**PIRI REIS UNIVERSITY**
**FACULTY OF ENGINEERING**

# Feasibility Study For a New Route in Istanbul Maritime Transport and Hull Optimization of The Suitable Vessel Type

**BERAT TAŞTAN**
**20230201302**

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF BACHELOR OF SCIENCE
IN
THE DEPARTMENT OF NAVAL ARCHIECTURE AND MARINE ENGINEERING

**MARCH 2026**

Approval of the Faculty of Engineering

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**ACKNOWLEDGEMENT**

I would like to take this opportunity to express my deepest gratitude to my academic advisor Prof. Dr. Şebnem Helvacıoğlu for her invaluable guidance, support, and expertise. She has been instrumental in helping me to widen my horizon in the field of Naval Architecture and Marine Engineering, especially during the design of the 37-meter double-ended electric passenger vessel for the city of Istanbul.

I would especially like to thank Dr. Adem Viran for his valuable support in the line optimization work, as well as İsmail Alkış for his technical support during the generation of the hull form.

My deepest appreciation goes to my family for their unending love, support, and patience during my entire educational journey. Without their support, I would not be able to reach this milestone.

I would also like to thank my dear friends as well as my dear sister, İkbal Taştan, for their support in keeping my spirits high during this long journey.

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## ABBREVIATIONS AND SYMBOLS

**EU** : European Union
**IMM** : Istanbul Metropolitan Municipality
**IDO** : Istanbul Sea Buses
**NMC** : Nickel-Manganese-Cobalt
**ESS** : Energy Storage System
**CAD/CAM** : Computer-Aided Design / Computer-Aided Manufacturing
**LOA** : Length Overall
**ITTC** : International Towing Tank Conference
**ISO** : International Organization for Standardization
**SFOC** : Specific Fuel Oil Consumption
**$NO_x$** : Nitrogen Oxides
**$SO_x$** : Sulfur Oxides
**PM** : Particulate Matter
**OPEX** : Operational Expenditure
**AHP** : Analytic Hierarchy Process
**NURBS** : Non-Uniform Rational B-Splines
**MCR** : Maximum Continuous Rating
**$CO_2$** : Carbon Dioxide
**3D** : Three Dimensional
**$R_t$** : Total Resistance
**$P_e$** : Effective Power

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## ABSTRACT

### Feasibility Study For a New Route in Istanbul Maritime Transport and Hull Optimization of The Suitable Vessel Type

The increase in Istanbul's population has highlighted the need to develop low-emission alternatives by increasing the environmental impact of fossil fuels during transportation. Within the scope of the rapidly advancing green transformation processes worldwide, there is a need for an environmentally friendly electric ferry design in maritime transport and a pilot route for this transformation. Such an application would serve as a reference for coastal cities like Istanbul. This project will study a new sea transport route in Istanbul that can help reduce road traffic and support public transport. The city's traffic, population, and sea connection points will be examined to develop an effective route. Technical, economic, and environmental analyses will be made to see if the route can be used in a practical way. In addition, the best type of vessel for this route will be designed, and the hull will be improved to increase energy efficiency. During the process, design changes that reduce fuel use and lower carbon emissions will be studied carefully. The goal is to create an environmentally friendly and sustainable vessel concept. At the end of the project, a new sea transport model will be suggested that can fit into Istanbul's transport system, with high energy efficiency and low emissions. This research aims to show the importance of sea transport in city transportation planning and to support future sustainable transport strategies.



***Keywords:*** *Sea transport, feasibility study, hull optimization, sustainable transport, Istanbul*


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# ÖZET

## İstanbul deniz taşımacılığında yeni bir güzergah için fizibilite çalışması ve uygun gemi tipinin gövde optimizasyonu

İstanbul'un nüfus artışıyla birlikte, ulaşımda fosil yakıtların çevresel etkisinin artması, düşük emisyonlu alternatiflerin geliştirilmesi ihtiyacını ortaya çıkarmıştır. Dünya çapında hızla ilerleyen yeşil dönüşüm süreçleri kapsamında, deniz taşımacılığında çevre dostu bir elektrikli feribot tasarımı ve bu dönüşüm için bir pilot güzergâh ihtiyacı bulunmaktadır. Böyle bir uygulama, İstanbul gibi kıyı şehirleri için bir referans görevi görecektir. Bu proje, İstanbul'da kara trafiğini hafifletebilecek ve toplu taşımayı destekleyecek yeni bir deniz ulaşım hattının fizibilitesini incelemeyi amaçlamaktadır. Şehrin ulaşım yoğunluğu, nüfus dağılımı ve deniz bağlantı noktaları değerlendirilerek etkin kullanılabilen bir hat önerisi geliştirilecektir. Belirlenecek güzergâh için teknik, ekonomik ve çevresel analizler yapılarak hattın uygulanabilirliği bir çok açıdan değerlendirilecektir. Bununla birlikte, seçilen hat üzerinde hizmet verecek en uygun gemi tipinin gövde yapısı tasarlanacak ve enerji verimliliğini artırmaya yönelik optimizasyon çalışmaları gerçekleştirilecektir. Süreç boyunca yakıt tüketimini azaltacak, karbon salınımını minimuma indirecek tasarım parametreleri konusunda önem gösterilecektir. Böylece çevre dostu ve sürdürülebilir özelliklere sahip bir deniz aracı konsepti ortaya konulması hedeflenmektedir. Projemizin sonucunda, İstanbul'un ulaşım altyapısına entegre edilebilecek, enerji verimliliği yüksek ve emisyon etkisi düşük bir deniz ulaşım hattı modeli önerilecektir. Bu araştırma, şehir içi ulaşım planlamasında deniz taşımacılığının önemini vurgulayarak sürdürülebilir ulaşım stratejilerine katkı sağlamayı amaçlamaktadır.

***Anahtar Kelimeler:*** *Deniz ulaşımı, fizibilite çalışması, gövde optimizasyonu, sürdürülebilir ulaşım, İstanbul*

# 1. INTRODUCTION

Maritime transportation has been one of the most important transportation methods used extensively throughout history. In an ancient city like Istanbul, which connects two continents and is home to great civilizations, maritime transportation is both a culturee transportation has been one of the most important transportation methods used extensively throughout history. It is a fast, environmental friendly, low cost and scenic transportation alternative for both locals and tourists. However, in recent years, due to reasons such as increasing population and vehicle traffic, the increasing importance of maritime trade has revealed the need for cleaner and more sustainable transportation options, bringing with it rising fuel costs and increasing awareness of environmental pollution. Jul.

Within the scope of sustainable development goals, environmentally friendly electric urban transportation systems have started to become increasingly widespread around the world. Electric ferries, in particular, have a very important place in reducing greenhouse gas emissions, minimizing air pollution and providing quieter and more comfortable journeysithin the scope of sustainable development goals, environmentally friendly electric urban transportation systems have started to become increasingly widespread around the world. Electric ferries, in particular, have a very important place in reducing greenhouse gas emissions, minimizing air pollution and providing quieter and more comfortable journeys. Technological advances in battery, electric propulsion systems and fast charging infrastructure make fully electric passenger ferries for inner city waters increasingly viable.

The selection of an electric ferry line that can be implemented in Istanbul requires the evaluation of many interconnected factors such as route length, passenger demand, energy consumption and coastal charging infrastructure together and the development of a rigorous decision system, and the line should be taken into account in feasibility studies.

In addition, the hull structure of the most suitable ship type to serve on the selected route will be designed and optimization studies will be carried out to increase energy efficiency. During the process, importance will be given to design parameters that will reduce fuel consumption and

minimize carbon emissionsn addition, the hull structure of the most suitable ship type to serve on the selected route will be designed and optimization studies will be carried out to increase energy efficiency. During the process, importance will be given to design parameters that will reduce fuel consumption and minimize carbon emissions. Thus, it is aimed to put forward a marine vehicle concept with environmentally friendly and sustainable features. As a result of our project, a marine transportation line model that can be integrated into the transportation infrastructure of Istanbul, with high energy efficiency and low emission impact will be proposed. This research aims to contribute to sustainable transportation strategies by emphasizing the importance of sea transportation in urban transportation planning.

## 2. LITERATURE REVIEW

### 2.1 Maritime Transport in Istanbul

Istanbul is a crucial cultural and transportation hub connecting the E uropean and Asian sides of the city. The city's maritime transportation consists of IMM-operated services like City Lines, private operators, and small-scale motorized ferries, serving 53 docks (IMM Annual Report ,2024). One of the most important functions of maritime transport is to provide a fast and affordable alternative to land transport during peak traffic hours. When integrated with the city's most important transport modes, such as the Metro Marmaray, metrobus, and buses, maritime transport has become one of Istanbul's cultural elements and an efficient service. When integrated with the city's most important transportation vehicles, such as the Metro Marmaray, Metrobus, and buses, maritime transportation has become one of Istanbul's cultural elements and an efficient service. Ferry transportation in Istanbul has a socio-cultural and economic heritage dating back 200 years (Şehir Hatları Corporate History, 2025) . Today, City Lines, private operators, and sea buses constitute Istanbul's inland maritime transport (see in Figure 1). Ferries operating in Istanbul contribute significantly to air pollution, noise, and high operating costs, and most of the vessels are in poor condition. Therefore, modernization and electrification are becoming increasingly important.

| Type | Unit | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| Active Pier | Number | 43 | 43 | 52 | 53 | 53 |
| Line | Number | 21 | 22 | 33 | 34 | 32 |
| Voyage (x1,000) | Number | 180 | 214 | 264 | 332 | 324 |
| Ship/ Engine* | Number | 28 | 28 | 29 | 30 | 30 |
| Rental Engine | Number | 28 | 31 | 51 | 53 | 49 |
| Rental Car | Number | 2 | 2 | 2 | 2 | 2 |
| Sea Taxi | Number | - | - | 4 | 4 | 7 |
| Annual Passengers Carried (x1,000) | Person | 20.088 | 24.486 | 38.113 | 40.077 | 39.870 |
| Annual Number of Vehicles Carried | Number | 453.158 | 516.924 | 496.554 | 519.694 | 538.124 |

**Figure 1:** Annual report, (IMM 2024)

### 2.1.1 Historical development and current status

Sea transportation in Istanbul has been directly shaped by the geographical location of the city and has developed through various technological and infrastructural transformations throughout history. Because the city is located on two continents, around a strategic location such as the Bosphorus, it has been an important center for both local and international sea transportation for many years (Ozkapici et al., 2016). In this context, the city's position as a transit point between the Sea of Marmara and the Black Sea has ensured that maritime transport retains its importance across a wide spectrum, ranging from port operations and small scale passenger transport to global trade. The history of ferry routes connecting the European and Asian sides of Istanbul dates back to the late Ottoman period. The primitive ferry examples seen in Europe and America in the early 19th century reflect the general technical level of the first marine vessels used in Istanbul; for example, the transition from chainpulled river crossing boats to steamships increased both capacity and speed (Kocaman, n.d.) In the 21st century, maritime transport has come to the fore again with various transportation projects.

For example, with the completion of the Istanbul Canal project, it is anticipated that a large portion of international freight transport will be shifted from the existing Bosphorus routes to the canal (Kızıltaş & Karakale, 2025). Historically, changes in fuel technology have also played an important role in maritime transport. Although the transition from steam ships to diesel-powered ships brought cost advantages, it also increased dependence on oil. In the modern era, with the discussion of hybrid and fully electric systems, the goal is to replace the high-emission solutions of the past with technologies that have a low carbon footprint (Yilmaz & Danişmani, 2020). Electric ferry projects seem particularly viable for short/medium-distance routes, and it is assumed that operational challenges may perhaps be overcome by advancements in battery developments (Gagatsi et al., 2016a).

