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Abstract

Title of Dissertation: **Alternative Marine Fuel Transition: A multi-criteria appraisal with insights for container ship operators.**

Degree: **Master of Science**

This paper responds directly to an uncontroversial truth that, the solutions to the most pressing energy issues within international shipping must take fresh considerations on. Solutions may also result in the energy ecology having to reconstitute itself. Furthermore, it is argued that meaningful transition should be a function of avoiding linear, singular thinking about the future.

Chapter II reviews key literature and discourse on the methodology on existing emissions and the fuel options that are the subject of this study, as a precursor to the full methodology of the study, Chapter III.

The experiment, Chapter IV, is comprised of Multi-Criteria Decision-Making data processing and experimentation on dependent variables. The performance of fuel alternatives for an existing vessel is understood through future scenarios and analysed in the Chapter V, the penultimate facet of this study.

KEYWORDS: Alternative fuels, Multi-criteria, Energy Planning, Green Shipping, GHG Emissions, Transition

Table of Contents

Declaration	Error! Bookmark not defined.
Acknowledgements	Error! Bookmark not defined.
Abstract	i
Table of Contents	iv
List of Tables	vii
List of Figures	viii
Figure 1: Voyage Specifications	viii
.....	viii
Figure 2: Trade between chosen voyage regions	viii
Nomenclature	ix
I. INTRODUCTION	10
The Global Transition toward Sustainability	10
A Shifting Energy Consciousness	10
Decarbonizing International Shipping	11
The Research Problem	12
The Research Question	13
II. LITERATURE REVIEW	14
Policy and Regulation	14
Climate Change and International Shipping	14
Emissions Abatement	15
Technology	15
Operational Efficiency	16
Alternative Fuel Technology	17
Beyond Abatement	17
Fuel Options	18
Fuels to be studied.....	18
III. METHODOLOGY	19
Research Strategy	19
Research Paradigm	19
Quasi-Experimental	20

Research Design	21
Vessel	21
Voyage	22
Research Operationalization	23
Sensitivity and Limitations	23
Evaluation	24
Data	25
IV. EXPERIMENT	27
Baseline Values	27
Stakeholder Engagement	28
External Validity	28
Survey	28
Performance Criteria	29
Safety.....	30
Externalities.....	30
Price.....	31
Environment	31
Technology.....	33
TOPSIS	33
Normalised Ratings	33
Weighted Normalised Ratings	34
Ideal Solutions	35
Positive (Zenith) & Negative (Nadir) Ideals	35
Separation and Closeness	35
Preference Order	36
V. ANALYSIS AND CONCLUDING REMARKS	37
Experiment Findings	37
Preference Order Rankings	37
Temporality	38
Future Scenarios	38
Alternative Fuel Ecology	39
Direct and Indirect Transitions	39
Democratizing the Fuel Market	41
The Future of Green Shipping Management	41

Absorbing External Benefit	42
VI. APPENDICES	44
Appendix 1: Target Vessel	44
Appendix 2: Benchmark Values.....	44
Appendix 3: TOPSIS Performance Values	45

List of Tables

Table Number and Title	Page Number
Table 1: Alternative Fuel Options	19
Table 2: Alternative Fuel Data Points	28
Table 3: Stakeholder Survey	31
Table 4: Normalized Ratings	36
Table 5: Weighted Normalized Ratings	36
Table 6: Ideal Solutions	37
Table 7: Distance from Ideals	38
Table 8: Preference Order Rankings	39

List of Figures

Figure 1: Voyage Specifications

Port of origin (Departure from)	Osaka, Japan
Port of destination (Arrival to)	Napoli, Itali (16 days)
Distance (Nautical Mile)	8838
Fuel price (USD / Ton), HFO 380	427.75
Auxiliary engine daily consumption	10
Daily Charter rate (USD/Day, for 300 days)	15,250
Vessel Maximum Applicable Speed (knots)	22.8
Vessel Minimum Applicable Speed (knots)	18.8

