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Exploring the feasibility of installing Smart-Kite's airborne wind energy system on commercial ships

By

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Abstract

On the issue of climate change, which is one of the biggest problems of the century we live in, measures are being taken at the level of states. The importance of decarbonization in the road map drawn on this subject is increasing day by day, and the necessary action plans are tried to be taken. In parallel with this trend, such a revolution can be observed in the shipping industry. The shipping industry plays a crucial role in global trade and is an important factor that makes globalization possible. However, the concept of increasing clean green energy is putting pressure on this sector to take the necessary steps. Due to the industry's own operational features, some challenges need to be addressed. AWES, one of these renewable energy solutions, draws attention as it is a developing advantageous, multi-directional system that can generate energy using high-altitude wind power. In order to integrate the AWES system into the shipping industry, this system should be examined from different perspectives, and its advantages and disadvantages should be determined. AWES must meet the requests of the shipping industry at the customer level and be a feasible and safe solution. It also needs to appeal to the shipping market in general but find a sweet spot first to prove its technology and expand it from a larger scale. It is necessary to compete with other green energy solutions and come forward in operational, technological, and financial terms. At the same time, it is necessary to meet the global operations of the shipping industry at the service level and be compatible. In this thesis, these different perspectives will be analyzed, and the integration of AWES into the shipping industry will be evaluated.

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List of Abbreviations

GHG: Greenhouse Gas
CO2: Carbon Dioxide
CH4: Methane
N2O: Nitrous Oxide
IMO: International Maritime Organization
AWES: Airborne Wind Energy System
SOx: Sulphur Oxide
NOx: Nitrogen Oxide
MARPOL: International Convention for the Prevention of Pollution from Ships
ECA: Emission Control Areas
SEEMP: Ship Energy Efficiency Management Plan
EEDI: Energy Efficiency Design Index
GT: Gigaton
TEU: Twenty-Foot Equivalent
DWT: Deadweight Ton
AIS: Automatic Identification System
MMSI: Maritime Mobile Service Identity
MBM: Market Based Measures
TRL: Technology Readiness Level

1. Introduction

1.1. Global-View

Climate change due to global warming has become a reality and the biggest problem of our population. We see the effects of climate change, such as sea-level rise, unusual weather conditions in the season, droughts, wildfires. To find a solution for this ongoing negative trend of greenhouse gas (GHG) emission, nations have gathered together and signed Paris Agreement in 2016. Carbon dioxide (CO_2) is responsible for the vast majority of GHG emissions along with methane (CH_4), Nitrous Oxide (N_2O), and Fluorinated Gases. Figure 1 illustrates the emission of CO_2 trajectory in the world starting from 1900 until 2020. The reason for the sharp decline in 2020 is due to the Covid-19 pandemic. The Paris agreement was determined and agreed that the global warming level must be kept under 2 ° Celsius, ideally aiming for 1.5° Celsius [1].

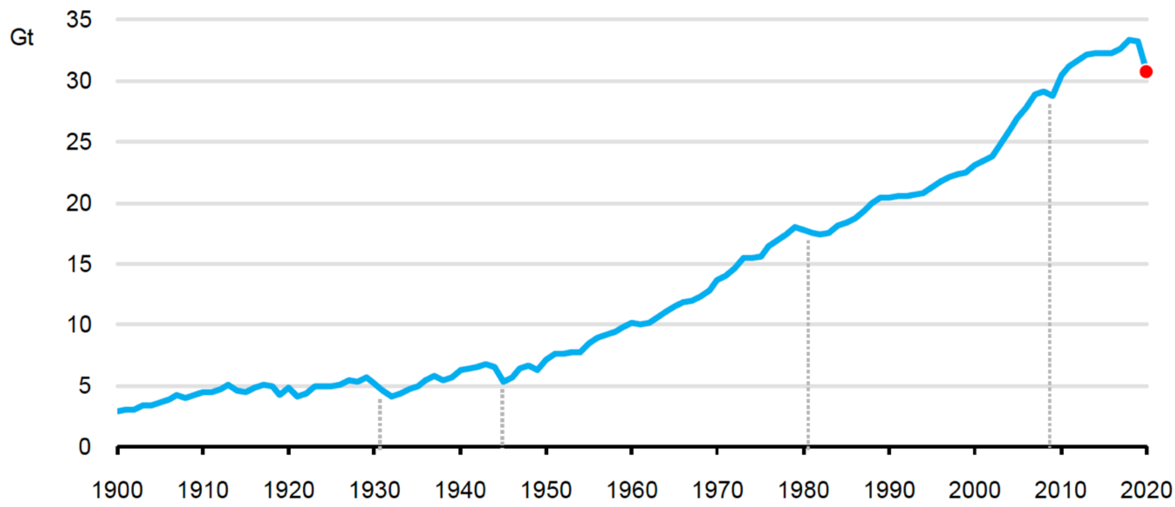

Figure 1 Global energy-related CO2 emission and annual change [1]

The shipping industry follows the same exponential emission trajectory to global warming and human health negatively. Even though the maritime industry was not a part of the Paris agreement. International Maritime Organization (IMO), the maritime industry's regulatory body and standard-setting authority with 174 members states and three associate members, has put compulsory emission limitations and guidelines to be followed by all ships. The objective is to mitigate the various hazardous emission from vessels as low as possible and zero-out emission by the end of this century [2].

1.2. Challenges and Limitations

During the writing of this thesis, some challenges were encountered and attempted to be overcome. First of all, airborne wind energy system (AWES) is a new and developing technology that causes limited resources in the literature. Many resources are about introducing AWES further and launching different versions of it. However, there are no specific resources other than the use of this system on the land. In addition, although it is given the appearance of acting together for decarbonization in the shipping industry, it has been found that the flow of information is not transparent and clear when using any green energy solution in any maritime company, and the sources and interviews in the literature also support this assumption. In light of these difficulties, this study has been designed as a pre-conceptual approach, and it is aimed to shed light on the possible implementation of the future AWES in the shipping industry.

On the other hand, during the writing of this thesis, the limitations that I have faced here is no physical product available in the market yet, and hence the project was limited to facts and data from published sources in the public domain. Therefore, theoretical approaches were taken as references for this thesis.

1.3. Scope and Objectives

This thesis aims to check the feasibility of installing Smart-Kite's airborne wind energy system on commercial ships. This airborne wind energy system is a kite/plane-like system that a generator is placed on board. The objectives of this thesis are to examine AWES implementation on the ships based on five different perspectives in operation and analysis. In the light of these analyses, the installation of AWES is generally interpreted onto ships.

1.4. Methodology

The case study is implemented to evaluate the feasibility of a rigid airborne wind system on commercial ships as an auxiliary power generator. The methodology was chosen for this; firstly, there will be a review of the literature with particular aspects that mainly focus on the emission by ships and the green energy movement of the industry. Secondly, an industrial case will be introduced. Thirdly, the industrial case will be examined from a different perspective for implementation in the sector with input from interviews from the industry and support of literature. Fourthly, based on the literature review and interviews, final reflections and recommendations will be presented, followed by discussing this kind of implementation in the industry. Lastly, the conclusion will be presented.

1.5.Structure of the Thesis

The structure of this thesis is arranged into seven chapters.

- Chapter 2 involves a literature review of the shipping industry from an energy shift point of view
- Chapter 3 involves the introduction of airborne wind systems and working principles
- Chapter 4 corresponds industrial analysis under five sub-group and SWOT analysis
- Chapter 5 reflects the final reflections and recommendations about the implementation of this technology on the ships.
- Chapter 6 illustrate the discussion of this kind of implementation on ships based on TOWS summary and analysis summary
- And chapter 7 involves the conclusion of comprehensive studies

2. Literature Review

2.1. Global Energy Activity, Environment

Climate change has become a reality that needs to be realized immediately and take counteractions. Therefore, different scenarios are prepared to take action regarding climate change. The main difference between these scenarios is how quickly and effectively the world switches to green energy solutions and energy-efficient systems. Since climate change is a global effect, this energy transition needs to be implemented globally, not singly. In addition, it should be carried out in all sectors according to their own capacities so that a common purpose can be served. In order to keep the global temperature rise below 2 degrees, as seen in figure 2 below, the CO2 limit has been determined as 790 gigatons (GT) [3].

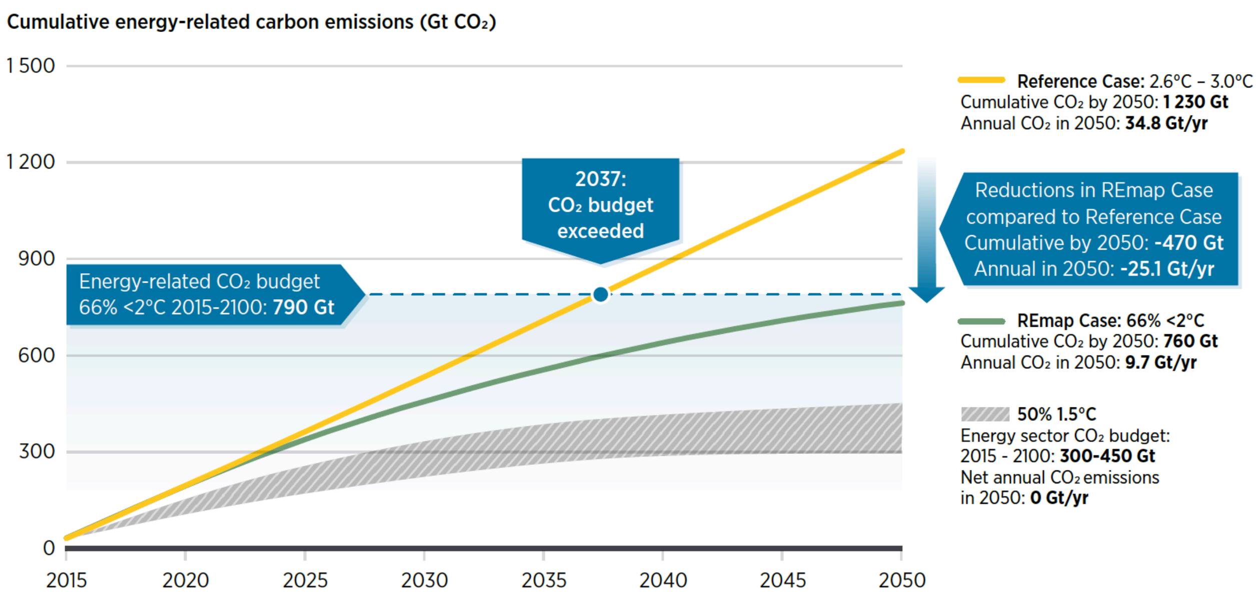

Figure 2 CO2 emission reduction scenarios from 2015 to 2050 [3]

Furthermore, if we go with the current energy efficiency rate, it is estimated that this threshold value will approach between the years 2035-2040. In addition to this scenario, two more scenarios have been studied. The first scenario, green line, illustrates just below 2-degree scenario, prevents to reach the threshold value just near and CO2 emission trajectory until 2050. However, it is ideal for keeping the global temperature rise at 1.5 degrees which is the grey area in the figure. For a 1.5-degree scenario, a reduction of 470 gigatons of CO2 emission is required. For the last two reduction scenarios mentioned, the common thing is that energy-efficient systems should be used to meet the current energy needs [3]. The aggressiveness of this implementation makes the difference between 2 degree and 1.5-degree scenarios.

In order to achieve the year 2050 decarbonization target, the renewable energy production capacity, which was 15% in 2015, must reach approximately 66% in 2050. In order to move forward in line with this goal, investments and research in green energy solutions in all sectors around the world are gaining momentum [3].

2.2. Maritime Transport Activity, Environment

The shipping industry plays a vital and fundamental role in providing transport services worldwide, and the sector carries around 90% of the goods, volume-based. This carriage responsibility of the shipping industry has been overgrowing due to the globalization of the world. The fact that it is relatively cheap compared with the aviation industry for over-sea transportation, making the industry a favorable option for transport [4]. The shipping industry carried 2.605 million tons in 1970, whereas that number became 11 million tons in 2019, which means 50 years of volume-based growth of the shipping industry is more than 400% [5].

Figure 3 Different ship types activity all around the world [6]

Source: https://www.marinetraffic.com/ (accessed 9 March 2021 09:30)

As can be seen in figure 3 demonstrates the activities around the world indicate tremendous marine traffic. In figure 3, green ship figures represent cargo vessels that include bulk carriers, whereas red vessel figures represent tanker and dark blue represents passenger's vessels. It is seen that there is a majority maritime traffic of cargo vessels around the world.

Shipping industry activity correlates with gross world domestic product growth and economy [7]. Based on the PWC report based on the 32 largest economies, which generate 85% of the total economy, the world's economy will exceed two times in size in 2050 than in 2020 [8]. Therefore, the transport demand of the shipping industry is expected to increase dramatically, as shown in figure 4. The demand for containership transport will skyrocket and ascend more than 300%, whereas bulk carrier demand will be rise around 50%.

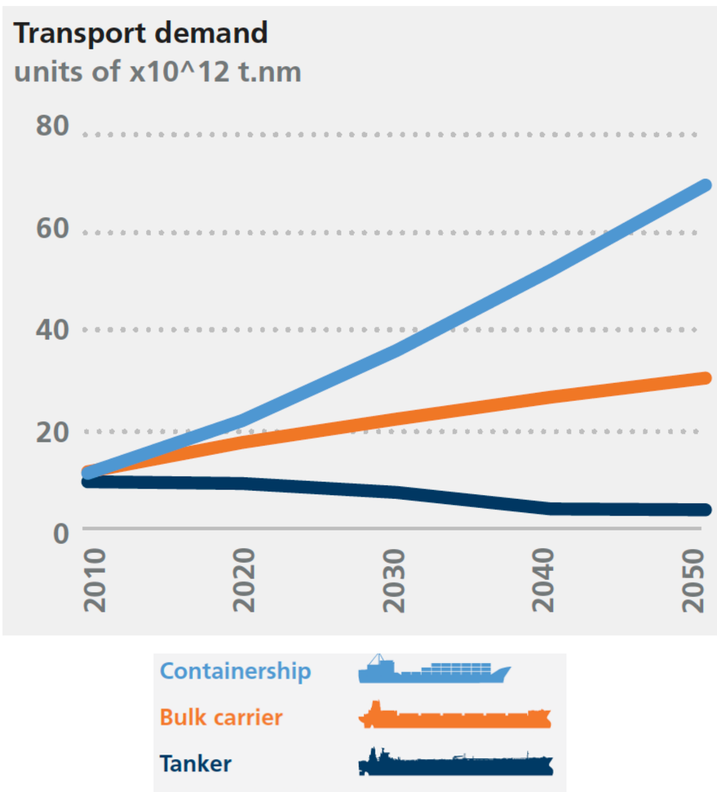

Figure 4 Transport Demand Projection of Three Different Shipping Types from 2010 to 2050 [9]

When it comes to how thousands of ships and massive constructions are powered, most ships are powered by diesel engines. Almost %95 of them burn bunker oil, also called heavy fuel oil. Using this type of fuel is relatively cheaper than any other fuel but at the same time low quality (it is also called "bottom of the barrel"). Therefore, when it burns, it releases many dangerous gases that affect climate change and human health directly or indirectly [10]. These emissions are derived from fuel consumption which is related to its engine room's technological level.

Noticeable and majority emissions from the shipping industry can be listed as Carbon Dioxide (CO2), Sulphur Oxide (SOx), Nitrogen Oxides (NOx). These pollutants from the shipping industry, as a result of burning fossil fuel, impact the world we live in numerous ways; some of the most vital and undesired effects are;

- Carbon dioxide is one of the greenhouse gases that capture the heat in the atmosphere and release it slowly over time (based on NASA 300 to 1,000 years) to provide heating function on the earth's surface. Carbon dioxide, along with other greenhouse gases, exists in the atmosphere at a moderate level to keep the world at average heat. However, the abundance of these gases in the atmosphere (primarily due to burning fossil fuels) causes over-heating of the earth. Thereby, it causes an imbalance of the environmental phenomena (climate change effects), global warming. Moreover, the fact that it can stay in the atmosphere for that long time, the impacts might be irreversible [11].

- SOx and NOx, emission of these gases into the atmosphere primarily cause sulphuric and nitric acid, which affects human health, the environment in a brutal way. Moreover, when these gases reach the soil, it causes forest damage or deforestation and affects biodiversity severely [12].

2.3. Regulations for air emission from ships and reaction of the industry

Considering these adverse effects on human health, the environment and increasing public and political awareness about climate change and hazardous gas emissions have put the maritime industry under pressure to regulate its functionality stricter. Therefore, International Maritime Organization has generated its roadmap and regulations to reduce the CO2 emission and air pollutants from ships [13]. For that reason, the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted and initiated by IMO in 1973. This statement aims to mitigate or prevent pollution from ships as much as possible and plays a central role as a regulator. MARPOL has been alive document throughout the years by continuous updates depending on the position of the sector and the world. The latest release of MARPOL, which is Annex VI focused on air pollution from ships, set the rules and limitations for the maritime industry from a technical and operational point of view [14].

The major limitation in ANNEX VI was the reduction of the Sulphur limit from the current 3.50% to 0.50% globally, along with putting that limit as 0.1% for Emission Control Areas (ECA) and EU ports, as it is seen in figure 5, entered into force by 1 January 2020 for all ships. Additionally, implementing stricter reductions in NOx emission under the term "Tier III" put an emission limit for installing engines as NOx emission is directly related to the engine fuel efficiency [15].

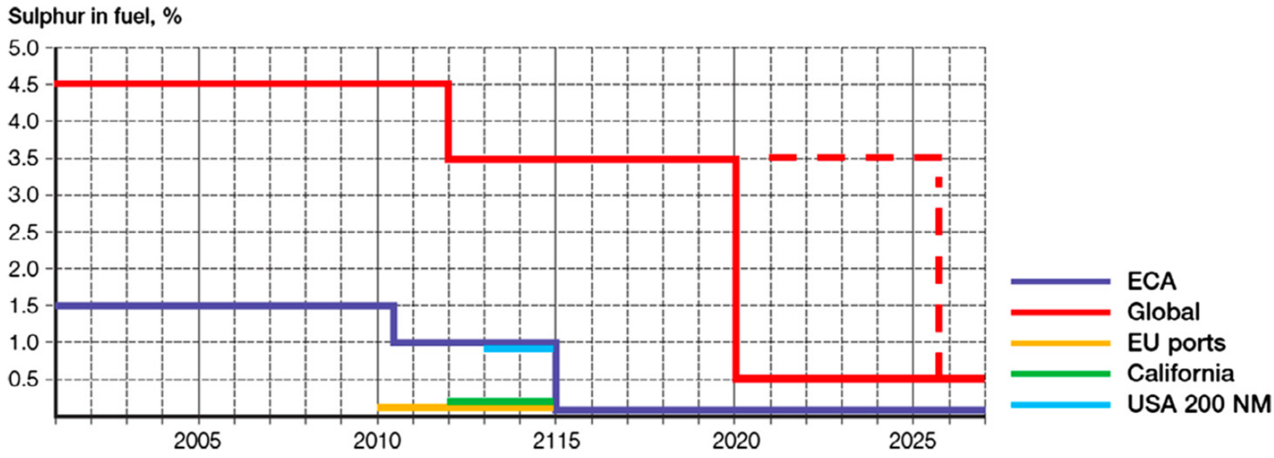

Figure 5 The evolution of global and local Sulphur regulations set by IMO [10]

By putting these limitations as mandatory compliance, based on Finnish Meteorological Institute findings, the outcome of these regulations over Sulphur emission reduction will be around 8.5 to 8.9 million metric tons yearly from 2020 to 2024. This reduction represents approximately %77 lower Sulphur emission thanks to MARPOL VI [16].