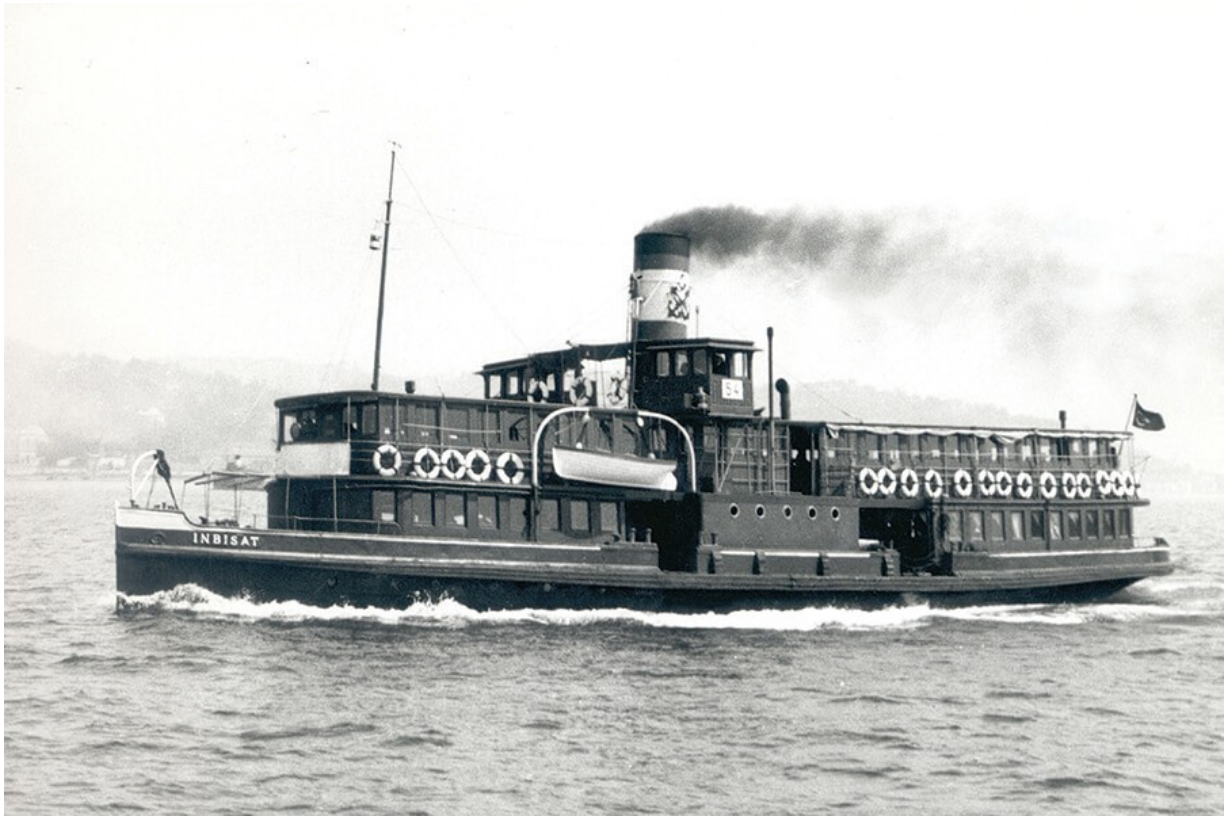



**Figure 2:** Inbisat ferry, Istanbul

Reviewing past trends seems to confirm that Istanbul has always looked for solutions to match the demands posed by maritime transport developments. Thus, while Istanbul's geographical and socio-economic conditions seemed to call for advances in multi-modal transport solutions, it is irrefutable that maritime transportation has always remained viable for both disaster-related logistics and relieving traffic congestion (Ozkapici et al., 2016).

### 2.1.2 Current lines and operation models

The maritime transportation system in the İstanbul region consists of an heterogeneous system with routes differing in size, carrying capacity, and operational character. The routes for ferryboat services offered by the Şehir Hatları, İDO, and smaller private firms are organized according to the demand factor and technical capacity. Analyzing the geographical distribution of existing routes shows that there are routes covering small distances between the shores with high passenger density, as well as routes covering medium to long distances parallel to the shoreline. Currently, Şehir Hatları operates 34 different routes, as shown on the map below (Özgül, 2023).

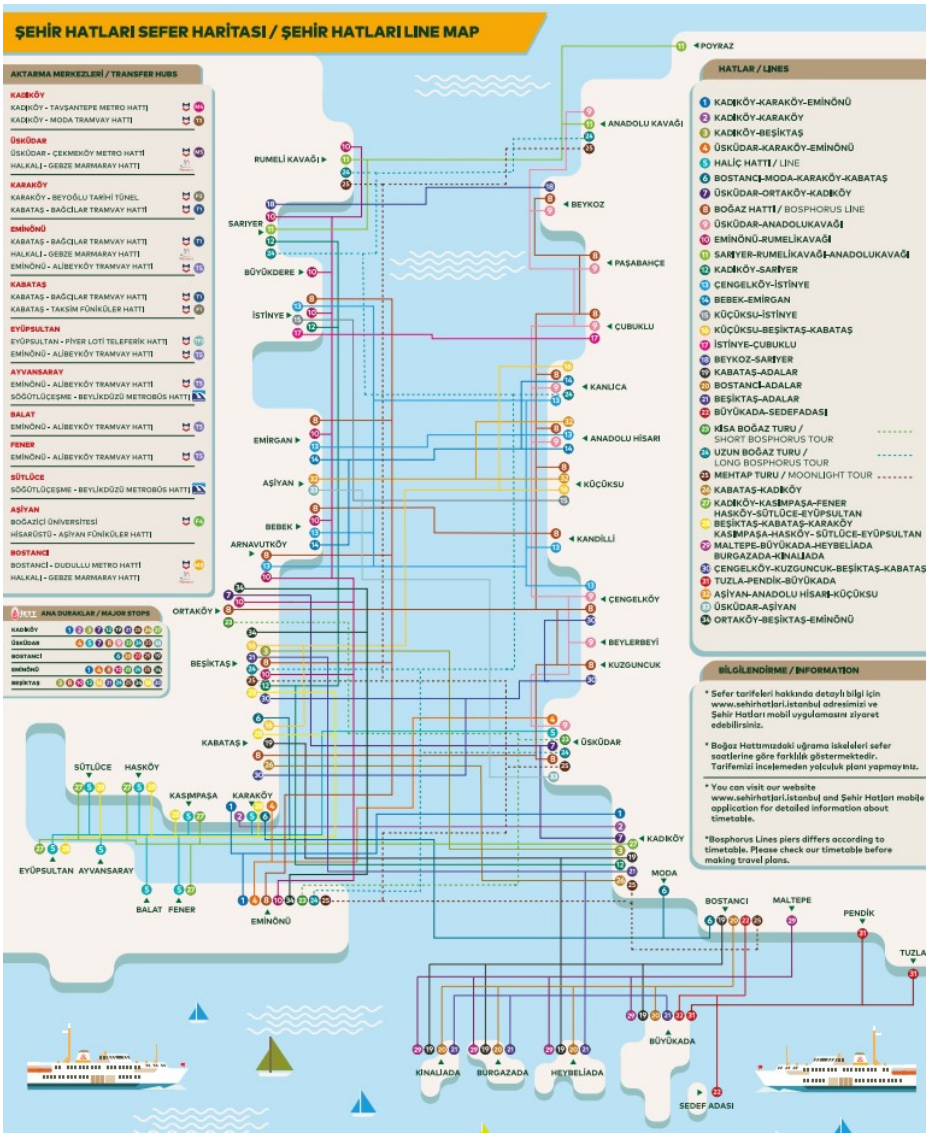



**Figure 3:** Şehir Hatları Line Map (https://sehirhatlari.istanbul, 2025)

For example, the Eminönü–Kadıköy line is historically the city's busiest ferry route and carries both tourists and commuters. Similarly, the Eminönü–Üsküdar line has been attractive to both local users and visitors to the city. Such short-distance lines generally operate with high frequency and provide easy integration with other modes of transport, such as the metro and buses, in terms of passenger transfer (Yilmaz & Danişmani, 2020).

Given the modal distribution in the city, maritime transport has high potential to relieve road traffic. However, the current situation shows that only a limited portion of this potential can be utilized.




**Figure 4:** Ship types in the Şehir Hatları ferry fleet (Created with artificial intelligence)

### 2.1.3 The role of sea transportation in urban transportation

In an urban setting such as Istanbul, maritime transport plays an important role in the sustainable designing process of public transportation systems. In fact, the geographical nature of the city, which spans across two different continents with its geographical features divided by water streams, makes maritime transportation an alternative means of transport that is strategic enough to relieve the traffic on roads (Kocaman, n.d.). With the increase in the number of vehicles on the roads, congestion at major points such as the Bosphorus Bridge points is an ever-present phenomenon, while the congested roads have the potential to provide the required transport capacity at major points such as the peak hours (Kızıltaş & Karakale, 2025). Zero-emission or hybrid vessels also have the potential to significantly reduce $CO_2$ and NOx emissions. For example, in some cases implemented in Europe, fully electric ferries have reduced operating costs by approximately 30% compared to diesel engines, while also having a positive impact on air quality (Gagatsi et al., 2016a).

**Table 1:** "Green" EU ferries. (Gagatsi et al., 2016a)

| Ferry Operator | Country | New technology vessels (fleet) |
|---|---|---|
| Scandlines Denmark A/s | Denmark | 2 (9) |
| Viking Line ABP | Finland | 1 (8) |
| Scandlines GmbH | Germany | 6 (9) |
| Norled | Norway | (80) |
| Fjord1 Nordvestlandske AS | Norway | 12(60) |
| Stena Line Scandinavia | Norway | 1 (35) |
| Cal Mac | Scotland | 2+1(27) |
| Green City Ferries | Sweden | 1 (1) |

This situation contributes to reducing noise pollution as well as the carbon footprint within the city (Arish et al., 2025). Evaluating fuel cell systems in line with the zero-emission target is particularly important in metropolises such as Istanbul, where air pollution problems are high (Pfeifer et al., 2020).

