Journal of Naval Sciences and Engineering
2020, Vol. 16, No.2, pp. 143-170
Mechanical Engineering/Makine Mühendisliği

RESEARCH ARTICLE

**An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

ENERGY SYSTEM ANALYSIS AND MODELLING OF AN ELECTRIC POWERED FERRY*

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Date of Receive: 08.05.2020 **Date of Acceptance: 16.09.2020**

ABSTRACT

Today, approximately 85% of world trade is carried out by sea and ships are indispensable elements of transportation, logistics and trade. But on the other hand, approximately 2.5% of global green gas emissions, which have adverse effects on air quality and public health, is originated from ships and maritime transportation activities. Considering this situation, the International Maritime Organization promotes the use of renewable/alternative energy sources on ships, rather than fossil fuels. In the 11st Development Plan of Republic of Turkey, it is also aimed to convert the ships used for vehicle and passenger transportation in a short distance into "all-electric" concept. In this study, energy system analysis and modelling of a new generation ferry with a diesel electric propulsion system, which is used for vehicle and passenger transportation, have been carried out by using the Reference Energy System approach and Long-range Energy Alternatives Planning System software. In conclusion of the study, results of analysis related to the ferry's energy system, which also include theoretical emission estimates for conversion scenario of the ferry's energy system into hybrid concept, have been presented. Additionally, some suggestions for increasing energy efficiency of the ferry have been presented as well.

Keywords: *Ship Energy Efficiency, Ship Energy System Analysis, Reference Energy System, Electrical Ships, Marine Technology.*

ELEKTRİKLE ÇALIŞAN BİR FERİBOTUN ENERJİ SİSTEM ANALİZİ VE MODELLENMESİ

ÖZ

Günümüzde, dünya ticaretinin yaklaşık %85'i denizyolu ile yapılmakta olup gemiler, ulaştırma, lojistik ve ticaretin vazgeçilmez unsurlarıdır. Ancak öte yandan, küresel sera gazı emisyonlarının yaklaşık %2.5'i gemilerden ve deniz taşımacılığı faaliyetlerinden kaynaklanmakta, emisyonların hava kalitesi ve insan sağlığına olumsuz etkileri bulunmaktadır. Bu durumu göz önünde bulunduran Uluslararası Denizcilik Örgütü, gemilerde fosil yakıt yerine yenilenebilir/alternatif enerji kaynaklarının kullanımını teşvik etmektedir. Ülkemizin 11. Kalkınma Planı'nda da kısa mesafeli araç ve yolcu taşımacılığında kullanılan gemilerin "tam elektrikli" hale dönüştürülmesi hedeflenmektedir. Bu çalışmada; Referans Enerji Sistemi yaklaşımı ve Long Range Energy Alternatives Planning System yazılımı kullanılarak, deniz ulaşımında kullanılan yeni nesil diesel elektrik tahrikli bir arabalı feribotun enerji sistem modellemesi ve analizi yapılmıştır. Çalışmanın sonucunda, feribotun enerji sisteminin hibrit konsepte dönüşüm senaryosu için teorik emisyon tahminleri de dahil olmak üzere feribotun enerji sistemine ilişkin analiz sonuçları sunulmuştur. Ayrıca feribotun enerji verimliliğinin arttırılmasına yönelik de bazı öneriler de sunulmuştur.

Anahtar Kelimeler: *Gemi Enerji Verimliliği, Gemi Enerji Sistem Analizi, Referans Enerji Sistemi, Elektrikli Gemiler, Deniz Teknolojisi.*

1. INTRODUCTION

In Turkey, especially in the Marmara region, there are intensive domestic (cabotage) cargo, vehicle and passenger transportation activities by sea. İstanbul, Çanakkale and İzmir are the leading cities where the seaway is frequently used in urban transportation. Especially, İstanbul is the leading city of maritime transportation activities as well as of many other business sectors in Turkey. In Istanbul, short-distance passenger and vehicle transportation activities in scope of urban transportation, are carried out by the ships of the İstanbul Metropolitan Municipality, as well as by the passenger and vehicle ferries of private enterprises.

According to the statistics of the Ministry of Transport and Infrastructure (MoTI), number of passengers and vehicles carried by sea in domestic has significantly increased during the last 15 years. For example; the number of vehicles transported by sea in domestic was increased to 13.4 million in 2019 from 6.9 million in 2004. Similarly, the number of passengers transported by sea in domestic was also increased to 150.3 million in 2019 from 112.8 million in 2004. It is stated that providing Special Consumption Tax (ÖTV)-free fuel to the ships carrying passengers and cargo in domestic, which has been implementing since 2003, has a significant effect on those increases (MoTI, 2020).

Turkey is also aware of the importance of maritime transportation at international and domestic level, like other developed countries in the world. Although the maritime transportation has a great importance for development of transportation systems and logistics, economy and trading capacities of countries; on the other hand it is known that approximately 2,5% of global green gas emissions (GHG), which have adverse effects on air quality and public health, originates from ships and maritime transportation activities. Considering that situation, the International Maritime Organization (IMO), as the United Nations (UN) specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships, has established very important environmental regulations during the last 15 years in accordance with the aim of reducing the Carbon dioxide (CO_2) emissions from shipping and maritime sector by 50% until 2030 and by 70% until 2050, compared with the year 2008. Briefly, these regulations are related with the Energy Efficiency Design Index (EEDI) for reducing CO_2 emissions of new ships, Ship Energy Efficiency Management Plan (SEEMP) and Data Collection System (DCS) for Ship Fuel Consumption for existing ships, Sulfur (S) content limits for marine fuel oil, Nitrogen oxide (NO_x) emission limits for internal combustion marine engines and Emission Control Areas (ECA) in terms of NO_x and Sulfur oxide (SO_x) for the different sea areas of the world (IMO, 2019).