On the other hand, to complied with these regulations, the maritime industry firstly turned its face towards alternative fuel oil types that contains less sulfur to be eligible to sail. The most commonly used fuel types are marine diesel gas oil or very low Sulphur oil types rather than bunker oil. However, the price difference between fuel types is considerable such as that the estimated expense of this shift is around $30Billion / year (vary between $10Billion / year and $60Billion / year) [16]. For price difference illustration, different type oil prices based on Hong Kong is as below;

- Very-low Sulphur Oil: 514 US Dollar / Mt
- Marine Gas Oil: 528 US Dollar / Mt
- IFO180 (Type of Bunker Oil): 423 US Dollar /Mt
- IFO380 (Type of Bunker Oil): 408 US Dollar /Mt [17] (Accessed on 19.03.2021 by 08:27 GMT+1)

Addressing another GHG emission type, CO2 emission from the shipping industry is responsible for around 3% of CO2 emission globally, with 1-million-ton CO2 emission on average from 2007 to 2012 [13]. Similarly, under the MARPOL VI treaty, Ship Energy Efficiency Management Plan (SEEMP) was a mandatory guideline followed by all ships. This guideline aims to trigger and carry forward the movement of more energy-efficient ships. In that way, mitigation of CO2 emission will be tracked, and continuous development will be ensured [18].

These limitations have led the industry to look for alternative and permanent solutions from technical perspectives such as advanced technological implementation in the engine room, retrofitting their current systems, operational optimization, and searching implementation of renewable energy industry technologies to zero-out or mitigate their GHG emission as much as possible.

IMO has taken actions to regulate emission and finally reduce it gradually. Therefore, under the MARPOL treaty, The Energy Efficiency Design Index (EEDI) was a mandatory guideline for constructing new ships. These guidelines aim to ensure that newly designed ships are constructed based on the latest regulations from an air pollution point of view using technologically advanced equipment, engines, and fuel. To ensure continuous improvement and innovative solutions in the maritime sector, it was decided that EEDI will be tightened every five years [18].

The reduction effect of CO2 emission along with other GHG emissions through IMO regulations under the MARPOL VI treaty is expected to be seen in the following years as 40% less carbon emission and GHG emission in 2030 and 70% less carbon emission, and 50% less GHG emission by 2050 as is illustrated in figure 6. As seen from these goals, IMO is striving for continuous development of less GHG and CO2 emission throughout the following decades and finally zero-out emission by the end of this century.

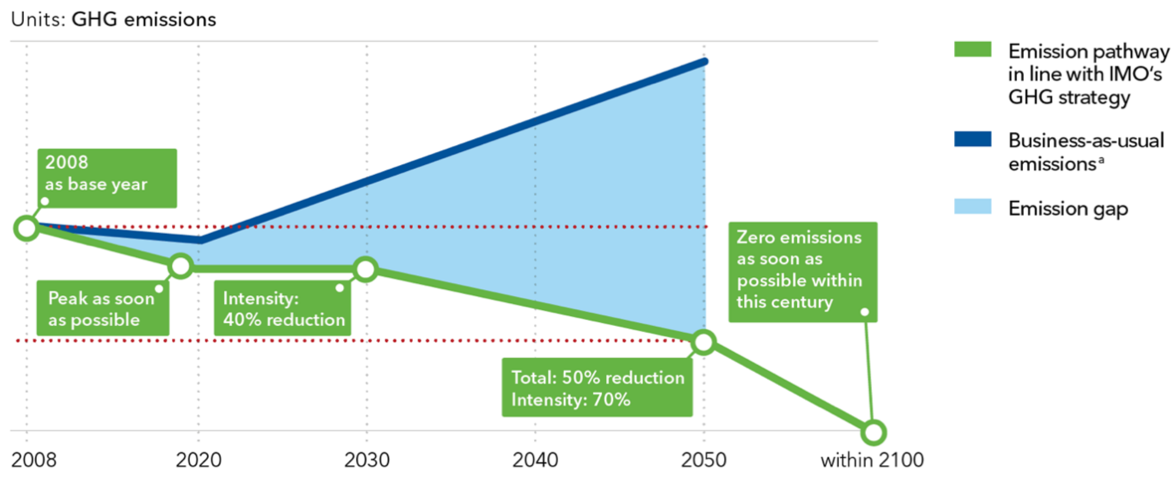

Figure 6 IMO Strategy for major reductions in GHG emissions for shipping industry [19]

2.4. Future of Maritime Industry

Undoubtedly, the shipping industry has been playing a pivotal role in transportation service worldwide and will be undertaking this responsibility at increasing rate for the upcoming years. However, IMO's ambitious and aggressive limitations regarding reducing emissions directed the shipping industry towards the necessity of technological revolutions and sustainable energy solutions. Therefore, some breakthrough changes have to be implemented to comply with the GHG emission reduction plan, and those changes are mainly related to the operational and technological point of view [20].

To achieve the objective of IMO, Bouman has reviewed 150 research about possible technological and operational changes in the shipping industry to reduce the CO2 emission and put all these works together as a comprehensive study under twenty-two measures, as it is in figure 7 with it is possible reduction effect. Only operation measures fall into the operational point of view in figure 7, four (4) possible solutions. The other eighteen (18) possible solutions fall into the technological perspective, including hull design, power & propulsion system, alternative fuels, and alternative energy sources. Solid bars on the figure represent the expected reduction area, and the thin line corresponds to the whole spread of studies about the individual measurement. Points on the bar and thin lines indicate the number of studies and research conducted for that particular measurement to express the reliability of the reduction number [21].

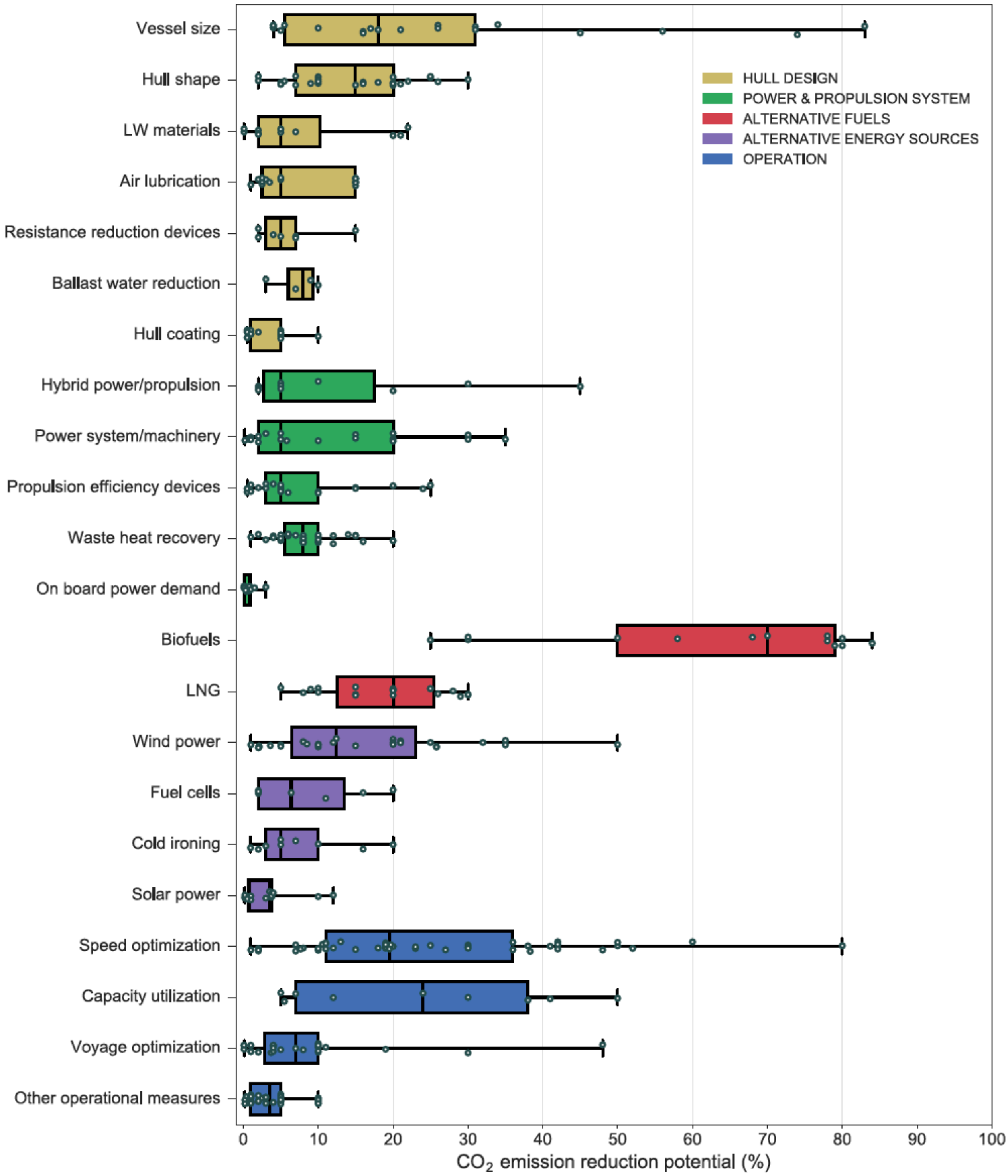

Figure 7 Potential CO2 reduction measures from individual measures [21]

- Operational Measures in figure 7 focus on abatement of CO2 emission via optimization of the operational factors such as speed optimization, capacity utilization, voyage optimization, and other operational measures. These variables are related to engine combustion capacity and fuel consumption. These measures are applicable for all existing ship fleets and new-build ships. The correlation between speed and fuel consumption is illustrated in figure 8. The faster ships get, the more fuel is needed. Which it means, releasing more GHG emission.

Speed knots	Main engine fuel consumption tons/day
16	44
15	36
14	30
13	24
12	19
11	14

Figure 8 How speed affects fuel consumption for a Panamax bulk carrier [22]

- Technological measures in figure 7 focus on energy efficiency and savings via improved design, advanced technological power and propulsion systems, alternative fuels, and alternative energy sources. Retrofitting on the ships might be needed or only applicable for new-build ships to implement these technological solutions.

It is inevitable for the shipping industry to go through a technological revolution as IMO's limitations will be tightened regularly for the upcoming years. Such as EEDI will be tightened every five years, and phase 4 will be introduced by 2030, which will contribute to 40% energy efficiency progress in ships compared with 2008 [23]. The ship's energy efficiency represents the grams of carbon dioxide per capacity mile in this context. Each new build ship must meet the demand of IMO regulations to sail in the sea legally [24].

When we focus on alternative fuels and alternative energy sources on the figure, for simplicity and as an aim of this paper, even though biofuels usage as a fuel has a considerable effect on reducing CO_2 theoretically, it comes with its challenges to implement. Such as, biomass production to use it as fuel may differ from region to region, also may differ depending on the processing of biomass which these two factors affect the quality of the fuel. As another alternative fuel, the usage of LNG as fuel would still contribute to the CO_2 emission even though it is lower than marine fuel oil [21]. Alternative fuel types are also discussed for possible implementation in the shipping industry, such as hydrogen, methanol, and ammonia. These are the alternative fuels that the full life cycle assessment study of these have not concluded yet, which means the impact of using these fuels is not fully known. However, if ammonia as a fuel option is taken into consideration which is more advantageous than hydrogen from a cost and storage point of view and has cost advantageous than methanol. The total investment cost of implementing ammonia as primary fuel is 1-1.4 trillion USD includes every operation, supply chain, land-based infrastructure, and necessary retrofit for ships to be adaptable for this fuel type. Considering all these points, focusing on only one type of innovative fuel type would cost the industry enormous investment expense and the possibility of fluctuation with the supply of that fuel type. Moreover, the experts widely concluded that relying solely on one technology to meet the IMO's goal would not be adequate. Instead, a combination of technologies may lead to a better result from an operational and economic perspective [24].

On the other hand, renewable energy solutions have a considerable reduction effect over CO_2 reduction. Wind power is the most notified option from figure 7 that may reduce emissions maximum up to 45% and average more than 20% slightly [21]. Powered by wind ships are known by the industry already. Therefore, it is a solid option to implement and zero-out emission from the energy that wind power can produce.

Below, figure 9 illustrates the likely possible shipping industry pathway for the future. As mentioned before, IMO has limited SOx emission and aggressive GHG emission reduction plan and EEDI to ensure new-build ships are according to regulations. Furthermore, in the future, eco-friendly, zero-emission ships will be introduced in the industry through technological revolutions. Therefore, there is a trend of following sustainable and green energy solutions in the shipping industry to keep up with the time.

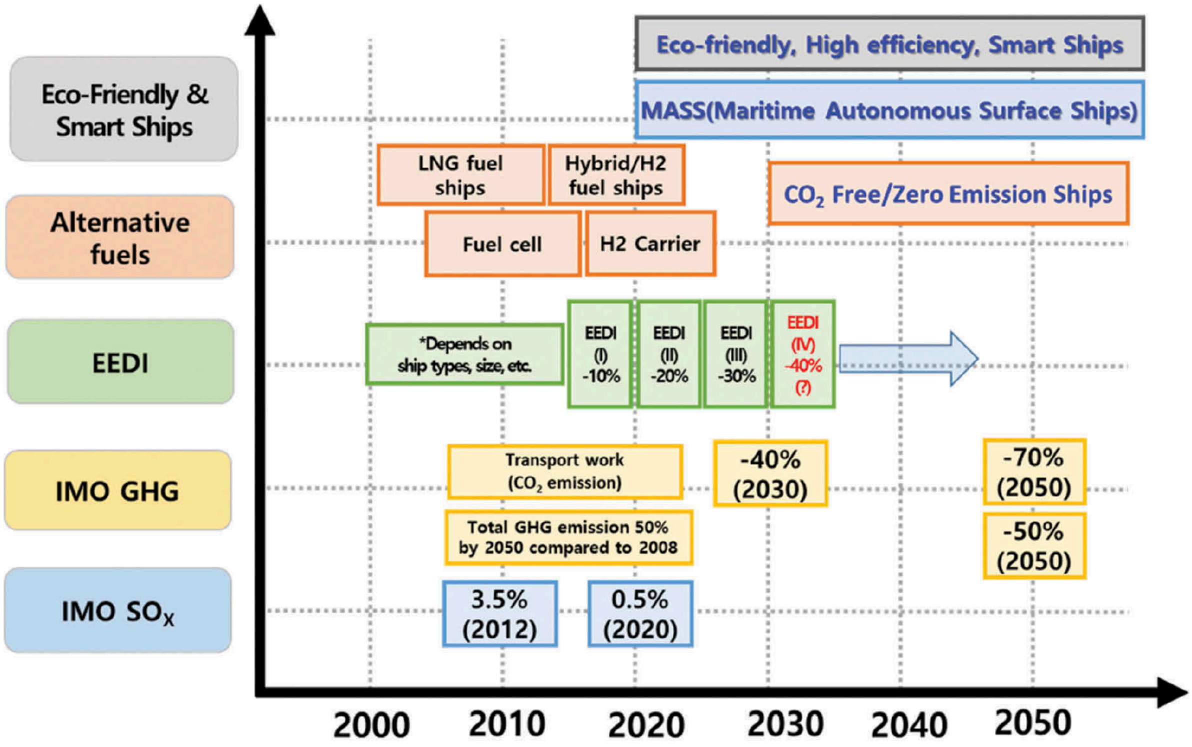

Figure 9 Effect of IMO Regulation on Ship Technology Trend by the time [23]

To sum up this chapter, figure 10 below illustrates both the impact of the regulations on the maritime industry and the industry´s reaction to comply with these measures. To mitigate the GHG emission from ships, the industry has increased the focus on possible renewable energy implementations such as wind, solar, batteries, and biofuel as sources of energy onboard.

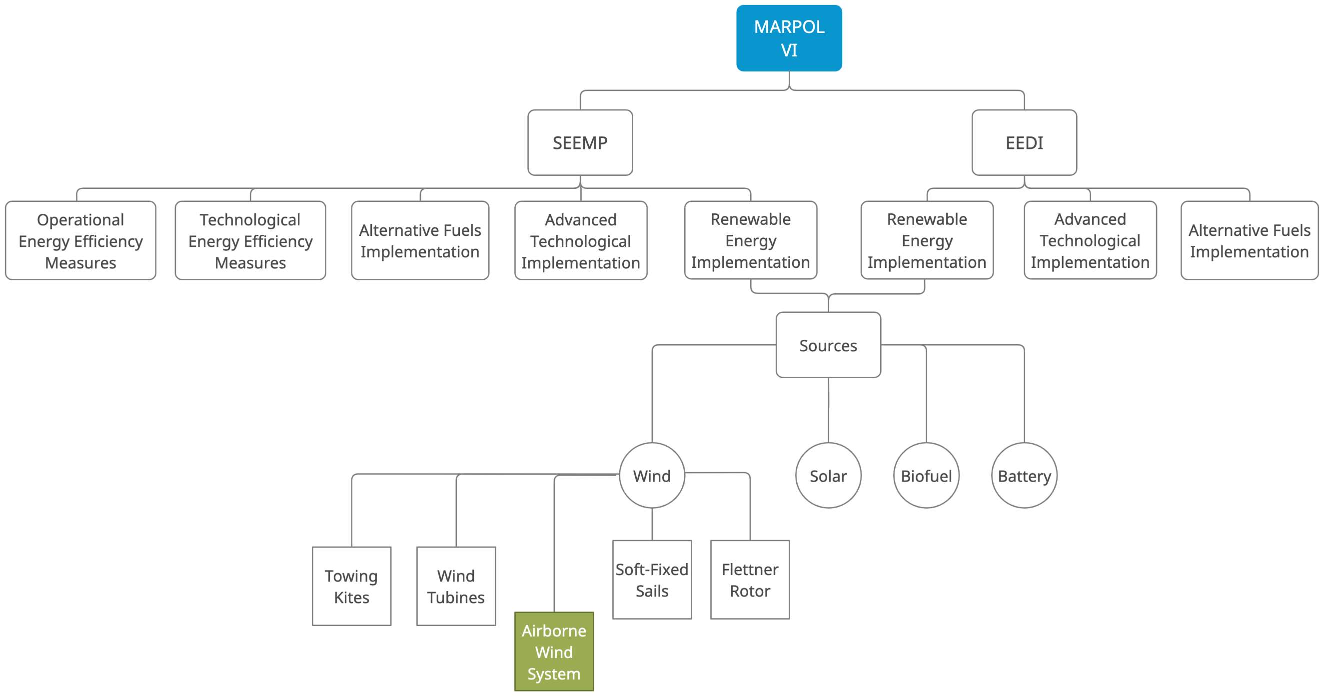

Figure 10 Marpol VI and Reactions of Maritime Industry

3. Industrial Case

3.1.Airborne Wind Energy System (AWES) Introduction

The wind has been the main driving power of the ships until the engine steams powered by coal and heavy fuel oil. Afterward, marine diesel oil has been started to use by ships due to its negative contribution to climate change and human health. Recently, the maritime industry seeking ways to implement renewable energy to produce power. Among these renewable energy alternatives, airborne wind energy system (AWES) technology has become a real potential to focus on GHG emissions reduction of the maritime industry.

