A Decision-Making Tool Based Analysis of Onboard Electricity Storage

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Abstract—**Energy has been used in maritime transportation, while fossil fuels began to be used more extensively since the industrial revolution to carry more products and obtain higher propulsion power. However; climate change appeared as one of the striking problem areas around the globe, where the scale and speed of rising concerns about climate change are unfortunately increasing. Greenhouse gas emissions are one of the most significant issues about climate change, including the maritime sector and alternative energy resources like renewables and respective hybrid power systems that are considered to be used in maritime transportation. However there is a big challenge about energy storage in terms of the technology penetration and respective costs.**

In this paper, the current energy storage technologies on a chemical tanker ship have been analyzed in the Reference Energy System perspective and an alternative scenario has been developed. Rectifiers and batteries are the available energy storage systems which are used in case of blackout and emergencies. Low voltage direct current fed systems are GMDSS, emergency lighting, bridge navigational instruments, etc. Batteries are kept charged by rectifiers to be used in case of emergency or need for temporary power. Current energy storage technologies of a chemical tanker ship were fulfilled via Long-Range Energy Alternatives Planning system and the current situation has been specified by the statistical data, to obtain the base scenario. As an alternative scenario, the required secure and cost-effective level of electricity storage in battery groups has been analyzed, according to IMO regulations and respective technology improvements. The results show that, energy storage is a viable solution to back up the vital navigation systems onboard and alternative resources can supply the electricity for storage purposes to encompass a more secure future, in a cleaner atmosphere.

Keywords—Reference energy system, Energy modelling, Ship energy system analysis, Storage, LEAP

I. Introduction

The maritime sector is the most widely used sector in the transportation sector from past to present. While the ships were carrying the products, human power and wind were used as the energy source until the beginning of the 19th century and after than steam power started to be used. Later, in the second half of the 20th century, internal combustion engines have been used more widely onboard, and therefore the use of heavy fuel oil (HFO) became increasingly widespread. And today, as shown in Fig.1 HFO and marine diesel oil (MDO) is used as fuel in the vast majority of the maritime industry [1].

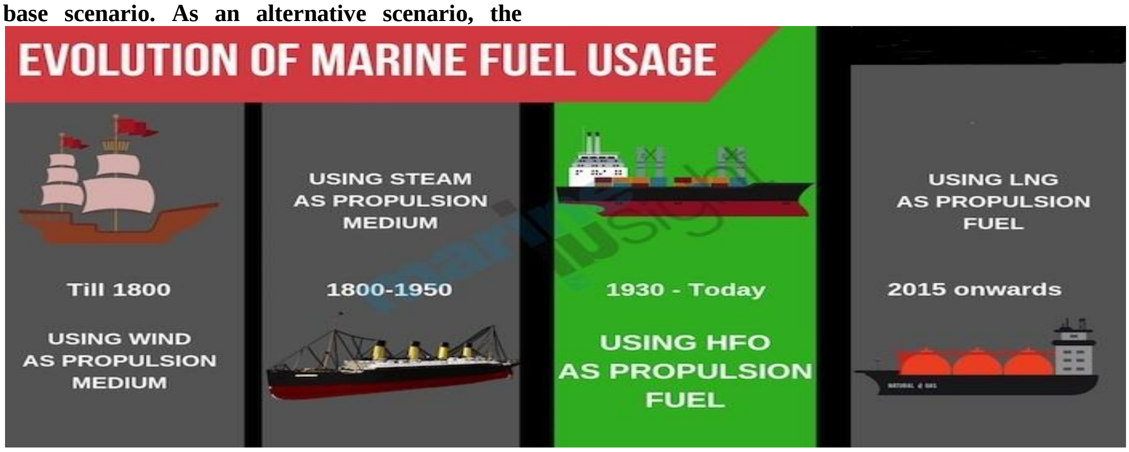

Fig. 1. Evaluation of marine fuel usage [1].

