statistic) which test the significance of the variation and/or group differences then

becomes: $F = \frac{S^2_b}{S^2_w} \text{-----} (3.4)$

The significance of the differences will be tested using f-statistic. ANOVA was used to analyze data with respect to objectives 4, 5 and 6; and the responses of the respondents were compared for decision on most potentially scalable alternative energy source for marine transportation in Nigeria.

Based on the outcome of objectives 4,5 and 6; the ranking of the alternative energy preference for marine transportation by local maritime industry stakeholders based on the scalability potentials of each energy type can be done in order to arrive at objective 7. Using the methods discussed above, the data collected for the study was analyzed.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Data Presentation

Under this section the data obtained from the field survey and used for the study is presented. The data presented in this section form the basis for further analysis using the analytical software.

Table4.1: Respondents’ average rating of relative preference of economic sub-criteria for LNG alternative energy option

Sub-Criteria	Weighting score															Sub-criteria		
	More important than					equal					less important than							
Capita cost (CC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	EC
Energy cost (EC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	MC
Maintenance cost (MC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CC

Source: Field survey

The first objective of the study is to determine the relative importance of energy cost, capital cost, and ease of access to maintenance and cost economic sub-criteria for implementation of alternative energy options for marine transportation in Nigeria. Table4.1 above shows the average rating of the expert respondents sampled for LNG alternative energy type. It shows that three economic sub-criteria influence the decision of operators in preference of alternative energy sources from economic stand point. These are energy cost, capital cost and accessibility to and cost of maintenance of technology. The comparisons represent the mean ratings and judgments of the experts respondents sampled in the study and it also indicates the comparative strength of their preferences for the economic sub-criteria which influence the implementation of alternative energy types from economic standpoint. The table indicates that for LNG energy option, capital cost with a mean score of 9 on the right hand side with energy cost is preferred as

more important than energy cost while energy cost when compared with maintenance cost is less important than maintenance cost. Maintenance cost with a score of 8 on the right hand side is less important when compared with capital cost. We employed the data in table 4.1 above for further analysis to determine the relative importance of the economic sub-criteria in the preference of LNG alternative energy option.

Table4.2: Pair-wise Comparison Matrix of Respondents average rating of relative importance of economic sub-criteria for electric drive alternative energy option

Criteria	Weighting score																Criteria	
	More important than								equal				less important than					
Capita cost (CC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	EC
Energy cost (EC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	MC
Maintenance cost (MC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CC

Source: Field survey

Table4.2 above shows the average rating of the expert respondents sampled for Electric Drive alternative energy type. It shows that three economic sub-criteria influence the decision of operators in preference of alternative energy sources from economic stand point. The comparisons represent the mean ratings and judgments of the experts respondents sampled in the study and it also indicates the comparative strength of their preferences for the economic sub-criteria which influence the implementation of alternative energy types from economic standpoint. The table indicates that for electric drive energy option, capital cost with a mean score of 9 on the left hand side with energy cost is preferred as more important than energy cost while energy cost when compared with maintenance cost is more important than maintenance cost. Maintenance cost with a score of 3 on the right hand side is less important when compared with capital cost. We also employed the data in table 4.2 above for further analysis to determine

the relative importance of the economic sub-criteria in the preference of battery electric drive alternative energy option.

Table4.3: Comparison Matrix of respondents’ average rating of relative importance of economic sub-criteria for Ammonia alternative energy option

Sub-criteria	Weighting score															Sub-criteria		
	More important than					equal			less important than									
Capita cost (CC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	EC
Energy cost (EC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	MC
Maintenance cost (MC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CC

Source: Field survey

Table4.3 above shows the average rating of the expert respondents sampled for Ammonia alternative energy type. It shows that three economic sub-criteria influence the decision of operators in preference of alternative energy sources from economic stand point. The comparisons represent the mean ratings and judgments of the experts respondents sampled in the study and it also indicates the comparative strength of their preferences for the economic sub-criteria which influence the implementation of alternative energy types from economic standpoint. The table indicates that for ammonia energy option, capital cost with a mean score of 6 on the left hand side with energy cost is preferred as more important than energy cost while energy cost when compared with maintenance cost is more important than maintenance cost. Maintenance cost with a score of 5 on the right hand side is less important when compared with capital cost. The data in table 4.3 above was also employed for further analysis to determine the relative importance of the economic sub-criteria in the preference of ammonia alternative energy option.

Table 4.4: Respondents average rating of relative importance economic sub-criteria for Hydrogen alternative energy option

Sub-criteria	Weighting score															Sub-criteria		
	More important than					equal					less important than							
Capita cost (CC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	EC
Energy cost (EC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	MC
Maintenance cost (MC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CC

Source: Field survey

Table 4.4 above shows the average rating of the expert respondents sampled for Hydrogen alternative energy type. It shows that three economic sub-criteria influence the decision of operators in preference of alternative energy sources from economic stand point. These are energy cost (EC), capital cost (CC) and accessibility to and cost of maintenance of technology (MC). The comparisons represent the mean ratings and judgments of the experts respondents sampled in the study and it also indicates the comparative strength of their preferences for the economic sub-criteria which influence the implementation of alternative energy types from economic standpoint.

The table indicates that for hydrogen gas energy option, capital cost with a mean score of 3 on the left hand side with energy cost is preferred as more important than energy cost while energy cost when compared with maintenance cost is more important than maintenance cost. Maintenance cost with a score of 3 on the right hand side is less important when compared with capital cost. The data in table 4.4 above was also used for further analysis to determine the relative importance of the economic sub-criteria in the preference of hydrogen gas alternative energy option.

Table4.5: Respondents average rating of relative importance of economic sub-criteria for Methanol alternative energy option

Sub-criteria	Weighting score															Sub-criteria		
	More important than					equal					less important than							
Capita cost (CC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	EC
Energy cost (EC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	MC
Maintenance cost (MC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CC

Source: Field survey

Table4.5 above shows the average rating of the expert respondents sampled for Methanol alternative energy type. It shows that three economic sub-criteria influence the decision of operators in preference of alternative energy sources from economic stand point. These are EC, CC and accessibility to and MC. The comparisons represent the mean ratings and judgments of the experts respondents sampled in the study and it also indicates the comparative strength of their preferences for the economic sub-criteria which influence the implementation of alternative energy types from economic standpoint.

The table indicates that for methanol energy option, capital cost with a mean score of 5 on the left hand side with energy cost is preferred as more important than energy cost while energy cost when compared with maintenance cost is more important than maintenance cost. Maintenance cost with a score of 2 on the right hand side is less important when compared with capital cost. We also employed the data in table 4.5 above for further analysis to determine the relative importance of the economic sub-criteria in the preference of methanol alternative energy option.