For this purpose, Smart-kite, a start-up company, is working on installing airborne wind energy system technology onto ships. So far, the company's primary input is successful in the running simulation of Makani Energy 600mW airborne wind kite. The objective is to implement an airborne wind technology system on ships to contribute decarbonization of the industry.

Airborne wind energy systems are tethered and controlled flying devices to harvest wind at high altitudes. The use of tether provides a system to reach and adjust to the desired altitudes. This flexibility of moving upward and downwards provides to perform in the most efficient area to convert wind power into useful electricity. AWES is a general term, but there are commonly used two different kinds of electricity generation exist in the market, from airborne wind systems [25].

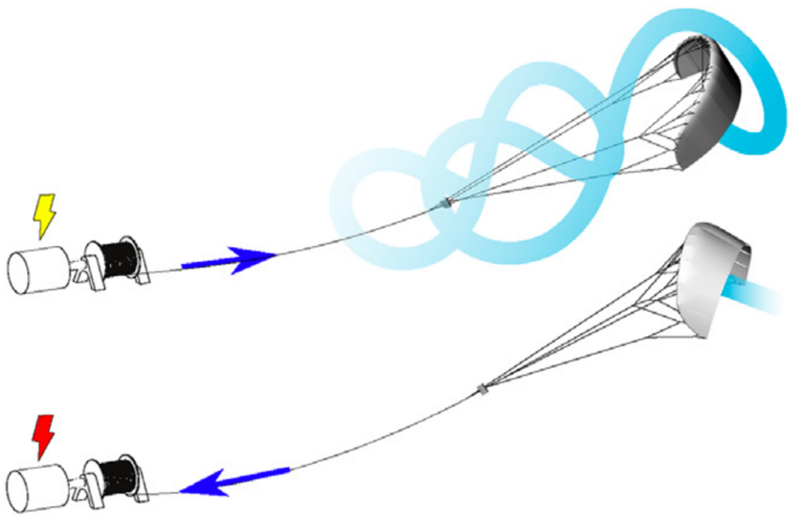

Figure 11 Working mechanism of AWT generator on the ground [26]

Figure 11 above indicates the sketch model of the AWES in which the generator is placed on the ground. The flying device for this system is a soft-kite system. On-ground AWES consists of two phases of functioning called reel-out and reel-in, as shown in figure 11. Reel out phase where electricity is being converted through the sudden motion of the kite/parachute, and this motion rotates the winch. The generator connected to the winch converts the kinetic energy of the rotation of the winch into electricity. When the AWES reaches out its maximum point, which is the length of the tether, then the second phase starts, which is the reel in phase. In another saying, pulling the system back phase. At this phase, electricity is consumed to pull the system back [26].

On the other hand, figures 12 and figure 13 below indicate the sketch model of AWES which the generator is placed on the board. The flying device for this system is a rigid kite system. The flying device is controlled on a path that follows a big loop thanks to crosswind. While flying on that loop, wind rotates to wind turbines on the flying device. Rotation of the wind turbines is transferred to the generator on the board, and conversion occurs as seen in the simple scheme on the figures.

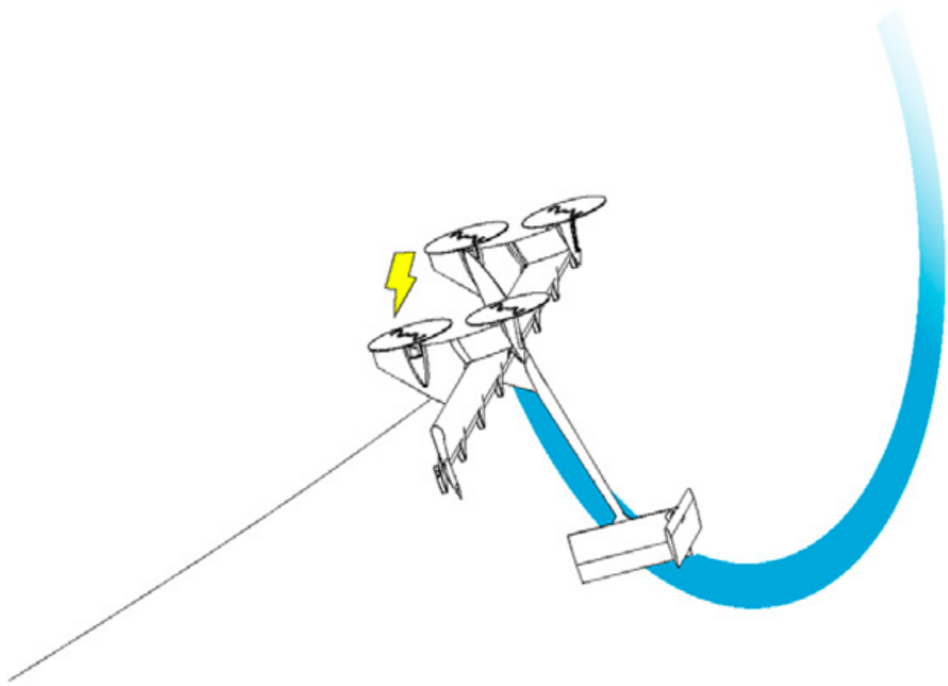

Figure 12 AWES Generator on-board [26]

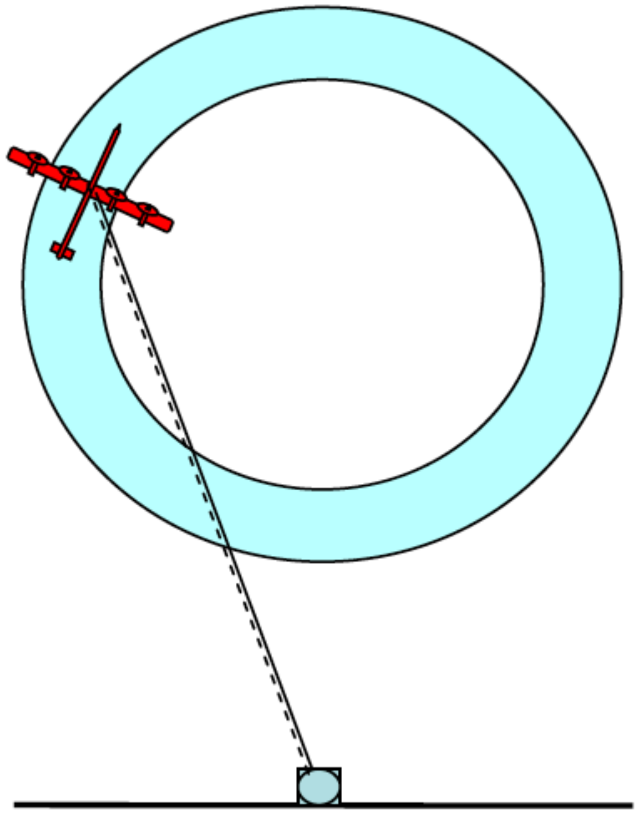

Figure 13 Sketch of AWES with onboard generator [25]

Afterward, that useful electricity being transferred down to the ground. This airborne wind energy system model has similarities with conventional wind turbines from an operational perspective, such as blades turning via wind. Mechanical energy is converted into useful electricity by a generator. This model uses a tether to control the flying device and electrical conduction between the flying device and the ground. Consumption of electricity takes place during the take-off and landing of the flying device.

When we compare this technology with its closest and most available neighbor technology, conventional wind turbines, AWES has some significant features that made it step forward. These features are grouped below;

- Material, less material (90% less material) is used for the AWES than horizontal wind turbines (HWT), positively affecting decreased environmental impact and considerably less CO_2 footprint. Visual illustration of material difference is illustrated in figure 14.

- Wind resources, since AWES can go even higher and higher altitudes where the wind is strong and consistent from 200m-1000m, can reach the most efficient area where HWT are stable constructions around 100-200m.

- Load hours, due to AWES's flexibility to be in the different layers of the atmosphere load hours of AWES can be much higher than HWT.

- LCOE, due to its need for less material and a considerably more straightforward system, LCOE of AWES is expected to be less than HWT.

- Mobility, AWES can be deployed at one point to function and moved to another point quickly, whereas HWT is stable construction.

- Scalability, AWES can be upgraded easily, and power output can range from kW to mW [27].

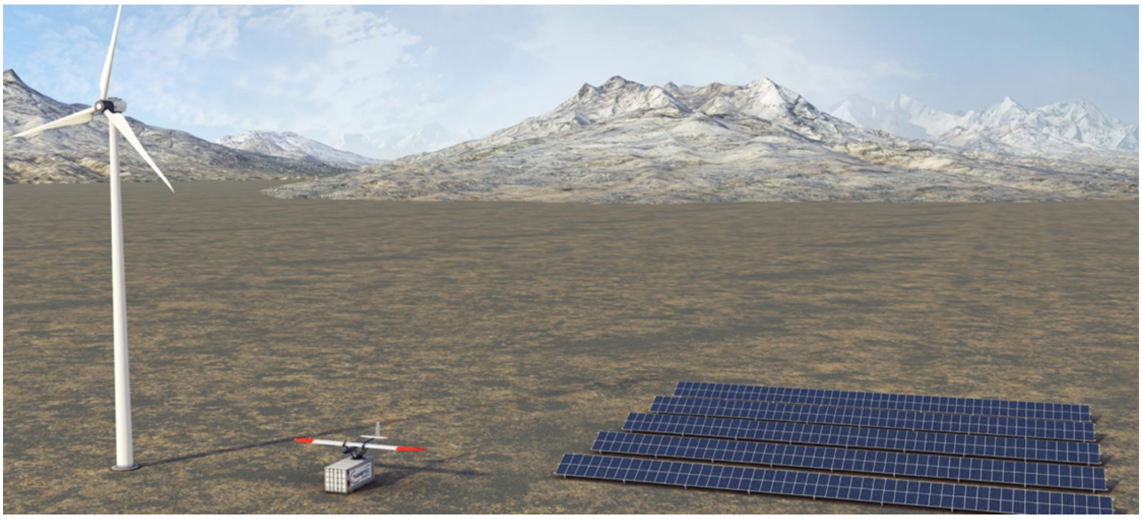

Figure 14 Scalability Comparison of 100kW energy production [28]

3.2. Journey into AWES

AWES consist of below fundamental sub-systems;

a. Ground Station: the ground station is the hub of the AWES for vertical take-off and landing. Also, it contains a drum in which the tether is rolled around. When the AWES take-off, the drum reel out the tether for the AWES to reach the high altitude and, another way around when the AWES starts to descend, then reel in the tether for the AWES to land vertically on the ground station. High bandwidth radio links ensure communication between AWES and the ground station. In that way, the ground station has knowledge of the altitude of the AWES and release or rewind the tether accordingly [29]. Figure 15 represents the example of the ground station for the Makani M600 model. However, it is essential to note that the design of the ground station may change depending on the model.

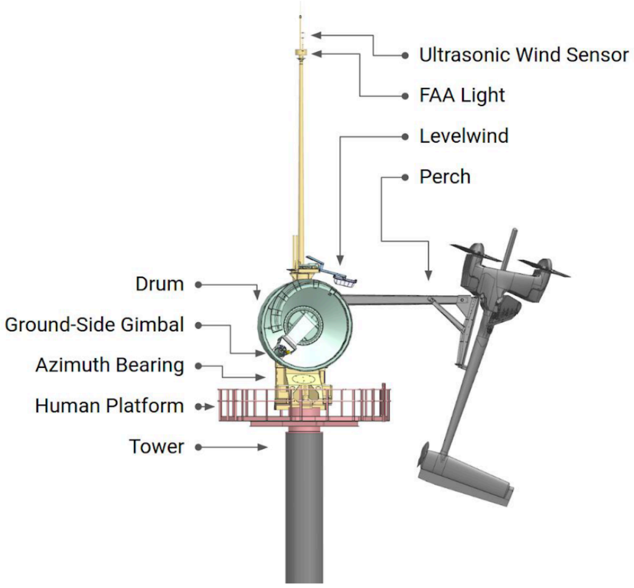

Figure 15 Example of AWES ground station model, Makani M600 ground station [29]

b. Tether: The tether's role in the system keeps the flying device (AWES) connected to the ground. The tether is expected to overcome some challenges, such as withstand high tensile stress and endure repetitive strain/stress cycles. Also, be flexible enough with low weight not to affect flying device functioning. Moreover, it needs to be robust enough to survive harsh environmental conditions. Besides, tether has another functionality in the system to transmit the generated electricity down to the ground.

Material selection should be done accordingly and should have the outer protective layer as a conductor to ensure the continuous flow of electricity [30]. Diverse expectations from a tether bring engineering challenges to meet all the demands of it. Therefore, there is a need for a tether to have several layers, as shown in figure 16, which illustrates the example design of the tether for the Makani M600 model AWES. This tether was designed to endure 250kN tension and carry through 1MW electrical power. Carbon fiber core ensures endurance against strain and stress. Helically conducted aluminum electrical conductors make it possible the electric transmission as well as providing low mass. The squishy layer is a separator between carbon fiber core and aluminum conductors. The outer part of the tether is covered with a protective layer and fluted to provide less aerodynamical drag. This tether design performed very well at the Makani's test flights [29].

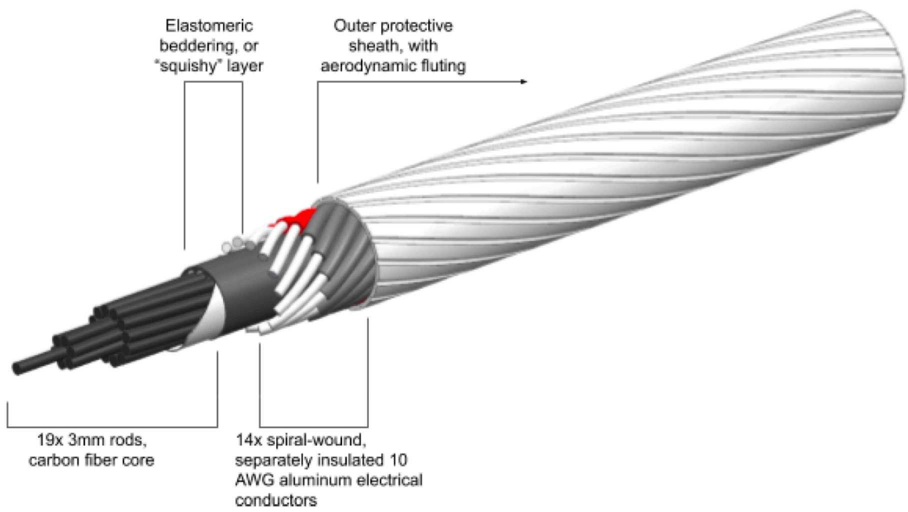

Figure 16 Tether design of Makani M600 model [29]

c. Bridle line: Bridle is an attachment between tether and AWES. Depending on the flying device's design, the bridle line can be attached to several points on the AWES to stabilize the flying machine and distribute tensile stress from the AWES to the tether, as shown in figure 17.

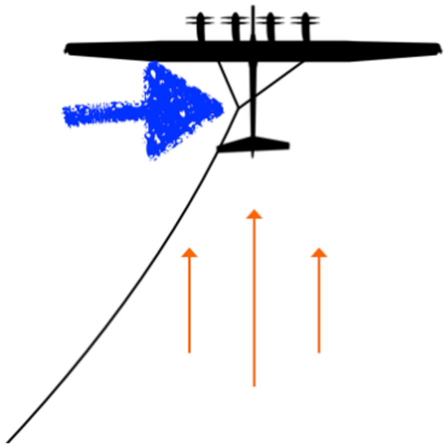

Figure 17 Bridle Line on AWES [31]

d. Generator / Motor: both of the description represents the same system. AWES needs energy during take-off and landing. The electrical motor receives electricity from the local system to power the system to reach the desired altitude and land on the ground station. On the other hand, once AWES reaches the desired height and starts to function in a loop by crosswind power, the motor act as a generator and produces energy via turning of the turbines [31]. One crucial point about selecting the motor is low weight and high efficiency to minimize the electricity mass [30].

e. Turbines: turbines are specially designed of aerodynamic profiles which turn by the wind. Depending on the design of AWES, the number of wind turbines may change. Turbines are the first step of generating electricity. The kinetic energy of wind is turned into mechanical energy by the rotation of the turbines. On the other hand, while take-off and landing operations, turbines behave as propellers and lift the AWES to the desired altitude with the power from the electrical motor [30].

f. Rotor: the system that converts the mechanical energy of turbines to the generator. The movement of rotation of wind turbines is transmitted to the generator via a rotor. Below in figure 18, the rotor position with the yellow marked number six can be seen. Every turbine has a rotor that connects to its generator.

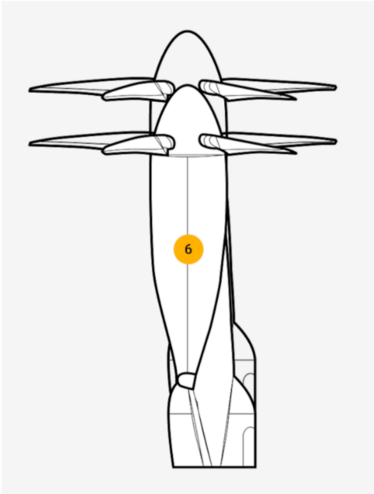

Figure 18 Rotor system on AWES [31]

g. Control System (Flight Controller) is the command mechanism of the system, the so-called brain of the AWES. It makes the flight safe by optimizing flight trajectory and controlling the kite. One of its crucial tasks is determining the loop to fly based on wind velocity and direction and control other sub-systems of the AWES [29].

h. AWES Electric System: the electric system of AWES depends on the configuration of the electrical system installation. Powertrains may be grouped to connect in parallel or series. Any design here depends on the system. Transfer of the electricity from board to ground may be alternating current (AC) or direct current (DC). However, for that reason, there might be a necessity for a converter or inverter on the board or the ground. Whichever option is designed, it is essential to note that the converter or inverter should work bilaterally as AWES consumes energy at take-off and landing operation. Below in figure 19 is the example of AWES electric system structure.