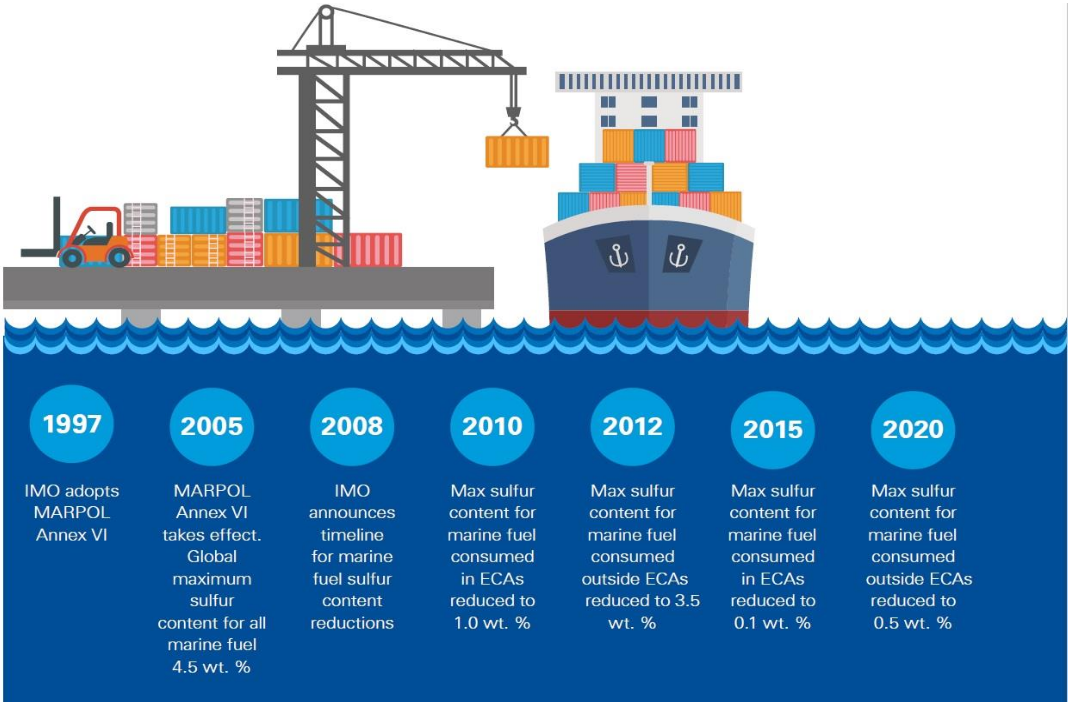

Fig. 2. Marine fuel sulfur content [2].

While HFO is used only in main engines, MDO is used as fuel in both main engines and auxiliary engines. HFO has been the most used marine fuel since the 1960s. Although HFO is viscous and dirty, it is inexpensive and widely available around the world. So HFO propelled a long period of steady growth in international maritime, which carries over 90% of intercontinental trade by volume each year. For many, it is crucial in the maritime shipping industry [3].

However, the low price of HFO does not reflect its effects on the environment and human health. HFO releases SOx and other greenhouse gases (GHG), which causes global warming, acid rains and respiratory diseases. Therefore, the maritime sector negatively affects our environment and our health [3]. To prevent these negative effects, efforts have been made to take measures on a global scale in the maritime sector as in all sectors.

The global maritime sector is facing an onslaught of legislation to boost its ecological performance by the decision of the International Maritime Organization (IMO). As shown in Fig. 2 from January 2020, a majority of vessels have to burn fuel revealing less sulfur. A challenge requiring even more innovation, although, is an aim to halve shipping's carbon emissions by 2050 means the world's future maritime vessels not only will have to depend on a broader range of fuels but also adopt energy efficiency measures [4].

Although alternative fuels to fossil fuels and alternative technologies to currently used technologies continue to be developed worldwide, there is not yet a fully reliable fuel or technology that can be used in long-distance ships. Clean energy sources used at short distances are expected to be developed in the following years and to be used at long distances [5].

Therefore, in this study, we will analyze how much we can meet the electricity needs of a chemical tanker ship by 2021 with the help of batteries to be replaced by an auxiliary engine and how much we can reduce the emission rate.