Table4.6: Respondents average rating of importance of economic sub-criteria for Advanced bio-fuel (HVO) alternative energy option

Sub-criteria	Weighting score															Sub-criteria		
	More important than					equal					less important than							
Capita cost (CC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	EC
Energy cost (EC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	MC
Maintenance cost (MC)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	CC

Source: Field survey

Table4.6 above shows the average rating of the expert respondents sampled for HVO alternative energy type. It shows that three economic sub-criteria influence the decision of operators in preference of alternative energy sources from economic stand point. These are EC, CC and MC. The comparisons represent the mean ratings and judgments of the experts respondents sampled in the study and it also indicates the comparative strength of their preferences for the economic sub-criteria which influence the implementation of alternative energy types from economic standpoint. T

he table indicates that for HVO energy option, capital cost with a mean score of 4 on the left hand side with energy cost is preferred as more important than energy cost while energy cost when compared with maintenance cost is more important than maintenance cost. Maintenance cost with a score of 9 on the right hand side is less important when compared with capital cost. We also employed the data in table 4.6 above for further analysis to determine the relative importance of the economic sub-criteria in the preference of HVO alternative energy option.

Table4.7: Respondents response on the level of main current usage of alternative energy ship types in their Fleet.

Energy options		LNG	Diesel	Battery electric	Ammonia	Hydrogen gas	HVO	Methanol
Frequency of response types	1	15	250	2	0	0	0	0
	0	235	0	248	250	250	250	250

Source: survey

Recall that objective-3 seeks to compare the scalability of the alternative energy options for marine transportation in Nigeria based on the level of main current usages of the alternative energy sources for marine purpose in Nigeria. The table4.7 above presents the data on the level of main current usage of each identified alternative energy option for marine transportation in Nigeria by the sampled population of ship operators and owners in Nigeria. The rating was based on scale between 0 and 1. While 0 represents the non-availability and use of vessel operating on a given alternative energy type in the marine fleet of an operator, 1 indicates the presence and current use of a vessel operating on the given alternative energy types in the marine fleet of an operator.

A total of about 324 questionnaires representing the sample size were issued to respondents, but only about 250 survey instruments representing about 77% of the sample size, were properly filled and returned. It indicates that while all the 250 ship operators/respondents have marine diesel powered vessels in their fleet, 15 operators in the offshore sector have LNG vessels in the fleet, and only 2 offshore operators have electric powered marine vessels in their fleet. The current main use of other alternative energy sources such as ammonia, hydrogen gas, methanol and HVO is zero.

Table4.8: Respondents response on the scalability of alternative energy options based on global production capacity and locations

Energy options		LNG	Battery electric	Ammonia	Hydrogen gas	HVO	Methanol
Frequency	Scalability rating(s)						
	0	-	-	-	-	-	-
	1	-	5	35	-	235	-
	2	-	-	-	180	15	35
	3	-	55	145	-	-	75
	4	-	90	70	-	-	35
	5	1	100	-	35	-	105
	6	249	-	-	35	-	-

Source: survey

Table 4.8 above shows the data obtained from the survey carried out on the scalability potentials of the alternative energy options for marine transportation in Nigeria. The calibration of the scalability is on scale between 0 and 6; since there are 6 alternative energy options for marine transportation identified in the study. While 1 indicates the least scalable energy option, a score of 6 indicates the most scalable alternative energy option based on global production capacity and access to production location. Respondents are to rate the scalability of each energy option on this scale, based on the access of the operators to the global production locations and capacity of each alternative energy option. The frequencies of the rating by the respondents are thus shown in table4.8.

4.9: Respondents response on the scalability of alternative energy options based on availability of bunkering infrastructure on land (in ports)

Energy options		LNG	Battery electric	Ammonia	Hydrogen gas	HVO	Methanol
Frequency	Scalability scores						
	0	-	1	39	45	50	145
	1	-	16	1	-	-	-
	2	-	4	9	3	-	30
	3	-	1	1	-	-	45
	4	-	1	-	2	-	30
	5	-	25	-	-	-	-
	6	250	-	-	-	-	-

Source: survey

Table 4.9 above shows the data obtained from the survey carried out on the scalability potentials of the alternative energy options for marine transportation in Nigeria. The calibration of the scalability is on scale between 0 and 6; since there are 6 alternative energy options for marine transportation identified in the study. While 1 indicates the least scalable energy option, a score of 0 indicates that there is no potential for scalability of the given alternative energy option, a score of 6 indicates the most scalable alternative energy option based on availability of bunkering infrastructure on land/in port. Respondents are to rate the scalability of each energy option on this scale, based on the availability of bunkering infrastructure on land. The frequencies of the rating by the respondents are thus shown in table4.9.

4.2 Results and Discussion of Findings

Table4.10: Relative Importance scores of economic sub-criteria for LNG alternative energy option for marine use in Nigeria

SUB -CRITERIA	Capital Cost	Energy Cost	Maintenance Cost	Average scores
Capital Cost (CC)	0.012	0.63	0.11	0.253
Energy Cost (EC)	0.11	0.56	0.079	0.250
Maintenance Cost (MC)	0.88	0.37	0.63	0.631
Consistency ratio (CR) =				0.083

Source: Authors calculation

Table4.10 shows the result of the analysis of the pair-wise comparison of the relative importance of economic sub-criteria for LNG alternative energy option for implementation for marine use in Nigeria. The result indicates that capital cost, energy cost and ease of and maintenance cost has average relative importance scores of 0.253, 0.250, and 0.631 respectively.

This implies that the ease of and maintenance cost with highest relative importance score of 0.631 constitute the most important economic sub-criteria to ship-owners and operators in the decision to adopt and use LNG as alternative energy source to diesel. This is following by capital cost and with relative importance score of 0.253 and lastly energy cost with relative importance score of 0.250. The ease of access to maintenance and maintenance cost constitute the most significant economic consideration for use of LNG alternative energy option among Nigeria ship operators. The consistency ratio (CR) of the preference rating of the economic sub-criteria is 0.083 which is less than 0.10 and indicates a consistent pair-wise comparison.

See figure4.1 below ranks the economic sub-criteria for LNG energy option use in marine transportation in Nigeria in order of decreasing relative importance.