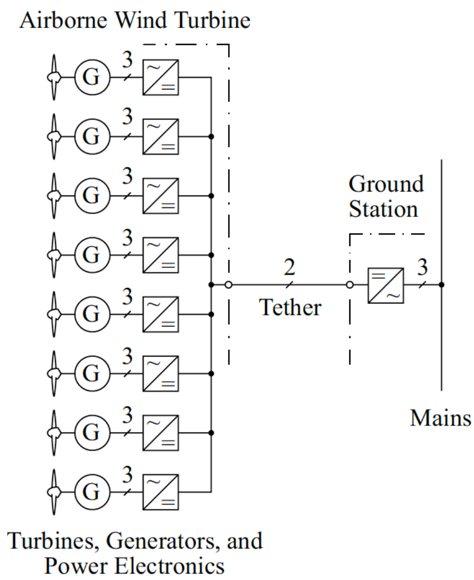

Figure 19 Example of AWES basic electric system structure [30]

i. AWES Structure: AWES structure is one of the most critical points as it contains electrical and mechanical sub-system and components on the structure, so the design should be robust enough to carry all the sub-systems onto it and at the same time endure the G-force that is produced while following the loop. So, the structure's design should be aerodynamically feasible to keep the whole system floating and light enough to complete its loop function. In figure 20 can be seen the example of Makani's design example of the kite.

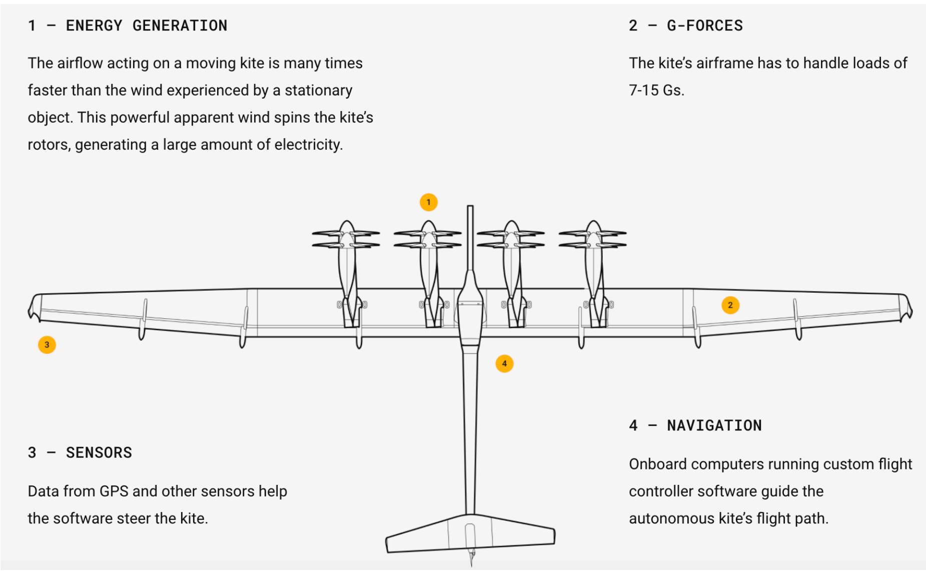

Figure 20 AWES design example [31]

3.3. Global Studies

The mastermind of this airborne wind technology was Miles Loyd, who worked for the first time during 1970. He concluded that it was feasible to produce energy up to 45mW using this technology based on his study. However, due to insufficient funds, he could not put this theoretical result into practice [32].

Studies and research being conducted already about this technology all around the world. Organizations, research centers, and universities strive to develop the most robust and most efficient design of the system to implement. As figure 21 illustrates, the number of organizations and institutions involved in this technology has been increasing. Google, Shell, RWE, and Engie are some of the investors of this technology to develop [27].

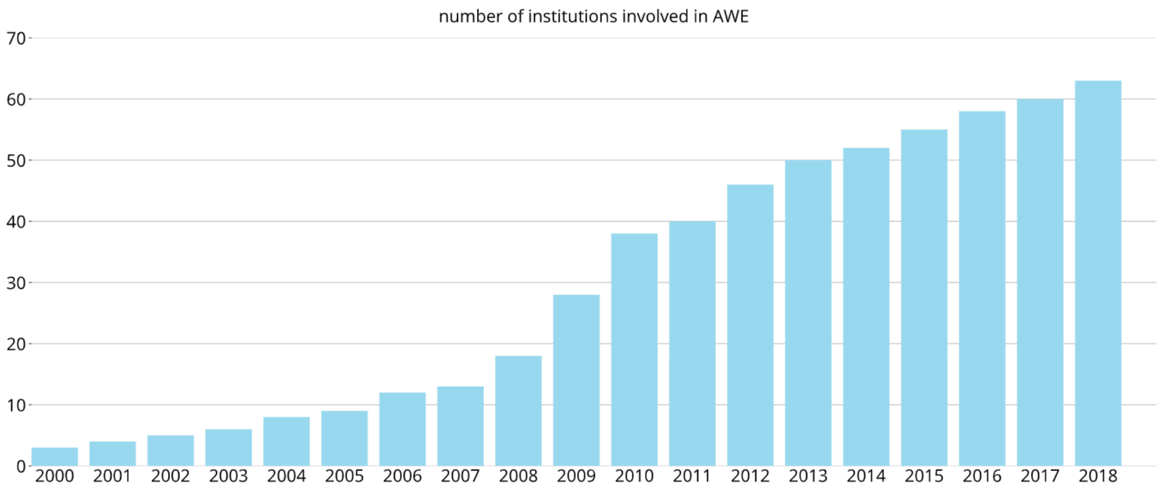

Figure 21 Number of institutions involved in AWE research increment from 2000 to 2018 [33]

4. Industrial Analysis

In this chapter, AWES implementation on commercial ships from different perspectives is analyzed based on literature review and interviews with three shipping companies for this thesis's purpose under the reference number 41, 42 and 43. Interview questions can be found in Appendix 9.1. Due to the confidentiality of the answers, findings are presented anonymously. Firstly, the structure of the analysis part is a market analysis that is undertaken where the expectation from AWES is underlined. Secondly, competition analysis is represented where it is compared with other renewable energy solutions. Thirdly, customer analysis is illustrated. Fourthly, financial analysis is undertaken. Then, suppliers and service analysis are investigated. And lastly, SWOT analysis is represented based on the first five analyses from 4.1 to 4.5.

4.1. Market Analysis

When emission rates are divided between the different vessels and their operations to narrow down the focus area, %85 of the total emissions from the shipping sector are derived from international shipping activities, including container ships, tanker vessels, and cargo vessels [34]. Figure 22 illustrates the IMO calculation of fuel consumption for different vessel types, directly related to the emission rate in 2018. Based on figure 22, it is seen that container vessels are the most fuel-consumed shipping type, which is followed by a bulk carrier and an oil tanker, respectively. Also, almost %90 percent of the fuel consumption is due to main engine activities.

Due to the international shipping's sector being heavily dependent on fuel, IMO has put in action at the Marine Environment Protection Committee (MEPC) 70th session, where the adaption of obligatory data is gathered for consumption of fuel oil for the ships, which classified as five thousand (5,000) gross tonnage and above which started by 1 January 2018. Classified ships will report how much oil they consume yearly to the flag State at the end of every year. The flag state is responsible for reporting these gathered data to the IMO database [35]. This act aligns with the objectives of IMO to reduce GHG emissions progressively by encouraging the sector and owners to take action.

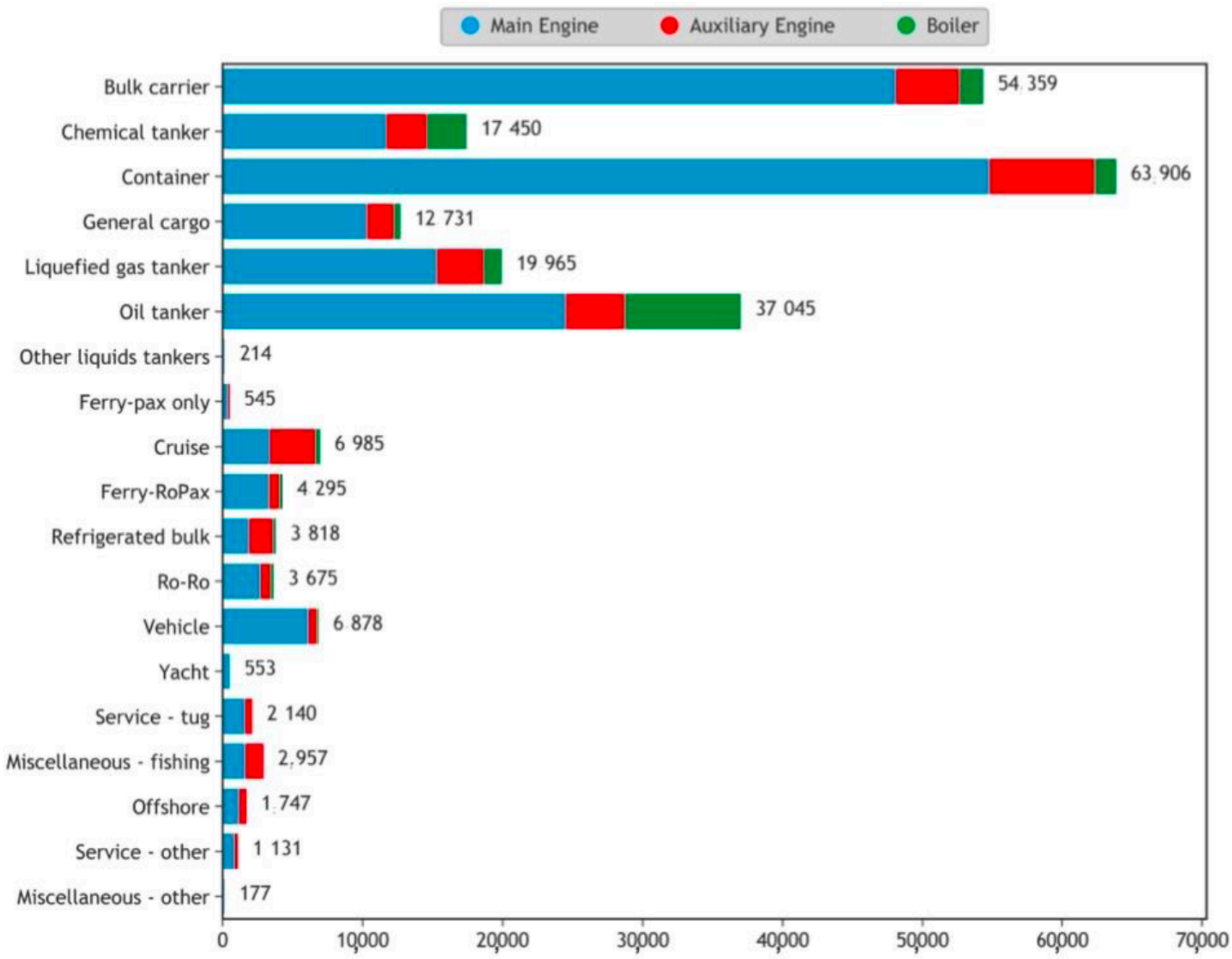

Figure 22 International, voyage-based allocation, HFO equivalent fuel consumption (thousand tones) ,2018 [36]

In the light of these data from IMO, when it is focused on implementing AWES installation onto commercial ships, the main focus is ship types that weigh less than ten thousand (10,000) deadweight tons (DWT). The reason for focusing specifically on these ships is that these ships abound worldwide. Even though they carry less of the total cargo compared to large and very large ships, those with less than 10,000 deadweight tones emit more greenhouse gas emissions per unit cargo according to the distance taken [37]. Moreover, the sweet spot within the target market can be defined as 5,000 – 10,000 dwt ones based on IMO regulation of reporting fuel consumption yearly for vessels 5,000 dwt and above. In that way, the effects of AWES implementation will be observed more quickly.

Table 1 illustrates the potential target market in the shipping industry for the possible implementation of AWES, also taken into consideration the data from interviewees that AWES is more compatible for supporting auxiliary engine power system which aligns with table 1 due to the huge difference between main engine power and auxiliary engine power.

In table 1, container ships have different units than any other ship type. Measurement of container ships is TEU (Twenty-foot Equivalent) container. So, the capacity of one containership is based on the capacity of total TEU containers. Therefore, the selection of container ships was made based on auxiliary engine power proximity to other ship types on the chart.

Ship Type	Size	Unit	Number of Vessels	Avg. Days at sea	Avg. Days international	Avg. Main engine power (kW)	Auxiliary Engine Power Output(KW)			
							At berth	Anchored	Manoeuvring	Sea
Bulk Carrier	0-9,999	dwt	696	178	58	1,796	110	180	500	190
Chemical Tanker	5,000-9,999		844	185	217	3,109	330	490	560	580
Container	0-999	TEU	861	196	163	5,077	370	450	790	410
	1,000-1,999		1271	210	270	12,083	820	910	1750	900
General Cargo	5,000-9,999		2245	176	238	3,15	240	130	490	180
Oil Tanker	5,000-9,999		779	142	136	2,761	375	375	560	375

Table 1 5,000-10,000 DWT ships [36] (Data taken from Table 17 and Table 35 of IMO fourth GHG report)

These figures are taken from IMO's fourth GHG study report in 2020 and analyzed based on table 17 and table 35 in the report. There are 4 types of vessels are mentioned in the report as type 1, type 2, type 3 and type 4. The number of vessels in the category of type 1 and 2 is based on the IMO classification. Type 1 vessels are detected by the Automatic Identification System (AIS) and matched with the IMO dataset. In contrast, Type 2 vessels are the ones that matched with Maritime Mobile Service Identity (MMSI) dataset. To have a clear figure for the possible target market spot, type 3 and type 4 vessels registered in neither of the datasets are not considered [4]. Based on table 1, the number of total vessels as the potential market for AWES implementation is approximately six thousand and seven hundred (6,700) vessels [4].

When it comes to energy needs, auxiliary engine systems powered by a marine diesel generator need to work all the time and continue to provide electricity to various ship systems. Even the vessel at berth is anchored or at sea, needs to run uninterruptedly. Depending on the energy need and vessel design, marine diesel generator power capability and its number may change [38]. However, the most important part to substitute one marine diesel engine completely by installing AWES on board to prevent the inefficient process.

In addition to these, to encourage the market to direct towards renewable energy solutions or decarbonization solutions, IMO has been working on Market-Based Measures (MBM) because this possible implementation of AWES encourages shipowners to invest in green energy. The reason for putting forward MBM is that studies have revealed that solely the usage of SEEMP and EEDI would not be adequate to reach the main emission goal of the shipping industry [39]. For that reason, under the roof of IMO, member states, associate members, and observer organizations have made proposals to IMO to adapt it in the shipping industry as a package to support the industry in reducing GHG emissions. Ten (10) proposed market-based measures are considered by the committee and shared on the IMO website. However, there is no consensus yet about the implementation of market-based measures [40]. The complete version of these ten proposed market-based measures can be found in appendix 9.2, taken from the IMO website.

Based on the interviews, green energy in the shipping industry is reasonably related to market-based measures. All interviewees pointed out the importance of proper MBM. One of the interviewees mentions that his company planned to install 2-3 rotor sails on a ship to initiate their green energy transition. After completing this investment's financial benefit, it turns out that the payback time of these rotor sails ranges from 10-17 years. So, interviewees emphasized that without an extensive support package in the market, no shipping company would invest with that long payback time [41] [42] [43].

4.2. Competition Analysis

The primary green energy solutions for the shipping industry can be grouped as wind, solar, and biofuel. To benefit from sustainable renewable energy sources, there may need to be a fundamental operational change to ensure maximum benefit from the green energy sources such as weather routing to ensure stronger wind or more sun. This situation might be challenging for the shipping sector. On the other hand, for the possible installation of a green energy source, the only retrofit might be enough or it needs to be installed for new construction designs [4]. Each of the sources comes with its advantages and disadvantages. Under this section, competition analysis is conducted between wind, solar, and biofuel energy types. Wind-based energy is further divided into the below sub-groups.

→ Towing Kites
→ Soft Sail Systems
→ Airborne Wind System
→ Flettner Rotor Sail System

- **Solar Power in Maritime Industry,** solar photovoltaic applications transform the sunlight into usable electrical energy by small individual photovoltaic cells that produce about 1 or 2 watts of power [44]. Using solar photovoltaic applications in the maritime industry is applicable and feasible from a technological point of view to produce clean energy as an auxiliary system. However, the limitation of using this green energy comes from its requirement to have a large area for installation to produce meaningful energy. It brings a significant challenge to the shipping industry, especially cargo ships, container ships, and tankers. Therefore, using this technology for small vessels or ships less than 400 tones [4].

- **Biofuel Energy in Maritime,** biofuels are seen as a potential alternative fuel to replace fossil fuel or mix with fossil fuel at some certain proportion. Biofuels are categorized as the first, second, and third generation of biofuels. This classification is made depending on the feedstock used and technology used for the process [45].

  First-generation biofuels production depends on the extraction of sugar, lipid, or starch from the plants and processing these raw materials. The most significant disadvantage of first-generation biofuel production is that feedstock is used for food, so there might be a conflict between fuel vs. food debate. The production of second-generation biofuels as raw materials is not used for food purposes. They are harvested from non-food crops, wood residues, and intentionally grown grasses and trees to extract cellulosic feedstock. There are concerns about reaching the same quality of feedstock worldwide, which may cause instability of engine operation. Lastly, the third-generation biofuels are the end product of specially projected energy crops such as algae. It is a non-food source and can be grown on land or in the water. This technology is still under development, and it is far from being a viable energy source in the maritime industry [4] [45].

- **Wind Power in Maritime Industry,** the maritime industry relied on wind power to sail away until the invention and implementation of steamships in the industry. Pursuing the effective, fast voyage goals has put wind power out of the options until the trend of decarbonization in the shipping industry. The industry shows signs of going back to wind power applications to comply with the limitations and has effective operation thanks to advanced technology [24]. During the time, wind power applications have increased, as was aforementioned.