II. RES CONCEPT AND ENERGY DECISION SUPPORT TOOLS

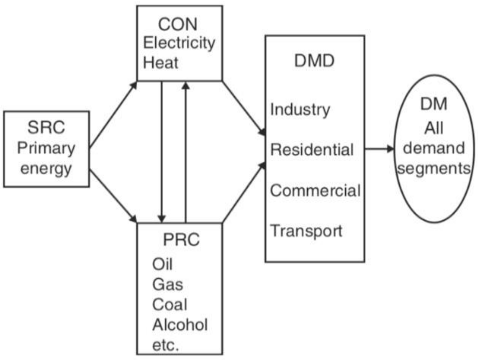

Fig. 3. Simplified representation of a typical RES [6].

The Reference Energy System (RES) is a representative network that shows energy transitions and transformations from sources to demand technologies that meet demands. It is a set of parameters that define the characteristics of technologies and resources, such as fixed and variable costs, technology availability, performance and pollutant emissions. [7].

RES is a flowchart showing the current status from each primary energy source to each end-use request through various conversion and processing steps shown in Fig. 3. This scheme is defined for a moment in a given time period (e.g. 2010 or 2015), and a reference scenario is created and developed to compare existing technology or energy requirements with alternative scenarios to be developed. [8].

A. Reference Energy System of a Chemical Tanker Ship

To better discover the chemical tanker ship energy system and to make connections among its components, the chemical tanker ship's RES has been formed and illustrated energy resources, storage technologies, conversion/process technologies, energy carriers and demands, as shown in Fig. 4.

Different approaches are utilized to plan and optimize an energy system as a whole in terms of energy, economy and ecology aspects from the engineering point of view. Various energy modeling tools have been developed to date on both micro and macro scales such as a single apartment, building, city, country or a region. Some of these modelling tools are;

- EnergyPLAN,
- Energy and Power Evaluation Program (ENPEP),
- MAED,
- REAP,
- RETScreen,
- MARKAL
- LEAP [9].

B. Long-Range Energy Alternatives Planning (LEAP)

LEAP, the Long-range Energy Alternatives Planning System, is a commonly used energy modeling software tool for energy policy determination and climate change mitigation assessment developed by the Stockholm Environmental Institute (SEI).

First, an overview of the current situation should be provided based on recent information and data for the reference year and a basic scenario is then developed. The next evaluations are made by developing alternative scenarios against this basic scenario.

LEAP consists of the technique that can be used to develop various scenarios of envisaged energy demand and environmental impact, depending on how energy is consumed, transformed, processed and produced in a given region, vehicle or economy under a range of values for economic, environmental parameters and constraints. The LEAP model has a flexible data structure that is easy to use. It is also rich in energy technologies and technical and end-use details. It has been extensively adopted at local, national and international levels, including many academic research and government agencies, to identify energy supply and demand, identify environmental impacts of energy use and predict potential challenges in the future.

The LEAP model is one of the widely used energy decision support tools for evaluating energy consumption and greenhouse gas emissions in the home, trade, transportation and industry sectors around the world.