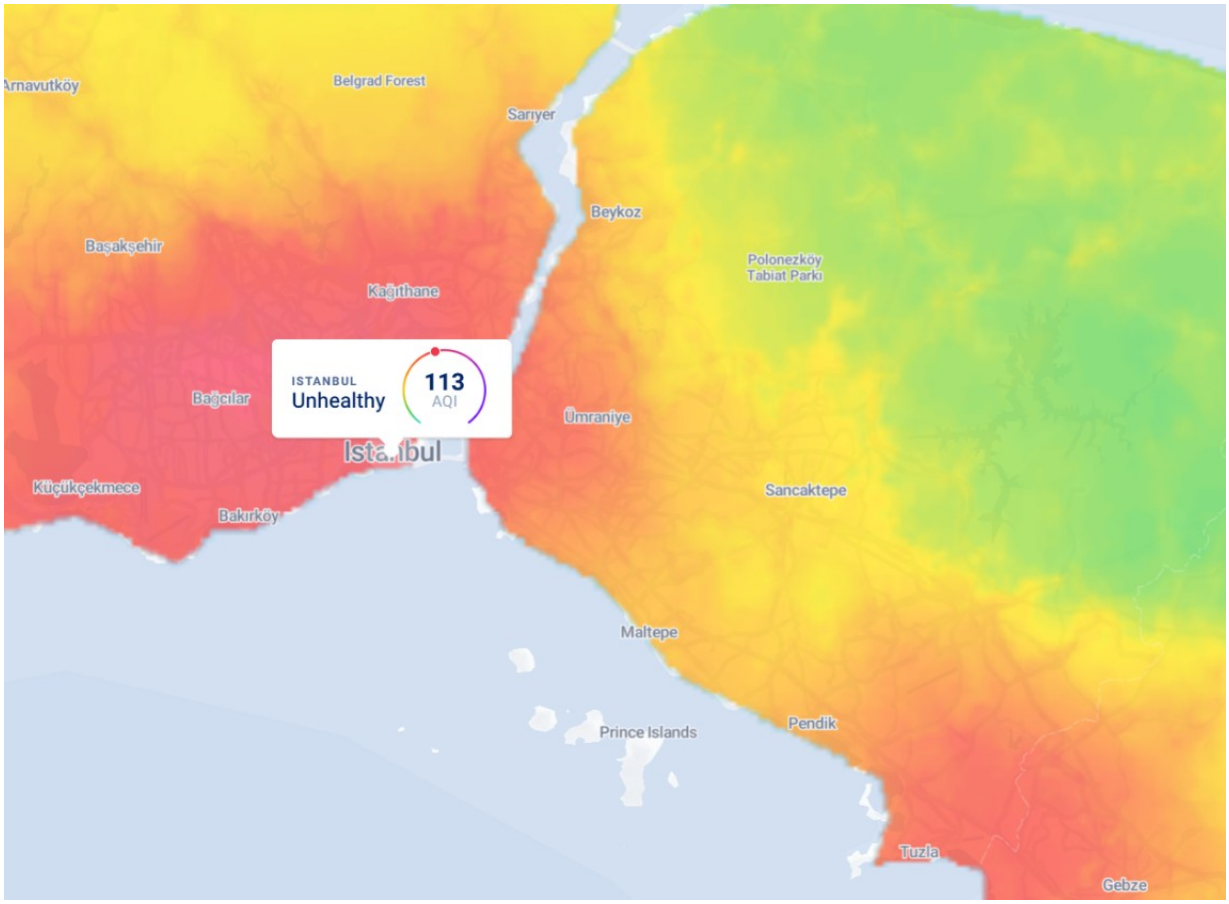



**Figure 5:** Istanbul air quality map (www.air.plumelabs.com)

From a modal integration perspective, maritime transport is multifunctional in urban transportation. Coordinated operation of metro stations, bus stops, other public transport subsystems, and docks speeds up passenger transfer. However, due to frequent schedule incompatibilities in current planning, waiting times increase and total travel time rises. Once such operational incompatibilities are resolved, maritime transport will offer a total travel time advantage comparable to road transport (Pense, n.d.). Seaborne connections that provide fast

access, especially on short-distance routes, promise more stable travel times compared to land-based alternatives.

This can increase user preference in terms of predictability during peak traffic hours. In economic terms, the high initial investment for electric ferries seems quite discouraging. However, with lower operational costs associated with electric ferries, as well as their advantages highlighted in fuel-saving studies, such initial investments can be offset (KOCAMAN, 2020). There has been an improvement in battery technology with higher energy density, which translates to reduced charging periods. There has been an estimated 80% reduction in battery cost expected by 2040, which will further improve the economics associated with new investments (Pense, n.d.).

## 2.2 Passenger Ferry

### 2.2.1 Ferry types and design criteria

In passenger ferry transport applications, the determination of the ferry type is essentially associated with the operational demands of the transportation route and involves an integrated assessment of technical, economic, and environmental demands. For routes where the distance is small and the service is intensive, several factors, including propulsion methods and ship shape, are critical in the type selection process. In this respect, the main priorities in this process are defined as the structure of the ferry's energy system, range adequacy, charge compatibility, and maneuverability (PENSE, 2022, p. 63). There are essentially two main types of ferry hull designs, namely monohull and multihull designs. While monohull ferries are normally less expensive to build and are used in small to medium-capacity services, ferries with catamaran designs provide increased passenger comfort in terms of increased deck size and stability. High stability is particularly important on routes with strong regional winds and wave effects (Gagatsi et al., 2016, p. 9). It is known that a narrow hull form can reduce drag resistance and increase energy efficiency; this type of form optimization contributes to lower fuel or electricity consumption even over short distances. In terms of design criteria, the ferry's docking method is also a critical factor. Passenger ferries with bow-type docking systems allow for rapid loading/unloading by contacting the pier with bow fenders, which reduces the time spent at the pier on the route (Pense, n.d.)

However, the fact that the line in question is intended solely for passenger transport makes this type unnecessary. When choosing between fully electric solutions and hybrid diesel-electric combinations in the energy propulsion system, battery capacity and charging speed are the most important limiting parameters.

Li-ion battery technology currently allows for high voltages to be achieved as needed through modular connections with 3–4 V cell voltage; thanks to its high energy density, the necessary power requirements can be met despite limited deck space (Malla, 2020) . For example, battery compartments with a capacity of 2.4 MWh enable 15 nautical miles of round-trip operation with a capacity of 400 passengers. To ensure that charging times do not affect the frequency of trips, port infrastructure must be adapted to be compatible with fast charging systems. In fully electric passenger ferries, the high motor response speeds increase maneuverability, while the quiet operation reduces noise pollution, providing both environmental and social benefits (Gagatsi et al., 2016a).

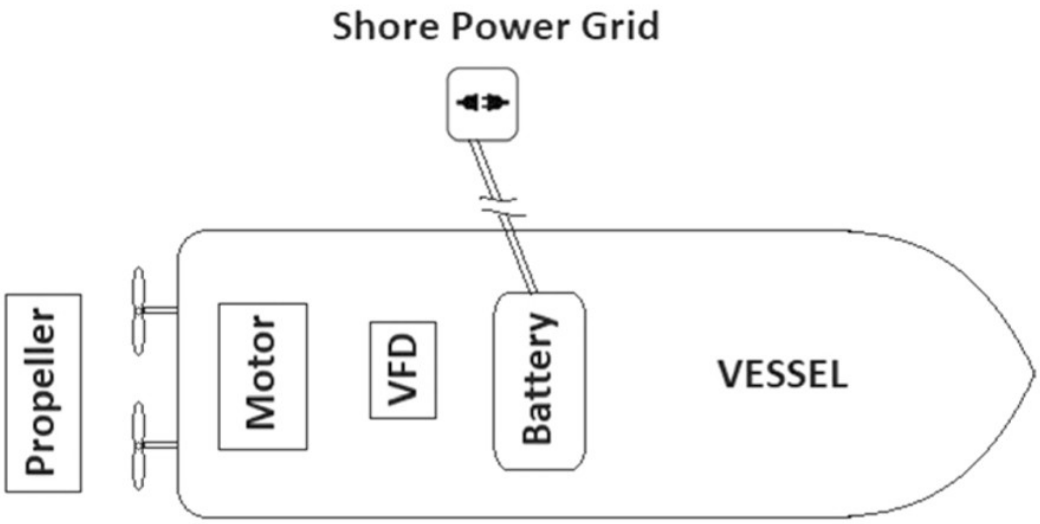



**Figure 6:** All electric vessel system configuration (Malla, 2020)

### 2.2.2 Electric drive system

Electric propulsion systems are preferred in modern passenger ferries to increase energy efficiency and minimize noise and emission levels. When evaluated in conjunction with the hull

and form optimization criteria defined in the previous section, these systems offer a particularly advantageous structure for short-distance and high-frequency routes. The most important feature of electric propulsion mechanisms is their ability to provide high torque at low speeds, thereby increasing maneuverability.

Furthermore, the reduction in mechanical transmission components eliminates the need for long shaft lines, which reduces both weight and maintenance requirements (Arish et al., 2025).

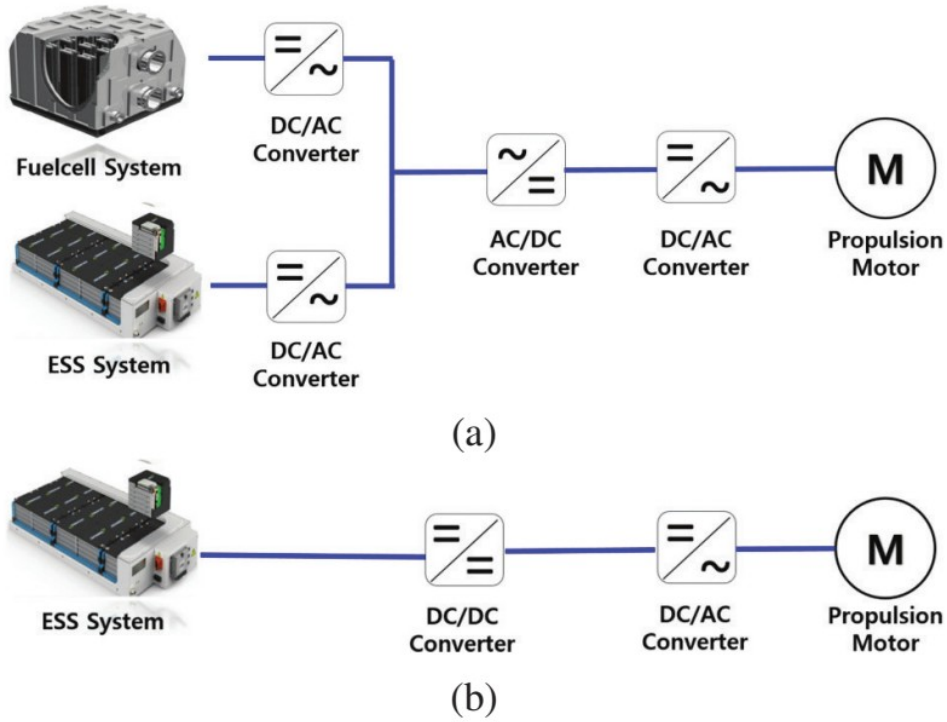



**Figure 7:** Pure-electric propulsion, (a) with fuel cell, and (b) without fuel cell (Arish et al., 2025)

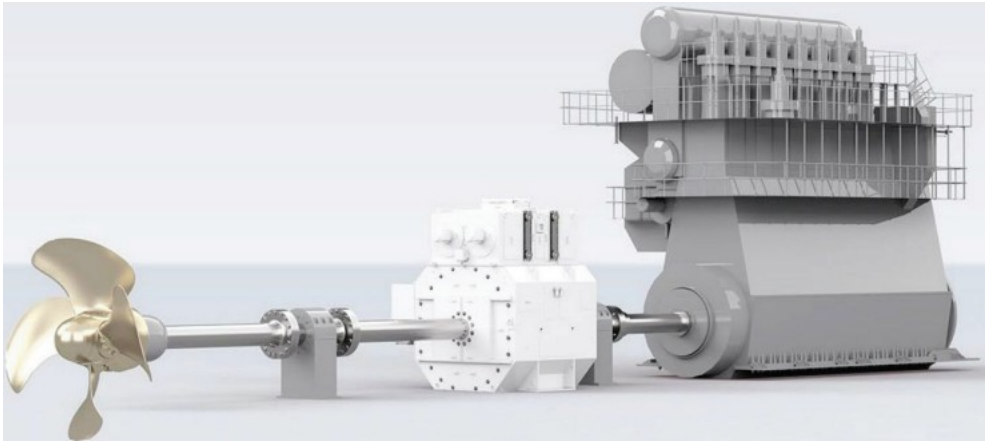


**Figure 8:** In-hull with drive motor propulsion(Arish et al., 2025)




**Figure 9:** Azimuth propulsion, (a) L-drive, and (b) Z-drive(Arish et al., 2025)

In a fully electric propulsion system configuration, the energy source is supplied directly from the ship's batteries. These batteries are mostly Li-NMC chemistry and offer sufficient capacity in limited space due to their high specific energy values (Pense, n.d.). For example, in NMC622 or NMC811 cells, the nickel content has been increased to enhance energy density and improve range performance. However, DoD (Depth of Discharge) management is critical in extending battery life, and the operational success of electric passenger ferries generally depends on the performance of the battery technology used and its compatibility with the ship's energy systems, in line with manufacturer recommendations. Parameters such as the chemical composition,

energy density, charge-discharge efficiency, life cycle, and safety measures of the batteries to be used are decisive from a technical, economic, and environmental perspective.