It seems so that all these regulations and their additional costs to shipowners have accelerated the maritime industry's efforts to make more use of the alternative/renewable energy sources on board ships and at sea ports. Especially in Northern European countries, which are prominent with their fjords within the ECA areas, all-electric ferries equipped with Li-ion battery energy storage technologies instead of using fossil-based fuels has already started to be widely used in maritime transportation. Many of those all-electric ferries and other kind of all-electric ships such as tug boats, ro-pax, etc. have been built in the Turkish shipyards, especially in the Yalova Shipyards Region. On the other hand, 399th item of 11st Development Plan of Turkey, which also complies with the IMO's general environmental objectives, promotes to convert the ships which are used for transportation of vehicles and passengers in a short-distance into environmentally-friendly and energy-efficient fully electrical (all-electric) ships (TBMM, 2013). So, it seems that the all-electric ships will be widely used for domestic maritime transportation in Turkey in the near future as well. However, there are very few numbers of scientific studies on the electrical ships, since they are started to be used only in the last few years.

Therefore, it is expected that this study will contribute to both relevant scientific literature and objectives of the IMO and implementation of 11st Development Plan of Turkey.

2. LITERATURE REVIEW

There are many researches and studies in the national and international literature on reducing greenhouse gas emissions from ships and on increasing energy efficiency of ships. For example, Yiğit (2018) studied on ship design projects to meet ship energy demand from alternative sources such as renewable energy sources and energy supply from the shore. Talay, Deniz and Durmuşoğlu (2014) studied on methods of increasing energy efficiency in ships, ship design practices, machinery technology, propulsion and propeller systems, operational maintenance-attitude, and expressed a number of methodological suggestions for reducing CO2 emissions and increasing energy efficiency of ships. Baldi (2016) stated in his Ph.D. thesis study that heat losses occurring in the machinery systems can be recovered efficiently and thus the ship's energy efficiency can be increased, by analyzing energy and exergy to determine the energy flows and inefficiencies in the ship's energy system. Tillig et al. (2016) examined environmental and economic measures to reduce the fuel consumption and exhaust emissions of ships, and stated that in order to reduce energy consumption; the energy flow in the energy system should be analyzed at the component and subsystem level, including the interactions between components. Vassalos & Cichowicz (2014) conducted a methodological study to examine the performance-based energy efficiency of a container ship and its impact on ship design and operation. Johnson et al. (2013) evaluated IMO's Ship Energy Efficiency Management Plan (SEEMP) guide in terms of ISO 50001 standards and International Safety Management (ISM) Code requirements. Durmaz, Kalender and Ergin (2016) experimentally investigated emissions emitted from 883 kW main diesel engine of a 81 meters conventional ferry and annual emissions of the ferry were determined as 4467.3 tons of CO_2, 97 tons of NOx, 6.2 tons of CO, 5.6 tons of HC and 0.77 tons of SO_2.

In the literature, there are various studies in which the energy systems of ships were analyzed and modelled with the Reference Energy System (RES) approach. For example; Benli, Sulukan and Alkan (2019) studied on RES modelling and analysis of a frigate-type naval ship. Yan et al. (2019) examined energy system components of a cruise ship. Sulukan, Özkan and Sarı (2018) studied on energy consumption characteristics and demand sectors by examining RES modelling and analysis of a generic ship. Yılmaz et al. (2018) established and analyzed a RES model of a crude oil tanker's energy system in order to examine the relationships between energy carriers, technologies and demand sectors. There are also several studies in the literature that show that, RES approach can be applied to different topics and sectors with the aim of energy and energy planning of countries or a region. For example, Mutluel and Sulukan (2014) established a RES model of residential sector in Turkey in order to provide a technical support to decision-makers. Yophy, Jeffrey and Peng (2011) made an assessment on the future energy and climate policies with the LEAP model application for the long-term forecast of Taiwan's energy supply and demand. Shabbir and Ahmad (2010) analyzed air pollution and energy demand from urban transportation in Rawalpindi and Islamabad with the LEAP energy model. Sulukan et al. (2010) studied on the determination of the optimal energy strategies for Turkey with a MARKAL model.

3. METHODOLOGY

In this study, energy system analysis and modelling of a new generation ferry with diesel electric propulsion system, which is used for vehicle and passenger transportation, are carried out by using the Reference Energy System (RES) approach and LEAP (Long-range Energy Alternatives Planning System) software.

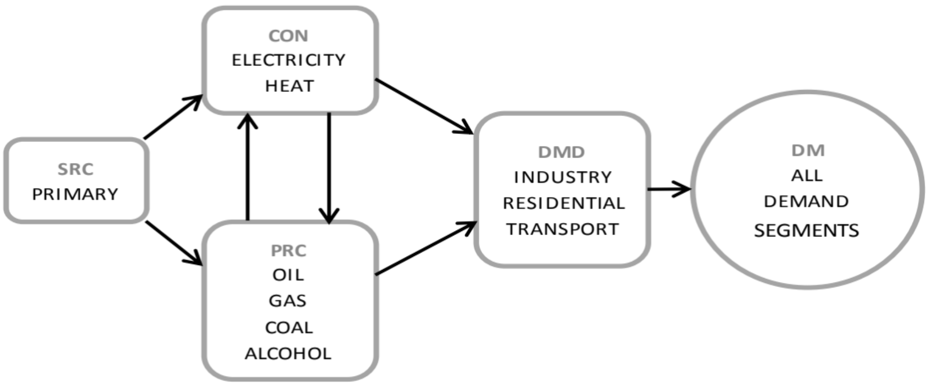

Figure 1. A simplified illustration of main components of a typical RES model (Sulukan, Özkan & Sarı, 2018).