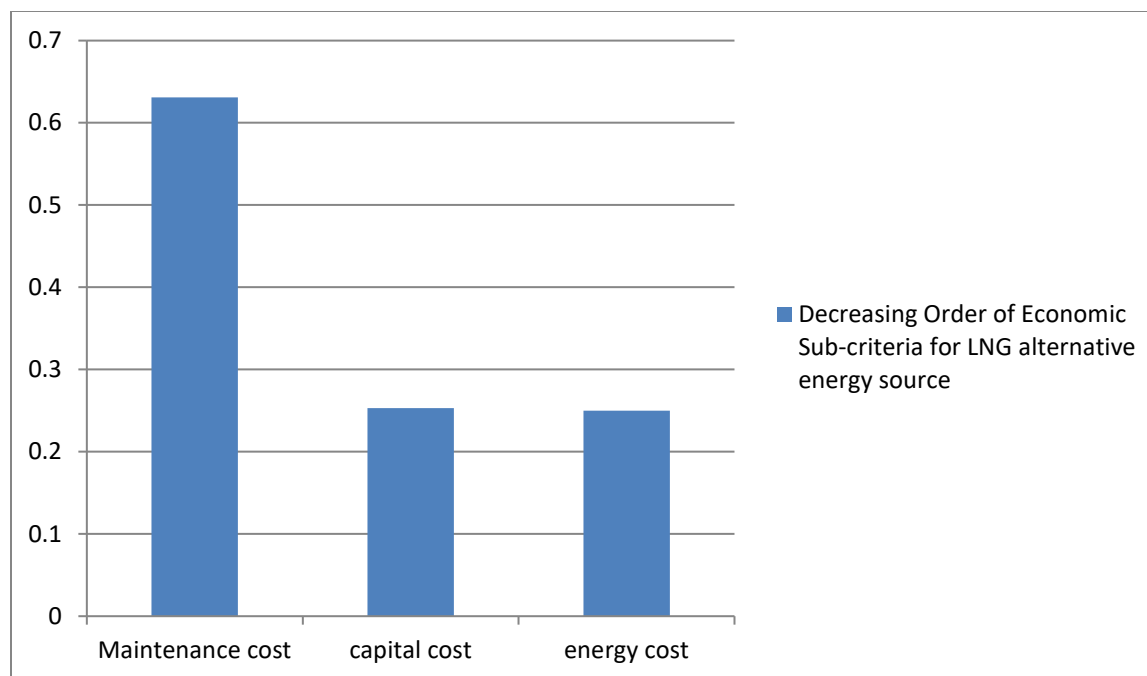


Figure4.1: Decreasing Order of Economic Sub-criteria for LNG alternative energy source.
Source: Authors calculation

Table4.11: Relative Importance Scores of economic sub-criteria for electric drive alternative energy option for marine use in Nigeria

SUB -CRITERIA	Capital Cost	Energy Cost	Maintenance Cost	Average scores
Capital Cost (CC)	0.242	0.887	0.039	0.39
Energy Cost (EC)	0.027	0.098	0.840	0.32
Maintenance Cost (MC)	0.731	0.014	0.120	0.29
Consistency ratio (CR) =				0.075

Source: Authors calculation

Table4.11 shows the result of the analysis of the pair-wise comparison of the economic sub-criteria influencing ship operators economic decisions and preference of electric drive alternative energy option for implementation for marine use in Nigeria. The result indicates that capital cost, energy cost and ease of and maintenance cost has average relative important scores of 0.39, 0.32, and 0.29 respectively.

This implies that the capital cost having relative importance score of 0.39 constitute the most important economic sub-criteria to ship-owners and operators in the decision to adopt and use

electric drive as alternative energy source, for marine transportation in Nigeria. This is followed by energy cost with relative importance score of 0.32 and lastly maintenance cost with relative importance score of 0.29. Thus capital cost constitutes the most significant economic sub-criteria considered by ship owners and operators in the preference of electric drive as alternative energy option for marine transportation in Nigeria, from economic stand-point. The consistency ratio (CR) of the original preference rating of the economic sub-criteria is 0.075 which is less than 0.10 and indicates a consistent pair-wise comparison by the expert population sampled. Figure4.2. below ranks the economic sub-criteria for electric drive alternative energy option use in marine transportation in Nigeria in order of decreasing relative importance.

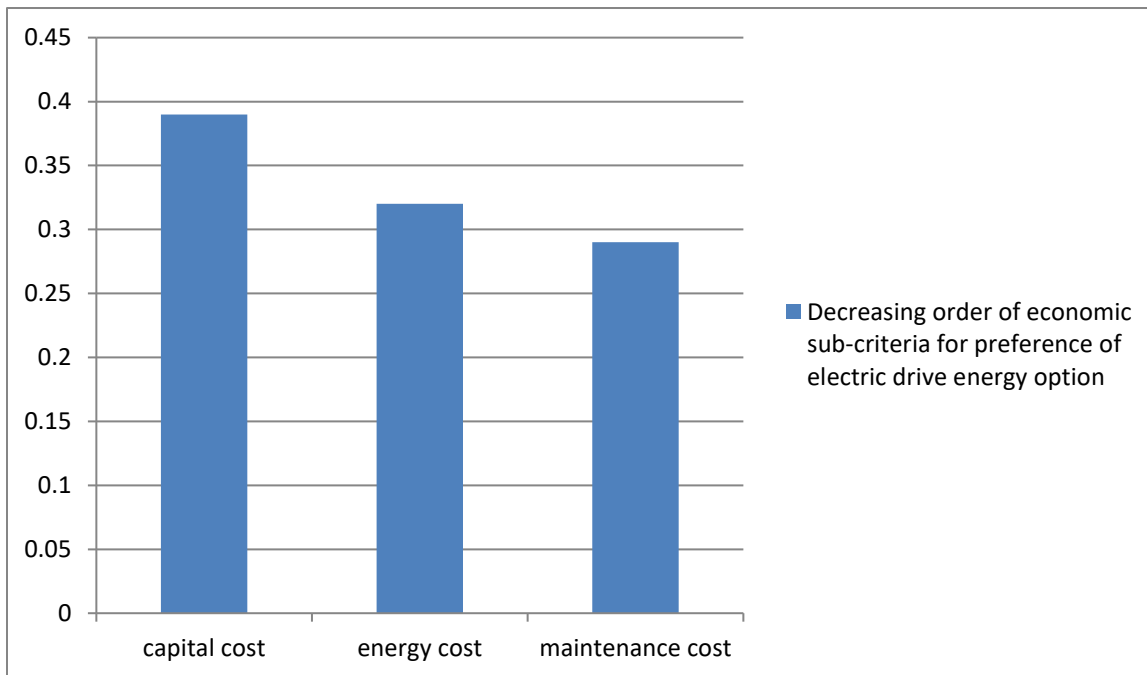


Figure4.2: Decreasing order of economic sub-criteria for preference of electric drive energy option. Source: Author’s calculation.