    - **Towing Kites** are attached to the vessel by a tether and generate propulsion power via the power of the wind at high altitudes. This system consists of three fundamental sub-systems. The first one is a flying system that contains towing kite, control pod, and towing rope. The second one, launch and recovery system, and the third one is the control system, as shown in figure 23, the visual illustration of this system on the vessel [46]. The disadvantage of this system is that if the wind conditions are not favorable, the system cannot run. Moreover, when the vessel is at berth or anchored, the system cannot run as it works only as an auxiliary power source to the propellers. It might be a risky investment for ship types in parking positions some period of the year, such as tankers.

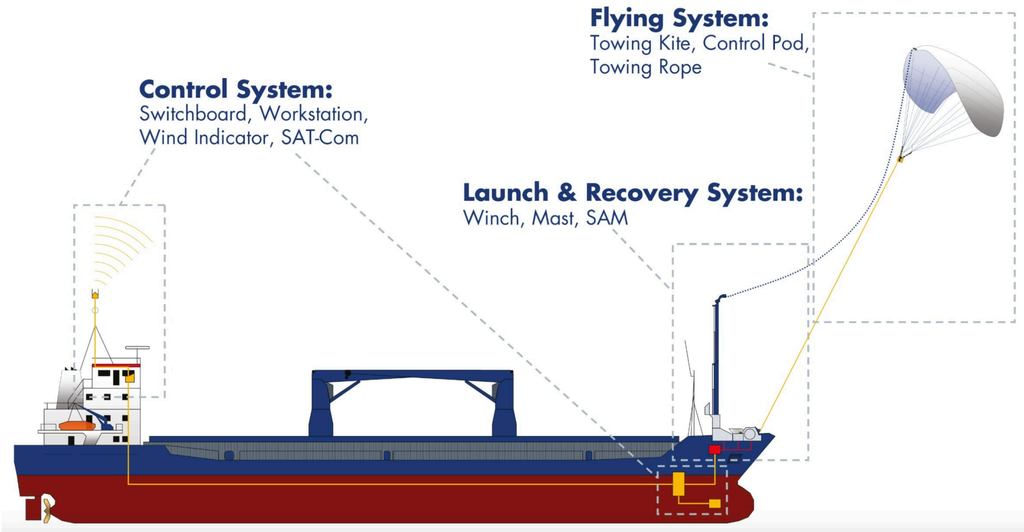

Figure 23 Towing-Kite Installation example on a vessel [46]

- **Soft Sail Systems** traditional soft sail systems are attached to the hull and use the wind's power to propel the vessel, whether primary propulsion or auxiliary propulsion. Recent soft sail systems can be controlled from the bridge quickly to harness the wind most efficiently. The disadvantage of this system same as towing kites. If the wind conditions are not favorable, then the system cannot power the vessel. Also, if the vessel in a parking position, the system cannot provide energy as it works for the main propellers.

- **Flettner Rotor Sail System** works based on the Magnus effect. As it can be seen in figure 24, the Magnus effect working mechanism in Flettner rotor sail system is when the wind goes through an already rotating cylinder, it generates a pressure difference between two halves of the rotor sail, and this generates a thrust power which is perpendicular to the wind direction [4]. In figure 25, E-SHIP 1 vessel can be seen as already with the Flettner rotor sail system installed. The disadvantage of this technology is that the system will not run effectively if the wind is not favorable. Moreover, when the vessel is not sailing away, the system will be in a hold position and will not generate value. In addition, Flettner rotor sail systems take considerable space on the hull for its placement. Therefore, if the hull is used for other purposes, such as placing containers or cargo for container vessels, it might be a risky investment. It would be a conflict between more containers versus rotor sail.

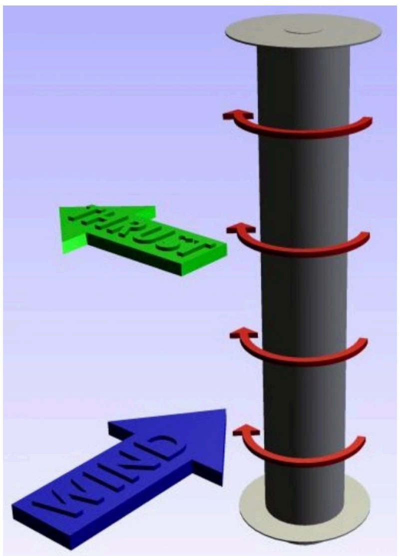

Figure 24 Magnus Effect Visual Illustration [47]

Figure 25 Flettner Rotor System installed on vessel, E-SHIP 1 [48]

- **Airborne Wind System** is a tethered flying device to reach higher altitude to harvest the wind through wind turbines and transfer the power to the ground station by a tether. Higher altitude means might be 300-1000 meters, two or four times higher than wind turbines, and more consistent, stronger wind flow at that high altitude as wind speed goes up depending on altitude. Consistent wind provides constant electricity production, and stronger wind provides more wind power as wind power output depends on the cube effect of wind velocity. So, wind speed increment from 5m/s to 10m/s will show its effect over the wind power output eight times more [32].

  Illustration of wind speed increment by altitude can be seen below in figure 26 that measured above central London. The average wind speed at 120 m altitude is 7.0 m/s whereas, at 250 m altitudes, wind velocity increase to 9.3 m/s, and 500m altitude average wind speed is 11.6 m/s. The capability of AWES to access the higher altitudes will lead to increased wind power output with the increment of wind speed. In addition, wind flow at the high altitudes is stable and constant as there are no obstacles, any form that can behave as barriers like forests or buildings. It makes AWES available all around the world regardless of location [32].

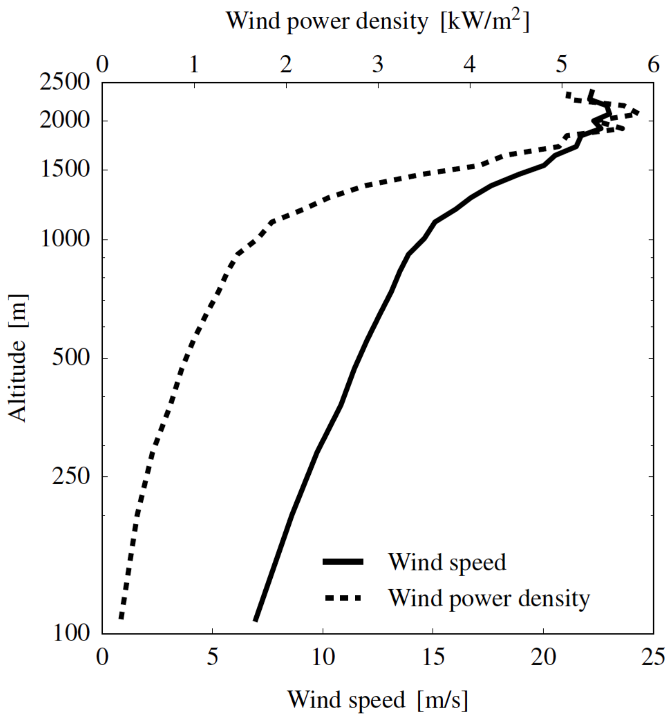

Figure 26 Mean wind speed and wind power density profiles above central London, a city with large energy demand, the wind speed has been measured for 4578 hours using a Doppler lidar. [32]

One of the advantages of the AWES implementation on the ships is, the AWES can run all the time unless the ship goes through narrow channels, bridges, and close to port areas. Therefore, even the ship at berth or anchored, AWES system can run at high altitudes to provide energy to the ship and substitute for the marine diesel generator.

In addition, AWES has the capability of taking off and landing vertically on the ground station. Taking less space on the hull will be a great advantage for the ships that carry goods or containers on that hull.

4.3. Customer Analysis

Reviewing the goals of IMO for progressive decarbonization of the shipping industry can be visualized for the timeline as in figure 27. The main objective is to cut the primarily CO2 emission by %70 and reduction of %50 from total GHG emission by 2050. The reason for 42 years of progress considering the baseline as 2008 is that the shipping sector is in the category of "Harder-to abate sectors" and other sectors including aviation, cement plants, iron, steel plants, and road freight defined by the International Energy Agency (IEA). This is because of the longevity of asset usage, which is heavily dependent on energy and full electrification of these sectors [34]. The other reason for the gradual decarbonization of the shipping industry is various stakeholders' interests in reflecting dissimilarity between each other. Therefore, reaching a consensus and common path for the abatement of GHG emissions requires covering all related stakeholders of the shipping industry [49].

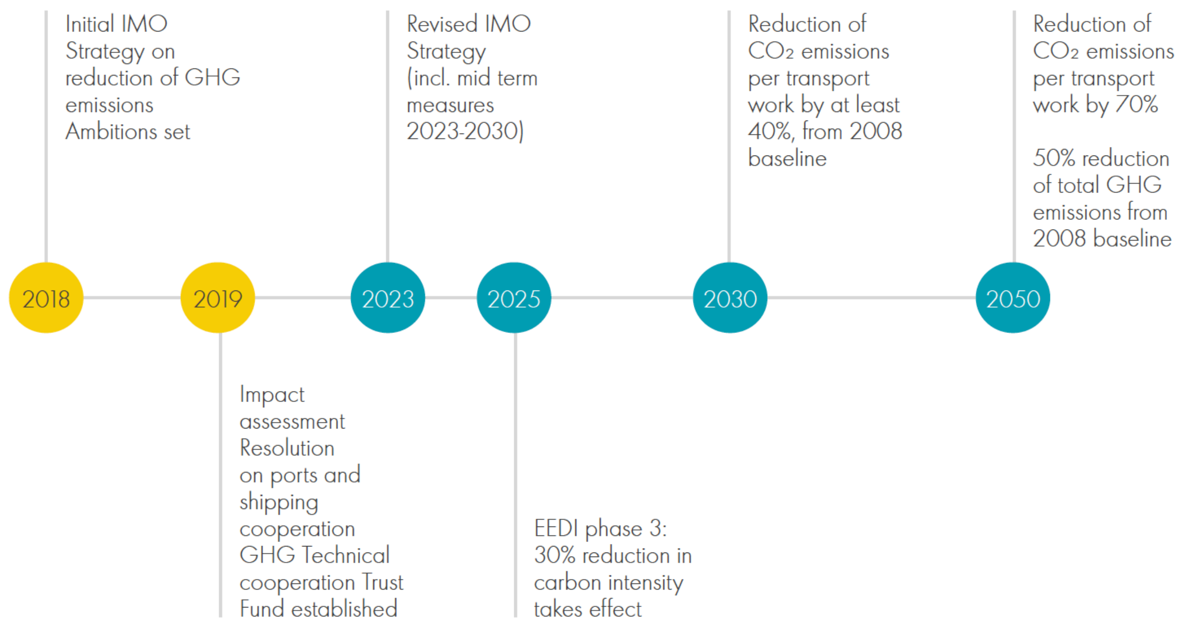

Figure 27 IMO Timetable to reduce GHG emissions until 2050 [34]

Depriving carbon of the industry requires a dramatic and large-scale change in the industry, including financial investments in sustainable solutions. Due to diverse stakeholder's interests in the industry, financial investments are not only related to the shipowners but also directly or indirectly related to shipping stakeholders. Figure 28 illustrates the comprehensive stakeholder web of the shipping industry. The figure shows six main categories associated with the interest of the stakeholders of that group. Therefore, there is a need for proper and comprehensive incentives, policies, and measures to encourage the stakeholders to step up, take action and emphasize the awareness and realization of its urgent necessity. These so-called incentives and policies are directly associated with the market-based measures that IMO has been working on and striving to reach a consensus between stakeholders [49].

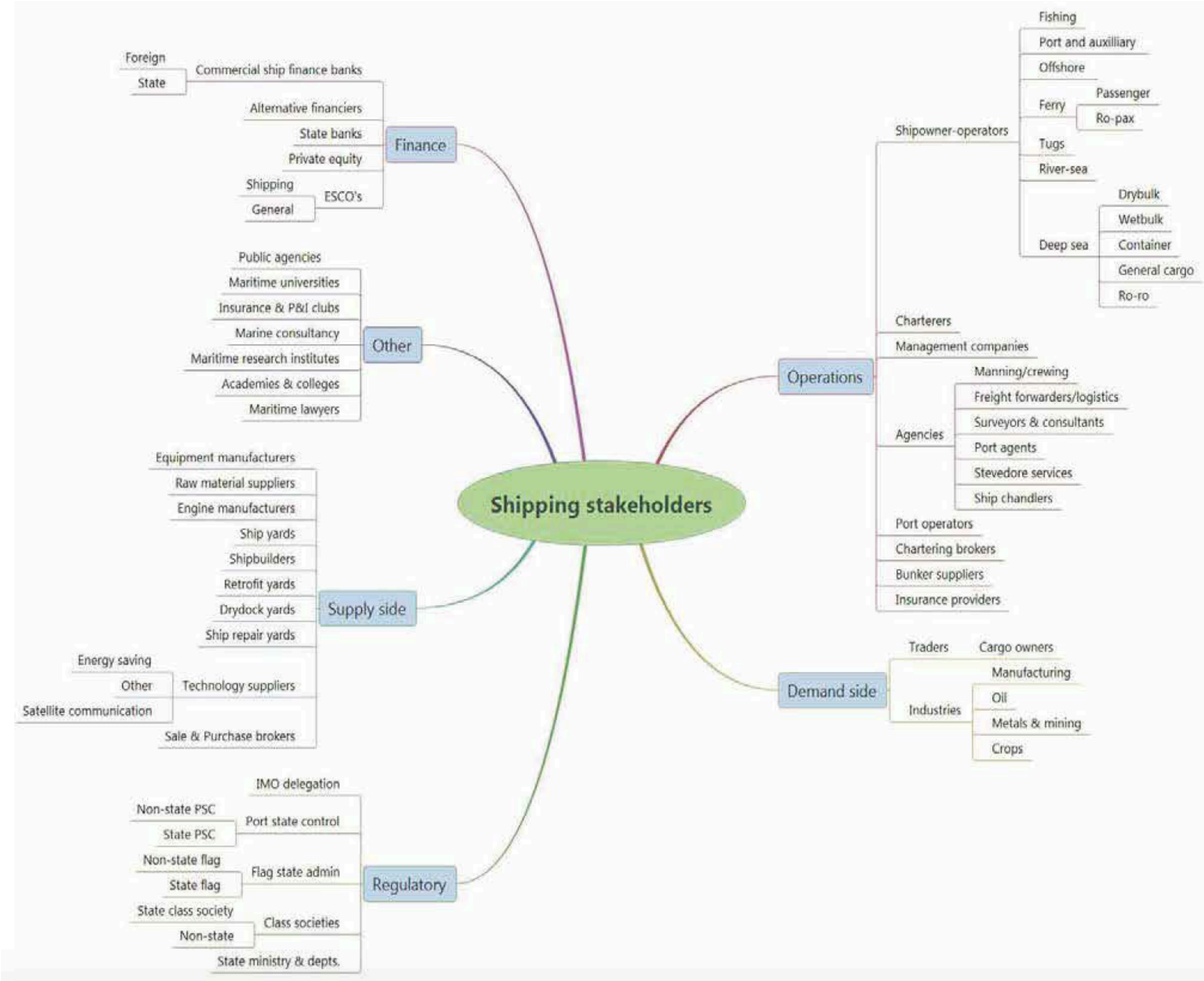

Figure 28 Shipping Stakeholders Web [50]

To align with the IMO's environmental concerning limitations and goals, shipping industry owners have been taking actions individually and discussing policies and investments related to all stakeholders in the industry. Based on the interviews have undertaken for this paper with three different shipping companies, the mutual answer for the latter part was that they have been waiting for the right and broad investments and actions of the regulatory bodies like IMO for alternative fuel types to be used instead of fuel oil and encouraging obligatory measures to make it worldwide. Their concern is that upcoming zero-carbon or very low-carbon fuel type/s will not have established proper infrastructure to meet the shipping industry's demand. It will cause whether it is tough to buy it or a huge price difference between alternative fuel type and current fuel type (HFO, MGO, etc.). So, customers do not want to take the risk of putting their selves into ambiguous situations as they may need to retrofit their current system to be able to use those alternative fuel types [41] [42] [43]. This output from personal interviews also aligns with the report of Shell under the name of "Decarbonizing Shipping: All hands-on deck." This report comprises 82 interviews with CEOs, financiers, shipbuilders, etc., from the shipping industry. 85% of the interviewees agreed that there is a lack of market and customer demand in the industry [34].

On the other hand, individual actions and investments in the shipping industry mostly contain operational, technological, and seeking alternative zero-carbon emission types such as renewable energy solutions [49]. To align with the focus of this thesis, operational and technological progress will not be detailed.

Based on the interviews, all three companies were undertaking feasibility studies to implement renewable energy solutions on the fleet as an auxiliary energy generator. Those solutions are rotor sails, wing sails, and soft-kite systems to reduce their carbon footprint and work towards the IMO's final goal of being a carbonless industry by the end of this century. However, there have been common concerns about the installation of green energy sources. Such as it was a common expression of interviewees that if the fuel oil prices keep on the same price level and IMO does not provide sufficient incentives and measures towards the green energy solution, then it would be hard to implement it, as green energy solutions are at the higher price level than commonly used fuel oil prices. There was a concern of green energy solution adaptability on the ships as it has not been proven yet totally from technological and operational points of view. So, transparency of the data about renewable energy installation on ships plays a crucial role in technology alignment in the industry [41] [42] [43]. Similarly, the International Renewable Energy Agency (IRENA) also pointed out the same concerns for the shipping industry to align with green energy solutions, which matches the interviews' output. Therefore, significant endeavors and adequate support must be provided to the industry to increment possible renewable energy options in the shipping industry [37].

As one of the options of renewable energy source and as a focus on this thesis, when the idea of a possible implementation of AWES on to ships was introduced to interviewees, before going into details of technological and safety aspects of this installation, some majority ideas were that this technology was found the more suitable option to support the auxiliary engine rather than main engine room which power the propeller. Since AWES has not been proven technologically, it is risky to support the propeller system as it is the only force that moves the ship forward. On the other hand, in a scenario that acts as a support system for the auxiliary engines, it needs to replace one auxiliary engine to produce equal power. One of the interviewee's auxiliary engines produces 1.1-1.3mW, whereas another one was 800kW power. The justification of this claim comes with its reason is that diesel engines are more efficient at higher loads where it consumes optimal fuel and performs most efficiently. So, it is undesired to produce energy that equals half of the diesel engine via AWES and covers another half through the diesel engine. It will lead to non-optimal operation and usage of the ship's asset [41] [42] [43].

4.4. Financial Analysis

In the below sub-sections, the financial analysis of AWES is analyzed based on initial investment and production investment & operating cost.