The RES is a flowchart showing all possible routes from each primary energy source to each end-use (demand) sectors through various conversion steps (Sulukan, 2017). In other words, the RES is a set of parameters that reveals the characteristics of technologies and resources used to provide energy balance and is a network of all technological activities required for energy supply and end-use activities. There are usually five main components of a typical RES model which are primary energy sources (SRC), energy conversion technologies (CON), energy processing technologies (PRC), energy end-user (demand) technologies (DMD) and demands (DM) (see Figure 1) (Sulukan, Özkan and Sarı, 2018).

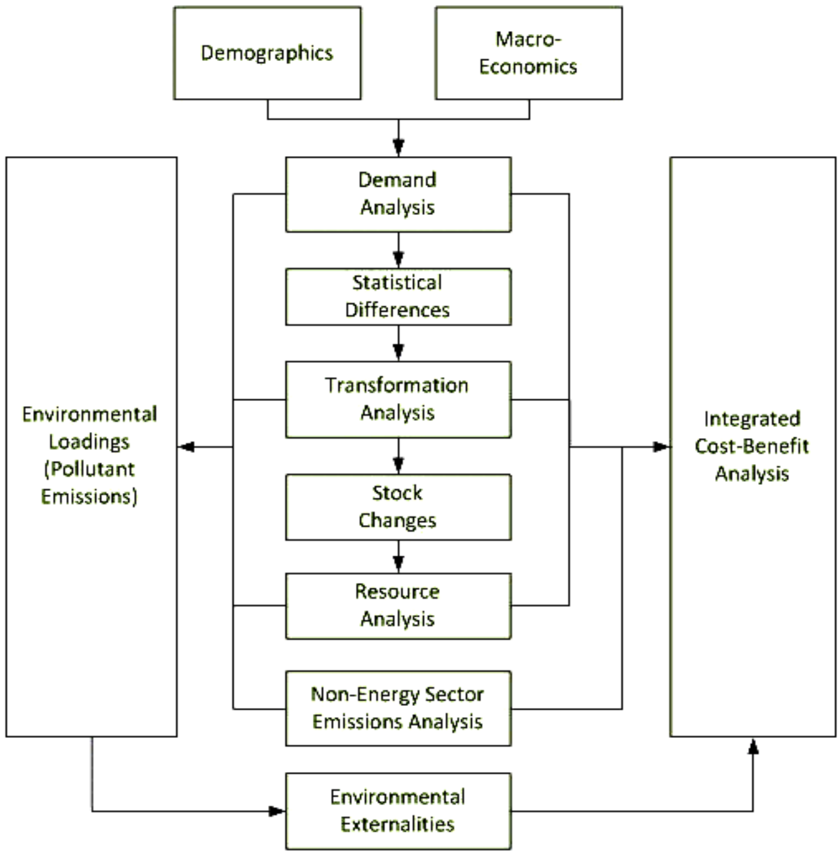

Figure 2. General structure of a LEAP model (LEAP, 2019).

In accordance with the RES concept explained above, the RES model of a new generation ferry with diesel electric propulsion system has been established by using data of 2019, as the reference year, and then, the same model including numerical data of the RES parameters has been created in the LEAP software for analysis. Of course, there are various decision support tools used for modelling energy systems for different purposes. In this study, we have preferred to use the LEAP software for the energy system analysis and modelling of the ferry, since it is complied with the RES concept and has a Technology and Environmental Database (TED) through of which the theoretical emission estimates of energy technologies can be calculated, as well. Figure 2 shows the general structure of a LEAP model (LEAP, 2019). The LEAP can model energy systems according to various scenarios and calculate the energy consumption, conversion and production amounts in an energy system by considering a set of demographics (population etc.), macroeconomics (GDP, prices etc.) and environmental assumptions.

Table 1. Technical particulars of the ferry analyzed in this study.

Type	**Vehicle & Passenger Ferry**
Length (m)	64
Breath (m)	18
Drought (m)	3.3
Speed (knots)	12-13
Vehicle Capacity	80
Passenger Capacity	590
Main Energy System	Diesel Electric Generators (4 x 600 kWh)
Propulsion System	Electric Converters & Motors + Voith Schneider Propellers (VSP)

Table 1 shows that basic technical particulars of the ferry with a diesel electric propulsion system analyzed in this study which is used for short-distance vehicle and passenger transportation in İstanbul and operated by İDO.

4. APPLICATION OF RES CONCEPT TO FERRY

The RES model for the ferry, which has been developed in scope of this study, is shown in the Figure 3 and Figure 4 below.

4.1. Resource Technologies

The main energy resource of the ferry is diesel oil (EN 590) which is an imported fossil-based oil product. Diesel oil is only used by diesel generators with internal combustion diesel engines on board ferry. The electricity may also be rarely imported from shore while the ferry is berthed for maintenance.

4.2. Storage Technologies

The main storage technologies are diesel oil tanks on board the ferry.