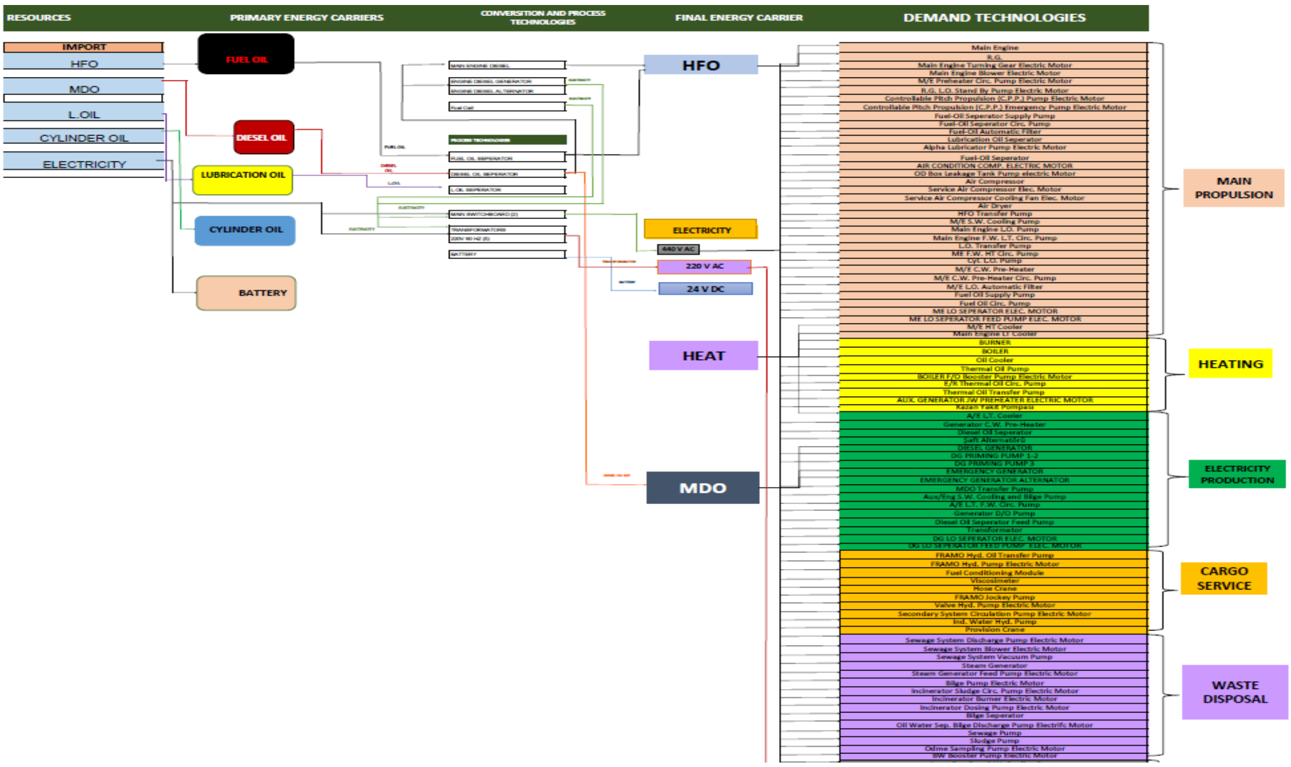

Fig. 4. Reference energy system of a chemical tanker ship.

III. Energy System Modelling of a Chemical Tanker Ship Via LEAP

A. Information about Energy System of a Chemical Tanker

Fig. 5. Photo of the chemical tanker.

In this study, the energy system of a chemical tanker ship has been analyzed. This ship was built in Turkey in June 2011. This ship owned by Transal Shipping Company can carry a total of 26000 DWT and 29537 m^3 cargo which is shown in Fig. 5.

Batteries are used in ships to keep certain systems and devices in service during power outages, a malfunction in the power supply system or an emergency. In the chemical tanker ship we analyzed, batteries are used in systems such as Electronic Chart Display and Information System (ECDIS), radar, communication systems, emergency lighting, emergency auxiliary engine start system, main engine alarm and indicators and free-fall lifeboat. In this study, we aimed to develop alternative scenarios by analyzing not only battery systems; but also all energy systems.

In the RES, which is constituted after the scanning of demand, demand technologies, process and conversion technologies and resources in the chemical tanker ship and shown in Fig. 3, meets 14 demands in total by 187 technologies.

The energy needs of the chemical tanker ship are met by fossil fuel and electricity. All electricity and fossil fuels are imported. Imported electricity is converted into suitable end-use energy through conversion and processing technologies and used by demand technologies. Imported fossil fuel directly used by conversion and process technologies to provide appropriate final energy carriers to demand technologies.

B. Basic Parameters of a Chemical Tanker Ship

In line with the determined parameters, 2017 was chosen to create the basic scenario with the information provided from the Transal Shipping Company. The parameter assignments are made according to 2017 data and the basic parameters are shown in Fig. 6, where it is determined to be analyzed annually until 2050.