Table4.12: Relative Importance scores of economic sub-criteria for Ammonia alternative energy option for marine use in Nigeria

SUB -CRITERIA	CC	EC	MC	Average score
Capital Cost (CC)	0.74	0.83	0.039	0.31
Energy Cost (EC)	0.12	0.14	0.77	0.34
Maintenance Cost (MC)	0.15	0.03	0.19	0.12
Consistency ratio (CR) =				0.064

Source: Authors calculation

Table4.12 shows the result of the analysis of the pair-wise comparison of the economic sub-criteria influencing ship operators economic decisions and preference of ammonia alternative energy option for implementation for marine use in Nigeria. It indicates that that capital cost, energy cost and ease of and maintenance cost has average relative important scores of 0.31, 0.34, and 0.12 respectively. This implies that the energy cost has the most relative importance score of 0.34 constitute the most important economic sub-criteria to ship-owners and operators in the decision to adopt and use ammonia as alternative energy source, for marine transportation in Nigeria. This is followed by capital cost with relative importance score of 0.31 and lastly maintenance cost with relative importance score of 0.12. Thus energy cost constitutes the most significant economic sub-criteria considered by ship owners and operators in the use of ammonia as alternative energy option for marine transportation in Nigeria. The consistency ratio (CR) of the original preference rating of the economic sub-criteria is 0.064 which is less than 0.10 and indicates a consistent pair-wise comparison by the expert population sampled.

Table4.13: Relative importance scores of economic sub-criteria for hydrogen gas alternative energy option for marine use

SUB -CRITERIA	CC	EC	MC	sum	Average score(s)
Capital Cost (CC)	0.43	0.73	0.04	1.20	0.40
Energy Cost (EC)	0.14	0.24	0.84	1.22	0.41
Maintenance Cost (MC)	0.43	0.034	0.12	0.58	0.20
Consistency ratio (CR) =					0.052

Source: Authors calculation

Table4.13 shows the result of the analysis of the pair-wise comparison of the economic sub-criteria influencing ship operators economic decisions and preference of hydrogen gas alternative energy option for implementation for marine use in Nigeria. The result indicates that capital cost, energy cost and ease of and maintenance cost has average relative important scores of 0.40, 0.41, and 0.20 respectively. Energy cost having the most relative importance score of 0.41 constitute the most important economic sub-criteria to ship-owners and operators in the decision to adopt and use hydrogen gas as alternative energy source, for marine transportation in Nigeria. This is followed by capital cost with relative importance score of 0.40 and lastly maintenance cost with relative importance score of 0.20. Thus energy cost constitutes the most significant economic sub-criteria considered by ship owners and operators in the preference of hydrogen gas as alternative energy option for marine transportation in Nigeria, from economic stand-point. The CR of the original preference rating of the economic sub-criteria is 0.052 which again, is less than 0.10; and indicates a consistent pair-wise comparison by the expert population sampled.

Table4.14: Relative importance scores of economic sub-criteria for Methanol alternative energy option for marine use

SUB -CRITERIA	CC	EC	MC	sum	Average score
Capital Cost (CC)	0.15	0.15	0.05	0.35	0.12
Energy Cost (EC)	0.77	0.76	0.84	2.37	0.79
Maintenance Cost (MC)	0.08	0.09	0.11	0.28	0.09
Consistency ratio (CR) =					0.071

Source: Authors calculation

Table4.14 shows the result of the analysis of the pair-wise comparison of the economic sub-criteria influencing ship operators economic decisions and preference of methanol alternative energy option for implementation for marine use in Nigeria. It indicates that that capital cost, energy cost and ease of and maintenance cost has average relative important scores of 0.12, 0.79, and 0.09 respectively. This implies that the energy cost has the most relative importance score of 0.79 and constitute the most important economic sub-criteria to ship-owners and operators in the decision to adopt and use methanol as alternative energy source, for marine transportation in Nigeria. This is followed by capital cost with relative importance score of 0.12 and lastly maintenance cost with relative importance score of 0.09. Thus energy cost constitutes the most significant economic sub-criteria considered by ship owners and operators in the use of methanol as alternative energy option for marine transportation. The CR of the original preference rating of the economic sub-criteria is 0.071 which is less than 0.10 and indicates a consistent pair-wise comparison.

Table4.15: Relative importance scores of economic sub-criteria for HVO alternative energy option for marine use

SUB -CRITERIA	CC	EC	MC	sum	Average score
Capital Cost (CC)	0.44	0.77	0.02	1.23	0.41
Energy Cost (EC)	0.11	0.19	0.84	1.14	0.38
Maintenance Cost (MC)	0.44	0.03	0.14	0.61	0.20
Consistency ratio (CR) =					0.062

Source: Authors calculation

Table4.15 shows the result of the analysis of the pair-wise comparison of the economic sub-criteria influencing ship operators economic decisions and preference of HVO alternative energy option for implementation for marine use in Nigeria. The result indicates that capital cost, energy cost and ease of and maintenance cost has average relative important scores of 0.41, 0.38, and 0.20 respectively. CC having the most relative importance score of 0.41 constitute the most important economic sub-criteria to ship-owners and operators in the decision to adopt and use HVO as alternative energy source, for marine transportation in Nigeria. This is followed by energy cost with relative importance score of 0.38 and lastly maintenance cost with relative importance score of 0.20. Thus capital cost constitutes the most significant economic sub-criteria considered by ship owners and operators in the preference of advanced bio-fuel as alternative energy option for marine transportation in Nigeria, from economic stand-point. The CR of the original preference rating of the economic sub-criteria is 0.062 which again, is less than 0.10; and indicates a consistent pair-wise comparison by the expert population sampled.

4.16: Ranking the economic sub-criteria for preference of alternative energy options for marine transportation based on the relative importance scores of capital energy and maintenance costs.

Energy Option	Economic sub-criteria		
	maintenance cost	capital cost	Energy cost
LNG			
Relative importance Score(s)	0.63	0.253	0.250
Rank(s): decreasing order of importance	1	2	3
Electric Drive	Capital cost	energy cost	maintenance cost
Relative importance score	0.39	0.32	0.072
Rank(s): decreasing order of importance	1	2	3
Ammonia	Energy cost	Capital cost	maintenance cost
Relative importance score	0.34	0.31	0.12
Ranks(s): decreasing order of importance	1	2	3
Hydrogen Gas	Energy cost 0.41	capital cost	maintenance cost
Relative importance score:		0.40	0.20
Rank(s): decreasing order of importance	1	2	3
Methanol	Energy cost	capital cost	maintenance cost
Relative importance scores	0.79	0.12	0.09
Rank(s): decreasing order of importance	1	2	3
Advanced bio-fuel (HVO)	Capital cost	energy cost	maintenance cost
Relative importance score(s)	0.41	0.38	0.20
Rank(s): decreasing order of importance	1	2	3

Source: Prepared by author.