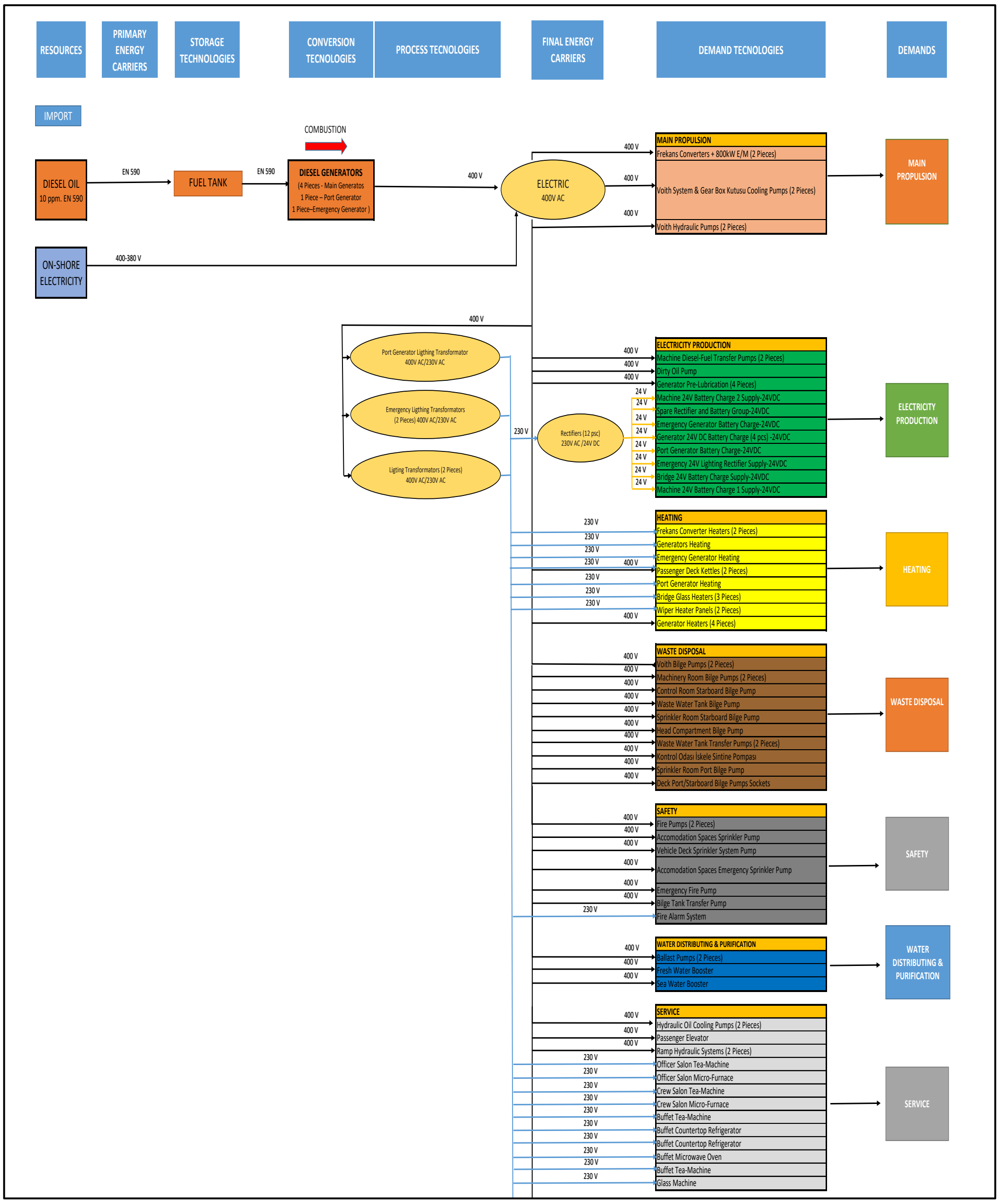

Figure 3. The RES model developed for the analyzed ferry.