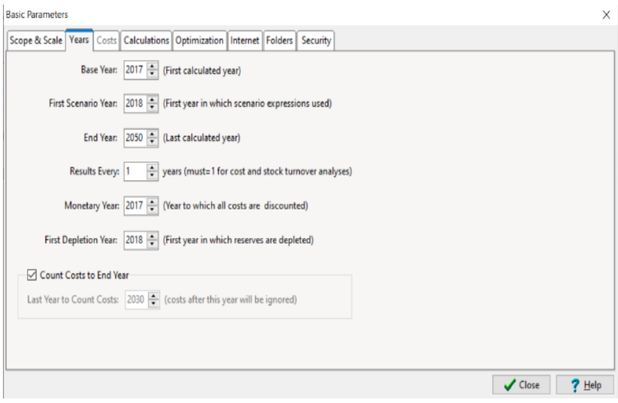

Fig. 6. Basic parameters.

After the basic parameters are defined, the demands and respective energy technologies to meet these demands are defined in LEAP. During this phase, energy sources are defined as primary energy carriers.

In the LEAP energy model, primary and final energy carriers are found under the "Resources" tab. While other parameters are defined by the user, primary and final energy carriers do not need to be defined by the user, they are defined automatically.

IV. Energy Balance Analysis

To calculate the energy consumption, one-year data and information from a chemical tanker ship were received from Transal Shipping Company. All energy demand and process conversion technologies in the energy system of a chemical tanker ship are defined to LEAP. Then, the information obtained was entered in LEAP and the energy consumption for the reference year was determined and shown in Fig.7.

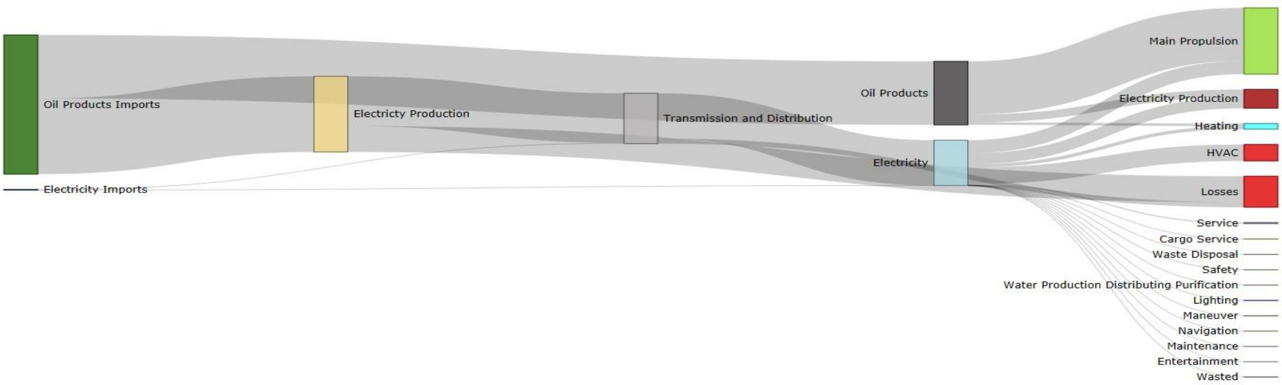

Fig. 7. Flow of energy described by a Sankey diagram.

A. Demands

Demands that constitute the energy balance of the chemical tanker ship are grouped under 14 main headings. These are shown in Table I.

TABLE I. ENERGY BALANCE OF CHEMICAL TANKER

Energy Balance for Area "STORAGE S2"			
Scenario: REF, Year: 2017, Units: Gigajoule			
	Electricity	Oil Products	Total
Production	-	-	-
Imports	1,032	219,333	220,365
Exports	-	-	-
Total Primary Supply	1,032	219,333	220,365
Electricty Production	78,294	-119,224	-40,930
Transmission and Distribution	-7,933	-	-7,933
Total Transformation	70,361	-119,224	-48,863
Main Propulsion	20,649	83,748	104,396
Electricity Production	17,173	12,470	29,643
Cargo Service	0,480	-	0,480
Heating	5,138	3,892	9,030
Waste Disposal	0,013	-	0,013
Safety	0,107	-	0,107
Water Production Distributing Purification	0,040	-	0,040
Service	1,667	-	1,667
HVAC	25,883	-	25,883
Lighting	0,123	-	0,123
Maneuver	0,010	-	0,010
Navigation	0,098	-	0,098
Maintenance	0,010	-	0,010
Entertainment	0,003	-	0,003
Total Demand	71,393	100,109	171,503
Unmet Requirements	-0,000	-	0,000