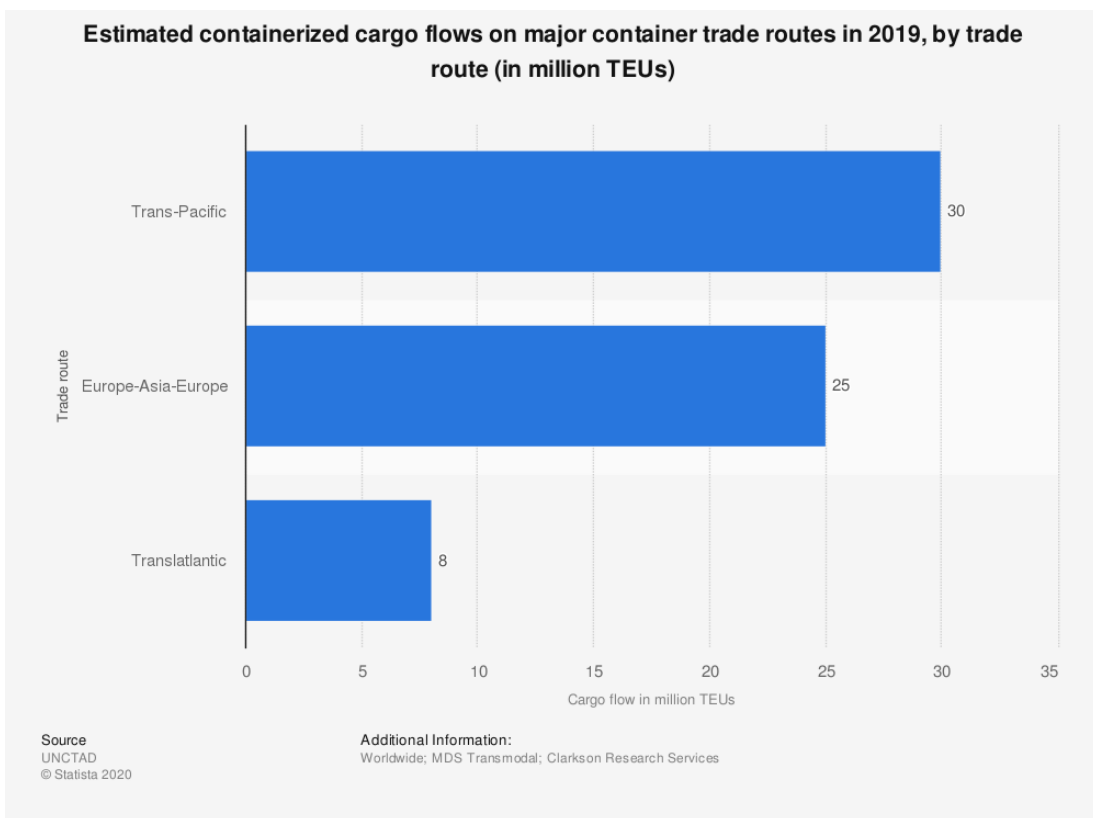


Figure 2: Trade between chosen voyage regions

Nomenclature

MCDM: Multi-criteria Decision Making

IMO: International Maritime Organization.

SO_x: Sulphur Oxide

NO_x: Nitrogen Oxide

GWP: Global Warming Potential

GHG: Greenhouse Gasses

EU: European Union

OPEX: Operational Expenditure

CAPEX: Capital Expenditure

NPV: Net Present Value

HFO: Heavy Fuel Oil

LNG: Liquefied Natural Gas

IPCC: Intergovernmental Panel on Climate Change

Maersk Laguna: Laguna

TEU: Ton-equivalent Units

UNCTAD: United Nations Conference on Trade and Development

MSDS: Marine Safety Data Sheet

I. INTRODUCTION

The Global Transition toward Sustainability.

A Shifting Energy Consciousness.

Throughout the storied history of energy, episodes of transition have occurred contemporaneous to the development of an energy consciousness. The relationship mankind has had with energy, punctuated by shifts from one resource to another, has and continues to play a pivotal role in the trajectory of societies. In this context, sustainability is understood as the property of a source of energy, to supply the demand of individuals, states and industries that exist and thrive as a result of a perceived abundance of energy.

Perhaps for the first time throughout this progression, we find ourselves redefining the necessitating factors for energy transition in general, and the definition of sustainability in particular. This is the transition not just in energy source, but in the underlying global energy consciousness. Grubler affirms this when he observes that; ‘the need for the “next” energy transition is widely apparent as current energy systems are simply unsustainable on all accounts of social, economic, and environmental criteria’ (Grubler, 2012).

The shift in global consciousness infers a transitional period, which highlights the aforementioned considerations. “In other words, ...an energy transition refers to the time that elapses between the introduction of a new primary energy source, or prime mover, and its rise to claiming a substantial share of the overall market” (Sovacool, 2017). The dominant narrative of the shift in energy consciousness is one that espouses a move **away** from finite, harmful fossil fuels and **toward** abundant, “clean” energy that puts mankind and his standard of living in tandem with the natural procession of the environment.

Decarbonizing International Shipping

It follows then, that the most urgent undertaking of this energy transition is to reduce the environmental degradation, caused by the current energy ecology. More specifically, the reduction of climate change; the single greatest anthropogenic consequence of the way we extract, consume and dispose of energy the world over. This is evidenced in the World Meteorological Organization’s statement on the State of the Global Climate. The statement reveals to us that “The global mean temperature for 2018 is estimated to 0.13 °C above the pre-industrial baseline (1850-1900)” (World Meteorological Organization, 2019).

The correlation is fairly intuitive. The rise of industry coincides with a rise in temperature. This is informed by a rise in demand for energy, it’s products, derivatives and outputs [from industry]. Additionally, it is also worth noting that the specific consequence that a change in energy use attempts to bring about is the reduction of the emission of Greenhouse Gasses (GHG’s)- chief among them being carbon.

Across a wide variety of international study, and indeed in the formulation of a concerted effort by all parties responsible and affected by the negative consequences of GH emissions, the state is no longer viewed as the sole unit of analysis. This is not to diminish its importance, but rather to signify the importance and complexity of other actors in the international system. It is at this moment, we introduce industry as a whole, with focus on the shipping industry.

The shipping industry is touted as the world's most global and globalizing industry, that has served and connected the planet and its people for centuries (Stopford, 2009). It should follow that, as societies have made use of large amounts of energy to develop themselves, the service that aggregates the project of modernity and development is also a large consumer of oil- and a polluter of the environment. To be precise, "it is fully recognised that CO2 emissions from the industry as a whole (some 2.2% of global emissions) are comparable to those of a major national economy" (International Maritime Organization , 2015).

This amount, comparable to the total emissions of Germany or Canada, is dominated by the consumption of marine (bunker) fuels; that power and propel ships much like the shipping industry powers and propels the global economy. Consequently, the premier regulatory administrative body of the shipping sector, the International Maritime Organization, has led the charge to be part of the global effort to reduce the emissions of greenhouse gasses in general, and to reduce the emissions of the shipping industry in particular.

The Research Problem

The problem that this paper will address is derived from a necessity to make good decision-making about the future, today. The challenge the research seeks to address is that of a particular stakeholder- any iteration of a vessel operator- and the need to make a balanced decision about the selection of a proposed future alternative.

Two things are the result of this problem. Firstly, it is to examine the relationship between a disaggregated spectrum of attributes and an equally diverse group of fuel alternatives. Secondly, the objective is to examine the ability of MCDM to respond to an evolving maritime energy reality through scenario experimentation and analysis. This includes managing the sensitivity of the predictive inputs of the model.

The Research Question

Questions that this problem finds efficacy in include: ‘What is the best alternative fuel for a vessel operator?’ ‘How do we evaluate fuel alternatives against competing demands?’ More explicitly, the research question that comes as a result of both macro and micro levels of context is;

What is the ideal alternative marine fuel option, for container ship operators?

Subsequent to this core question, is the subtext that acknowledges the use of vessel and voyage-based approaches. In this, an existing vessel and existing maritime route are introduced to increase the external validity of the research by taking real-world inputs for the decision-making modelling.