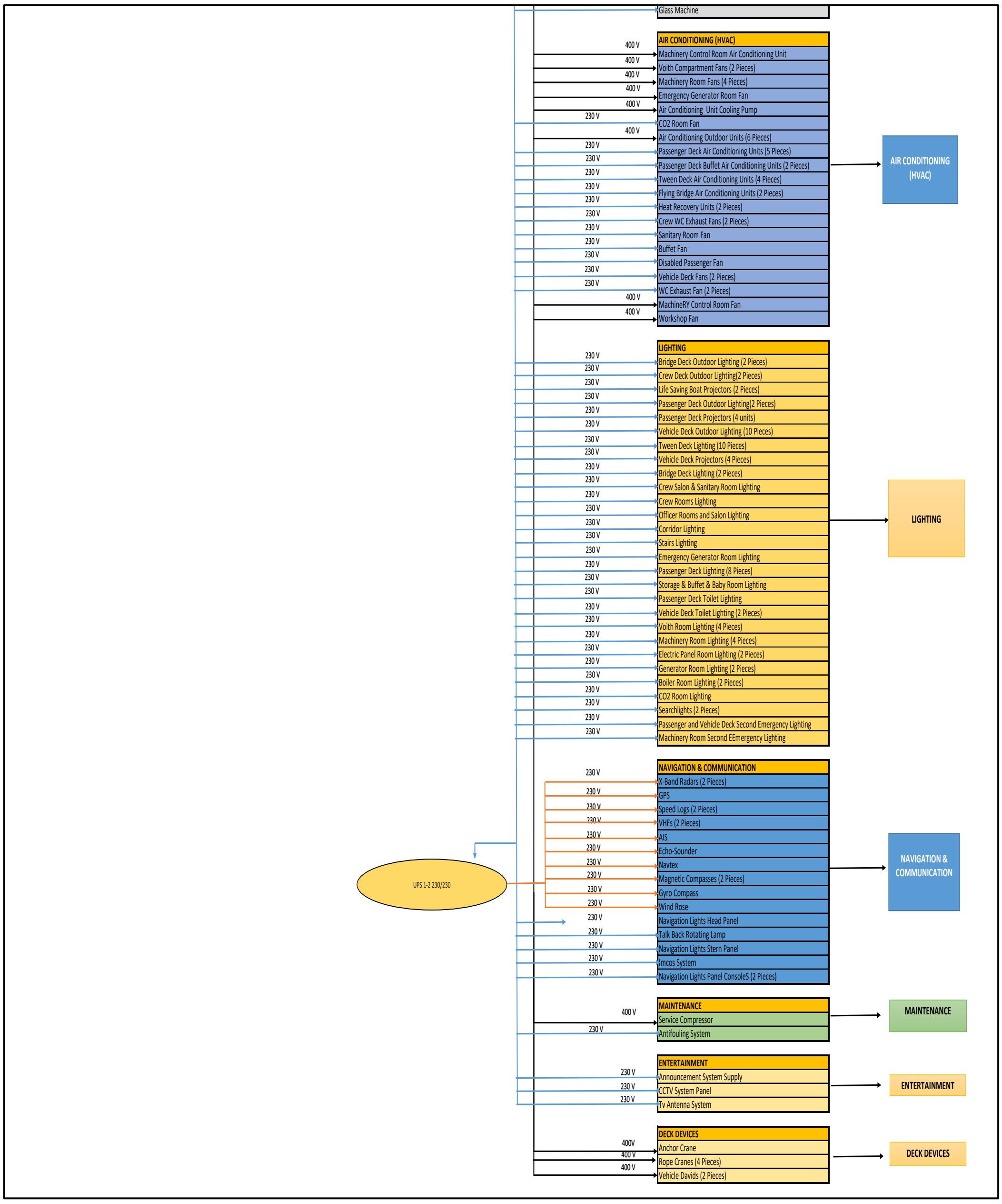

Figure 4. The RES model developed for the analyzed ferry (continued).

4.3. Primary Energy Carriers

The primary energy carrier is diesel oil as well as electricity imported from the shore when necessary.

4.4. Conversion Technologies

In general, the conversion technologies are converting the primary energy carriers to final energy carriers. The main conversion technologies of the ferry's energy system are diesel generators with internal combustion diesel engines which convert the thermal energy of diesel oil to the electricity.

4.5. Process Technologies

In general, the process technologies are changing the form, characteristic or location of the energy. The main process technologies of ferry's energy system are transformers, inverters and UPS which adjust the voltage and frequency of electricity.

4.6. Final Energy Carriers

The final energy carrier is electricity for the analyzed ferry.

4.7. Demand Technologies

In this study, many demand technologies including pumps, ventilation funs and electrical devices etc. in scope of 13 different demand sectors for the ferry have been detected.

4.8. Demands

As seen in the Table 2, demand sectors for the ferry have been described as "Main Propulsion", "Electricity Production", "Air Conditioning (HVAC)", "Safety", "Service", "Heating", "Waste Disposal", "Lighting", "Water Distributing & Purification", "Maintenance", "Navigation & Communication", "Entertainment" and "Deck Devices".

Table 2. End-use technologies and demand sectors of the analyzed ferry.

End-Use (Demand) Technologies	**Demands**
Frequency Converters + 800 kW E/M (2 Pieces)	Main Propulsion
Voith System & Gear Box Cooling Pumps (2 Pieces)	
Voith Hydraulic Pumps (2 Pieces)	
Machinery Diesel-Fuel Transfer Pumps (2 Pieces)	Electricity Production
Waste Oil Pump	
Generator Pre-lubrication (4 Pieces)	
Machine 24V Battery Chargers 2 Supply-24VDC	
Spare Rectifier and Battery Group-24VDC	
Emergency Generator Battery Chargers-24VDC	
Generator 24V DC Battery Chargers (4 pcs) - 24VDC	
Port Generator Battery Charge-24VDC	
Emergency 24V Lighting Rectifier Supply-24VDC	
Bridge 24V Battery Charge Supply-24VDC	
Machinery 24V Battery Charge 1 Supply-24VDC	
Frequency Converter Heaters (2 Pieces)	Heating
Generators Heating	
Emergency Generator Heating	
Passenger Deck Kettles (2 Pieces)	
Port Generator Heating	
Bridge Glass Heaters (3 Pieces)	
Wiper Heater Panels (2 Pieces)	
Generator Heaters (4 Pieces)	
Voith Bilge Pumps (2 Pieces)	Waste Disposal
Machinery Room Bilge Pumps (2 Pieces)	
Control Room Starboard Bilge Pump	
Waste Water Tank Bilge Pump	
Sprinkler Room Starboard Bilge Pump	
Head Compartment Bilge Pump	
Waste Water Tank Transfer Pumps (2 Pieces)	
Control Room Port Bilge Pump	
Sprinkler Room Port Bilge Pump	
Deck Port/Starboard Bilge Pumps Sockets	

End-Use (Demand) Technologies	**Demands**
Fire Pumps (2 Pieces)	Safety
Accomodation Spaces Sprinkler Pump	
Vehicle Deck Sprinkler System Pump	
Accomodation Spaces Emergency Sprinkler Pump	
Emergency Fire Pump	
Bilge Tank Transfer Pump	
Fire Alarm System	
Ballast Pumps (2 Pieces)	Water Distributing & Purification
Fresh Water Booster	
Sea Water Booster	
Hydraulic Oil Cooling Pumps (2 Pieces)	Service
Passenger Elevator	
Ramp Hydraulic Systems (2 Pieces)	
Officer Messroom Tea-Machine	
Officer Messroom Microwave Owen	
Crew Messroom Tea-Machine	
Crew Messroom Microwave Owen	
Buffet Tea-Machine	
Buffet Countertop Refrigerator	
Buffet Countertop Refrigerator	
Buffet Microwave Oven	
Buffet Tea-Machine	
Glasswasher Machine	
Machinery Control Room Air Conditioning Unit	Air Conditioning (HVAC)
Voith Compartment Fans (2 Pieces)	
Machinery Room Fans (4 Pieces)	
Emergency Generator Room Fan	
Air Conditioning Unit Cooling Pump	
CO2 Room Fan	
Air Conditioning Outdoor Units (6 Pieces)	
Passenger Deck Air Conditioning Units (5 Pieces)	
Passenger Deck Buffet Air Conditioning Units (2 Pieces)	
Tween Deck Air Conditioning Units (4 Pieces)	
Flying Bridge Air Conditioning Units (2 Pieces)	
Heat Recovery Units (2 Pieces)	