The total primary supply of a chemical tanker is 220,365 gigajoules and is shown in Table 1. The total demand of the chemical tanker ship is 171,503 gigajoules. Table 1 shows that 48,862 gigajoules of energy is lost during the energy process, conversion, storage and transportation phases. As we can see in Figure 7 and Table 1, the main demand for a chemical tanker vessel is utilized in main propulsion with the value of 104,396 gigajoules. Electricity generation, HVAC and heating demands follow the main drive propulsion.

B. Conversion and Process Technologies

Energy takes place in many forms around us. The first rule of thermodynamics is that energy can neither be created from nothing, nor destroyed, but can be transformed from one form to another. Process and transformation technologies change the form or amount of primary energy in an energy system and become useful energy for this energy system [10].

The main engine diesel, engine diesel generator and engine diesel alternator are defined as the conversion technologies of a chemical tanker ship. Fuel separator, diesel separator, oil separator, main switchboard, transformators and battery are defined as the process technology of a chemical tanker as shown in Fig. 4.

C. Primary and Final Energy Carriers

Different natural resources meet the energy needs as primary energy and final energy in an energy system. Primary energy is the state of energy in nature. Energy sources, which cannot be renewed since the beginning of the 20th century, are used as fuel and diesel oil. When the primary energy source is subjected to a conversion process, as shown in Fig. 8, it is called secondary energy [10].

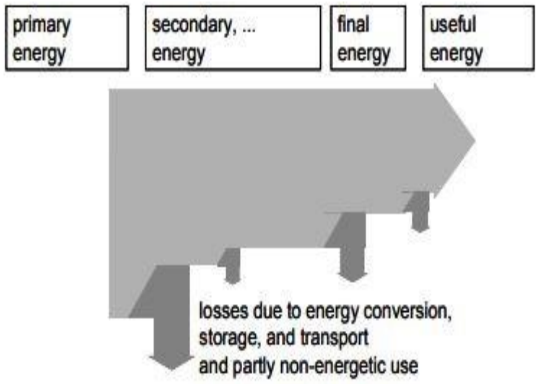

Fig. 8. Flow of energy described by a Sankey diagram [10].

In this chemical tanker ship HFO, MDO, heat and electricity are defined as “final energy carriers”. The final energy carriers are neither produced nor exported. All energy demand is imported.

V. SCENARIOS AND RESULTS

In this study, two scenarios were discussed. The scenario where no changes are addressed in the system is considered as Business As Usual (BAU). In another scenario, the diesel generator number 1 will be decommissioned in 2021 and the changes that occurred when the batteries will be replaced.

A. Results of the BAU Scenario

In this scenario, it is assumed that maritime transport will increase by 3 percent each year. Based on this, without any technology change, calculations were made to increase each demand by 3 percent. To meet the electricity demand of the chemical tanker ship.

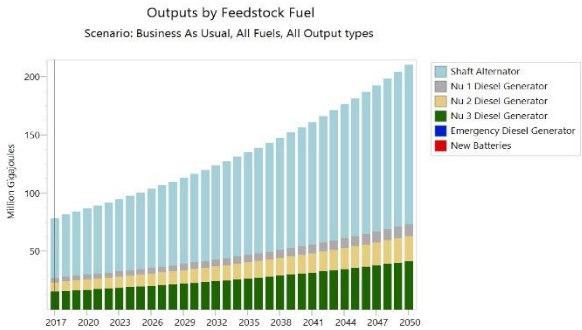

Fig. 9. Energy outputs by feedstock fuel in BAU Scenario.

Fig. 9 shows the energy outputs by feedstock fuel from each electrical technology.