In addition to this, is the use of MCDM tools to arrive at a decision, whose values will be manipulated to mimic an uncertain future. It is worth noting that, while it is not the main focus of the study, the study itself inevitably calls for an interrogation of MCDM instruments themselves; its robustness and its agility in handling a variety of considerations and scenarios.

II. LITERATURE REVIEW

It is acknowledged at this early stage that the research operates from the premise; a decision to select a fuel amongst a set of options does not take place in a vacuum. Alternative Fuels represents one planet in the emissions abatement galaxy of international shipping.

Policy and Regulation

Climate Change and International Shipping

Similar to its airborne counterpart, and contrary to rail and road transport; shipping is acutely situated in the spectrum of environmental and climate change policy. Doelle and Chircop, as part of a wholistic appraisal of the IMO's Greenhouse Gas Strategy, point out that the Paris Agreement 'does not specifically mention emissions from international shipping' (Doelle & Chircop, 2019).

One can see the unique way in which shipping is conceptualized with respect to its contribution to climate change. Academic and industry parlance converge where, as is the case in several publications, shipping accounts for emissions similar to an industrial and economic powerhouse such as Germany, and not an approximation of 2.2% of total global emissions (Acciaro & McKinnon, 2020).

While it may be easy to dismiss these observations as immaterial, the literature through which the trajectory of climate change policy is understood draws us to the complexity of both the challenges and solutions within international shipping. As far back as 2012, authors such as Anderson and Bows have pointed out the latent disparity between international commitments on climate change as well as the incumbencies on shipping, as an industry without a single identity, as well as [the IMO,] a central authority with limited power (Anderson & Bows, 2012).

In essence, the literature makes it clear that the peculiarity with which shipping is framed as a climate change actor is a function of its internal composition. It is argued here that; following from the literature, the inability of the international system to find a singular language to regulate perhaps the world's most ubiquitous industry presents a new challenge for the considerations that must inform decision-making about the climate. More so, it calls for a reimagination of the extent to which decision-makers must assess and identify their own risks and impacts (Mansouri, Lee, & Aluko, 2015).

Emissions Abatement

The community of actors across the international shipping community, lead of course by the IMO, have embarked on the development of a pool of emissions abatement technology. In the existing literature, authors have taken different approaches in understanding the nature and prospects for the use of **technology and operational efficiency** as emissions abatement sources.

Technology

The former, with proponents such as Bouman et al., evaluate the emissions saving potential of varying technological options, such as improvements in hull design and modifications in power and propulsion. It is argued that these methods result in a higher emissions reduction potential, particularly for newer vessels (Bouman, Lindstad, Riialand, & Strømman, 2017).

Further literature on the technological measures either developed by the IMO, or the actual implementation of a selected set of technologies- as found in the study conducted by (Rehmatullaa, Calleyab, & Smith, 2017). The paper offers significant parallels with this research. Both studies take place against an uncertain temporal backdrop, where significant changes in the way energy decisions are made in general, and how emissions can be reduced in particular.

Operational Efficiency

The starting point for engaging the literature on the operational measures associated with emissions reduction [from international shipping] is a change in posture for the inquiry that characterizes the research as a whole. Put simply, the difference between technological and operational abatement is akin to the contrast between *what* gets done, and *how* it gets done. In this case, what gets done is the reduction of emissions from international shipping.

(Perera & Mo, 2016) juxtapose regulatory controls on emissions, such as the Technical Code, SOx Emission Limit and the persistence of Emission Control Areas, with the energy efficiency measures employed by vessels (and their operators) to reduce emissions and its cost- both incurred or created.

With respect to the operational measures that are applicable to an existing/retrofit vessel, this study establishes a link to the research as it presents a different emissions abatement conception. For prudential reasons, it is also worth including that the body of literature that evaluates operational measures that steer energy efficiency in the direction of emissions reduction also includes nuanced studies that focus on ship emissions in ports (Winnes, Styhre, & Fridell, 2015) and the challenges associated with implementation (Dewan, Yaakob, & Suzana, 2018).

Alternative Fuel Technology

Beyond Abatement

As the term suggests, abatement responds to the needs of ameliorating a problem. It would be remiss to conclude that focusing simply on reducing the adverse impacts is not useful, let alone necessary and urgent. It follows then, that the literature on abatement and its two broad categories (technical and operational) must be followed by a body of work that draws from the premise that there is no single ‘silver bullet’, alternative fuel technology that will power the world’s fleet into a sustainable, carbon-free future (Walker, 2019).

Authors that continue this line of thinking, also raise awareness on the impact that a transition away from a single fuel- that has enjoyed a century of dominance. Existing literature is dynamic in the way it views and engages the journey toward the energy future of international shipping, regardless of how it is contrived. Authors such as (Dominković, Bačekovićb, Pedersen, & Krajačićc, 2018) provide meta-analysis on the prospects for alternative fuels within transition at a systemic level. The argument made by authors of this conviction is that, marine transport is faced with a different set of economic barriers, along with a rapidly policy landscape. This imbalance calls for greater harmony along the production and value chains in the fuels sector (Wan, Makhoulf, Chen, & Tang, 2018).

The literature also includes variations of studies that make use of multi-criteria decision-making tools to determine what the best fuel option would be, given a set of conditions and assumptions. This study intends to add to existing literature by making use of this evaluative technique (MCDM).

This research exercise, follows on the work of (Hansson, Månsson, Brynolf, & Grahn, 2019), (Hansson, Brynolf, Fridell, & Lehtveer, 2020) and (Ren & Lützenb, 2017). It is also worth noting that each study, comes with its own unique multi-criteria evaluation tool. The motivations for the instrument utilized in this study are given in subsequent chapter

Fuel Options

While it may seem that the best fuel option for decision-makers will arise as the best from as large a sample space as possible. This paper presents an alternative view, which argues firstly that the differences among fuel options, as the range broadens, is directly proportional to the ability of MCDM tools to conduct proportional and fair study. In addition to a wide sample space being more laborious than thorough, having a rationale behind the selection of fuel options to compare allows for the researcher to present refined, and not narrow findings.

Fuels to be studied.