End-Use (Demand) Technologies	Demands
Crew WC Exhaust Fans (2 Pieces)	
Sanitary Room Fan	
Buffet Fan	
Disabled Passenger Fan	
Vehicle Deck Fans (2 Pieces)	
WC Exhaust Fan (2 Pieces)	
Machinery Control Room Fan	
Workshop Fan	
Bridge Deck Outdoor Lighting (2 Pieces)	Lighting
Crew Deck Outdoor Lighting (2 Pieces)	
Life Saving Boat Projectors (2 Pieces)	
Passenger Deck Outdoor Lighting(2 Pieces)	
Passenger Deck Projectors (4 units)	
Vehicle Deck Outdoor Lighting (10 Pieces)	
Tween Deck Lighting (10 Pieces)	
Vehicle Deck Projectors (4 Pieces)	
Bridge Deck Lighting (2 Pieces)	
Crew Messroom & Sanitary Room Lighting	
Crew Rooms Lighting	
Officer Rooms and Salon Lighting	
Corridor Lighting	
Stairs Lighting	
Emergency Generator Room Lighting	
Passenger Deck Lighting (8 Pieces)	
Storage & Buffet & Baby Room Lighting	
Passenger Deck Toilet Lighting	
Vehicle Deck Toilet Lighting (2 Pieces)	
Voith Room Lighting (4 Pieces)	
Machinery Room Lighting (4 Pieces)	
Electric Panel Room Lighting (2 Pieces)	
Generator Room Lighting (2 Pieces)	
Boiler Room Lighting (2 Pieces)	
CO2 Room Lighting	
Searchlights (2 Pieces)	
Passenger and Vehicle Deck Second Emergency Lighting	

End-Use (Demand) Technologies	**Demands**
Machinery Room Second Emergency Lighting	Navigation & Communication
X-Band Radars (2 Pieces)	
GPS	
Speed Logs (2 Pieces)	
VHFs (2 Pieces)	
AIS	
Echo-Sounder	
Navtex	
Magnetic Compasses (2 Pieces)	
Gyro Compass	
Wind Rose	
Navigation Lights Head Panel	
Talk Back Rotating Lamp	
Navigation Lights Stern Panel	
Imcos System	
Navigation Lights Panel Consoles (2 Pieces)	
Service Compressor	Maintenance
Antifouling System	
Announcement System Supply	Entertainment
CCTV System Panel	
TV Antenna System	
Anchor Crane	Deck Devices
Rope Cranes (4 Pieces)	
Vehicle Davids (2 Pieces)	

5. ENERGY SYSTEM ANALYSIS RESULTS OF FERRY BY LEAP

5.1. LEAP Analysis Results for Ferry's RES Model

As seen in the Table 3, which shows LEAP analysis results of the ferry's RES energy balance, EN 590 diesel oil with a total thermal energy of 43.5 thousand GJ was consumed in the ferry in 2019.

Table 3. LEAP results of ferry's energy balance for RES.

Year: 2019, Units: Thousand Gigajoule (GJ)			
	Electricity	**Oil Products**	**Total**
Production	-	-	-
Imports	-	43.5088	43.5088
Exports	-0.0365	-	-0.0365
Total Primary Supply	-0.0365	43.5088	43.4723
Electricity Generation	37.2000	-43.5088	-6.3088
Electricity Transmission and Distribution	-1.8528	-	-1.8528
Total Transformation	35.3472	-43.5088	-8.1616
Main Propulsion	25.9189	-	25.9189
Electricity Production	4.2990	-	4.2990
Heating	0.0502	-	0.0502
Waste Disposal	0.0003	-	0.0003
Safety	0.0032	-	0.0032
Water Distributing & Purification	0.0142	-	0.0142
Service	0.1763	-	0.1763
Air Conditioning (HVAC)	4.3543	-	4.3543
Lighting	0.3596	-	0.3596
Navigation & Communication	0.0383	-	0.0383
Entertainment	0.0800	-	0.0800
Maintenance	0.0151	-	0.0151
Deck Devices	0.0013	-	0.0013
Total Demand	35.3108	-	35.3108
Unmet Requirements	-0.0000	-	-0.0000

According to our LEAP model, the efficiency of the electricity generation process (conversion technologies) by diesel generators was assumed as 85%, and the loss rate in the process of converting electricity into different voltages, types and frequencies (process technologies) was assumed as 5%. According to those assumes, total losses of 8,16 thousand GJ, which equal approximately 18% of diesel oil thermal energy consumed, was occurred in conversion and process technologies, while converting the fossil-based diesel oil's thermal energy to electricity and then transmitting and distributing of electricity to demand technologies. 25.9 thousand GJ for "Main Drive", 4.3 thousand GJ for "Electricity Generation", 50 GJ for "Heating", 3 GJ for "Waste Disposal", 3.2 GJ for "Safety", 1.4 GJ for "Water Distributing & Purification", 176.3 GJ for "Service", 4.35 thousand GJ for "Air Conditioning (HVAC)", 359.6 GJ for "Lighting", 38.3 GJ for "Navigation and Communication", 80 GJ for "Entertainment", 15.1 GJ for "Maintenance" and 1.3 GJ for "Deck Devices" of the ferry were consumed.