### 2.2.3 Battery technology

The operational efficiency of an electric ferry caters to the capabilities of the chosen battery technology and their suitability for the energy system of the vessel. Various model parameters like the composition of the batteries, energy density, charge and discharge efficiencies, life span of batteries, and safety features play a decisive role in these aspects (Kirkels et al., 2026). As of present, lithium-ion batteries are found to be the most commonly chosen energy storage system for the maritime transport industry, where NMC (Lithium Nickel Manganese Cobalt Oxide) batteries are differentiated based on their technical relevancy for use as a source for ferries based on their specific energy density and lifetime properties. Thereafter, an energy density of 150 Wh/kg becomes achievable with the usage of NMC batteries, which is four times greater compared to the lead–acid counterparts of the previous generation (Malla, 2020). In the case of ferries and ships, the mechanical properties of the batteries to cope with ship vibration levels and water and high-temperature environments are also of utmost importance and are recognized as decisive attributes of a quality energy storage system within the industry. Hence, arranging these batteries in modules not only aids in maintenance activities but also aids in proper thermal management systems. These cooling systems are designed to make use of closed-loop cooling systems or direct cooling systems based on seawater circulation systems. The capabilities of the Energy Storage Systems (ESS) vary between 1 MWh and 4 MWh and are applied for routes with higher requirements of capacity.

For example, the ESS calculation is expressed as follows:

$$ESS = \frac{400 \times Load}{\left[332 - 28.98 \ln\left(N \times D \times 360\right)\right]}$$

here, N represents the number of daily trips, D represents the design life (years), and Load represents the total load ("kWh") (Malla, 2020). Such calculations also form a reference in business cost planning.

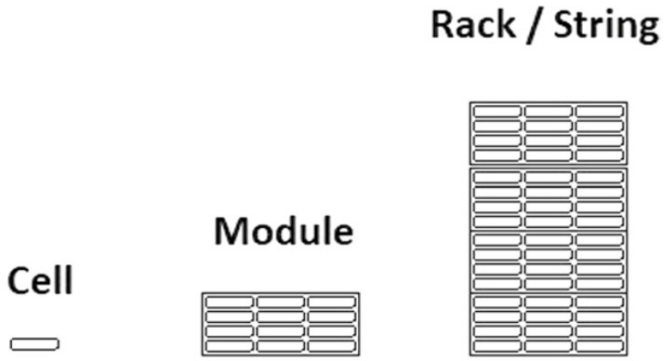



**Figure 10 Battery package definition (Malla, 2020)**

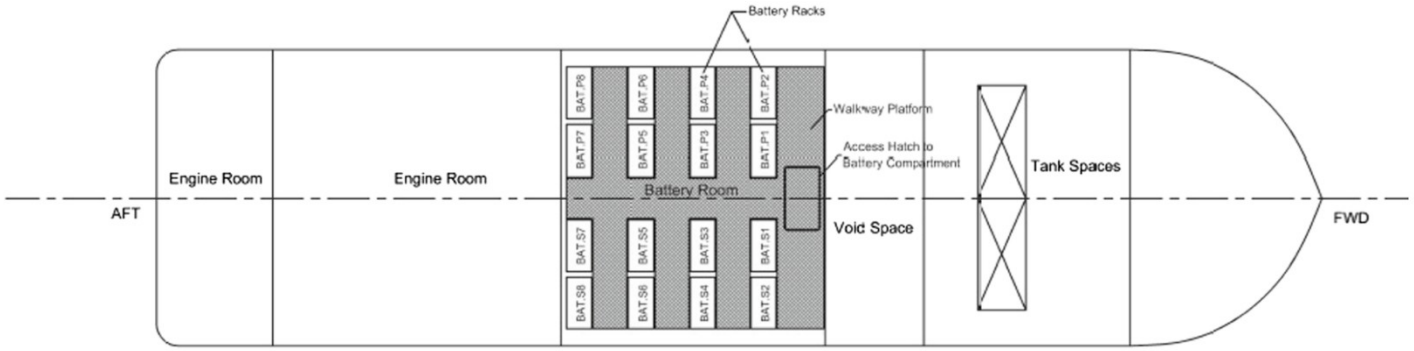



**Figure 11:** Battery compartment arrangement for a passanger ferry (Malla, 2020)

The compatibility of the charging infrastructure with battery technology is also decisive in practice. While port waiting times on short-distance routes provide sufficient time for fast charging units, limited charging opportunities on medium- to long-distance routes or routes with high demand loads can restrict battery use (Gagatsi et al., 2016, p. 6).

At this point, containerized battery exchange systems are being developed as an alternative solution; this method ensures operational continuity, especially on inland waterways with short stopping times (Kirkels et al., 2026, p. 8).

# 3. METHODS AND MATERIALS

## 3.1 Maxsurf

Maxsurf is a three-dimensional computer-aided engineering application that aims to optimize the ship's body form in the context of electric ferries. However, an important characteristic of the software application resides in its modularity; thus, it allows the parametric variation of the body form, aiming at a fast comparison between designs according to the different routs. Nevertheless, there are a series of technical issues in Maxsurf that ought to be carefully considered in the process.

For instance, the three-dimensional application restricts its ability to proceed with precise analyses in two-dimensional windows for designs, requiring further software in addition or a series of manual processes whenever there is a need for separate analyses in relation to sections or load schemes in a single work. Additionally, restrictions in the outputting process, such as the inability to proceed with the entire drawing in a single page, could hamper efforts to achieve pictorial accuracy in relation to the process of compiling engineering designs. Furthermore, due to the fact that there are no complete working designs, further tools ought to be utilized in an effort to produce precise production designs that could help in relation to logistic designs (ACAR, 2022). On the other hand, the hydrostatic efficiency and resistance application in the Resistance module in Maxsurf is unquestionably important in relation to the electric ferries' body form designs.

Using the module Resistance, the water resistance of the hull corresponding to different speeds can be calculated to determine the required power of the motor. The results of the modeling study can help in carrying out the necessary design validations. The results of the Resistance module characterize not only the geometry of the hull but also help in the strategies of propeller optimization.

Based on the relation of Maxsurf's speed and resistance to propeller selection, an optimal propulsion combination can be determined to form the required power balances within the framework of the integration of renewable energy sources.

The software also allows testing different displacement scenarios. For example, if capacity planning anticipates that the ferry will experience high passenger loads in summer and relatively low loads in winter, separate hydrodynamic analyses can be performed for each scenario. (Maxsurf User Manual, 2025)

The Maxsurf software has 6 separate modules. These are, in order, the Modeler, Resistance, Structure, Stability, Motions, and Multiframe modules. During the form design phase, other modules are also used to perform other engineering calculations and modeling for the ship.




**Figure 12:** Modules of the maxsurf software

## 3.2 Rhinoceros

The modeling system in the software uses Non-Uniform Rational B-Splines (NURBS), which aids in creating complex curved surfaces and thus smooth bow and stern designs. Rhinoceros also helps in synchronizing complex components in a single model.

The software helps in lessening the chances of errors in the process of creating models in a single file for the hull form, plating line, propeller hub, relation components, and areas for the energy system integration. It also helps in the comparison process between different designs because Rhinoceros' layer management system facilitates the comparison process between different designs. Macro commands in Rhinoceros help in quick measurement and drafting, thus improving efficiency.

Further, Rhinoceros provides data that can be easily incorporated into AutoCAD or other CAD/CAM systems, thus providing consecutive benefits within the manufacturing process. The data from the surfaces of the three-dimensional model can be directly channeled into sheet metal plasma cutters, and this helps in minimizing the period between designing and manufacturing. Further, the availability of algorithmic modeling applications like Grasshopper in the plugin framework allows one to provide parametric changes in the rudder or hull shapes to hydrodynamic modeling optimizations (Rhinoceros User Manual, 2025).




**Figure 13:** Rhinoceros 3D software icon

# 4. CASE STUDY

## 4.1 Feasibility of The Line

### 4.1.1 The Purpose and significance of feasibility studies

The purpose of the feasibility study is to determine the technical, economic, and environmental feasibility of the planned maritime route using scientific methods. During this process, decision support mechanisms are developed by considering both the integration capacity with the existing urban transportation system and operational parameters such as the energy efficiency of the proposed vessel type. Feasibility analyses evaluate the route length, demand profile, port infrastructure status, and limitations of the technology to be used. Capacity constraints in terms of battery range and charging speed are highly definitive in determining the choice of new generation vessels in the marine market, including electric or hybrid ferries (Pense, n.d.). Hence, the choice matrix designed in the current study is a primary tool in determining the best solution for a given route.

The main purpose of a feasibility study is to evaluate the viability of a given course, such as a sea route, within the existing technical, economic, and environmental frameworks. Feasibility studies can help reduce risks during the initial stages of transportation planning by pointing towards the areas of potential limitations during transportation planning.

Furthermore, feasibility studies also serve as an organized technique to make an informed choice among the different modes of transportation. A decision support tool, such as the decision matrix, is useful to compare different alternatives with respect to specified criteria. The significance of feasibility studies is evident in the sense that they help to identify an appropriate and realistic transportation solution.

### 4.1.2 Criteria and evaluation method

This decision matrix was refined through the compilation and integration of expert opinion, open source information, and an engineering perspective, to provide five possible routes. Each route was also evaluated on its own merit by a set of predefined criteria. The routes proposed may be Harem-Kabataş, Aşiyan-Kandilli, Küçüksu-Bebek, Kandilli-Bebek, and finally Beykoz-İstinye, with a focus on these five routes. Criteria included in the evaluation concerned route length or suitability to electric propulsion, suitability of pier electrical infrastructure, relative demand for public transportation, social value, and value through the reduction of pier occupation when charging. Criteria scoring took place with industry expert consultation, as well as direct observations. As a result of this study, the Küçüksu–Bebek line was scored as follows: Line length & suitability for electric propulsion 5; Pier electrical infrastructure suitability 3; Passenger demand potential 4; Environmental and social benefits 4; Operational efficiency 3. When the total scores were compared, this line was found to have the highest total value compared to the other candidate lines. The scoring system is supported by a linear weighting method. The weight of each criterion is determined according to the project objectives, and it is seen that environmental impact and technical suitability are higher for Küçüksu–Bebek.