Alternative fuels are generally distinguished by energy carrier. (Brynnolf, Baldi, & Johnson, 2016) describe the categorization of alternative fuels (and indeed the categorization utilized throughout this study) with respect to their primary energy source and subsequent *energy carrier*. The authors state that the type of energy carrier fuel is significant, as it informs the movers required to convert chemical energy into mechanical energy.

For the purposes of the study, Table 1 provides an outline of the alternative fuel options that will be compared in the study.

Fuel Name	Production/Source	Fuel Type
HFO	Refining of crude oil	Diesel-Quality
LNG	Liquefaction of natural gas	Gases
Ammonia	Electrolysis	Fuel Cell
Methanol	Biomass	Alcohol
Liquid Hydrogen	Electrolysis	Fuel Cell

Table(1): Alternative Fuel Options

III. METHODOLOGY

Research Strategy

Research Paradigm

It is important to outline the paradigm, as it the philosophy for incorporating the observations made in the preceding chapters, with the method in which the research will achieve its unique objectives. The manner in which information is sought, variables are utilized and inferences are made is all a function of the selected paradigm.

For this, an undoubtedly quantitative research exercise, the research paradigm is characterized in terms of three elements. Its *ontology* (what is the nature of the knowledge that is generated) and *epistemology* (how to arrive at the conclusions we make about produced knowledge) graduate to and inform the *methodology* (the pragmatic steps to take, in order to access knowledge) (Trochim, Donnelly, & Arora, 2016).

This research takes on a **Positivist** paradigm. It understands that the truth about the area of study it is concerned with is singular (Kivunja & Kuyini, 2017). More specifically, the units of measurement in this study (properties of alternative fuel options) have single, relatively uncontroversial numerical expressions. This describes the epistemic foundation of the research exercise. The methodology that the paradigm lends itself to, adds to the idea of singularity by positing that the research variables can be measured, modelled and (where necessary) predicted and is unpacked in throughout the remainder of the chapter.

Quasi-Experimental

Central to the broader research method, is the posture of the research, with the respect to its essential design characteristics. Following the view that information about the area of analysis is singular and can be measured, the research designed as Quasi-Experimental. What is implied by this is that the research model intends to **compare** and identify the kind of **correlation** between variables.

Different to the two contrasting ends of the quantitative research design spectrum, quasi-experimental research design incorporates both descriptive aspects of comparison, with testing- the essence of [purely] experimental design (Steven M. Ross, 2013). For this particular research the alternative fuel options are measured against a criterion, the performance of said alternatives is then compared and ranked.

Following this, the independent variables will be manipulated, and the changes in the performance of the [fuel] alternatives will be measured once more. What makes this approach *quasi*-experimental is that it employs the use of **non-equivalent groups designs**. What this means is that information on the performance of fuel alternatives is gathered at more than one stage. For this particular research, the time-series is punctuated by scenarios; as both backdrops for strategic decision-making as well as iterations of future complexity and uncertainty (Stewart, French, & Rios, 2013).

Research Design

Vessel

The actual features of the **Maersk Laguna** [an existing vessel] are used to carry the method out. It is for this vessel, that the performances of alternative fuel options are measured on. The vessel's features and dimensions are in Appendix 1.

The initial motivation for selecting a [fully cellular] container ship- *Maersk Laguna* - is its position as a major contributor to the overall emissions from international shipping. The Second GHG [Add abbreviation] Study by the IMO [Add Abbreviation] highlights key figures in this regard. It carefully reiterates the prospect for growth within the maritime sector as a whole:

Instead, it is assumed that the average growth of containerized transport is 2 percentage points higher than that of other cargo types. This results in 55% of the global tonne-miles being attributed to containers, as opposed to 24% in 2007” (Second IMO GHG Study 2009, 2009).

In addition to this, the Study also reveals that the CO₂ efficiency of container ships in the TEU [Add Abbreviation] bracket that the Laguna falls under is poor; which would immediately raise concern to any decision-maker committed to environmental and business sustainability in tandem. The percentage of 16.6% as a reflection of the amount of CO₂ emitted per tonne-km as an absolute value makes a container vessel a worthwhile candidate for this kind of inquiry. This makes alternative fuel as an emissions abatement solution highly sensible for a container vessel that wants to remain competitive and productive.

To illustrate the extent to which container shipping is anticipated to contribute increasingly to shipping emissions, one must look at the growth prospects for the container division. According to the most recent UNCTAD [abbreviation here] Maritime Transport Review, container shipping makes up for 23% of new ship deliveries and registered a percentage change of 4.89% (the highest of all vessel classes) with respect to its share of the world fleet (UNCTAD, 2019). These two figures about the present and future of the container ship market provide additional justification for the choice of a container ship.

Voyage

For reasons akin to motivating the selection of the Laguna, the chosen voyage represents significant sea traffic, underpinned by the significance of that route in connecting markets. Put simply, the route chosen is influenced by trade between regions, and the business of the ports. The usefulness of this method is that input values for the TOPSIS Analysis can be refined closer to the exactitudes of the vessel, which underpins the pragmatic value of the research.

The chosen trade route, as shown in Figure 1, is between Osaka (JPOSA) to Napoli (Neapel-ITNAP). The figure also contains some standard voyage specifications.

According to Container Trade Statistics [Add Abbreviation], the containerized cargo flows between the respective regions the ports in the voyage find themselves in (from the Far East/Asia to Europe) accounts for approximately 25 million TEU (UNCTAD, 2019). As Figure 2 indicates, trade between Europe and Asia is second only to trade within the Trans-Pacific region. Second place is no small feat as the Trans-Pacific region is the third largest free trade area in the world, contributing roughly 13.5% of the world's economic output (Drapkin, 2020).

Research Operationalization

Sensitivity and Limitations

It would be remiss to assume at any point that the research- conception and design to execution- is without challenges limitations. In fact, to state that this study is framed as **quasi-experimental** is its perceived as a limitation. Grabbe notes that quasi-experimental designs were initially undermined as a result of the lack of causality seen in true experimental designs (Grabbe, 2015).