Table 4.16 above indicates that for LNG alternative energy option, the most important economic concern and consideration by ship-owners for its full implementation for marine transportation in Nigeria is the ease of access to maintenance and maintenance cost rather than capital cost and energy cost. For electric drive and advanced bio-fuel (HVO) alternative energy options, the most important economic concerns of ship owners and operators is the capital cost of acquisition of

the electric drive and HVO ship propulsion technology rather than energy cost and maintenance cost. Lastly, for ammonia, hydrogen gas and methanol alternative energy sources, the most important economic consideration by ship owners and operators in Nigeria are the energy cost.

4.17: Comparing the Maturity for Scalability of Alternative Energy Options for Marine Transportation based on Level of Main Current Usages

Anova: Single-Factor Without Replication

<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Column 1(LNG)	50	18	0.36	0.235102
Column2(Electric drive)	50	6	0.12	0.107755
Column3Ammonia	50	0	0	0
Column4Hydrogen	50	0	0	0
Column5Biofuel-HVO	50	0	0	0
Column6Methanol	50	0	0	0

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	2.413333	49	0.049252	0.83874	0.766716	1.406423
Columns	5.28	5	1.056	17.98332	3.47E-15	2.250876
Error	14.38667	245	0.058721			
Total	22.08	299				

Source: Authors CalculatiOn

Recall that the third objective of the study is to compare the maturity for scalability of the alternative energy options for marine transportation in Nigeria based on the level of main current usages. The result in table4.17 shows that the aggregate level of main current usages of the alternative energy options for marine transportation as 18 and 6 respectively for LNG and Battery electric drive. Ammonia, Hydrogen gas, HVO and Methanol have 0 levels of main current usages. This shows an average of 0.36 and 0.12 level of main current usages of LNG and Battery electric drive powered vessels in the Nigeria maritime domain. It also implies that there are currently no vessels in the Nigeria maritime domain operating or powered by ammonia, hydrogen gas, HVO, and methanol alternative energy options. Thus, for scalability considerations from the perspective of main current usages, LNG and battery electric drive

energy options are more mature alternative energy options for implementation in marine transportation in Nigeria.

The test of hypothesis H_{03} shows f-score of 17.98, p-value of 3.47E-15, and f-critical of 2.251. Since the f-score (17.98) is greater than the f-critical (2.251; ie $17.98 > 2.251$), we reject the null hypothesis that there is no significant difference in the level of main current usages of the alternative energy options for marine transportation in Nigeria. We accept the alternate hypothesis that ‘there is significant differences in the maturity for scalability of alternative energy options for marine transportation in Nigeria based on the level of main current usages. This implies that LNG alternative energy option offers the most scalable alternative energy option for marine transportation in Nigeria based on the level of main current usages. Figure4.3 below for a pie chart depicting the degree of maturity for scalability of the alternative energy options for marine use in Nigeria based on the level of main current usages.

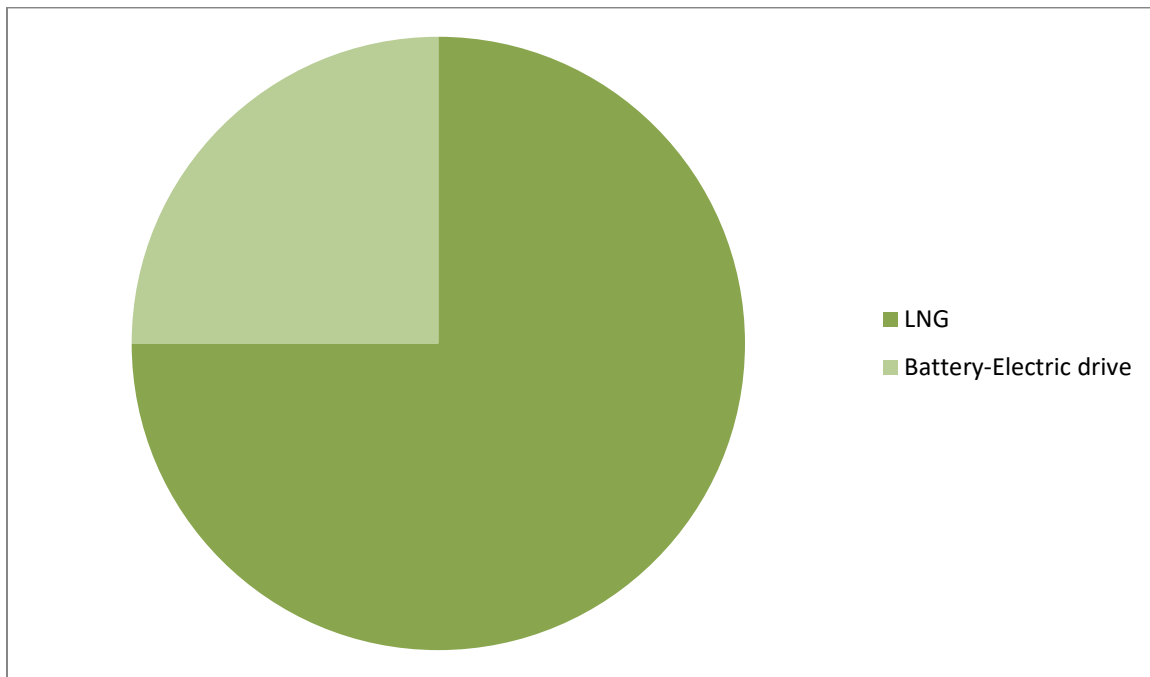


Figure4.3: Degree of maturity for scalability of alternative energy options for marine use based on the level of main current usages in Nigeria Source: Prepared by author.

Table4.18: Maturity for Scalability of Marine Alternative Energy Options Based on Global Production Capacity

SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Column 1LNG	250	1495	5.98	0.019679		
Column 2Electridrive	250	970	3.88	1.270683		
Column 3Ammonia	250	750	3	0.843373		
Column 4Hydrogen gas	250	745	2.98	2.549799		
Column 5Advanced bio fuel(HVO)	250	265	1.06	0.056627		
Column 6 Methanol	250	965	3.86	1.124096		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	3222.2	5	644.44	659.2669	0	2.220088
Within Groups	1460.4	1494	0.97751			
Total	4682.6	1499				

Source: Authors calculation

The fourth objective of the study is to compare the maturity for scalability of the alternative energy options for marine transportation in Nigeria based on the global production capacity and access to global product locations. The result in table4.18 shows that the aggregate score of each alternative energy option based on global production capacity and accessibility as 1495, 970, 750, 745, 265 and 965 respectively for LNG, Battery electric drive, ammonia, hydrogen gas, advanced bio-fuel (HVO) and methanol.