The annual energy expenditure of each device increases due to the aging of the devices and decreased efficiency due to the increase in energy demand, which is shown in table II. Energy outputs by feedstock fuel from electricity production devices increase from 78,294 million gigajoules to 210,399 million gigajoules until 2050. In this scenario, the shaft alternator is the most used device, followed by the No. 3 diesel generator and No. 2 diesel generator.

TABLE II. OUTPUTS BY FEEDSTOCK FUEL IN BAU SCENARIO

Outputs by Feedstock Fuel				
Scenario: Business As Usual, All Fuels, All Output types				
Branch: Transformation\Electricty Production\Processes				
Units: Million Gigajoules				
Branches	2020	2030	2040	2050
Shaft Alternator	56,472	75,894	101,995	137,073
Nu 1 Diesel Generator	4,109	5,522	7,421	9,974
Nu 2 Diesel Generator	8,905	11,967	16,083	21,614
Nu 3 Diesel Generator	17,142	23,037	30,960	41,608
Emergency Diesel Generator	0,054	0,073	0,098	0,131
New Batteries	-	-	-	-
Total	86,682	116,493	156,557	210,399

If we examine the environmental analysis in the BAU scenario, it is calculated that the increase from 8697,368 thousand metric tons of CO2 equivalent emissions in 2017 to 23324,001 thousand metric tons of CO_2 equivalent emission in 2050 which is shown in Fig. 10 and Table III.

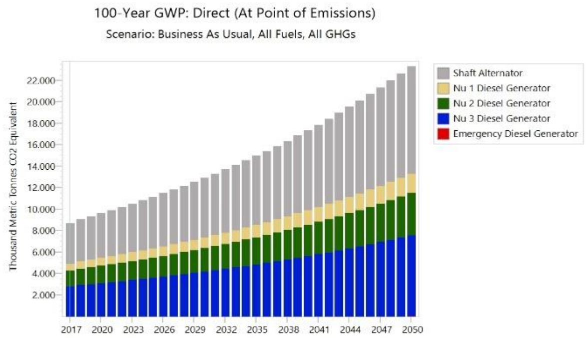

Fig. 10. CO_2 emission results in the BAU Scenario

TABLE III. CO_2 EMISSION RESULTS IN BAU SCENARIO

Direct (At Point of Emissions)				
Scenario: Business As Usual, All Fuels, All GHGs				
Branch: Transformation\Electricty Production\Processes				
Units: Thousand Metric Tonnes CO2 Equivalent				
Branches	2020	2030	2040	2050
Shaft Alternator	4.111,113	5.524,992	7.425,127	9.978,750
Nu 1 Diesel Generator	747,843	1.005,039	1.350,688	1.815,212
Nu 2 Diesel Generator	1.620,607	2.177,960	2.926,996	3.933,639
Nu 3 Diesel Generator	3.119,783	4.192,727	5.634,674	7.572,531
Emergency Diesel Generator	9,834	13,216	17,761	23,869
Total	9.609,180	12.913,934	17.355,247	23.324,001

B. Results of Scenario 1

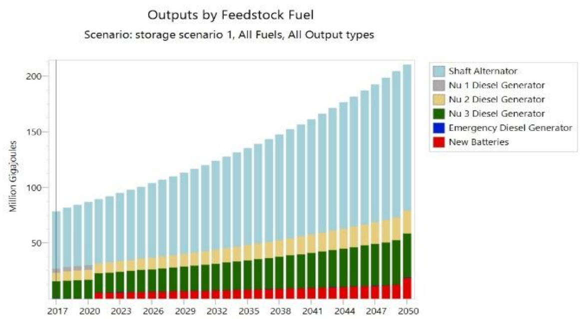

Fig. 11. Energy outputs by feedstock fuel in Scenario 1.

In this scenario, it is foreseen to use batteries at the chemical tanker ship instead of the No. 1 diesel generator and to use the electricity need for berthing maneuvers, port departure maneuvers, in emergencies, sails through narrow waters and straits for at least 4 hours. Also, the use rate of each device increased by 3%.