**Table 2:** Line/Criteria table

| Line / Criteria | K1 | K2 | K3 | K4 | K5 | Total |
|---|---|---|---|---|---|---|
| Küçüksu – Bebek | 5 | 3 | 4 | 4 | 3 | **19** |
| Kandilli – Bebek | 5 | 3 | 3 | 4 | 3 | **18** |
| Harem– Kabataş | 4 | 4 | 2 | 3 | 4 | **17** |
| Aşiyan – Kandilli | 5 | 2 | 4 | 3 | 2 | **16** |
| Beykoz– İstinye | 4 | 1 | 2 | 3 | 2 | **12** |

**Table 3:** Types of Criteria

| | |
|---|---|
| **K1** | Route length and suitability for electric propulsion |
| **K2** | Pier electrical infrastructure adequacy |
| **K3** | Passenger demand potential |
| **K4** | Environmental and social benefits |
| **K5** | Operational efficiency |

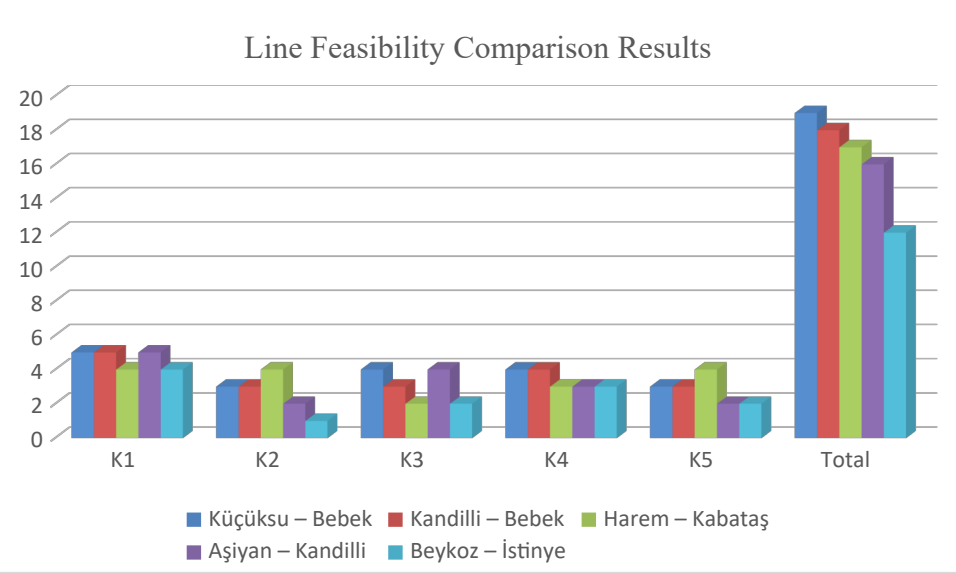
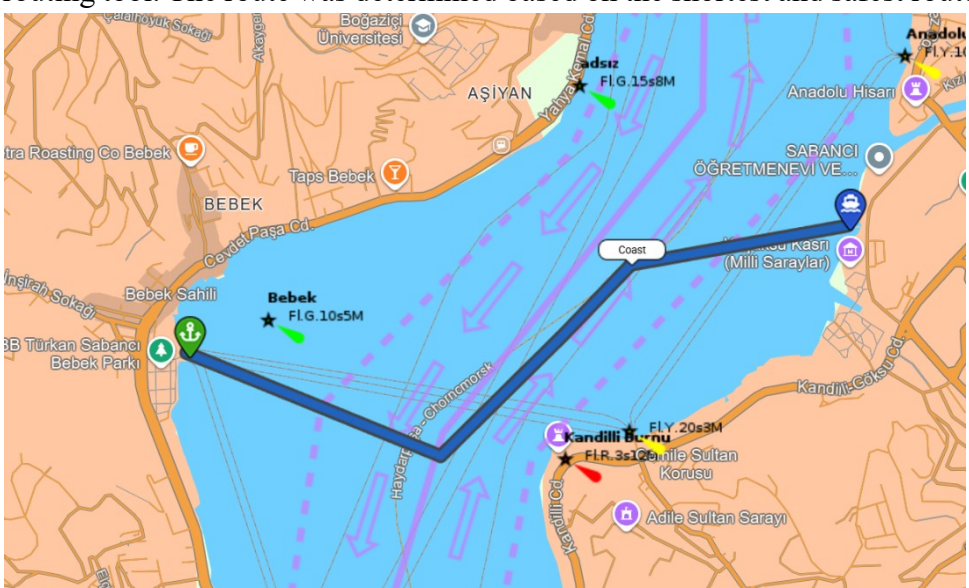



**Figure 14:** Column Chart comparison

The sea route for the selected Küçüksu-Bebek line was created using boatrouting.com, an online maritime routing tool. The route was determined based on the shortest and safest route between



piers, following existing navigation routes within the Bosphorus. Based on the measurements, the line length was calculated as 1.24 nautical miles.

**Figure 15:** Route View

Among the most important social and functional reasons for choosing the Küçüksu-Bebek corridor has been its ability to reduce travel time from destinations on the Anatolian side for Boğaziçi University constituents. The existing transportation conditions force these people to work through lengthy routes by road as well as over bridge crossings either through lengthy routes or through ferry transportation. The adverse consequences arising out of river bridge entry congestion, especially during peak periods, cause negative effects such as time loss as well as reduced transportation convenience (Kızıltaş & Karakale, 2024). Within this context, the proposed maritime line has become an alternative route for not using the bridge but enabling the crossing from the Bebek coast to Küçüksu in an efficient manner. The reduced route further helps to remove time loss, which has become an important factor for university constituents with regard to reaching their places on time for their classes.

Based on discussions with Adem Viran, along with expert views from experienced professionals in this particular field, it can be identified that the Küçüksu-Bebek corridor route is quite practicable (Viran A, Private Conversation, Üsküdar,2025).

The Bebek-Küçüksu route has features that enable the analysis of the route within the scope of public transportation as well as its role in the augmentation of tourism potential and the strengthening of cultural connections along the Bosphorus. In terms of its geographic location, the route passes through a region with a high visual attractiveness of the Bosphorus, creating a desirable experience for both local and foreign tourists. The Bebek shoreline in the European side of the city represents a touristic center with a distinctive characteristic of having coastside cafeterias, restaurants, and high-end shopping centers. On the Asian side, Küçüksu represents a location with a rich culture, possessing a historic palace and a natural park area. The direct sea connectivity of the two points adds a completely fresh element to the tourism in the Bosphorus. The short duration allows the tourists to spend more time at the destination points, which

increases the depth of the destination's involvement with the culture.

The use of electric ferries along the route takes place with reduced acoustic emission levels, reducing the engine and propellers' vibration and enabling the tourists to view the scenery along the route with minimal contact with the natural environment. This technical element represents a substantial component of the tourism value chain. Additionally, the absence of emissions by the use of electric propulsion systems ensures the maintenance of the quality of the ambient air along the routes near residential areas. The element has the potential to create a positive image, especially along the coasts with high levels of tourism.

## 4.2 Alternative Design Purpose and Requirements

In a city as complex as Istanbul in both geographical and demographic terms, the sustainability and efficiency of transport infrastructure is a factor of utmost importance. Being a city connecting two continents, Istanbul is under a high level of demand for both road and marine transport. Nevertheless, the negative effects of road transport, such as traffic congestion, air pollution, and noise, enhance the importance of marine transport. This situation emphasizes the importance of sea transport, especially along the routes along the coastline connecting populous centers.

In the context of this thesis, the design of a 37-meter double-ended electric-powered passenger ferry is suggested as an innovative engineering solution to meet the specific needs of the Istanbul Strait operation and environmental conditions. The basic purpose of this design is to develop a vessel with zero emissions in its operation while at the same time ensuring maximum

operational efficiency. This is achieved due to the fact that the vessel is not equipped with the conventional single-ended and diesel-powered propulsion system, which takes much longer to berth and depart from the harbor area. Consequently, the number of operational rounds in the same period is increased, which in turn enhances the vessel's efficiency. Additionally, the electric propulsion system eliminates the need to consume fossil fuels, which in turn results in zero emissions into the environment. This is an important milestone in the development of Türkiye in the field of maritime engineering and the achievement of sustainable operation in the future.

This is also the purpose of the ferry's design: not only is it meant to reflect a modern approach from a technical perspective but also from an aesthetic and functional viewpoint. Thus, the interior is designed with a strong emphasis on the comfort of passengers, accessibility for people with disabilities, as well as safety. The success of this project can be a reference for other routes with similar geographical and operational characteristics, contributing to the promotion of electric maritime transport.

### 4.3 Innovative Aspects and Technological Approach

The innovative features, which form the basis for the proposed 37-meter electric passenger ferry vessel, have been created with the objective of ensuring maximum efficiency, sustainability, as well as comfort for the passengers. With regard to the innovative features, the most outstanding characteristic of the proposed vessel is the fact that it has a double-ended symmetrical hull form, which enables the vessel to operate equally in both directions. This characteristic eliminates the need for 180-degree turning, as is the case with the conventional single-ended vessel, during the berthing process, thus minimizing the time as well as the energy required for the process. The symmetrical hull form also enables the vessel to dock as well as leave the dock more quickly, thus providing the potential for increased operational frequency, as well as the maneuverability, which reduces the possibility of collisions during the operational process.

The most revolutionary change in this ferry is the use of a completely electric propulsion system, which means the use of fossil fuels is completely eliminated in this system. Instead of the use of traditional diesel engines, lithium-ion batteries, which have high energy density, and electric motors, which rotate quietly, are used in this system. This completely electric propulsion system allows the zero emission of carbon, zero emission of nitrogen oxides, and zero emission of sulfur oxides into the atmosphere, which is very beneficial to the environment, especially in areas like the Istanbul Strait, which has a lot of natural beauty and a sensitive ecosystem.

Collectively, these innovations change the 37-meter electric double-ended vessel from a conventional transportation vessel to a maritime version of the smart city concept. When compared to conventional vessels, reduced costs of operation and maintenance, long-lasting components, and a high degree of automation make the long-term sustainability and economic feasibility of the project viable. The vessel has been specifically designed to meet the unique conditions of the Istanbul Strait and provides a model that could be used as a reference point for other coastal cities that have similar geographical and operational characteristics. In this sense, the project plays a significant role in the promotion of the adoption of electric propulsion technology in maritime transportation and the achievement of environmental sustainability.

### 4.4 Determining Boat Type and Dimensions

As stated at the beginning of this section, the alternative design proposed within the study is based on a monohull configuration. In order to provide a viable alternative to existing vessel types and to achieve the targeted advantages, it was decided to carry out the design study using this hull form. By comparing the modern equipment of similar reference vessel types with the operational requirements of the vessel proposed in this project, a set of design assumptions was established. Based on these assumptions, tables were prepared in line with the joint evaluations conducted together with Engineer İsmail Alkış. (Alkis İ, Online Studies, 2026)

**Table 4:** General information about the designed ferry.

| Parameter | Value |
|---|---|

| | |
|---|---|
| Vessel Type | Double-ended electric passenger ferry |
| Main Function | Urban passenger |
| Length Overall (LOA) | 37.0 m |
| Beam Overall | 8.5 m |
| Depth | 3.0 m |
| Design Draught | 1.5 m |
| Passenger Capacity | 194 |

## 4.5 Creating the Hull Form

The studies regarding the development of the vessel hull form were performed by using the Modeler module of the Maxsurf program, which is commonly used in the maritime design field. This process was performed with the technical support of Engineer İsmail Alkış (Alkis İ, Online Studies, 2026). After the vessel hull form was determined with the desired design goals, the hydrostatic properties of the vessel were analyzed by using the Maxsurf Stability module, and the suitability of the vessel was evaluated.