This shows average accessibility and global production capacity ratings on a scale between 0 and 6 of 5.89, 3.88, 3.0, 2.98, 1.06 and 3.86 respectively for LNG, electric drive, ammonia, hydrogen gas, HVO and methanol alternative energy sources. This implies that LNG with an average accessibility and production capacity rating of 5.89 on a maximum scale of 6 is the most accessible and has the most satisfactory global production capacity. This is followed in that order by electric drive (3.88), methanol (3.86), ammonia (3.0), hydrogen gas (2.89) and advanced bio-fuels-HVO (1.06). Thus, for scalability considerations from the perspective of accessibility and

global production capacity, LNG energy option is also the most mature alternative energy option for implementation for marine transportation in Nigeria.

The test of hypothesis H_{04} shows f-score of 659.266, p-value of 0, and f-critical of 2.220 at 5 degrees of freedom. Since the f-score (659.266) is greater than the f-critical (2.220; i.e. $659.266 > 2.220$), we reject the null hypothesis that there is no significant difference in the level of global production capacity and accessibility of the alternative energy options for marine transportation in Nigeria. We accept the alternate hypothesis that ‘there is a significant difference in the maturity for scalability of alternative energy options for marine transportation in Nigeria based on the level of global production capacity and accessibility to production locations. This implies again that, LNG alternative energy option offers the most scalable alternative energy option for marine transportation in Nigeria accessibility and global production capacity. This is followed by electric drive electric drive and methanol. Figure 4.4 below for a pie chart depicting the degree of maturity for scalability of the alternative energy options for marine use in Nigeria based on the global production capacity and accessibility.

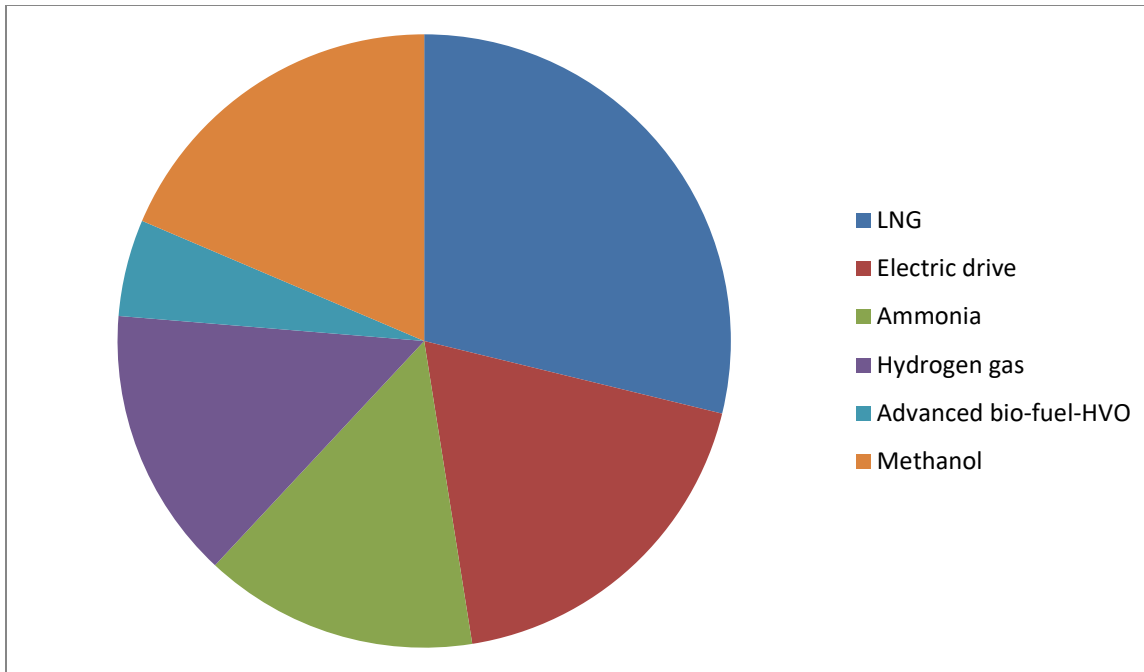


Figure4.4: Degrees of maturity for scalability of alternative energy options for marine transportation in Nigeria based on global production capacity and accessibility.

Source: prepared by author

Table4.19: Comparing Maturity for scalability of alternative energy options for marine use in Nigeria based on availability and bunkering infrastructure on land

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Column 1 LNG	250	1500	6	0
Column 2Electric drive	250	830	3.32	3.632129
Column 3 ammonia	250	110	0.44	0.729317
Column 4hydrogen gas	250	70	0.28	0.804819
Column 5HVO	250	0	0	0
Column 6Methanol	250	315	1.26	2.442169

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	6900.083	5	1380.017	1088.279	0	2.220088
Within Groups	1894.5	1494	1.268072			
Total	8794.583	1499				

Source: Author's calculation

The fifth objective of the study is to compare the scalability of the alternative energy options for marine transportation in Nigeria based on the availability and bunkering infrastructure on land. The result on table4.19 shows that the average score of each alternative energy option based on availability and bunkering infrastructure on land is 6, 3.32, 0.44, 0.28, 0.0 and 1.26 respectively for LNG, Battery electric drive, ammonia, hydrogen gas, HVO and methanol.

This implies that similar to the level of current main usages and global production capacity, LNG has with an average availability and bunkering infrastructure score of 6.0 on a maximum scale of 6, have the most availability and bunkering infrastructure on land rating. This is followed in that order by electric drive (3.32), methanol (1.26), ammonia (0.44), and hydrogen gas (0.28). HVO has availability and bunkering infrastructure on land score of 0. Thus, for scalability considerations from the perspective of availability and bunkering infrastructure on land, LNG

energy option offers the most mature alternative energy option for implementation for marine transportation in Nigeria.

The test of hypothesis H_0 shows f-score of 1088.27, p-value of 0, and f-critical of 2.220 at 5 degrees of freedom. Since the f-score (1088.27) is greater than the f-critical (2.220); i.e. $1088.27 > 2.220$, we reject the null hypothesis that there is no significant difference in the level of availability and bunkering infrastructure on land of the alternative energy options for marine transportation in Nigeria. We accept the alternate hypothesis that ‘there is a significant difference in the maturity for scalability of alternative energy options for marine transportation in Nigeria based on the level of availability and bunkering infrastructure on land. This implies again that, LNG alternative energy option offers the most scalable alternative energy option for marine transportation in Nigeria from the perspective of availability and bunkering infrastructure on land. This is followed by electric drive electric drive and methanol. See figure4.5 below for a bar chart comparing the maturity for scalability of the alternative energy options for marine use in Nigeria based on the availability and bunkering infrastructure on land