It can also be added that the spectrum of quantitative research methodologies has a corresponding gradient of validity. Validity of the research design and methodology has **internal** (the strength of the design itself) and **external** (its practical usefulness) denominations.

The focal limitation/threat to the **internal** validity is that the research is designed primarily to test the relationship between two variables (the relationship between fuel alternatives and their attributes). This is positioned as a threat to the internal validity, as the research is designed merely to show *correlation*, and not necessarily causation. A true experimental research design would [making use of the scientific method] test two groups of variables for *causation*.

The researcher mitigates this threat by making use of scenarios in the latter stage of the research. Through the use of future states (scenarios), as an analytical framework highlights its experimental properties. The performance of the alternatives (against criteria in TOPSIS) is likely to fluctuate as the independent variables are manipulated.

This research divides variables into two groups to carry the research technique out; Dependent *control* variables and Independent, *treatment*, variables (Grabbe, 2015). The second limitation, the **external** threat, is concerned with external factors producing errors in output. Errors ultimately threaten the applicability of the model, as it is conditioned by external influence. A main source of this limitation is the potential for bias, in selecting which variables will fluctuate when a future scenario is introduced. This is in contrast with the random selection method that experimental approaches selecting employ to avoid bias.

The research manages this threat, through conducting a sensitivity analysis for the initial TOPSIS evaluation of ideal alternative fuel option. Secondly, the researcher attempts to avoid bias by selecting criterion that is common throughout adjacent and preceding studies

Evaluation

It is worth noting that decisions on how to handle the inevitable transition toward sustainable energy are made within the context of a high-risk, capital-intensive and operationally inelastic shipping industry (Stopford, 2009). The number of factors and stakeholders to consider, coupled with competing objectives add a significant degree of complexity to selecting the ideal alternative fuel. The area of decision-making that shipowners are faced with, appears in academic and industry parlance as *energy planning*.

Energy planning is understood as the act of developing long-term policies and positions to meet energy needs in the most efficient and environmentally responsible manner (Kaya & Kahraman, 2011). Kaya and Kahraman go on argue that multicriteria decision-making instruments are most effective in helping-decision makers navigate the complexity and uncertainty associated with [energy] transition.

The two main multicriteria instruments nominated by the researcher to carry the methodology out are the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). **TOPSIS**, as a decision-making technique, finds both the ideal and ‘anti’-ideal alternative.

Data

Owing to the fact that the evaluation of alternative fuel options requires a more wholistic conception of what informs the right decision, we can anticipate a great deal of heterogeneity between the kinds of data that must be collected to conduct the evaluation and subsequent experiment.

In fact, the *multitude* which lends itself to the concept of Multi-Criteria Decision-Making [Abbreviate as MCDM] speaks not just to the number of criterion that alternatives are measured up against. Taha and Daim add that “These methods can handle both quantitative as well as qualitative criteria and analyze conflict in criteria and decision maker” (Taha & Daim, 2013).

It is important that, relative to the varied nature of each criteria for selecting the best alternative fuel option, the data and its numerical expressions must be consistent. Without consistent data and measurable variables, the TOPSIS model collapses and scenarios will not be quantifiable. Table 2 illustrates the data for each evaluative criterion, which is sourced for each alternative fuel option.

<i>Criteria</i>	<i>Values</i>	<i>Delineation</i>
Technological Diffusion	Aggregation of existing data on similar existing target vessels.	Capital and operational expenditure changes.
Externalities	IPPC figures, adjusted to emission factors of relevant pollutants. This also includes calculations on [median] port variables.	The public health effects of air pollution as a result of international shipping.
Fuel Price	5-year average fuel price at nearest major bunkering port on prescribed voyage.	The sum of (among sundries) distribution costs, availability and levies/taxes.
Safety	Assignment of numerical values (index) for Maritime Safety Data Sheet Hazard Statements.	The physical and general health risk associated with handling, storing and burning fuel on-board.
Environment	IPCC Global Warming Potential figures.	Air emission levels and detriment caused to the environment.

IV. EXPERIMENT

This chapter contains the alternative fuel experiment. The experiment begins with a TOPSIS analysis; allowing for multiple objectives and attributes to be compared on a single metric. Following that, the input variables will be manipulated by way of Scenarios. The findings will be detailed and discussed in the chapter that succeeding chapter.

Baseline Values

It is necessary to note at this stage that baselines values were taken for the existing vessel, without a scrubber or any abatement measure. The sole motivation for this approach was to ensure that the feasibility of each alternative is not compromised by the existence of technology and measures that affect different fuel options differently.

Additionally, the researcher is aware of the advent of a global pandemic, which has

Table 2: Author's summary of data operationalization

had a profound impact on the performance of the industry in general, and fuel markets in particular. In instances where averages are gathered as values, the researcher has elected to take all values until the end of the first week of the year concurrent.

It is necessary to hold certain values constant, as they can develop into extraneous variables, which threaten to skew the relationship between variables that the experiment is concerned with uncovering. Benchmark figures and details of the vessel, and associated costs are found in Appendices 1-2.

Stakeholder Engagement

External Validity

It follows from an understanding that the difficulty of contemporary energy challenges within international shipping mirror the characteristics of the industry. There are many actors, competing motives, more than one proposed method and an evolving regulatory regime. Therefore, making decisions can be expected to be equally difficult.

The research has already prescribed and detailed MCDM techniques. For this study, it is the bedrock of the internal validity. External validity may be derived from the use of an existing vessel and route but alone this may not suffice in achieving truly applicable solution. Coupled with this is that any decision-making model that considers differing factors must itself be able to manage this competition for primacy.

Survey

Pursuant to this, the researcher embarked on a stakeholder engagement endeavour, in order to further connect the research with decision-makers and maintain external validity for the research. In doing this, the researcher was able to gather the weighting for the decision matrix in the TOPSIS analysis. This allows for each criterion to carry weighting, signalling importance to stakeholders.

Table 3 contains survey questions, for which two stakeholders took part.