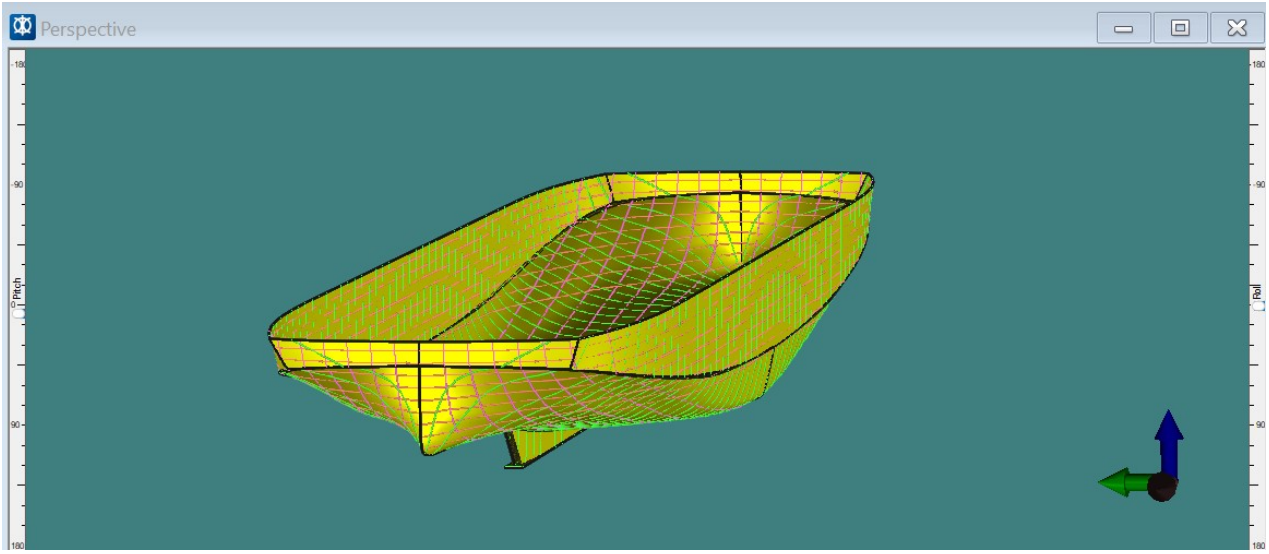


**Figure 16:** Form perspective view

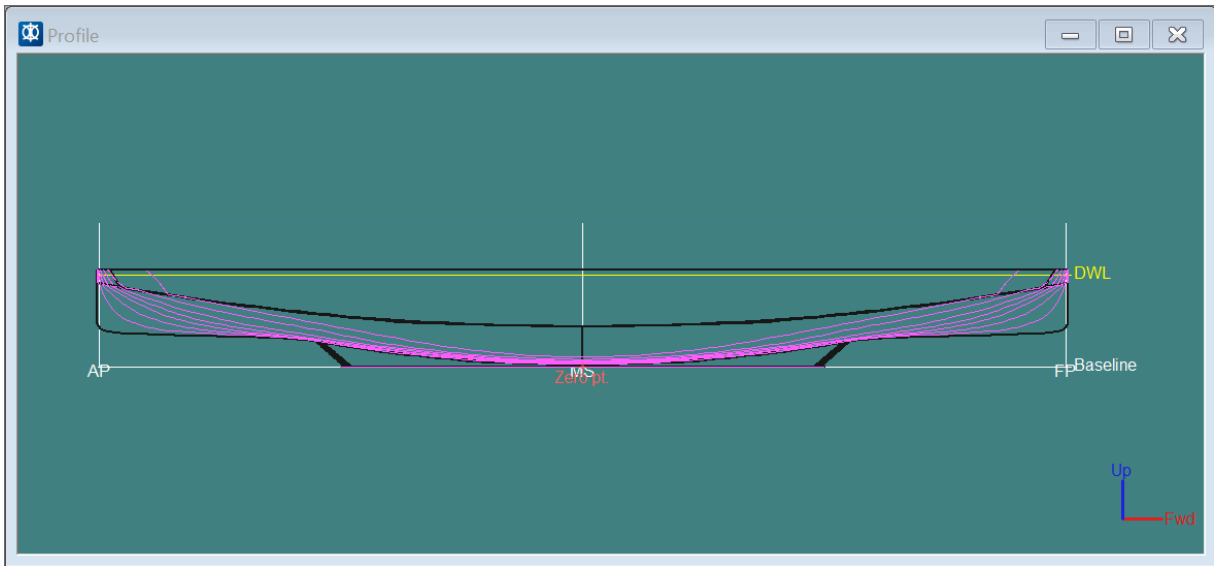



**Figure 17:** Form profile view

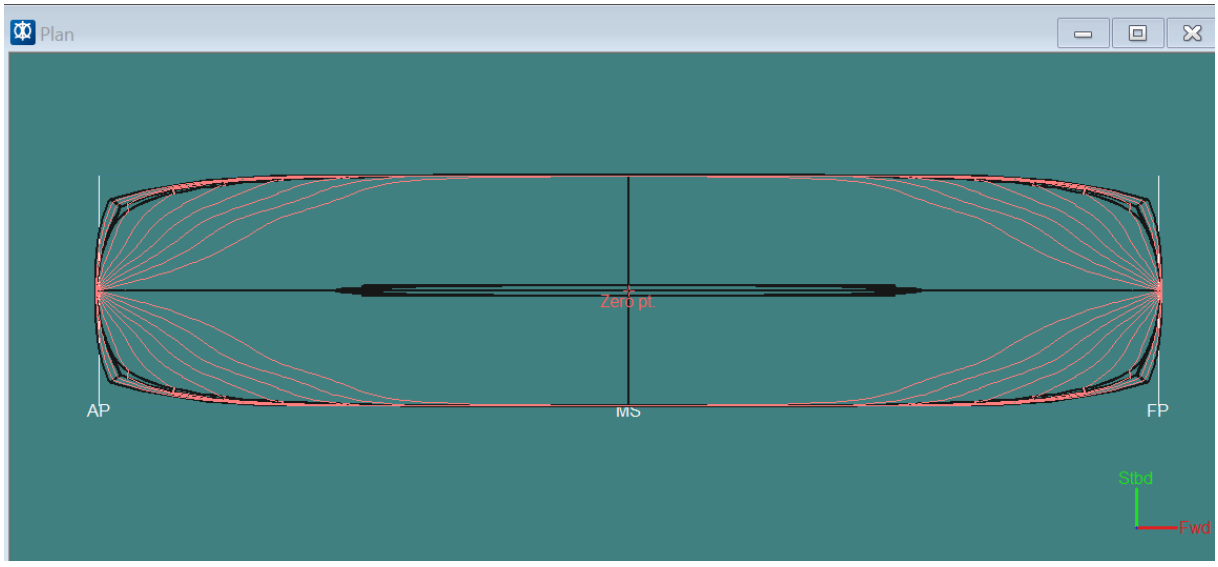



**Figure 18:** Form top view

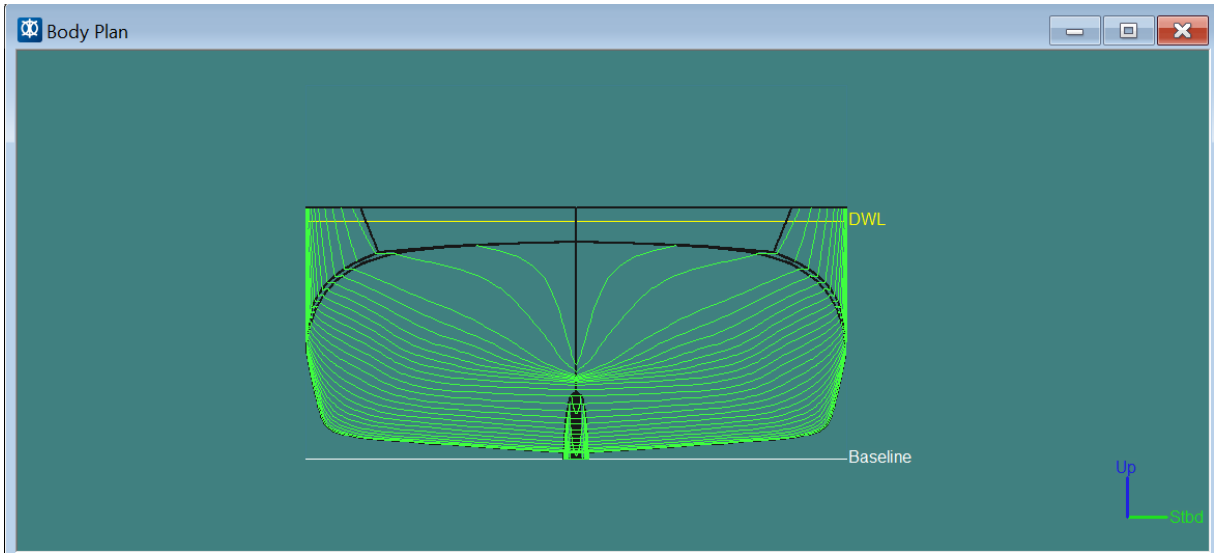



**Figure 19:** Form front view

Once the process of hull form generation and the hydrostatic analysis were completed, the model design was moved to the Maxsurf Resistance module. At this point, speed-power analysis was done, and the power requirements needed to meet the operational requirements were determined from the results achieved.

## 4.6 Determining Design Speed and Power Requirements

After the completion of the vessel form, the steps of which have been explained in Section 4.5, the results of the resistance and speed-power analyses were evaluated and are presented in Table 5 and Table 6

**Table 5:** Maxsurf Resistance analysis results

| Item | Value | Units | Holtrop |
|---|---|---|---|
| LWL | 37 | m | 37 |
| Beam | 7.977 | m | 7.977 |
| Draft | 2.012 | m | 2.012 |
| Displaced volume | 292.804 | m^3 | 292.804 |
| Wetted area | 292.233 | m^2 | 292.233 |
| Prismatic coeff. (Cp) | 0.543 | | 0.543 |

| | | | |
|---|---|---|---|
| Waterpl. area coeff. (Cwp) | 0.826 | | 0.826 |
| 1/2 angle of entrance | 32 | deg. | 32 |
| LCG from midships(+ve for'd) | 0 | m | 0 |
| Transom area | 0 | m^2 | 0 |
| Transom wl beam | 0 | m | -- |
| Transom draft | 0.158 | m | -- |
| Max sectional area | 14.578 | m^2 | -- |
| Bulb transverse area | 14.578 | m^2 | 14.578 |
| Bulb height from keel | 1.172 | m | 1.172 |
| Draft at FP | 2.1 | m | 2.1 |
| Deadrise at 50% LWL | 3.8 | deg. | -- |
| Hard chine or Round bilge | Round bilge | | -- |
| | | | |
| Frontal Area | 0 | m^2 | |
| Headwind | 0 | kn | |
| Drag Coefficient | 0 | | |
| Air density | 0.001 | tonne/m^3 | |
| Appendage Area | 0 | m^2 | |
| Nominal App. length | 0 | m | |
| Appendage Factor | 1 | | |
| | | | |
| Correlation allowance | use 19th ITTC formulation | | Calculated by method |
| Kinematic viscosity | 1.19E-06 | m^2/s | |
| Water Density | 1.0259 | tonne/m^3 | |

**Table 6:** Speed-power analysis results

| Speed (kn) | Froude No. LWL | Froude No. Vol | Holtrop Resist (kN) | Holtrop Power (kW) |
|---|---|---|---|---|
| 8 | 0.216 | 0.51 | 145.3 | 597.826 |
| 8.25 | 0.223 | 0.526 | 145.2 | 616.224 |
| 8.5 | 0.23 | 0.542 | 145.2 | 634.945 |
| 8.75 | 0.236 | 0.558 | 145.3 | 654.001 |
| 9 | 0.243 | 0.574 | 145.4 | 673.406 |
| 9.25 | 0.25 | 0.59 | 145.7 | 693.178 |
| 9.5 | 0.257 | 0.606 | 146 | 713.329 |
| 9.75 | 0.263 | 0.622 | 146.3 | 733.862 |
| 10 | 0.27 | 0.638 | 146.7 | 754.763 |
| 10.25 | 0.277 | 0.653 | 147.2 | 776.012 |
| 10.5 | 0.284 | 0.669 | 147.7 | 797.59 |
| 10.75 | 0.29 | 0.685 | 148.2 | 819.487 |
| 11 | 0.297 | 0.701 | 148.7 | 841.714 |

| | | | | |
|---|---|---|---|---|
| 11.25 | 0.304 | 0.717 | 149.3 | 864.304 |
| 11.5 | 0.311 | 0.733 | 150 | 887.309 |
| 11.75 | 0.317 | 0.749 | 150.7 | 910.794 |
| 12 | 0.324 | 0.765 | 151.4 | 934.842 |
| 12.25 | 0.331 | 0.781 | 152.3 | 959.542 |
| 12.5 | 0.338 | 0.797 | 153.2 | 984.997 |
| 12.75 | 0.344 | 0.813 | 154.2 | 1011.316 |
| 13 | 0.351 | 0.829 | 155.3 | 1038.616 |

On the basis of the evaluation of obtained speed-power relationships, two basic propulsion system configuration types were identified: an optimum design with a service speed of 10 knots and a maximum speed-oriented design with a service speed of 12.5 knots.