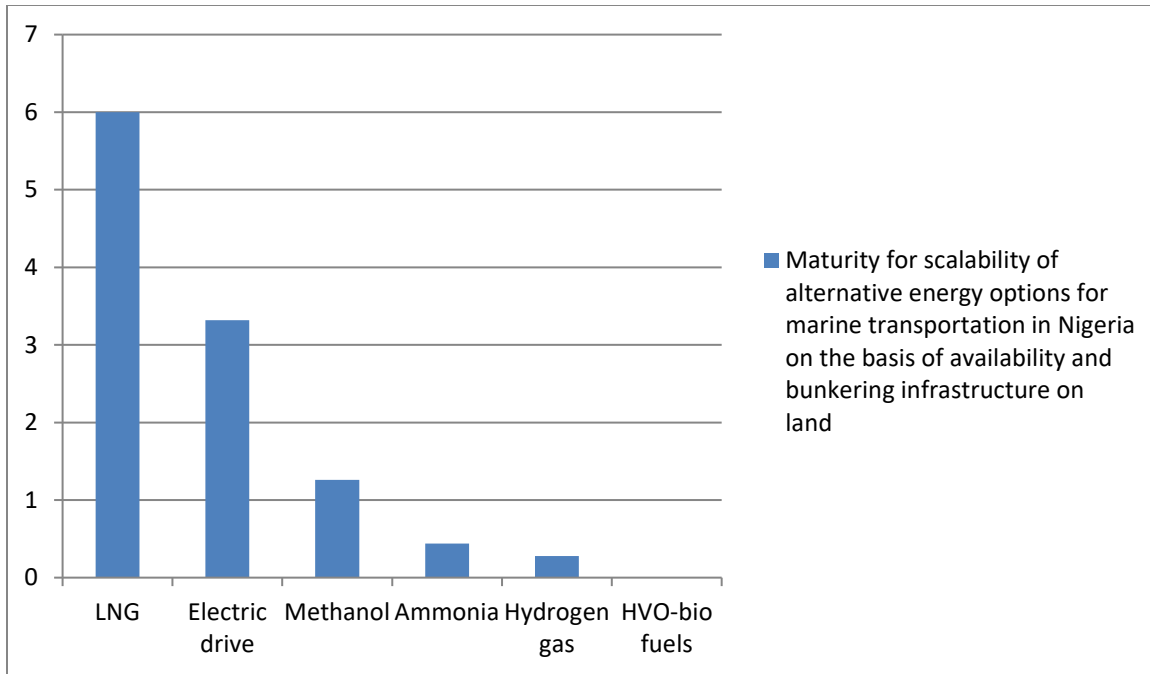


Figure4.5: Maturity for scalability of alternative energy options for marine transportation in Nigeria on the basis of availability and bunkering infrastructure on land.

Source: prepared by author

Table4.20: Alternative energy options for marine transportation in Nigeria arranged in decreasing order of maturity for scalability based on three identified criteria.

Criteria	Alternative energy option(s)	Average score	Rank
Level main current usage	LNG	0.36	1 decreasing
	Battery Electric Drive	0.12	2 order
Global production capacity and accessibility	LNG	5.98	1 of maturity
	Electric drive	3.88	2 for
	Methanol	3.86	scalability
	Ammonia	3.0	3
	Hydrogen gas	2.55	4
	Advanced bio-fuels – HVO	1.06	5
Availability and bunkering infrastructure on land	LNG	6	1
	Electric drive	3.32	2
	Methanol	1.26	3
	Ammonia	0.44	4
	Hydrogen gas	0.28	5

Source: Author's

Table 4.20 above indicates that based on the three scalability sub-criteria, LNG has a scalability ranking of 1 and highest mean scalability score. As a result, LNG is the alternative energy source with the most scalability potentials and maturity for implementation for marine use in Nigeria. This is seconded by electric drive with a maturity for scalability ranking of 2.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The result indicates that for LNG alternative energy option, the most important economic concern and consideration by ship-owners for its full implementation for marine transportation in Nigeria is the ease of access to maintenance and maintenance cost rather than capital cost and energy cost. For electric drive and advanced bio-fuel (HVO) alternative energy options, the most important economic concerns of ship owners and operators is the capital cost of acquisition of the electric drive and HVO ship propulsion technology rather than energy cost and maintenance cost. Lastly, for ammonia, hydrogen gas and methanol alternative energy sources, the most important economic consideration by ship owners and operators in Nigeria are the energy cost.

The scalability potentials of the alternative energy sources shows that, apart from diesel, LNG is presently the most scalable alternative energy option for implementation for marine transportation in Nigeria based on the level of main current usage, global production capacity cum accessibility, and availability of bunkering infrastructure on land.

5.2 Recommendations

It is recommended that:

- (i) the Nigeria authorities should commence the process of implementing the use of alternative greener energy for maritime transportation by first implementation the use of LNG energy as alternative to diesel energy source.
- (ii) LNG ranks best with regards to maturity for scalability in Nigeria and ship-owners and operators already considers it more economically beneficial and considers the

capital cost and energy cost of LNG fuel option acceptable and within reach. Since only the maintenance cost of LNG technology option is a significant economic sub-criterion most considered by operators, authorities should set strategies in place to develop LNG ship propulsion technology maintenance facility in Nigeria to make accessibility to maintenance of LNG shipping technology easy and limit the costs of maintenance to operators.

- (iii) The implementation of use of electric drive for marine propulsion in Nigeria should also be prioritized to follow LGN. Electric drive is second most preferred alternative energy type after LNG.

5.3: Contribution to Knowledge

The study has for the first time developed a ranking of the alternative energy sources for marine transportation in Nigeria based on the level of current usage, global production capacity and accessibility and availability cum bunkering infrastructure, using AHP as tool. The ranking is presented based on the result and findings of the study as shown below:

Table4.20: Alternative energy options for marine transportation in Nigeria arranged in decreasing order of maturity for scalability based on three identified criteria.

Criteria	Alternative energy option(s)	Average score	Rank
Level main current usage	LNG	0.36	1 decreasing
	Battery Electric Drive	0.12	2 order
Global production capacity and accessibility	LNG	5.98	1 of maturity
	Electric drive	3.88	2 for
	Methanol	3.86	scalability
	Ammonia	3.0	3
	Hydrogen gas	2.55	4
	Advanced bio-fuels – HVO	1.06	5
Availability and bunkering	LNG	6	1



infrastructure on land	Electric drive	3.32	2
	Methanol	1.26	3
	Ammonia	0.44	4
	Hydrogen gas	0.28	5

Source: Author's

As shown in table 4.20, LNG has a scalability ranking of 1 and the highest mean scalability score. As a result, LNG is the alternative energy source with the most scalability potentials and maturity for implementation for marine use in Nigeria. This is seconded by electric drive with a maturity for scalability ranking of 2.