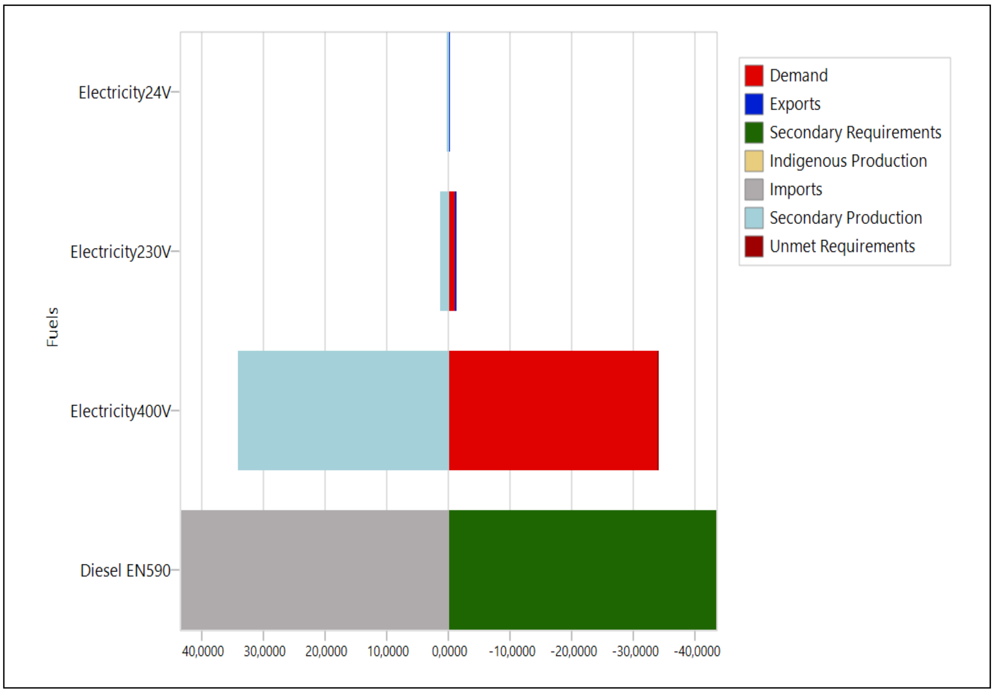

Figure 5. Energy balance by energy carriers.

Figure 5, gives a further detailed energy balance of the ferry in terms of energy carriers, and shows that 440V electricity with a total amount of 33.96 thousand GJ, 230V electricity with 1.24 thousand GJ and 24V electricity with 0.108 thousand GJ were used by demand technologies of the ferry and there was a balanced distribution. In addition, most of the electricity was used for the “Main Propulsion” system, “Electricity Production” and “Air Conditioning (HVAC)” system in the ferry.