After the three-dimensional modeling of the hull form and the specification of the hydrodynamic boundary conditions, the total resistance ($R_t$) values to be overcome in order to attain the desired speed during service was determined through the application of advanced numerical hydrodynamic analysis methods. Based on the Froude number-dependent data provided by the resistance modules included in the analysis software, the friction resistance, wave resistance, and aerodynamic resistance values were combined to obtain the effective power required for the bare hull ($P_e$). By using the resistance values and the intended speed during operation, the power-speed curve evaluation was performed. By incorporating the values of the propulsive efficiency coefficients in the calculations, it was conclusively determined that the main propulsion motor configuration with 400 kW x 2 represents the best solution for the propulsion system.

### 4.7 General Plan and a 3D Model

In the general arrangement of the 37-meter ferry, wide entrance/exit ramps and areas have been designed to allow the simultaneous movement of passengers from both ends of the vessel. The seating arrangement has been planned primarily along the window sides to allow the passengers to enjoy the panoramic views of the Bosphorus while on the voyage. The accessibility of the passengers with disabilities has also been considered in accordance with the international ISO norms, and barrier-free areas have been included in the interior arrangement.

The enclosed deck, which is symmetrically constructed, has the capacity to carry 156 + 2 to 6

passengers, and the open deck has the capacity to carry 32 passengers, thereby carrying a maximum of 194 persons in total. Figure 20 is the profile view related to the general arrangement plan.

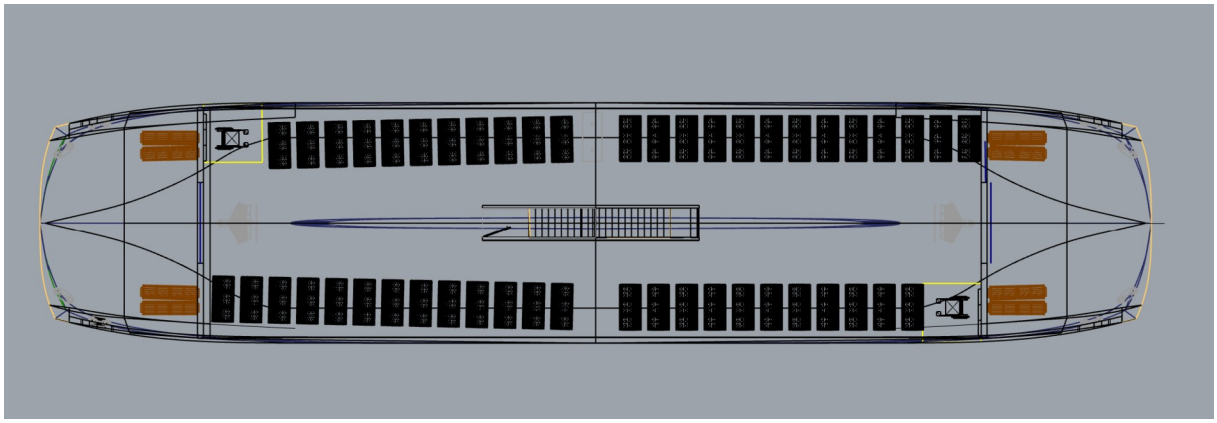


**Figure 20:** Ferry seating layout

After the final hull form was determined and the layout arrangement was made to satisfy the requirements, the three-dimensional modeling process was started. At this stage, solid modeling was done using the Rhino software, and the results are shown in Figure 21 and Figure 22.

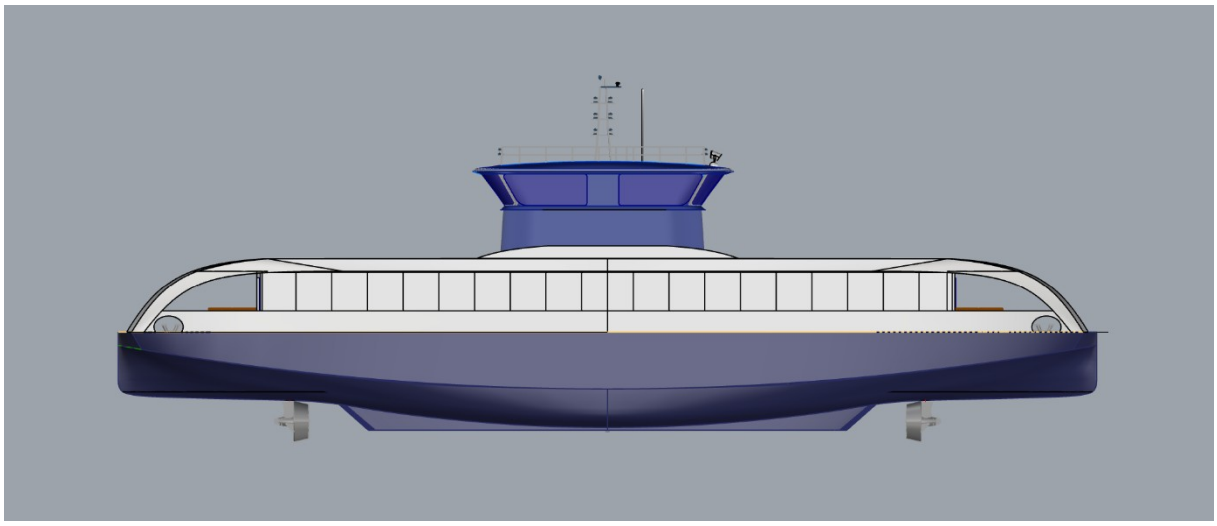


**Figure 21:** Ferry 3d profile view



**Figure 22:** Ferry 3d perspective view

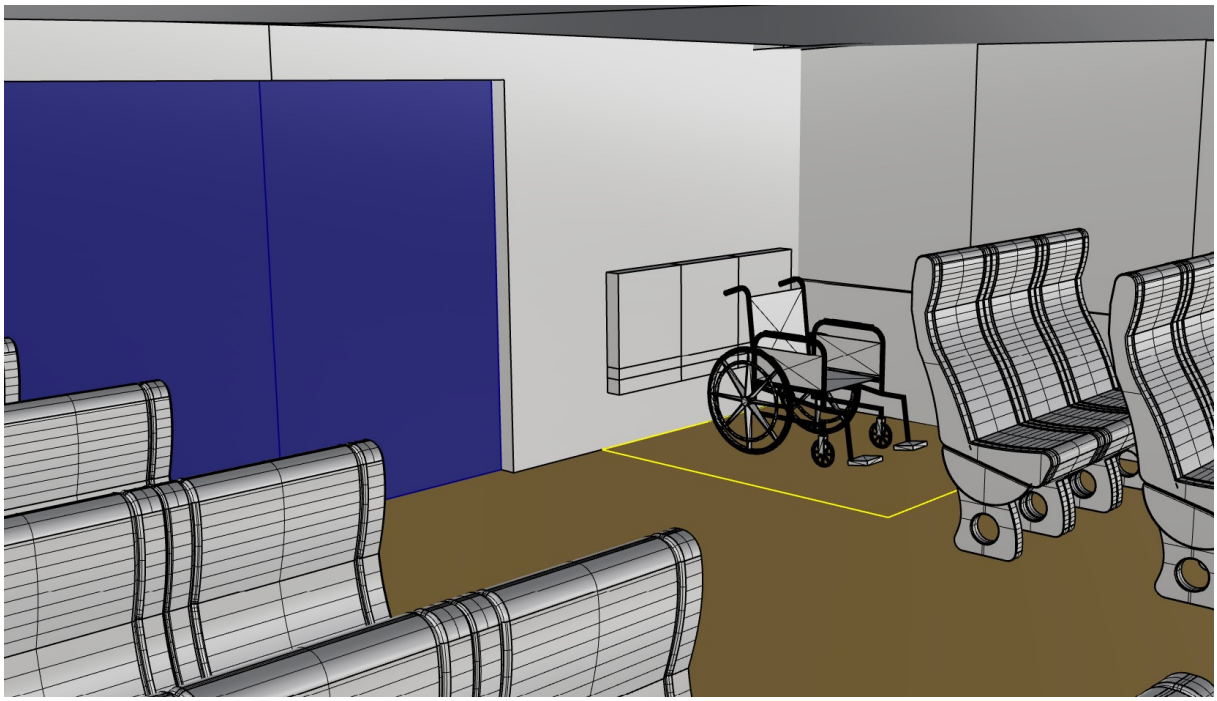


**Figure 23:** Interior disabled passenger area design

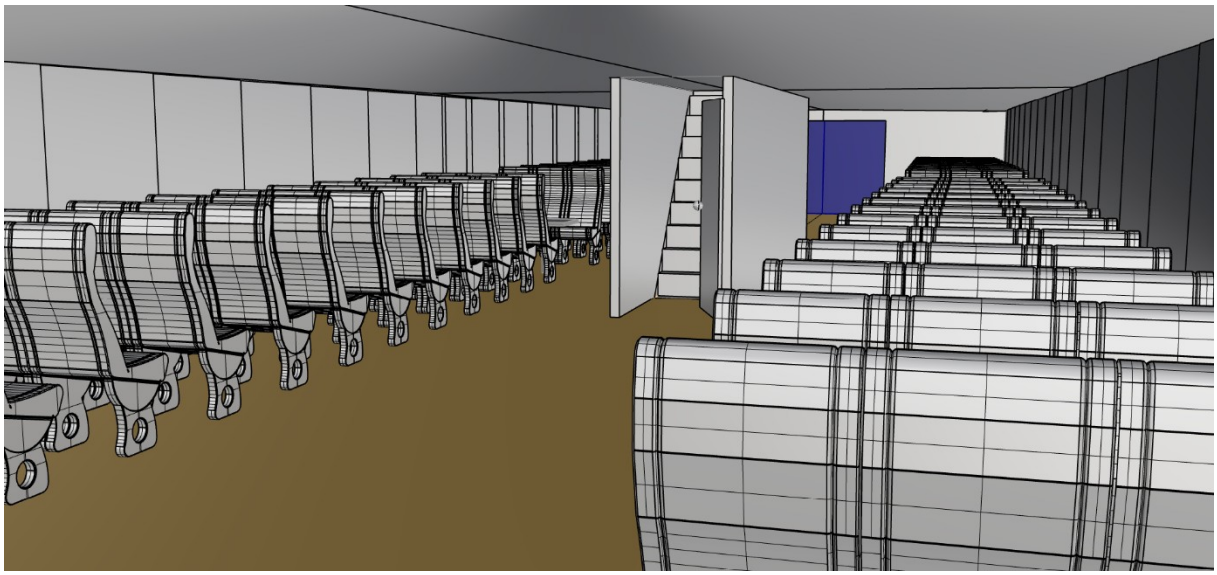


**Figure 24:** Interior passenger area design

## 4.8 Tank Capacities

In accordance with the operational requirements of the ferry, the capacities of the tanks were determined, and the weight distribution of the vessel was planned accordingly. Based on the calculations made with the assistance of Engineer İsmail Alkış (Alkis İ, Online Studies, 2026), the selected machinery and capacities of the tanks can be summarized as follows:

**Table 7:** Tank capacities

| Tank Type | Capacity ($m^3$) | Calculation Basis |
|---|---|---|
| Day Tank | 4.48 | Daily 10 hour operation |
| Settling Tank | 4.50 | 1 day buffer |
| Storage Tank | 4.08 | Remaining for 7-day autonomy |
| Total Fuel Oil | 13.06 | 7 day autonomy |
| Fresh Water | 1.74 | Machinery cooling only |
| Gray Water | 20.50 | 7 days |
| Black Water | 10.80 | 7 days |

| | | |
|---|---|---|
| Total Bilge | 0.91 | 7% |
| Oily Bilge | 1.30 | 10% |
| Dirty Oil | 0.52 | 4% |

These capacities of the tanks were established to ensure the vessel had enough storage during the period of operation and also to satisfy the maritime regulations set by international law. The weight distribution and the positioning of the tanks within the vessel would also be analyzed using the Maxsurf software to satisfy the stability requirements.