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APPENDIX-1

**FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, DEPARTMENT OF
MARITIME MANAGEMENT TECHNOLOGY**

**RESEARCH TOPIC: ANALYSIS OF ALTERNATIVE SOURCES OF ENERGY FOR
MARINE TRANSPORTATION IN NIGERIA**

**THIS IS A QUESTIONNAIRE DEVELOPED TO COLLECT RESEARCH DATA ON THE
ABOVE PROJECT TOPIC AND IS INTENDED TO BE ADMINISTERED TO
RANDOMLY SELECTED INDIGENOUS SHIPOWNERS IN NIGERIA**

SECTION A: PRELIMINARY SECTION

**Please Fill this section with your personal information and proceed to subsequent sections
to kindly provide responses to the questions to the best of your knowledge.**

- (i) Occupation: -----
- (ii) Sex: -----
- (iii) Name of company:-----
- (iv) Educational Qualification: -----
- (v) Location of company:-----
- (vi) Dominant ship types : -----

SECTION (B)

The Nigerian Indigenous ship-owners employ multiple ship-types using varied alternative energy options and contribute significantly to the carriage and development of coastal trade in Nigeria. Most importantly, they provide employment to numerous seafarers and many others whose livelihood is dependent on the sea for sustenance. Marine Diesel fuel types currently dominate energy usage for ship propulsion by indigenous ship owners.

(Please select the options below that best describes your experience in the industry (√).

- (1) Are you aware of the adverse environment effects of the use of heavy diesel fuel oil for marine transportation related to the high emission performance of diesel fuel?

Yes	No	Neutral

- (2) Are you aware of the current IMO emission regulations particularly the Sulfur cap and GHG regulations that came into force in 2019; to regulate the use of heavy diesel oil for marine transport and reduce the environments impacts?

Yes	No	Neutral

- (3) Do you agree that the implementation of the emission regulations by the ship-owners in Nigeria will increase their operating cost, affect their profits, their local and global competitiveness with foreign ship-owners?

Strongly agree	Agree	Strongly Disagree	Disagree

- (4) If your answer to (3) above is yes, do you agree that the availability, adoption and use of alternative energy types, other than heavy diesel oil, will preferable help local ship-owners to overcome the challenges of marine diesel fuel type usage?

Yes	No	Neutral

SECTION C

The IMO in order ensure safe and sustainable global environment by eliminating and reducing emissions from shipping, and to help ship owners overcome the challenges posed by the emission regulations has developed various alternative energy sources for marine transportation.

(5) Please select the various alternative energy sources, other than marine diesel fuel, that, you are aware of their application for ship-propulsion in the maritime transport sector?

LNG	BARTRY ELECTRIC	AMMONIA	HYDROGRN GAS	ADVANCED BIO-FUEL (HVO)	METHANOL

(6) Please indicate the number of vessels in your fleet:

No. of ships

(7) Please indicate by writing how many vessels in your fleet are currently powered by the various alternative energy types.

LNG	DIESEL	BARTRY ELECTRIC	AMMONIA	HYDROGRN GAS	ADVANCED BIO-FUEL (HVO)	METHANOL

(8) Based on your experience, on a preference scale from 1 – 6, please rate by ticking (√), your preferred alternative energy type other than diesel, based on propulsive performance of the fuel type (Note: 6 indicate best performance while 1 indicates least performance.

Diesel is used as the basis of comparison as the best performer).

ENERGY SOURCE	1	2	3	4	5	6
LNG						diesel
BARTRYELECTRIC						diesel
AMMONIA						Diesel
HYDROGEN GAS						diesel
ADVANCED BIOFUEL (HVO)						diesel
METHANOL						diesel

SECTION D: SCALABILITY OF ALTERNATIVE ENERGY SHIP TYPES

The IMO notes that Scalability is a measure of the possibility and/or level of use and maturity of various alternative energy and relative technology types, as basis scaling-up to massive use of such technology and energy type. Scalability is viewed to depend on (i) main current usages (ii) availability of fuel type and related bunkering and maintenance infrastructure on land (iii) global production capacity and locations.

(9) Please indicate the number of vessels in your fleet currently that operate on various alternative energy types.

ENERGY SOURCE	0	1	2	3	4	5	others
LNG							
BARTRYELECTRIC							
AMMONIA							
HYDROGEN GAS							
ADVANCED BIOFUEL (HVO)							
METHANOL							
MARINE DIESEL							

(10) Availability of energy/fuel types is important to ensure unhindered access to energy/fuel for ship operations. Please rate the percentage availability rate of each alternative energy type in Nigeria.

ENERGY SOURCE	0%	10%	20%	30%	40%	50%	60%	70	80	90	100%
LNG											
BARTRYELECTRIC											
AMMONIA											
HYDROGEN GAS											
ADVANCED BIOFUEL (HVO)											
METHANOL											
MARINE DIESEL											

(11) Please rate the current availability rate of bunkering and maintenance infrastructure of each alternative energy source in Nigeria.

ENERGY SOURCE	0%	10%	20%	30%	40%	50%	60%	70	80	90	100%
LNG											diesel
BARTRYELECTRIC											diesel
AMMONIA											diesel
HYDROGEN GAS											diesel
ADVANCED BIOFUEL											diesel

HYDROGEN GAS	
ADVANCED BIOFUEL (HVO)	
METHANOL	
MARINE DIESEL	

(15) Please indicate the estimated revenue you earn from the use of a unit ton and/or one megawatt of each alternative energy type

ENERGY SOURCE/TYPE	REVENUE (USD)
LNG	
BARTRYELECTRIC	
AMMONIA	
HYDROGEN GAS	
ADVANCED BIOFUEL (HVO)	
METHANOL	
MARINE DIESEL	

(16) On a scale 1 -10, rate the most alternative energy technology types in terms of which technology type (engine technology, storage technology, etc) offers the most expensive cost of capital acquisition.

Alternative Energy Technology types	1	2	3	4	5	6	7	8	9	10
LNG										
BARTRYELECTRIC										
AMMONIA										
HYDROGEN GAS										
ADVANCED BIOFUEL (HVO)										
METHANOL										

(17) For conversion of marine diesel engine technology type to alternative energy technology types and pathways, which alternative energy types offer the most expensive capital conversion costs? Please rate the conversion costs of each alternative energy technology type, on the scale below.

Alternative Energy Technology types	1	2	3	4	5	6	7	8	9	10
LNG										
BARTRYELECTRIC										
AMMONIA										

HYDROGEN GAS										
ADVANCED BIOFUEL (HVO)										
METHANOL										

(18) Which alternative energy types offer the most expensive capital maintenance costs?

Please rate the maintenance cost of each alternative energy technology type on the scale below.

Alternative Energy Technology types	1	2	3	4	5	6	7	8	9	10
LNG										
BARTRYELECTRIC										
AMMONIA										
HYDROGEN GAS										
ADVANCED BIOFUEL (HVO)										
METHANOL										