Fuel Attribute and Rating:	Not Important at all (1)	Slightly Important (2)	Important (3)	Fairly Important (4)	Very Important (5)	<i>No Option/ Prefer not to Answer</i>
Price of a fuel						
Technology						
Environmental Safety						
Existing Regulation						
Public Health						

Performance Criteria

The criteria for selecting the best alternative fuel was selected after consulting literature on existing studies and factoring the climate reality in all of its permutations. What is meant by climate reality is what Wan et al. refer to when they describe international shipping as heavily reliant on fossil fuels, subject to stalling regulation and still catching up to technology (ZhengWan, Makhloufi, Chen, & Tang, 2018).

Essentially, in order for a vessel operator to select the most ideal fuel for the Laguna, they are to consider factors beyond considerations internal to the shipping firm. They are to take into account moving parts, beyond their purview, if they are to achieve sustainable, energy efficient fuel planning.

Safety

Safety refers to the handling of the fuel and its own chemical properties. In general, this criterion intends to establish the exposure to health and operational safety threats. Given that alternative fuel options draw from different energy sources, and the conversion from chemical to mechanical energy varies, safety becomes a prominent consideration.

Given the host of properties a fuel may have and the high level of detail required in safety considerations; three values (from Maritime Safety Data Sheet requirements) were chosen to give a picture of alternative fuel safety:

1. **Flash-Point:** The lowest temperature at which a chemical can vaporize to form an ignitable mixture in air (ChemSafetyPro, 2016).
2. **Short-Term Exposure Limit:**
3. **Boiling Point:** The temperature at which liquid turns to gas. This value is especially significant, as some fuel options are held in a cryogenic state.

Externalities

Externalities, not to be conflated with the general emissions of GHG's , focus on quantifying the human cost associated with air emissions from international shipping. More so, a focus on the externalities constructed for this study seeks to establish a cognitive link between the dangers of GHG emissions in general, and the threat to health that these pollutants pose. This is done so as to pre-emptively fortify the significance of a study such as this one, against opposition on grounds that the effects of pollution are cumulative and are rarely experienced in a single lifetime.

Figure 3 outlines the externality, its impact and monetary cost- in Euros, per unit of fuel burned. It is also worth noting that the figures are national aggregates. They are taken from the destination port (Napoli), as found in the EU Handbook on the External Cost of Transport.

<u>Externality</u>	<u>Health Threat</u>	<u>External Cost</u> <u>(€/kg)</u>
Sulphur Oxide (SOx)	Respiratory: bronchitis, asthma.	25.4
Nitrogen Oxide	Cardiovascular: strokes, hypertension.	12.7
Particulate Matter (incl. Black Carbon)	High blood pressure, premature death [in children]	19

Figure 3: Externalities

Price

Price is a fairly self-explanatory consideration. While the paradigmatic shift within shipping calls for changes in the way that private actors engage the environment- the most public of public goods- it would be naïve to assume that the best fuel for vessel operators doesn't have to be one that it can afford. This consideration is the most pragmatic.

Environment

Perhaps the most straightforward of the criterion with respect to data and relevance in contemporary discourse and study on alternative fuels. Table 3 details the selected pollutants, and how the *cleanliness* of each fuel alternative was calculated.

Fuel	Greenhouse Gas	Emission Value	Totals	Rank
			<i>kg/MJ</i>	
Ammonia	Carbon Dioxide (CO2)	30	58000.5	2
	Methane (CH4)	0.0005		
	PM10-Black Carbon	28		
HFO	Carbon Dioxide (CO2)	78	106000.5	4
	Methane (CH4)	0.0005		
	PM10-Black Carbon	28		
Methanol	Carbon Dioxide (CO2)	92.79744444	120797.4	5
	Methane (CH4)	0		
	PM10-Black Carbon	28		
Hydrogen	Carbon Dioxide (CO2)	22.4	50400.5	3
	Methane (CH4)	0.0005		
	PM10-Black Carbon	28		
LNG	Carbon Dioxide (CO2)	57	85280	1
	Methane (CH4)	0.28		
	PM10-Black Carbon	28		

Technology

The term technology as a performance criterion cannot go without any form of qualification. The ambiguity of the term with respect to a decision of this nature would compromise the internal validity of the study. More so, a clearly defined technological criteria requires an instrument that can guide proper decision-making.

For the purpose of this study, technology is understood as the cost of retrofitting the Laguna to achieve utilization of the alternative fuel. The costs are categorised as OPEX and CAPEX. Because the target vessel of the study is already 8 years into its lifespan, the change in costs are evaluated through a NPV (abbreviate) calculation. NPV ‘represents the surplus, at market price, the [investor] may earn, by selecting the specific project’ (Diakomihalis, 2003).

TOPSIS

For reference, the description of the different steps of the [TOPSIS] experiment is from (Papathanasiou & Ploskas, 2018). Additionally, all numerical values, formulae and spreadsheet data can be found in the Appendices.

Normalised Ratings

Normalisation refers to creating uniformity across values. The significance of this as a first step is indicative of the fact that decisions of this kind are made complex as there are differing units of measurement across the criteria. Normalisation refers to ranking alternatives using a formless numerical value. The Normalised Ratings are shown in Table 4:

	<i>LNG</i>	<i>Hydrogen</i>	<i>Ammonia</i>	<i>HFO</i>	<i>Methanol</i>	<i>Attribute Weights</i>
Safety	0.467392	0.430433	0.278363	0.455012	0.558347	0.15
Technology	0.482643	0.173100	0.313992	0.786541	-0.140904	0.30
Price	0.310260	0.820710	0.243775	0.347583	0.223461	0.25
Externalities	0.49893	0.006	1.123	23.611	12.700	0.10
Environment	0.43180	0.25520	0.29368	0.53672	0.61164	0.20

Weighted Normalised Ratings

What follows from this, is the factoring in of the weighting associated with each criterion. In this step, the Normalized Ratings are simply multiplied by the Attribute Weighting value (as a percentage). Table 5 contains those values.