4.4.1. Initial Investment

AWES is a promising, open-to-improvement innovative renewable energy technology that is ready to reveal technological, environmental, and financial advantages of its own. The system should be used widely and be economical to reach these promised features of the AWES. However, unless it is individually funded, AWES companies will need funding and investment to realize the potential of the technology and prove the commercial profitability of the technology. Figure 29 illustrates mainly the technology and main funding sources correlation journey for the AWES companies such as Smart-Kite. Along the way of the technological advancement of AWES, companies will be exposed to contact with different investors with varying aims. Each development stage has its own goals, investments, risks, and success criteria to complete. Development stages will be explained respectively, going into details of the need at that stage. The technology readiness level (TRL) is defined at every stage. TRL is a methodology for estimating the maturity of any technology that ranges from one (1) to nine (9). Being one (1) represents that it is a less mature technology, whereas being nine (9) is the most mature technology [51].

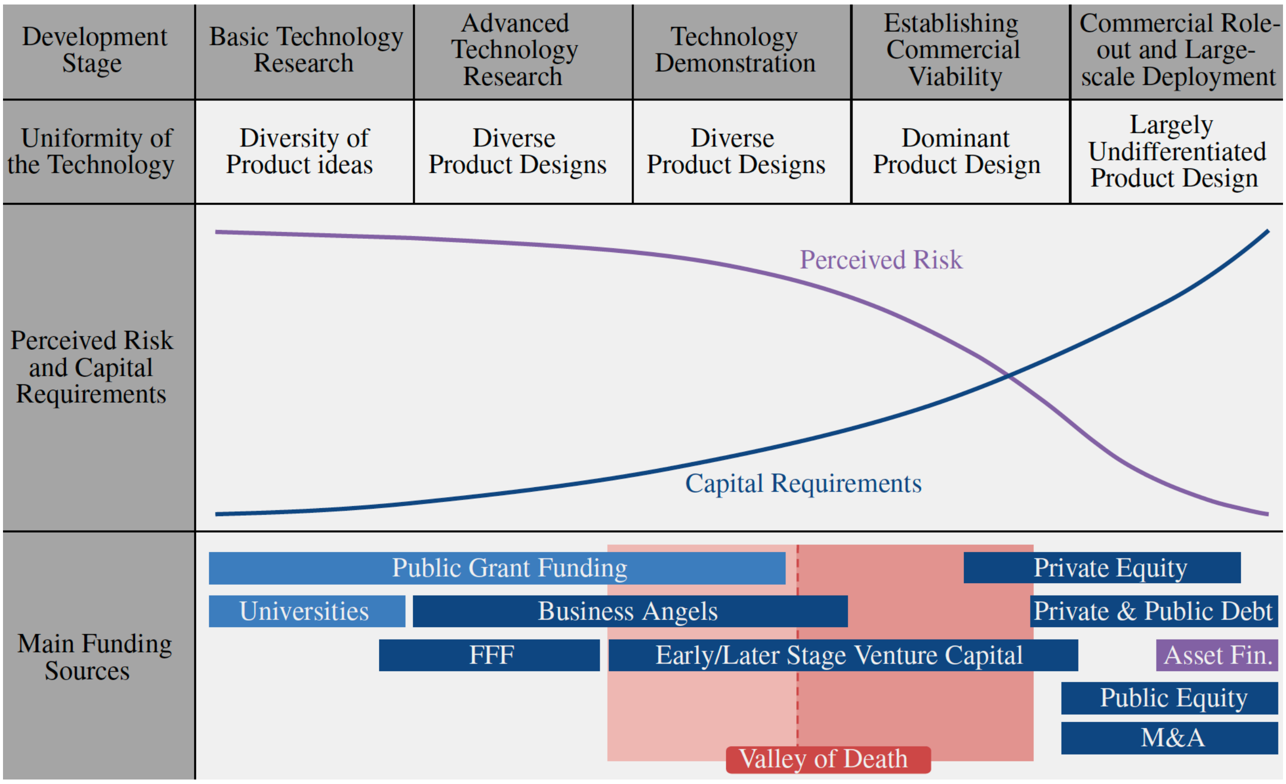

Figure 29 Technology-Risk-Funding Sources life cycle for a renewable energy technology [51]

- Basic Technology Research (R&D) is the first act of the development stage. This stage focuses on new AWES conceptional improvements, establishment, and put together essential principles and facts. The average needed investment for this stage is less than € 1 million. Primary funding sources are mainly universities via their fund or fund from Public Grants and international grant programs. The capital requirement at this point is the lowest, and risk is the highest as only an idea/concept is being emerged. This stage covers from one to four of the technology readiness level (TRL). Deployment scale of the AWES less than 1:10 or via simulation tools to verify the concept. Risk is seen relatively high at this stage [51] [52].

- Advanced Technology Research (Applied R&D) is the second step where the “studied concept” is tested at a larger scale. Fundamental design solutions should be finalized and freezes, such as wing type (soft/rigid), the generator and take-off generator, and landing. It is expected to have a prototype product, scale from 1:10 to 1:3. Perceived risk is still relatively high, but towards the end of this stage, risk tends to decrease as more technical and operational solutions become clear slightly. This stage´s TRL covers from four to six. Cost per unit is the highest at this phase, as it is not prioritized yet. More capital requirement is needed during this time, approximately € 1 -10 million. The first contact with financers and funders takes place at this stage which is called seed fundings. Funding may primarily be supported by family, friends, and fool around (FFF). Public fundings and international fundings are other options. However, these supports may not be sufficient to cover the investment. Therefore, there may need for external sources such as business angels who are wealthy, knowledgeable, and venturer individuals to finance this section. Business angel's funding strategies vary. Since perceived risk high at this stage, business angels claim interest from the company for their early contribution [51] [52] [53].

- Technology Demonstration (Pilot) is the pre-commercial phase where a full-scale prototype (1:1) of AWES is tested, under any weather circumstances, for an extended period of time to prove its design and technology concept. At the same time, it is expected to see the promised range of electricity production, capacity yield during a demonstration. As more details are clarified, and safe operation is demonstrated through real-life demonstration, perceived risk decreases. Cost per unit tends to decrease. This phase´s TRL covers six and seven. Supply chain searches and dialogues start to take place. The company may need more labor power in various departments. Market strategies and expansion plans start to take shape at this stage. Due to these activities, the company's capital requirement starts to ascend, and the typical investment needs range is around € 30-50 million. The “Valley of Death” period starts with this stage, and if the company survives through this period, it will prove its commercial viability. Financial needs would exceed the capability of business angels and public grant funding. Therefore, AWES company starts negotiations with venture capital investors, called series A funding after seed funding. Venture capital investors claim interest or a share stake from the company in exchange for investing due to its high risk and unproven technology concept. One feature of the venture capitals that they tend to be long-term funding if investors see potential in the company. Aside from financial support, venture capital investors contribute to the company's development through knowledge sharing and managerial advice. They are also referring companies to other investors, called “Signaling” in the economic literature. It is worth mentioning that most of the AWES companies in the sector are in the technology demonstration phase as they strive to find solutions for technical and operational issues for sub-system's functionality. Moreover, none of the AWES companies have proven long-time, under all weather conditions test yet [51] [52] [53].

- Establishing commercial viability is where small production of the end-product is verified. There is a convergence of manufacturing methodology and already defined component and concept readiness level at previous stages. Technical, operational, and maintenance-related details are defined and documented. LCOE is defined, and a plan to reduce the LCOE is defined with actions. The supply chain is clarified, and suppliers are certified. This phase´s TRL covers eight and nine. The perceived risk dropped drastically at this phase due to convergency at all of the technical perspectives. Due to extensive activities in the company, capital requirement increased sharply, and specific investment need varies between € 60-120 million. The market expansion started to ascend at this stage, and the company starts to promote itself and its technology. However, a company's fresh start in the sector may cause a lack of trust to fund the technology from banks, loan firms, and public equity. Therefore, this stage is the most critical pathway of the valley death period. All funding depends on venture capital investors, whether later-stage venture capital investors or series B funding. Effect of signaling is expected to have increased in the venture capital investors to have more financial contributors. AWES companies have not reached this stage yet [51] [52].

- Commercial roll-out and large-scale deployment are where serial production of the technology starts, and the TRL level is completed by reaching 9. Capital requirements continue to increase exponentially at this stage; however, investor portfolios expand due to a drop in perceived risk. Possible funders portfolio consists of banks, loan firms, and private & public equities. Market pull strategies start to take an active role in the company to take a stake in the market and strengthen its position in the sector attract more private equities. From this point on, the company is governed by board members, and the financial flexibility of the technology is at a peak point [51] [52].

On the other hand, after AWES reaches technological maturity and commercial viability, there are some financial processes that shipowners have to face in order to use this technology in the shipping industry. However, financiers were reluctant to fund these technologies as it is unproven, and it causes less financier to support the shipping industry. This conflict has affected smaller ship owners to get a new fund for the new ships due to instability in the industry [34]. One of the interviewees said that "Everybody wants to be green at some point, there is no doubt about it, but nobody wants to act alone."

On the other hand, to promote the green shift in the shipping industry, some initiatives were taken, such as Poseidon Principles [34]. Poseidon Principles is a shipping industry financer organization (so-called "Green Finance") generated by global shipping banks like Citi, Societe Generale, and DNB, and collaboration with big companies in the industry and experts. It aims to provide financial support to shipping companies that align with the IMO regulations and its principles [54]. In the shipping sector, it is common to view that this kind of finance organization's existence should increase in the market to encourage and support the shipowners at every economic level, from small ship owners to very large shipowners [34].

4.4.2. Production Investment and Operating Cost

It is also essential that the green technology solution, which will be AWES to align with this thesis's purpose, has to provide a financial benefit to the shipowners from a production investment and operation cost point of view. However, there is no precise performance and cost-related data in the shipping industry for AWES. The reason for this, firstly, there are plenty of ongoing technologies and applications at different development stages. Secondly, the monetary figures of product and benefits are not adequate to assess, and thirdly, the challenge of generating reliable and robust data due to lack of data of operating AWES on the ship to observe the interconnection with external and internal systems of the ship [4].

Even though the total cost of the AWE system cannot be revealed reliably, there are available data about the allocation of the cost drivers for the time being. As figure 30 illustrates, Makani was able to approximate the LCOE overall map of the M600 model for onshore based on three cost drivers as below.

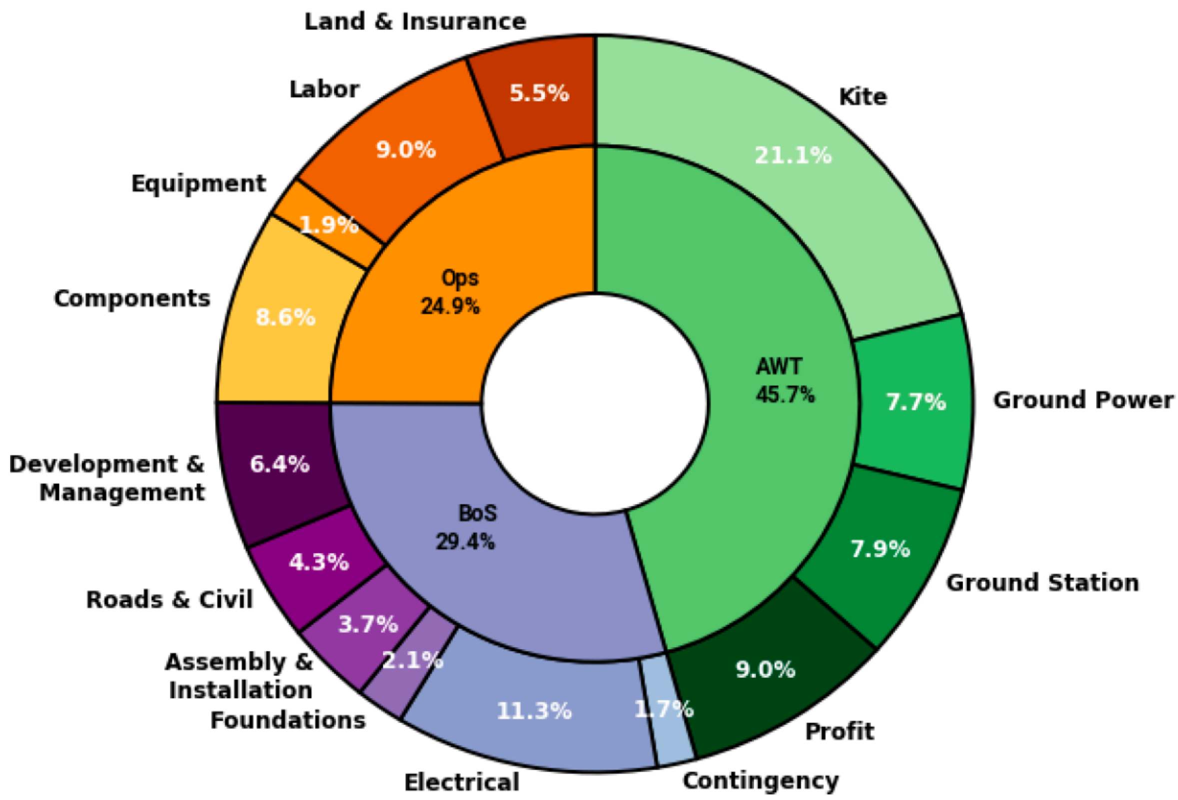

Figure 30 Makani M600 model, LCOE breakdown for onshore [29]

- **AWT,** represents the capital cost of the kite. In another saying, the cost of main systems. It is almost half of the LCOE comes from capital investment. Figure 31 is expected to have less share of "Ground Power" investment in the view of ship installation due to its short distance from AWES to ship electrical infrastructure to transmit.

- **BoS,** represents the balance of the system, which means the rest of the necessary functions and tasks to have the whole system run properly. One-third of LCOE comes from the expenses of the balance of the system. BoS expenses tend to decrease with increased system size. In the view of ship installation, it is expected to have less allocation of "Roads & Civil" because the system will be located on the ship.

- **Ops,** represents the operational system. It contains operational components, equipment, and labor. One-fourth of LCOE comes from operational system expenses. In another saying, maintenance expenses of the system. Consideration of ship installation is expected to have less share of "Land & insurance," as AWES will be placed on the ship. However, insurance may cover the whole allocation of it.

In addition, due to AWES features which require less material and higher workload hours, a decrease for LCOE in time is expected. Figure 31 represents the data of Kitemill company to represent it. It is important to note that figure 31 illustrates the AWES model where the generator is on-ground, as explained in the AWES introduction. However, both of the systems aim for the same principle. Therefore, it is reasonable to show the financial advancement of the system.

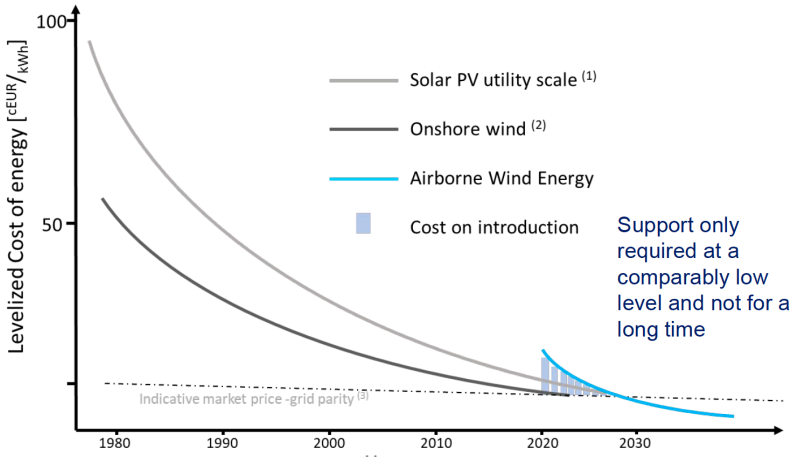

Figure 31 AWES LCOE reduction by years from 2020 to 2030 [55]

4.5.Supplier and Service Analysis

Under this section, firstly, the supplier portfolio of AWES will be detailed by re-introducing the fundamental sub-systems briefly of AWES and pre-conceptual approach of production these main sub-systems and auxiliary systems. Secondly, service analysis will be analyzed by looking at the different maintenance types for AWES and how it will be possible to implement these maintenance types.

As AWES is not in the commercial roll-out phase yet, production of parts and design of components may be handled internally in the company or handing over the 3rd party supplier under the name of special production. Not reaching some of these components as readymade may increase the cost of production investigated in the financial analysis chapter. However, even though AWES is not commercially viable yet, AWES companies and institutions are developing their ability to produce the necessary parts internally, and supplier portfolios are taking shape at this point. It is expected to see an increasing number of suppliers for the production of AWES parts parallel to the development of technology and financial robustness. This chapter analyzes the current AWES supplier portfolio based on the current development level and pre-conceptual ideas. Due to literature scarcity regarding manufacturer/producer parts of the AWES, this chapter is heavily based on the report of the European Commission with the title of “Study Challenges in the Commercialization of airborne wind energy systems.”

AWES consists of four fundamental sub-systems: ground station, tether, flying structure, and control system (includes sensors). Even though the control system is not separate but placed on the flying structure, it is reasonable to consider its own due to its fundamental and vital role in the operation. These central systems are not off-the-shelf due to the technological and operational requirements of AWES feature.

The ground station is the platform that AWES takes off and land automatically. Aside from that, it plays a bridge role between tether and grid connection for electricity transmission. There are various design studies on ground stations to find the best fit for the concept of AWES. Even though, ground station´s product ability seems similar to any other system in the market. There are ad-hoc features that need to be handled. The list below indicates the supplier's list of AWES ground station production.

- EMCE B.V., producer of AWES ground station
- DROMEC B.V., producer of AWES ground station
- ABB Switzerland, producer of the electrical system of the ground station and be a player of research of AWES concept
- GE, part supplier of the ground station and expressed interest in AWES concept
- Siemens is the producer of electrical components and, same as GE, shows interest in the AWES concept [52].

These companies are primarily producers of other renewable energy source solutions or any other applications in the market. Therefore, due to its proximity to the ground station, they have shown interest in being involved.

Tether is the connection between the flying structure and ground station physically and transferring produced energy down to the grid connection. Due to its crucial role in the operation, tether production requires some design and production challenging issues. These are mainly; it needs to be light enough to prevent drag force over flying structure, it needs to be robust and resilient enough to endure tensile strength, and it needs to ensure the electric transmission with the lowest loss. The current supplier list of tethers is listed below.

- DSM Dyneema B.V., manufacturer of the tether and show interest in research of AWES
- Covestro A/S, tether material producer and reflect the same interest in AWES research
- Lankhorst, Gleistein, and Lios producers of tethers [52].

Due to its complexity in the tether's material selection and design, the tether's supplier portfolio is relatively shorter. Therefore, it is important to expand the selection of suppliers with this production capability or establish a technology center/factory where it can produce the tether.