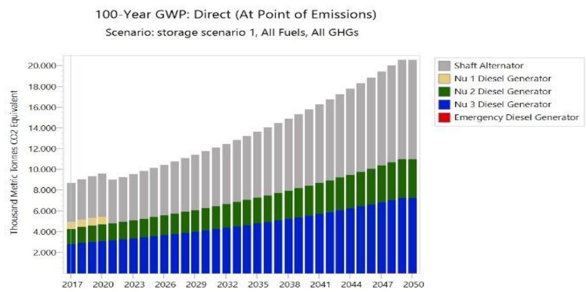

Fig. 12. CO_2 emission results in Scenario 1.

TABLE IV. OUTPUTS BY FEEDSTOCK FUEL IN SCENARIO 1

Outputs by Feedstock Fuel				
Scenario: storage scenario 1, All Fuels, All Output types				
Branch: Transformation\Electricty Production\Processes				
Units: Million Gigajoules				
Branches	2020	2030	2040	2050
Shaft Alternator	56,472	74,861	100,607	131,011
Nu 1 Diesel Generator	4,109	-	-	-
Nu 2 Diesel Generator	8,905	11,804	15,864	20,658
Nu 3 Diesel Generator	17,142	22,724	30,539	39,768
Emergency Diesel Generator	0,054	0,072	0,096	0,125
New Batteries	-	7,033	9,451	18,837
Total	86,682	116,493	156,557	210,399

When we examine the results of Scenario 1, as shown in Fig. 11 and Table IV; using new batteries; it has been seen that it reduces the usage of other systems harmful to the environment besides diesel generator number 1.

According to the environmental analysis of this scenario, it is seen in Fig. 12 that the CO_2 emissions decreased in 2021, by the introduction of new batteries instead of the No. 1 diesel generator.

TABLE V. CO_2 EMISSION RESULTS IN SCENARIO 1

Direct (At Point of Emissions)				
Scenario: storage scenario 1, All Fuels,				
Branch: Transformation\Electricty				
Units: Thousand Metric Tonnes CO2				
Branches	2020	2030	2040	2050
Shaft Alternator	4.111,113	5.449,798	7.324,073	9.537,465
Nu 1 Diesel Generator	747,843	-	-	-
Nu 2 Diesel Generator	1.620,607	2.148,319	2.887,161	3.759,683
Nu 3 Diesel Generator	3.119,783	4.135,665	5.557,988	7.237,655
Emergency Diesel Generator	9,834	13,036	17,519	22,814
Total	9.609,180	11.746,818	15.786,740	20.557,618

As can be seen in Table V, 9609,180 thousand metric tons of CO_2 emission in 2020 fell into 9002,958 thousand metric tons of CO_2 emissions in 2021. The CO_2 emission amount of the chemical tanker ship reaches the emission levels of 2020 again towards the end of 2024. Compared with the BAU scenario, it was observed that the CO_2 emission amount decreased from 23324,001 thousand metric tons equivalent level to 20557,618 thousand metric tons equivalent level in 2050. Besides, it has been calculated that a total of 35876,040 thousand metric tons of CO_2 equivalent emission can be reduced until 2050 since the number 1 diesel generator has not been used since 2021.

VI. Conclusion

In this study, electricity production processes demand analysis and environmental analysis were done by examining the interactions and relations in the energy system of a chemical tanker ship from the reference energy system and the entire ship energy system perspective, showing a network that characterizes the energy input-output processes between the resource-demand stages.

As a result of the analysis, it has been determined that with the change of new batteries instead of the No. 1 diesel generator, electricity production can be met and other technologies that use fossil fuel for electricity production can be reduced. In addition, it has been observed that by using new batteries, the CO_2 emission amount can be reduced and a positive contribution can be made to the target of reducing the carbon emission amount originating from ships determined by IMO.

VII. Future Work

In order to foresee the life cycle of the ship energy system analyzed in future studies, including financial aspects, technical, economic and ecological restrictions will be applied within the framework of the decisions made by international organizations such as the UN, EU and IMO.

In addition, alternative storage systems (such as fuel cell technology), and respective alternative fuels (such as hydrogen) and their costs, environmental and technical analyses are planned for future studies.

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