	LNG	Hydrogen	Ammonia	HFO	Methanol	Attribute Weights
Safety	0.070	0.065	0.042	0.068	0.084	0.15
Technology	0.145	0.052	0.094	0.236	-0.042	0.30
Price	0.078	0.821	0.244	0.348	0.223	0.25
Externalities	0.0499	0.0006	0.1123	2.3611	1.2700	0.10
Environment	0.086	0.051	0.059	0.107	0.122	0.20

Ideal Solutions

After collating the performances of the fuel alternatives across the selected criteria; the experiment now allows for the identification of ideal types. The ideal/anti-ideal

	LNG	Hydrogen	Ammonia	HFO	Methanol	A+	A-
Safety	0.070	0.065	0.042	0.068	0.084	0.084	0.042
Technology	0.145	0.052	0.094	0.236	-0.042	0.236	-0.042
Price	0.078	0.821	0.244	0.348	0.223	0.078	0.821
Externalities	0.0499	0.0006	0.1123	2.3611	1.2700	0.001	2.361
Environment	0.086	0.051	0.059	0.107	0.122	0.051	0.122

Table 6: Ideal Solutions

solutions are the best ‘scores’ from the Normalised Decision Matrix.

Positive (Zenith) & Negative (Nadir) Ideals

From the ideal types we can immediately infer the best and worst performing fuels for each respective category. Though the analysis doesn’t end at this point, it is worth noting that only one fuel achieves positive ideal status, more than once. That is Hydrogen. It also happens to fare the poorest on investment and cost related standards.

Separation and Closeness

Separation measures indicate the distance each alternative fuel is from the ideal solution. Closeness, in contrast is, a value between zero and one and determines how

close an alternative is to a fuel option. For the alternative fuel options, Table 7 bears reference. v

Distance from both Ideals	Ideal Type	
	Positive Ideal	Negative Ideal
LNG	0.1103268012	2.435370821274430
Hydrogen	0.765832795903561	2.363529422851450
Ammonia	0.249014037766251	2.326535292654480
HFO	2.376576329188910	0.549717675107428
Methanol	1.294284153115660	1.244575991690830

Preference Order

Preference order refers to a final ranking of the alternatives. The results of which are contained in the forthcoming chapter. This, given the inputs and weighting serves as a model for the kind of processes and outcomes that result in an ideal solution for an alternative fuel question.

V. ANALYSIS AND CONCLUDING REMARKS

Experiment Findings

Preference Order Rankings

Table 8 lists the alternative fuel options, ranked 1st to 5th.

LNG	0.956661466690804	1st
Hydrogen	0.755275119219583	3rd
Ammonia	0.903316145093764	2nd
HFO	0.187854560854221	5th
Methanol	0.490210535714912	4th

As the table illustrates; the ideal solution presented by this study, and quantified through data inputs is LNG. The least ideal option, is HFO . The latter result is undoubtedly true. The fraternity of vessel operators for the Laguna and its ilk would benefit none from committing to a future dominated by the past.

Temporality

The research intends to make clear the temporal complexion of the outcomes. Indeed, the result is only a function of an agnostic decision-making instrument doing what the researcher tells it to do with the inputs it is given. It follows then that the inputs themselves are bound by time constraints. This occurs as a result of equal parts practical and prudential considerations.

We can infer from these results then, that LNG is the best option for the remainder of the lifespan of the vessel. The TOPSIS analysis may not give comprehensive insight into the scalability (and longevity) of this decision, and how malleable it is, to changes in the future. It must be acknowledged regardless, that the experiment has produced LNG as the ideal candidate for alternative fuel adoption for the Laguna.

Future Scenarios

When engaging scenarios, the research intends to respond to the fact of an uncertain future with respect to energy in general, and marine fuel in particular. With respect to this kind of undertaking and its denotation, that of an **energy planning** exercise, decision-makers (such as vessel operators) must contend with many possible future states of affairs against which decisions are made, as well as the pre-emptive nature of making energy decisions.

With respect to optimising multi-criteria decision making, scenario thinking (and the planning that it finds expression in) serves two key functions according to Stewart, French and Rios. Firstly, scenarios can serve as the backdrop for strategic decision making (Stewart, French, & Rios, 2013).

More so, future scenarios about alternative fuels, or indeed shipping as a whole, allow for decision-makers to plan into the future, against certain contexts. This goes to echo a common sentiment found in this paper that solutions need to be robust and agile in responding to an ever-changing policy, market and technological landscape. From this, one gains insight into the second function that scenario planning offers to MCDM experimentation: Robustness. Later studies such as the one carried out by Guivarch, Lempert and Trutnevyte set techniques out to “broaden the capacity to deal with complexity and uncertainty” (Guivarch & Robert Lempert, 2017). Their techniques map out story, simulation and alternative scenario generation methods. This is essential in carrying out an energy planning exercise, as the decision maker and test their model, and the alternatives against many contexts.

Alternative Fuel Ecology

Direct and Indirect Transitions

Perhaps a challenge that comes with harnessing micro and macro level decisions in international shipping is the differences in speed and expedience that external variables and influences move. What is implied by this is that the decision to adopt one alternative fuel, over the other is influenced by the feasibility and progress of the fuel and all of its inputs and constituent parts across other industries. More so, the production of alternative fuels does not only present a disruption to the traditional fuels landscape.

The introduction of marine applications to the traditional downstream use of fuel chemicals brings with it, its own turbulence. For one, once a product reaches applicability for a new market, that product is subject to being malleable to the requirements of regulation, perspectives of the end-users and the technical feasibility to deliver the product- relative to the size of the industry.

Against the existential backdrop of an industry in transition, and perhaps taking a slightly tangential approach to environmental sustainability, transition in the alternative fuel ecology is indeed linked to similar transitions at all levels. Johannah Christensen writes that achieving decarbonization in shipping could serve as a catalyst for a “global energy transition” (Christensen, 2020). He goes on to illustrate this reality by stating that of the U\$1 trillion investment needed to reach the targets set by the IMO, it is dominated by land-based energy needs. Up to 87% of the figure quoted by the Energy Transitions Commission for the Getting to Zero Coalition must be committed to facilities and infrastructure that can produce affordable clean fuels, sustainably.