The flying structure is the main structure that flies the controlled loop to harvest the wind. It is connected to whether the bridle line or tether keeps the flying structure attached to the ground station. It is exposed to the aerodynamical and gravitational forces and the sub-systems and sensors' weight. It requires ad-hoc design and production. Therefore, the producer of the flying structure is AWES companies for now as below, and there is no external supplier portfolio shaped yet.

- Skysails, AWES company
- Ampyx, AWES company [52].

The Control system includes sensors are the so-called brain of the system. The control system is fed by sensors feedback and computes the operational condition of the AWES. Received feedback from sensors are wind speed, speed of the flying structure, tether length, attitude, angle of flying structure, and wings position. Based on these data, the control system is adjusting the loop and position of the flying structure to reach the most efficient electricity production and ensure safe operation. This vital role of the control system brings design, background coding of the system, and production challenges. The control system still under the research and improvement phase as it is not proven yet at long-term testing. Suppliers of this technology relatively limited, as is seen below.

- Xsens Technologies B.V.
- Aenarete [52].

On the other hand, keeping the AWES operating requires performing a proper and planned maintenance approach. Having also an emergency plan in case of an unexpected failure occurs other than planned maintenances. Therefore, service analysis is detailed, looking at different perspectives.

a. Preventive Maintenance (Planned Maintenance), documentation, and planned maintenance procedure should be prepared by the producer and designer of the AWES. It is essential to know the material's lifespan, mean time between failures, and possible failure phenomena. Most time and expense-consuming parts are the power plants in the system, such as motors, rotors, motor controllers, and cooling systems. These sub-systems and most of the powertrain components maintenance should be scheduled around every six months by the responsible crew members on the ship [29].

   The flying structure is exposed to harsh weather conditions, solar radiation, corrosion, and different force vectors such as gravity, drag force, and pull force. Due to those external factors, flying structures should be replaced a minimum of once a year. Depending on the full load hours of the system replacement period may be shortened and needs to be replaced more than once a year [52].

   Similarly, the tether is exposed to the same external impacts and electrical transmission through the tether, accelerating the tether's aging. When the current technology and design of the tethers are considered, the replacement period of the tether every 4-6 months in a year means replacement should occur twice or three times a year. There is a trade-off here; the heavier and thicker the tether to prevent short-term replacement, the more challenging issues show up in the design of the flying structure as it needs to carry the tether as the tether will apply downward force continuously.

b. Corrective Maintenance (Unplanned Maintenance) occurs in the system in case of an unexpected breakdown. Firstly, it has to be ensured that the AWES should land on the ship safely and adequately. Maintenance of the system will likely take more time than any other similar system in the industry, such as horizontal wind turbines, because modeling uncertainty is considerable, technology is not discovered yet thoroughly, and all the failure scenarios are unknown. For these reasons, Makani has concluded that 15% of the time, technicians are working on the failure but cannot fix the kites at that moment [29]. To prevent this scenario on the ship, a 24/7 customer service center should be provided by the producer of the AWES to reach for help and advice for the system and technology.

c. The producer of AWES should provide an inspection scenario, inspection method, guideline, checklist, and description. Visual inspection should be carried out after every operation when the system lands. In that way, unexpected failures may be prevented, such as detecting a deformed part on the flying structure or tether. AWES seller should clarify other inspection method frequencies such as x-ray, ultrasonic, eddy current, magnetic particle, etc... This inspection needs to be made by one of the ship crew members. After the guideline is followed and the checklist is completed, it must be stored physically or digitally.

d. Warranty services are the promise of the seller of AWES to guarantee the functionality of whether whole system or some specific system. A warranty agreement should be agreed upon with the customer based on operating hours and/or time. If any failure occurs to the sub-system during warranty coverage times, the seller must either replace or do maintenance rapidly. However, suppose that failure happens while the vessel is sailing away in the middle of the ocean. In that case, it will be costly for the seller to reach the vessel point by likely helicopter if there is a helicopter platform to land on the vessel. Otherwise, the customer will not be able to use and benefit from AWES until the vessel reaches any port. This type of scenario should be reviewed with the customer before selling. In addition, to cover the warranty period for all the customers, there needs to be a worldwide service/maintenance web to provide support for vessel owners at any location. Nominating suppliers to take over maintenance tasks or establishing sub-companies at strategic locations worldwide to support customers constantly might be needed.

4.6. SWOT Analysis

This section presents the SWOT analysis of the AWES based on the analysis from chapters 4.1 to 4.5. In that way, external and internal advantages and disadvantages of the system will be revealed. Considering that AWES is still in the technology demonstration phase, it is a helpful tool to detect external and internal factors of the system. In that way, there may be constructive work towards eliminating threats, shining its opportunities, using effective strengths, and improving weaknesses. Below, figure 32 indicates the SWOT analysis based on the analysis part titles before.

.

Opportunities of the AWES come from the stability and consistency of wind at high altitudes, which affects AWES to operate at full load for long hours. Moreover, the need of the market for new green energy solutions can be a great advantage for AWES. On the other hand, external threats of the AWES come from various perspectives that need to be deterred. These threats are mainly related to technological and economic difficulties as well as regulatory issues.

The strengths of the AWES are noticeable since they require less material and easy mobility of the system. On the other hand, internal weaknesses are mainly related to technological and operational issues like external threats.

Based on SWOT analysis output and interviews for this thesis, the most noticeable disadvantage of the system is operational safety issues deriving from a lack of technological provability. The outstanding feature of the AWES is the easy installation and mobility of the system.

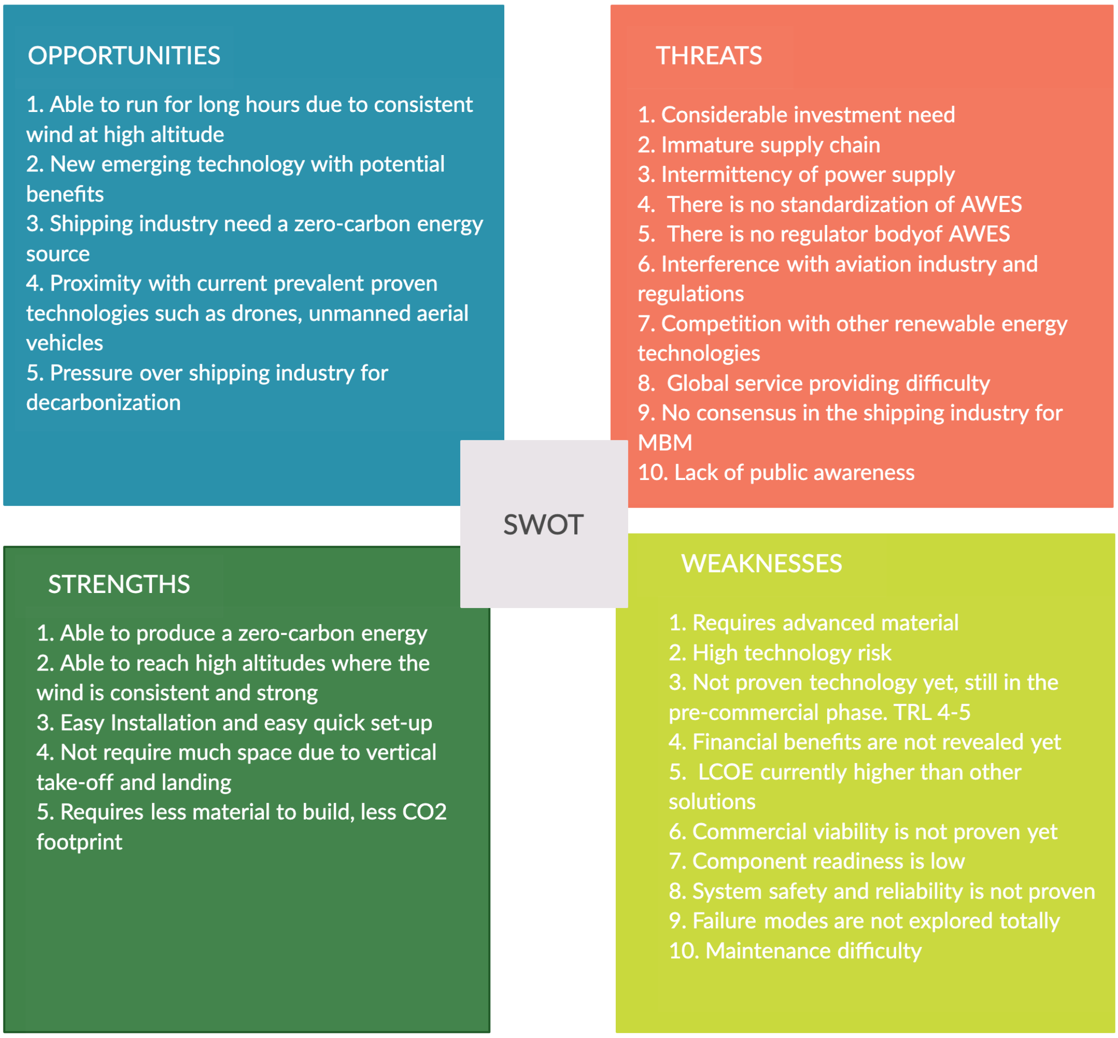

Figure 32 SWOT Analysis of AWES

5. Final Reflections and Recommendations

To achieve AWES to obtain a strong market share, the system's economic viability should be able to race with other solutions preferred by users. To reach that, threats of the system should be eliminated or reduced as low as reasonably practicable. Weaknesses should be progressed and turned into strengths. Opportunities of the system should be used wisely, and the complete functionality of the system should reveal all these opportunities. Finally, strengths should be used in the system to make it robust, resilient, and beneficial. In this section, SWOT analysis reflection is presented. Firstly, the opportunities and strengths of the system are mentioned briefly. Secondly, the focal points are the solutions and recommendations for threats and weaknesses by dividing into two perspectives as economical and technical. And lastly, the final reflections of the analysis part are presented in respective order.

AWES concept is a novel technology with benefits and outstanding features such as replacing the heavy metal tower of wind turbines with a tether to connect the system to the ground. The tether makes it possible to ascend the system to high altitudes where the wind is stronger and more consistent with generating power for long hours. Moreover, high altitude provides a system availability to be deployed all around the world. Replacing heavy material brings easy installation, quick set-up, and increased mobility of the system. Considering these advancements, experts believe that utilization of this technology will become prevalent. Therefore, more than 250 systems will be sold, and around 80MW of energy will be produced by AWES, as shown in figure 33.

AWES still in the technology demonstration phase, where technological advancement starts and financial gains are computed theoretically. This phase also contains “Valley of Death” where capital requirements start to increase; however, the technology risk is still high. Therefore, considerable investment is needed to progress with technological barriers to carry the technology to the subsequent phases. To ensure better traceability, solutions and recommendations are approached under two categories: technological and economic perspectives. These perspectives are the views that take the system further in the development path. Even though it is divided into two categories, these categories closely affect each other.

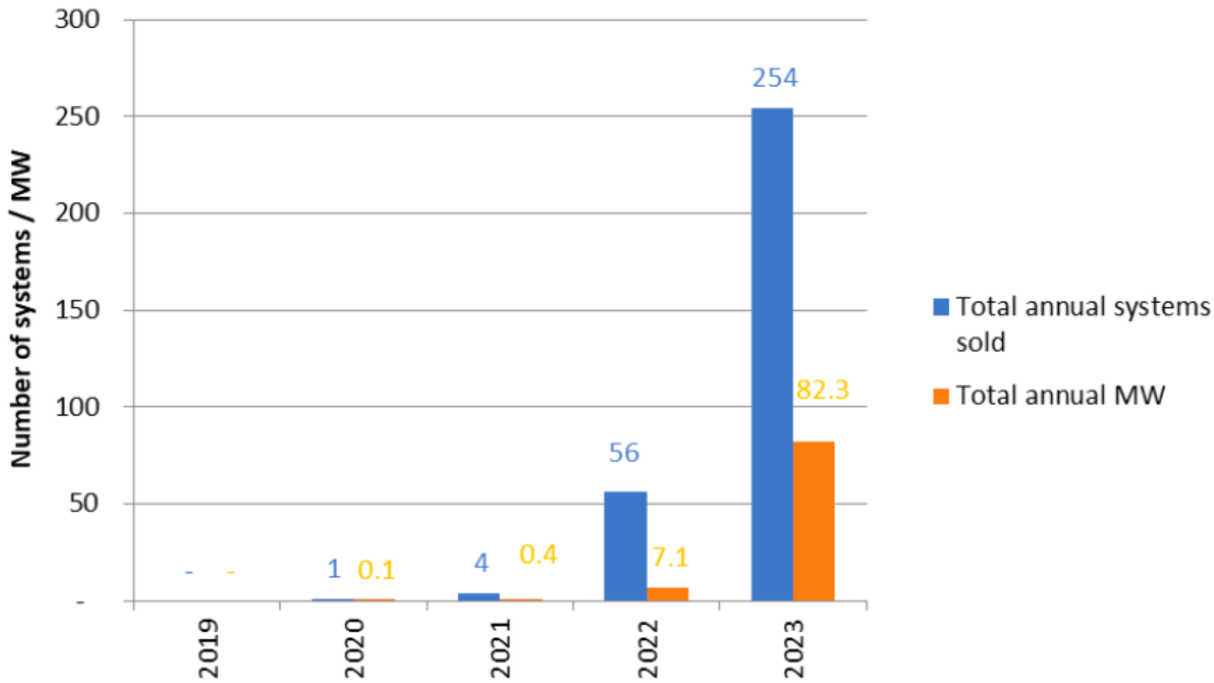

Figure 33 Annual numbers of commercial AWES sold and annual capacity in MW installed until 2023 [27]

- **Technological approach**, nature of AWES is made of high technology due to its automatic aerodynamical balance at high altitudes. The control system plays a vital role in the automatic command of the flying structure on its loop at high altitudes based on sensor feedback. Therefore, the reliability of the automatic control system needs to be approved for the safe operation of generating electricity. Aside from that, AWES contains required advanced material for tether, flying structure (kite), need of advanced aerodynamic calculations and simulations before the operation, ground station, and concept of automatic take-off and landing on the ground station. To carry the AWES into the technologically reliable device, component readiness and concept should be converged, automatic operations, and system safety & reliability should be proven by long hours of testing. As it is mentioned under financial analysis, the TRL of the system should be increased gradually. For this purpose, the airborne wind energy association has formed a working group to work towards these technological, operational, and safety issues. The purpose of this working group is to secure safe operations. There should be more of this kind of working group in the sector to accelerate the operational advancement and encourage sector stakeholders to act as pioneers in the market [56].

On the other hand, AWES does not have its standard in the sector, making it harder to fit the technology into a shape. The aviation industry has been used as a reference as the operation takes place at high altitudes. However, the concepts of the aviation industry and AWES are different from each other. Therefore, policymakers in the AWES sector need to produce a standard specifically for AWES, and this standard should align with the aviation industry as it interferes with aviation industry limits. Moreover, AWES standards should align with other markets in case of using this technology in other sectors such as the maritime industry.

- **Economic approach**, investment/funding is necessary for the development of the technology. However, AWES requires high capital intensity due to high technology and required advanced material needs. AWES´s range of investment that needs to be commercially viable is € 5-100 million. The fact that AWES still in the technology demonstration phase where risk is high leads investors to be reluctant to fund AWES technology. Moreover, funding reluctance not only derives from the TRL of AWES but also about the time length of the development phase, which is an unknown factor in the sector. Due to this unknown assessment, it triggers the lack of exit-mechanism for the investor [51]. To attract investors, the duration of development should be shorter, and LCOE should be competitive enough to get a market share in the renewable energy sector. At the same time, the system's output should be at enough level to be considered a fruitful investment. When all these points are collected, the issue is shaped identically to competitive LCOE, short-term development, low capital need, and available exit mechanisms. To succeed that, AWES companies should go for small-scale production and development rather than intermediate or big scale production and development to overcome the technological, operational, and safety issues. In that way, learning of technology is completed by analyzing the interconnection of sub-systems, components and investigating interdependency with external factors. In addition, it will require low capital intensity, duration of development will be relatively shorter at small scale than bigger scales, and LCOE will be computed more reliably [57].

  In addition, linking technology with other prevalent already proven technology may increase the trust in technology. Therefore, AWES should take as an example these technologies such as aerodynamical calculation, sensors, lightweight design of unmanned aerial vehicles, drones, airplanes. In that way, AWES may be seen as a combination of already proven technology.

5.1. Reflection of market analysis

The sweet spot market for AWES, which is ships with a 5,000-10,000 dwt, will help the AWES technology learn these ships' characteristics and behavior. However, the market analysis showed that some unknown numbers of ships are not registered in IMO, leading to dysfunctions and hardly any pressure. This lack of authority does not unite the orientation of the shared goal, which is the decarbonization by the end of the century. Apart from that, market-based measures should support and encourage AWES to be a green energy solution in shipping companies. As a result of the literature research and the interviews made for this thesis, it was found that shipping companies have high expectations from IMO in the subject of MBM. While shipping companies invest in AWES and spend workforce, other shipping companies continue to operate with fuel oil, which is easy to access and cheap, negatively impacting a potential investment and search for AWES. However, IMO was unable to reach a consensus on MBM yet, and this delay may cause a delay in AWES implementation.

On the other hand, it is important to comprehend the market size- sequence development path of AWES, as is illustrated in figure 34 below. Based on the technological and operational progress of AWES, more markets will be opened to fit in that market appropriately. However, offshore condition markets are requiring advanced, progressed, large scale and fully automated AWES. It is reasonable to classify the shipping sector in the offshore conditions market as AWES will operate at far sea conditions most of the time. AWES is still in the small-scale/ off-grid market considering the AWES current technological advancement to develop further and test its system.