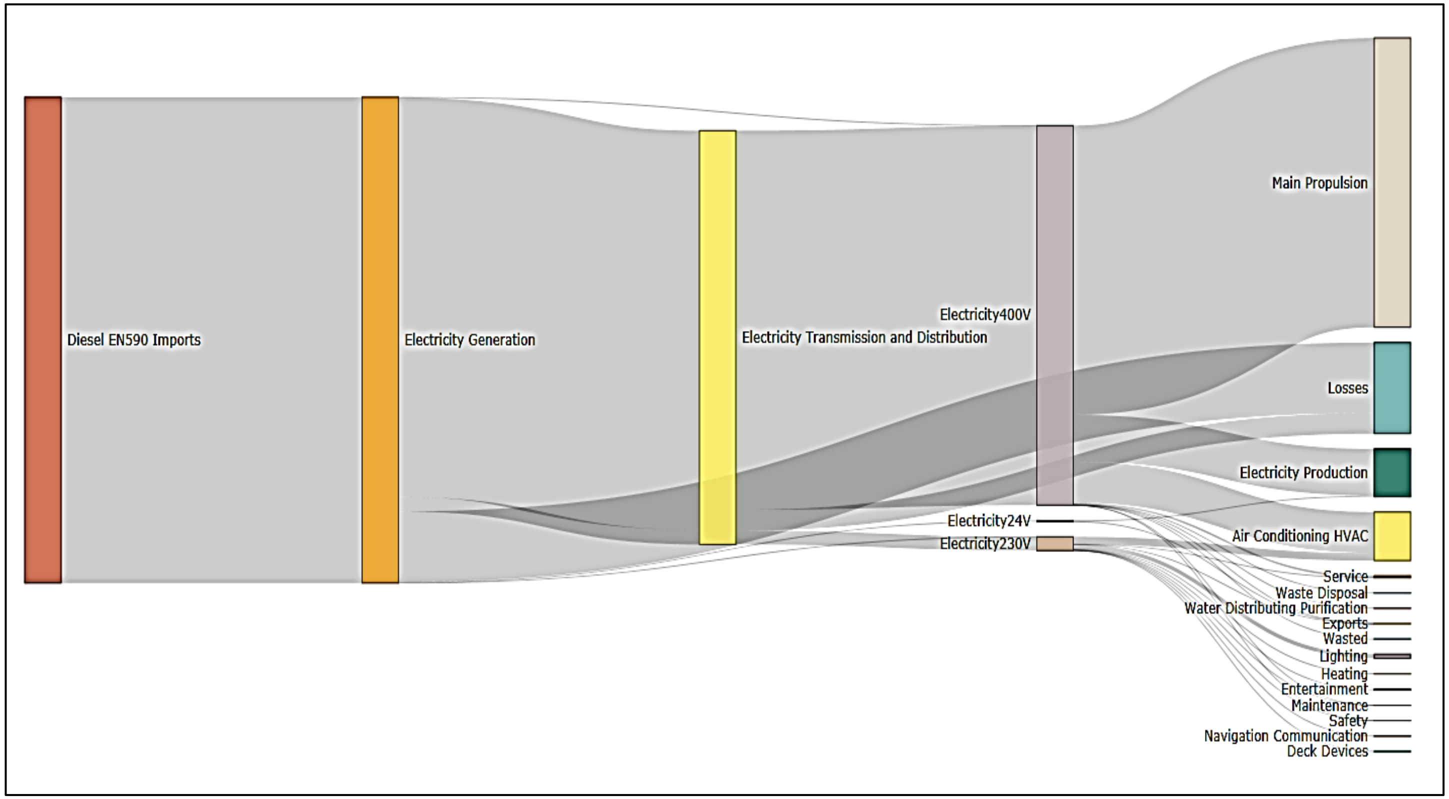

Figure 6. LEAP energy flow (Sankey) diagram of the analyzed ferry.

The Sankey diagram is used to visualize the energy balance flow of any system modelled in LEAP. Energy flow (Sankey) diagram provides an overview of energy flows from sources to energy demands. The Sankey diagram produced by LEAP in accordance with the model created in scope of this study, which shows energy flow of the ferry, is shown in Figure 6.

As seen from Table 3 and Figure 6, 35.3 thousand GJ was used by energy demand technologies and 73.4% (25.92 thousand GJ) of which was used for "Main Propulsion", 12.3% (4.35 thousand GJ) for “Air Conditioning (HVAC)” and 12.2% (4.3 thousand GJ) for "Electricity Production" respectively. Therefore, it would be useful to analysis these demand sectors, which have a significant share in the total energy consumption of the ferry. The more detailed analysis results show that 98.6% of a total amount of energy demand for "Main Propulsion" was used by "Frequency Converters", 1.2% by "Voith Hydraulic Pumps" and 0.2% by "Voith Gear Box Cooling Pumps". 72.13% of a total amount of energy demand for "Electricity Production" was used by "Charging" and 27.87% by "Lighting Transformers". 72.6% of a total amount of energy demand for “Air Conditioning (HVAC)” was used by “A/C Outdoor Units”, 9.4% by “Heat Recovery Units” and 9.4% by “Machinery Room Fans” respectively.

5.2. Theoretical Emission Estimates for Ferry’s RES Concept and Hybrid Conversion Scenario

In this part, LEAP based–theoretical emission estimates for the ferry's RES have been presented. In addition, emission estimates for a scenario, which assumes that the ferry's RES might be converted to a hybrid energy system, have also been presented. This scenario deals with the installation of an energy system based on Lithium-ion battery technology by removing two of the 4 equivalent generators used in the ferry to produce electricity. According to the scenario, total amount of energy to be produced through diesel generators will decrease by 50% compared to ferry’s RES, since half of the energy demand of the ferry will be provided with Lithium-ion batteries.

LEAP based–theoretical emission estimates for the ferry's RES and for a scenario which assumes that the ferry's RES might be converted to a hybrid concept are shown in Table 4. The "IPCC Tier 1 Default Emission Factors" tab in the TED database of LEAP was selected for the theoretical emission calculations of fossil-based fuel used by diesel generators of the ferry.

Table 4. Theoretical emission estimates of the ferry by LEAP.

Units: Metric Tones CO_2 Equivalent		
Effects	**RES (2019)**	**Hybrid Scenario**
Carbon Dioxide	3,156.56	1,578.28
Methane	3.915	1.958
Nitrous Oxide	6.917	3,459
Total	3,167.45	1,583.69

Table 4 shows that the CO_2 and other emissions from the ferry can be reduced by half, if it is assumed that the ferry's energy system is converted to hybrid concept.

6. CONCLUSION

According to the literature review carried out by this study, it has been observed that the Reference Energy System (RES) approach can be used for the analysis of energy systems of ships as well as for the analysis of energy systems in many different fields and sectors.

The RES model based on 2019 data for the ferry analyzed in this study has been developed and presented in Section 4. The LEAP analysis results of ferry's energy system have been also presented in Section 5.

In conclusion, it has been observed that most of the electricity produced based on diesel oil onboard the ferry was used for "Main Propulsion" with a share of 73.4%, "Air Conditioning (HVAC)" with a share of %12.3 and "Electricity Production" with a share of 12.2% respectively and some losses, which is approximately 18% of total diesel oil's thermal energy consumed, were also occurred in the energy system of the ferry in 2019. Accordingly, it is considered that regular maintenance of diesel generators with internal consumption engines and electricity transmission and distribution equipment is an important factor to increasing operational energy efficiency of the ferry.

According to the theoretical emission estimates as well, it has been also observed that the CO_2 and other emissions from the ferry can be reduced by half, if it is assumed that the ferry’s energy system is converted to hybrid concept with the installation of Lithium-ion battery technology.

ACKNOWLEDGEMENT

This article has been produced from M.Sc. Thesis which is entitled as "Energy System Analysis and Modelling of an Electrical/Hybrid Ferry Used for Maritime Transportation: Technical & Environmental Investigation" and was prepared at Marine Mechanical Engineering Department of Barbaros Naval Sciences and Engineering Institute of National Defence University (NDU) in Tuzla, Istanbul, Turkey. This is also a substantially extended version of the paper presented at the 10th International 100% Renewable Energy Conference (IRENEC 2020).

The Authors would like to thank to İstanbul Deniz Otobüsleri (İDO) for technical support to obtain more realistic results by using real data and specially thanks to Technical Fuel & Environmental Manager - Oceangoing Chief Engineer Mr. Yavuz ÇATAL for his professional support and technical guidance during the study.

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