The conviction of the researcher is that, there may be two levels of transition that international shipping must contend with. Firstly, the direct transition where vessel owners and operators select the best end product- to achieve the emissions targets. The second, a more indirect transition, refers to actors outside of the influence of the IMO. Indeed, energy transitions don’t take place in vacuums, but the challenge made evident by the research is the management of different levels of action and progress across the industries that provide inputs for what ends up being the single choice of fuel to use for a vessel.

The outcomes of the TOPSIS analysis are in line with the view that alternative fuels, and their diffusion is hindered almost solely by the cost of adopting the new fuel technology. Subsequently, the inference that can be made in this regard is that, for tributary industries and actors on the supply side of the alternative fuels market, cost reduction (either as a function of scale economies or innovation) will serve to make alternative fuels more competitive; resulting in a potential shift toward greater competition in terms of environmental responsibility and sustainable production.

Democratizing the Fuel Market

The prospect of a more price and cost-efficient alternative fuels market may provide some unintended market benefits for vessel operators. It has held true for several industries across many business cycles that democratizing an industry, allows for greater efficacy for consumers, and for a more diverse market. This claim is informed firstly by the notion that there is no ‘one-size-fits-all’ answer to the question of the fuel of the future.

The advent of marine fuels will prove impactful in (save for niched categories of vessels and engines) disaggregating the world fleet. The diversity of vessel types, functions, energy demands must also reflect in the range of fuels available to the industry. This may not be the greatest companion for firms and actors managing the rough waters of an energy transition, as short-medium term stability is incompatible with the discomfort of teething into a new way of doing things.

The key takeaways from the DNV-GL report state that 40%-80% of existing vessels will consume LNG (methane), while ammonia offers the most promise for new vessels (DNV-GL, 2019). What one can infer from this is that as the market for alternative fuels will have to travel across the transitional bridge; one that appears to be made up of a fossil fuel that is far cleaner- signalling environmental progress, and less costly, owing to its familial relationship with crude oil; the feedstock for bunker fuels.

The Future of Green Shipping Management

The dialectical relationship between vessel owner/operator (that works in the interest of private, economic interest) and regulators (the IMO in particular, with the arduous of serving as the only explicit source for environmental regulation) can be reimagined, with the advent of alternative fuel technology.

As it exists, in shipping and other energy-intensive industries, there is a gulf between the needs of private actors, to maximize profit and grow business and those of public

institutions. The research reveals that perhaps, our current climate reality is a result of the conceptual approach to addressing sustainability. It should not be the case, as illustrated through the experiment and its use of TOPSIS analysis, that one cannot reconcile private gain with public utility.

The standard approach, finds expression in a variety of schemes and incentives (which in essence are concessions on the part of those responsible for the general interest of society) that target harmony between profit and planet. It is designed to encourage behaviour that ultimately serves the public interest without compromising competitiveness. It is the view of the researcher that, holding private interest's constant (under the veils of 'development' 'competition') does more to protect unsustainable business, than it does promote new efforts at environmental responsibility.

Absorbing External Benefit

For the last of the concluding remarks, the research draws on the work and analysis of Jiang, Kronbak and Christensen, on the external cost of maritime shipping. As discussed in previous chapters, an externality is essentially a cost incurred as a result of activity from an external actor (Jiang, Kronbak, & Christensen, 2010). The authors ask a question critical to the future of green shipping practices in particular, and the movement toward green shipping in general.

In retrospect, it may be the case that the externalities category captures the true essence of the objectives of this study and its necessity. Essentially, this paper aspires to contribute to discourse that establishes less of an adversarial relationship between industry and regulators. Private actors, such as vessel owners, traders and financing institutions have a greater role to play in maximizing the benefits associated with reducing the harmful impact of emissions from international shipping.

The authors question the disproportional distribution of costs and benefits, in the mitigation of externalities. It is true that, international shipping is (proportionally) responsible for the public cost of air pollution. As it stands, and the anticipation is that perspectives will evolve, there is no demonstratable link between environmental responsible business practice and an increase in market share or profitability. This means that, a firm will incur all the costs of adopting technology and operations that reduce harm, but reap none of the benefits.

Invoking altruism, much like denying its existence, portends to solve this unique tragedy of the commons. It can be argued that there should be no incentive to doing the right thing. Actors within international shipping should do the right thing, because it's the right thing to do. The researcher argues here that the reality for shipping is far more complex.

With respect to the transition in general and alternative fuels in particular, doing the proverbial 'right thing' is a foregone conclusion. The challenge, upon closer inspection is selecting the correct pathway to achieve environmental results, without sinking the business. Because vessel operators would be selecting the "most right" option, incentives (benefit) go a very long way in influencing decisions. For this reason, the climate change policy instruments within international shipping may have to develop framework that locates value for business in selecting the optimal pathway toward environmental targets. This goes beyond making it possible for profit and planet to merely coexist.

VI. APPENDICES

Appendix 1: Target Vessel

Vessel Name	Maersk LAGUNA
Vessel type	Cellular Container Ship
Year of Built (Delivery date)	2012
Main Engine RPM (MCR)	100
Vessel value (USD)	74,000,000
Interest Rate (% per year)	7.5%
Gross Tonnage (t)	89097
Number of TEU	7564
Deadweight (t)	106043
Owner (Company)	Maersk (Denmark)

Appendix 2: Benchmark Values

Expenditure and Main Engine fuel Consumption

11	Total CAPEX	74,000,000
12	Total OPEX (USD/day)	6,287
13	Main Engine Daily SFOC at 20 knots (kg/kWh)	162.5
14	Ship Power (kW)	45740

Appendix 3: TOPSIS Performance Values

Performance Values	Unit of Measurement	LNG	Hydrogen	Ammonia	HFO	Methanol
Safety	Index Figure	0.590297903	0.543620426	0.351562465	0.574662457	0.705170839
Technology	Net Present Value (US\$)	11,026,958.54	3,954,829.29	7,173,790.60	17,970,133.45	-3,219,229.06
Price	USD\$/tonne	381.82	1010	300	427.75	275
Externalities	€/kg of fuel burned	15.4482	0.00635	1.12268	23.611	12.7
Environment	kg/MJ; kg of pollutant, per MJ of energy.	85280	50400.5	58000.5	106000.5	120797.4444

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