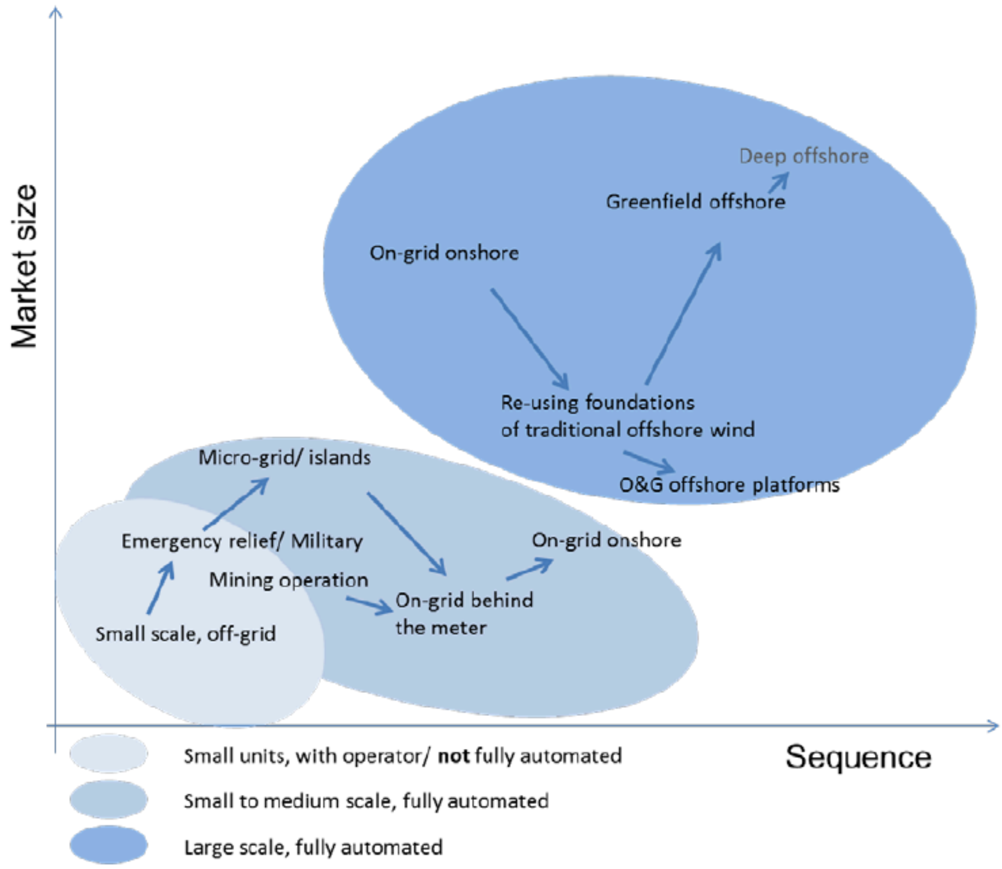

Figure 34 Market and sequence of potential AWES deployment [52]

5.2. Reflection of competition analysis

Shipping companies are investing and researching green energy solutions, and as competition analysis shows, diverse technologies and designs are currently being used in the market. The trial of these green energy solutions in the shipping industry will continue until the entirely feasible solution for the market is revealed and used widely. Currently, common systems are wind energy, solar energy, and biofuel-based energy solutions. If we keep biofuels out and focus on solar and wind energy solutions. The lack of natural sources that are constantly influential in both sources will reveal the issue of intermittency in power production but ships constantly need energy while cruising. Another issue is that the ships are not always on the move. However, the auxiliary engine power system should work even if it is not on the move so that energy can be supplied to the necessary internal systems of the ship. If we consider the first and second points, AWES steps forward with its unique solutions. It can provide energy flow even when the ship is parked, if not in the narrow channel and port. Also, the wind is consistent and stronger at high altitudes. However, AWES can only support the auxiliary engine power system with its current power generation capacity, and the propeller system continues to operate with the fuel oil used on board. Shipping companies tend to have more compact and single solutions than multiple energy solutions, bringing complexity to the operation. This fact can negatively influence AWES implementation on the ships. In addition, although all systems have advantages and disadvantages, all technologies but the AWS have been used in the shipping industry even as a prototype. This shows that they have overcome the trust barrier to enter the market.

5.3. Reflection of customer analysis

Aggressive decarbonization imposition and regulations in the shipping industry encouraged shipping companies to take necessary actions on this matter. Bu actions include forming essential departments, investigating green energy solutions, and preparing feasibility reports. However, the shipping industry has a broad web of stakeholders. Furthermore, if green energy solutions are implemented in the ship, all the stakeholders must be unified with the actively used technology. All the stakeholders have their own aims and purposes and need to know and actively use this shared AWES technology depending on their areas of responsivity. With this in mind, a sense of unification needs to be established within the shipping industry community.

In addition, the need for high energy by ships, which is particularly needed for propellers, constrains the AWES, which cannot meet that amount of energy needed to function properly. The current tendency in the shipping industry concerns low sulfur oil, and this will be shifted to low or zero-carbon oil in the near future in order to align with the decarbonization project imposed by IMO. However, the global availability and price of alternative oil factors are a concern in this regard. Additionally, another concern in the industry is that AWES´s LCOE is higher than the oil prices currently on the market. In this regard, they expect incentives from the shipping industry regulatory bodies so that the green energy solution generally and AWES become favorable to be chosen in the industry. Apart from this, another critical issue is that AWES is not a technologically and economically proven safe green energy solution so far.

Going back to the energy capacity of AWES, customers from the shipping companies require the AWES system to produce electricity as much as auxiliary generators. This is because auxiliary generators function inefficiently at low load. However, AWES still is at the demonstration phase and the electricity produced ranges from 200 to 300 kW, which does not meet the capacity of the auxiliary generators. On the other hand, the interviews showed that the customer's main concerns include safety and reliability. However, the AWS system does not have a verified technology.

5.4. Reflection of financial analysis

AWES is a novel technology that has started the development stage in recent years. Like all other technologies, AWES has operational, technological stages that must be passed to reach the level of mature technology. However, there must be a financial power behind these stages so that the investments can cover the necessary costs and expenses. The investor portfolio changes at every stage, and with this change, the purposes, desires, expectations, and perspectives of the funders also change. And at every stage, these changing characters of the funder must be met. However, the risk-averse approach is the general and common feature of the investor. In other words, investors are willing to invest in technologies that they believe will pay for their investments and trust. The main factors relate the confidence is the requirement for high capital intensity. And this encouraged these investors to invest in technology that requires less capital. Although AWES has clear technological advantages, in theory, the practicality of that technology requires verification. The process of verification should include technology, risks, funding, and maturity paths. This development requires investors to invest in its technology. Production investment and operation cost AWES still theoretical. These theoretically studies are slowing down to turn into a practical computation due to not testing the system for the long term to see the output. However, it is expected that the LCOE of the system will be cheaper than other green energy solutions due to AWES features.

As seen in figure 35 below, the summary and visual representation of the above narratives. Investment risk and LCOE are deriving from the same criteria. When we take into consideration of the AWES current progress condition, component readiness is not converged yet, and design studies are ongoing. Also, safety and reliability are not proven yet due to lacking long hours of testing of the system. Economic performance is ambiguous and computed theoretically, whereas LCOE projections have a competitive level by 2030. AWES is not recognized and unknown by social folks yet, but it is approved and accepted as it has a positive environmental contribution. Funding availability of the AWES depends on the technological, operational, and safety & reliability maturity. However, it is seen that investors are having a risk-averse approach to this technology. For instance, Google has withdrawn the fund from Makani AWES company after they failed the testing of 600Kw AWES in Haugesund, Norway. AWES has crashed onto the sea while testing. And, this has lead Makani company to discontinue its operation.

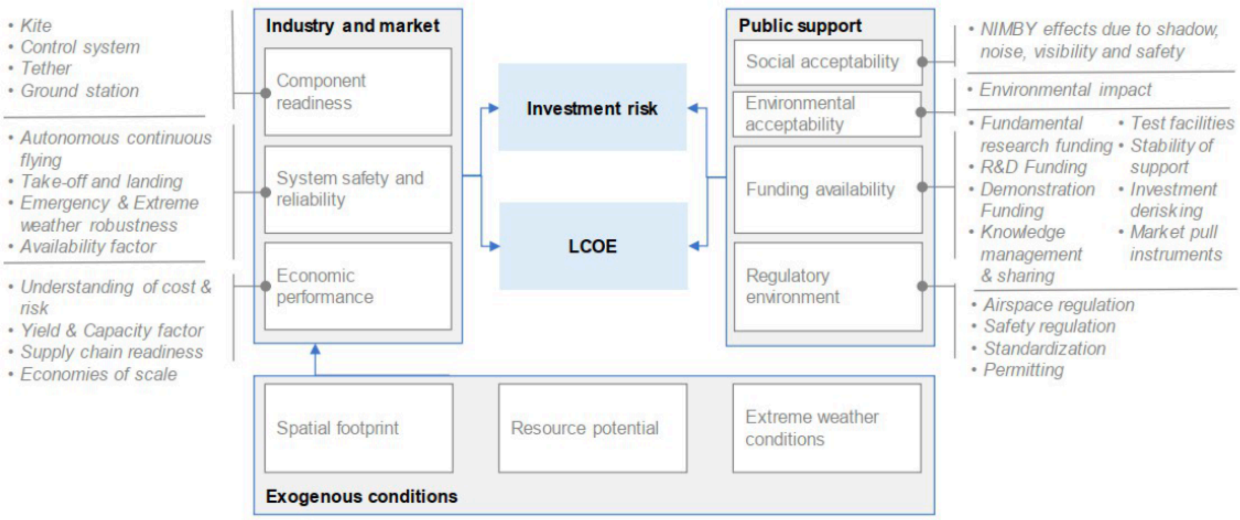

Figure 35 Overview of categorization barriers affecting the Investment risk and LCOE of AWES technologies [52]

5.5. Reflection of supplier and service analysis

AWES currently has a limited supplier portfolio. The lack of supply chain maturity of AWES directs them to produce their components in their factories or to ask for their supplies to produce these ad-hoc components. Since the technological and design needs of AWES's central four sub-systems mentioned above are different from the technological developments that are currently used, it can be understood the reason for the limited supplier list. In addition, this factor causes more cost and lead-time extension in terms of economy and lead-time. When this factor is compared to global operations of shipping companies, some difficulties might arise, primarily when a component is produced and dispatched to anywhere in the world. This might lead financially to extra costs.

On the other hand, shipping companies working on far seas will also lead to challenges in the maintenance of AWES. However, planned maintenance can be taken under control somehow with the guideline of the producer. The need to replace some parts of the system at some regular period requires shipping companies to have competent workers to deal with these operations. At the same time, keep these necessary sub-systems in the storage in the ship requires some spaces in the ship. In case of an unexpected breakdown, the producer of AWES may not reach the ships that need service due to the far sea's conditions of the vessel. And customers may not be able to use the AWES due to these failures. This possible locational difficulty of reaching the ship may arise when the case is warranty service involvement. These barriers will adversely affect any investment by shipping companies in this system.

6. Discussion

In this study, five findings were determined as the outcomes of the above industrial analysis part. In the light of these findings, AWES has positive and negative effects on the implementation of the shipping industry.

Firstly, as a result of market analysis, when looking at the advantages of s AWES, the shipping industry needs a green energy solution. This is the decarbonization trend that occurs both in the world and in the shipping industry. Although steps are taken towards the green energy solution in the shipping industry, it is seen that there is no intention to aim at a complete unity and a single target. Therefore, companies that want to pursue this goal have incentives expectations from IMO under the MBM policy, but consensus on MBM has still not been achieved. This misalignment would affect the implementation of AWES into the shipping industry.

Secondly, as a result of the competition analysis, although AWES is outpacing other green energy solutions with its advantages, it has not been used as a prototype yet. It has not been able to provide the necessary strength and feasibility to enter the shipping industry.

Thirdly, customer analysis enables AWES to work even when the ship is parked, making it ahead of other green energy solutions. However, looking at the disadvantages of this system, the first finding is that the trend as alternative energy is more compact and towards a single solution so that complexity in the shipping operation can be minimized. AWES's capacity to substitute only the auxiliary engine power outperforms this green solution in this regard. In addition, the fact that the system is still at TRL 4-5 levels technologically may increase the doubts about the development future of the system. It was concluded that one of the most important points for the shipping industry is safety & reliability point. At this point, AWES still lacks long hour testing and cannot be called safe operation, which creates a significant obstacle to the use of this system on ships. Although AWES is seen as a simple system from the outside, the requirement of high-altitude weather conditions and a highly autonomous system means that the reliability of the sensors and control systems called auxiliary systems must be increased.

Fourthly, as a result of the financial analysis, the high capital requirement of AWES and the insufficiency of exit mechanics cause investors to worry about investing in this technology and be risk-averse. This forces the possession of an investor portfolio, which is necessary for technological development. In addition, calculating the operational cost, still uncertain and theoretical, raises questions about the future and use of this technology. Fifthly, the fact that the supplier portfolio is limited and immature presents disadvantages to the production of parts and sub-systems in terms of both economic, producibility, and lead-time. In addition, the shipping industry operating in distant seas can cause service difficulties. AWES company is global like shipping companies, and that the service problems are solved at many points can be economically challenging for AWES companies.

Although AWES is a novel and promising technology, it is necessary to start from small-scale and on the land. Later, with the improvements to be made in the system's reliability, this system can provide energy production for offshore conditions or the shipping industry.

This thesis aims to install AWES, one of the renewable energy types, to serve the shipping industry's decarbonization trend. In order to comply with this purpose, the feasibility of AWES to the maritime industry needs to be examined from different aspects. These aspects are determined as market, competition, customer, financial, and supplier and service analyses for this thesis. These analyzes were grouped as external opportunities-threats and internal strengths-weaknesses with the help of SWOT analysis, and crucial points were presented.

It has been determined that among the things learned and recorded during the writing of this thesis, the fact that the shipping industry has a global, multinational and individual structure causes difficulties in achieving a common goal. It has also been observed that the operational difficulties inherent in ships cause difficulties in integrating any new green energy solution into that system. In these difficulties, it has been learned that the contribution of a system such as AWES, which is in the so-called beginning of the path of technological maturity, to the maritime industry is not possible at the moment.

Future corresponding work from this thesis should include some improvements on AWES and the shipping industry. The International Marine Organization should encourage shipping industry stakeholders by explaining and agreeing on market-based measures and promulgate additional encouraging regulations on the use of renewable energy systems. In addition, it is necessary to guarantee the flow and dissemination of information on this subject. In other words, the green energy solutions in the shipping industry should not be seen as a competition between shipping companies but as a point to be reached as a market and should be acted together. Also, to reach AWES technological maturity, high capital should be avoided and started as small size first, and more industry should be involved. In this regard, safety and reliability issues should be the first issue to be reviewed. It should not be the first question regarding integrating the system into the shipping industry.

7. Conclusion

The symptoms of global climate change have begun to show their effects more severely due to the ever-increasing release of greenhouse gas emissions since the industrial revolution. In order to first reduce and then stop greenhouse gas emissions, especially CO2, the sectors have started to carry out decarbonization studies in their fields. The shipping industry, which is one of these sectors and carries a large part of the transportation in the world, has started to take necessary precautions due to the increasing social pressure in this regard. Shipping companies have established relevant departments and increased their work on this subject, but IMO takes the lead in this change and determines the acceleration of the sector for decarbonization. AWES can be one of the solutions of the shipping industry, which is one of the green energy solutions. Considering that AWES is a new and developing technology, its disadvantages should be eliminated, and it should become more suitable for a sector such as the shipping industry that is in search of a solid and continuous solution. Therefore, the preliminary usage area of AWES should be land-based systems that then can be implemented into the shipping industry or shipping industry.

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9. Appendix

9.1. Appendix – 1

Interview Questions

1. Has your company ever considered reducing your carbon footprint by implementing a new kind of technology rather than retrofitting the current system? If yes, which technology was it, can you please tell me the story of this? If not, what was the blocking point for that? Can you please tell me a bit? If you choose to go through retrofitting current machinery, what was the motivation behind that?

2. What is the approach of the maritime industry to implement renewable energy solutions on vessels? If so, what are the steps being taken for that? If not, what is the reason for that?

3. Is your Company concerned about possible increased emission taxes?

4. What are the parameters of choosing or calculating the vessel´s route? What do you consider most? Is headwind one of the parameters that are taken into consideration?

5. What is the average consumption of energy while sailing away? Of course, this figure may change depending on the size of the vessel and its duty. I just want to hear the average.

6. How do you see the usage of marine diesel engines in the vessels?

7. How do you see the usage of renewable energy solutions in the vessels?

8. What do you think of this AWT technology from a safety and reliability point of view? What would be the features of that technology that convince you to install from a safety and reliability perspective?

9. Where is the best place on the hull of the vessel to implement this system? Why so?

10. What do you think about the AWES generally? What did you like most? What did you not like most?

11. If I may ask you to define the threats, opportunities, weaknesses, and strengths of this technology, how would you describe them?

9.2. Appendix – 2

1. **"International Fund for GHG emissions from ships (GHG Fund) (Cyprus, Denmark, the Marshall Islands, Nigeria and IPTA (MEPC 60/4/8)):** Establishes a global reduction target for international shipping, set by either UNFCCC or IMO. Emissions above the target line would be offset largely by purchasing approved emission reduction credits. The offsetting activities would be financed by a contribution paid by ships on every tonne of bunker fuel purchased.

2. **Leveraged Incentive Scheme (LIS) (Japan (MEPC 60/4/37)):** GHG Fund contributions are collected on marine bunker. Part thereof is refunded to ships meeting or exceeding agreed efficiency benchmarks and labelled as "good performance ships".

3. **Port State Levy (Jamaica (MEPC 60/4/40)):** Levies a uniform emissions charge on all vessels calling at their respective ports based on the amount of fuel consumed by the respective vessel on its voyage to that port (not bunker suppliers).

4. **Ship Efficiency and Credit Trading (SECT) (United Sates (MEPC 60/4/12)):** Subjects all ships to mandatory energy efficiency standards. As one means of complying with the standard, an efficiency-credit trading programme would be established. These standards would become more stringent over time,

5. **Vessel Efficiency System (VES) (World Shipping Council (MEPC 60/4/39)):** Establishes mandatory efficiency standards for new and existing ships. Each vessel would be judged against a requirement to improve its efficiency by X% below the average efficiency (baseline) for the specific vessel class and size. Standards would be tiered over time with increasing stringency. Existing ships failing to meet the required standard through technical modifications would be subject to a fee applied to each tonne of fuel consumed.

6. **Global Emission Trading System (ETS) for international shipping (Norway (MEPC 61/4/22)):** Sets a sector-wide cap on net emissions from international shipping. A number of allowances (Ship Emission Units) corresponding to the cap would be released into the market each year via a global auctioning process. The units could then be traded.

7. **Global Emissions Trading System (ETS) for international shipping (United Kingdom (MEPC 60/4/26)):** Differs from the Norwegian ETS proposal in two aspects: the method of allocating emissions allowances (national instead of global auctioning) and the approach for setting the emissions cap (set with a long-term declining trajectory).

8. **Emissions Trading System (ETS) for International Shipping (France (MEPC 60/4/41)):** Sets out additional details on auction design under a shipping ETS. In all other aspects the proposal is similar to the Norwegian ETS proposal.

9. **Market-Based Instruments: a penalty on trade and development (Bahamas (MEPC 60/4/10)):** Insists that the imposition of any costs should be proportionate to the contribution by international shipping to global CO2 emissions.

10. **Rebate Mechanism (RM) for a market-based instrument for international shipping (IUCN (MEPC 60/4/55)):** Compensate developing countries for the financial impact of a MBM. It could be applied to any maritime MBM which generates revenue" [58]. (Taken from IMO website)