Profile

Results

| | | |
|---|---|---|
| 1 | Draft Amidships mm | 1697.5 |
| 2 | Displacement t | 206.1 |
| 3 | Heel (deg) | 0.3 |
| 4 | Draft at FP mm | 1700.1 |
| 5 | Draft at AP mm | 1694.9 |
| 6 | Draft at LCF mm | 1697.5 |
| 7 | Trim (+ve by stern) mm | -5.2 |
| 8 | WL Length mm | 36961.2 |
| 9 | Beam max extents on WL mm | 7974.1 |
| 10 | Wetted Area mm^2 | 262451506.5 |
| 11 | Waterpl. Area mm^2 | 219951724.3 |
| 12 | Prismatic coeff. (Cp) | 0.477 |
| 13 | Block coeff. (Cb) | 0.461 |
| 14 | Midship Section Area Coeff. (Cm) | 0.842 |
| 15 | Waterplane Area Coeff. (Cwp) | 0.746 |
| 16 | LCB from zero pt. (+ve fwd) mm | 11.6 |
| 17 | LCF from zero pt. (+ve fwd) mm | 9.7 |
| 18 | KB mm | 1120.5 |
| 19 | VCG fluid (KG fluid) mm | 4409.0 |
| 20 | BMt mm | 4773.1 |
| 21 | BMl mm | 77665.5 |
| 22 | GMT corrected mm | 1484.6 |
| 23 | GML mm | 74381.6 |
| 24 | KMt mm | 5893.9 |
| 25 | KMl mm | 78789.1 |
| 26 | Immersion (TPC) (tonnes/cm) | 2.255 |
| 27 | MCT (Moment to Change Trim) (tonne.m) | 4.167 |
| 28 | RM at 1deg = GMT.Disp.sin(1) tonne.mm | 5339.1 |
| 29 | Max Deck Inclination (deg) | 0.2829 |
| 30 | Trim angle (+ve by stern) deg | 0.2829 |

Departure

| | Item Name | Quantity | Unit Mass tonne | Total Mass tonne | Unit Volume litre | Total Volume litre | Long. Arm arm | Trans. Arm arm | Vert. Arm arm | Total FSM tonne.m m |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Lightship | 1 | 181.310 | 181.310 | | | 0.0 | 0.0 | 4130.0 | 0.0 |
| 2 | Ballast Tank Aft | 50% | 13.026 | 6.513 | 12708.3 | 6354.2 | -16432.4 | 0.0 | 2048.6 | 55402.2 |
| 3 | Fuel Service Tank Aft | 100% | 4.665 | 4.665 | 5553.1 | 5553.1 | -7687.5 | 2918.0 | 2048.6 | 0.0 |
| 4 | Bilge Tank | 10% | 1.599 | 0.160 | 1751.3 | 175.1 | -1361.0 | -510.6 | 164.3 | 359.5 |
| 5 | Black Water Tank 1 | 10% | 2.452 | 0.245 | 1751.3 | 175.1 | -1361.0 | -510.6 | 164.3 | 551.2 |
| 6 | Black Water Tank 2 | 10% | 2.452 | 0.245 | 1751.3 | 175.1 | 1361.0 | -510.6 | 164.3 | 551.2 |
| 7 | Fresh Water Tank | 100% | 1.751 | 1.751 | 1751.3 | 1751.3 | 1366.1 | 726.1 | 568.2 | 0.0 |
| 8 | Fuel Service Tank Fwd | 100% | 4.665 | 4.665 | 5751.1 | 5553.3 | 7687.5 | -2916.0 | 2048.5 | 0.0 |
| 9 | Ballast Tank Fwd | 50% | 13.026 | 6.513 | 17703.2 | 6354.1 | 16432.4 | 0.0 | 2044.6 | 55401.6 |
| 10 | **Total Loadcase** | | | **206.067** | **43527.7** | **26091.0** | **10.8** | **5.8** | **3864.2** | **112265.5** |
| 11 | **FS correction** | | | | | | | | **544.8** | |
| 12 | **VCG fluid** | | | | | | | | **4409.0** | |

**Figure 25:** Maxsurf stability results

## 4.9 Electric Drive System

The electric propulsion system of the ferry has been designed in compliance with the requirements of environmental sustainability and operational efficiency. In this section, the elements of the electric propulsion system, the energy consumption patterns, the battery types, and the charging methods are analyzed in detail.

In fully electric marine vessels, the process of scientific and reliable battery capacity sizing involves the creation of an Electrical Load Analysis (Load Balance) Table. This process involves identifying the power demand of all electrical consumers on board vessels under different operating conditions. It involves analyzing whether certain systems are continuously operating or intermittently operating during cruising, maneuvering, stay in port, and night operation, and applying diversity factors accordingly to calculate the total instantaneous power demand. Table 8. presents a summary of all consumer systems of the 37-meter double-ended ferry and their estimated active power consumption in kW under different operating regimes.

**Table 8:** Electric load balance table

| System Description | Quantity | Unit Power (kW) | Normal Sailing (kW) | Maneuvering (kW) | Harbour / Charging (kW) | Night Anchorage (kW) |
|---|---|---|---|---|---|---|
| **Main Propulsion System** | | | | | | |
| Azimuth Thruster Motors | 2 | 400 | 320 | 160 | 25 | 0 |
| Deck Equipment | | | | | | |
| Fore/Aft Anchor Windlasses & Winches | 4 | 5 | 0 | 15 | 5 | 0 |
| Passenger Embarkation Ramps | 2 | 3 | 0 | 0 | 6 | 0 |
| **Engine Room and Auxiliaries** | | | | | | |
| Battery Liquid Cooling Pumps | 2 | 15 | 15 | 15 | 30 | 5 |
| Engine Room Ventilation Fans | 2 | 5 | 8 | 8 | 5 | 0 |
| Bilge and Fire Pumps | 2 | 10 | 0 | 5 | 0 | 0 |
| **Hotel Load** | | | | | | |
| Passenger Lounge Air | 2 | 25 | 35 | 35 | 35 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Conditioning (HVAC) | | | | | | |
| General Indoor and Outdoor Lighting | 1 | 10 | 5 | 5 | 5 | 2 |
| Navigation, Communication & Automation | 1 | 5 | 5 | 5 | 5 | 1 |
| Total Concurrent Power Demand | | | 388 | 248 | 116 | 13 |

As can be seen from the load analysis table, the "hotel load" due to the operation of other equipment on the vessel, excluding the propulsion motors, forms a considerable portion of the total load, mainly due to the air-conditioning systems designed to provide maximum passenger comfort. Instead of running the propulsion motor continuously at 100% Maximum Continuous Rating (MCR) to maintain an economical speed in Bosphorus conditions, it was assumed that the vessel would operate at an average load of 80% (320 kW) to maintain an economical speed in Bosphorus conditions. During berthing and station-keeping, the propulsion motor would be expected to draw approximately 25 kW at low speed.

### 4.10 Determining the Operation Profile and Time Allocation

To transform the load balance data into an effective model for the energy consumption (kWh), the voyage-based and daily operational profile for the Bebek-Kücuksu route was determined in minutes. Based on observations and simulations, the total block time for the standard one-way voyage was determined to be 19 minutes. Of this total time, 4 minutes is spent in port mode to ensure the safety of passengers during disembarkation and boarding. Thanks to the double-ended feature, berthing and departure times have been minimized to 7 minutes, which can be referred to as the maneuvering regime. The remaining 8 minutes can be referred to as the normal cruising regime. Therefore, the vessel operates normally for approximately 42%, operates in the maneuvering regime for approximately 37%, and operates in port mode for approximately 21%. The above operational profile is highly suitable for electric propulsion systems, which can operate at low speeds and eliminate the idle losses occurring in diesel-based systems.

### 4.11 Carbon Emission Analysis

One of the most important additional values of the developed 37-meter double-ended fully electric-powered passenger ferry vessel concept is the environmental benefits that this vessel would provide to the ecosystem of the Istanbul Strait, which is an environmentally sensitive and populated waterway. To understand this, the emissions of a hypothetical vessel using diesel power with the same power and acceleration characteristics were analyzed to compare the results. According to the load analyses provided in Section 4.8, the annual total energy demand of the vessel on the route from Bebek to Küçüksu was calculated to be around 1.43 GWh. Based on a specified SFOC value of 210 g/kWh for a modern marine diesel engine, it is estimated that the annual fuel consumption would be approximately 300 tons.

With the use of a specified conversion factor for fuel-to-carbon emissions, it is calculated that the annual emissions of carbon dioxide would be approximately 960 tons of $CO_2$. In contrast, the concept of a fully electric ferry eliminates tank-to-wake carbon emissions through the use of renewable energy for shore-charging. In addition, emissions of nitrogen oxides ($NO_x$), sulfur oxides ($SO_x$), and particulate matter (PM) would be entirely eliminated.

## 5. RESULTS AND DISCUSSION

Moreover, the conceptual design of the 37-meter double-ended electric passenger ferry designed in the scope of the present thesis study has shown the potential of the proposed design to provide a sustainable, efficient, and innovative solution to the existing transportation problem in the short-distance ring routes characterized by high passenger traffic, such as the Küçüksu-Bebek route in the Bosphorus. The feasibility of the proposed design has been shown in the following sections of the present study. Moreover, the feasibility of the proposed design has been shown in the following sections of the present study.

This section will discuss the main findings of the design, the results obtained from the design, and the significance of the results for the maritime sector.

## 5.1 Design Speed-Power Requirements and Hydrodynamic Resistance Analysis

Numerical resistance analyses were carried out to assess the hydrodynamic performance of the three-dimensional hull form, which provided the basis to scientifically calculate the required capacity of the electric motor to be used. Calculations based on the theory of ship resistance and propulsion have shown that the frictional, wave-making, and aerodynamic resistances must be overcome at the desired service speed. By using the effective power results of the $P_e$ component combined with the interaction parameters of wake fraction and thrust deduction, it was found that the most efficient way of fulfilling the power requirements is to use a 400 kW azimuth propulsion motor, where the full power demand is only provided by the aft motor that acts as the pusher, while the forward motor is kept free-running to provide the least possible hydrodynamic drag.

## 5.2 Ship Technical Specifications, Capacities and Electric Propulsion System Integration

All hydrodynamic and form optimization results obtained in this study finalized the vessel's technical characteristics, internal volume distribution, and electro-mechanical architecture. Contrary to conventional vessel designs, large fossil fuel tanks were not required. Only space for freshwater, grey/black water, and essential emergency systems was allocated, thus maximizing vessel's useful displacement. With the detailed electrical load balance and operational profile for the Bebek–Küçüksu route at 19 minutes, a marine-grade lithium nickel manganese cobalt battery system with a capacity of 450 kWh (usable capacity of 350 kWh) cooled via a liquid cooling system was selected. With the opportunity charging method, this system is proven to prevent the emission of 960 tons of CO2 annually while reducing operational energy expenses.

## 5.3 Environmental Impact and Sustainability

The installation of an electric propulsion system is the most significant environmental advantage of the project. The operation of the ferry will have zero exhaust emissions of carbon dioxide, nitrogen oxides, sulfur oxides, and suspended particulate matter. This will have a positive impact on the quality of the Bosphorus's air. This is considered a critical advantage,

particularly for the pier area or densely populated areas. The reduction of air pollution from conventional diesel engines will contribute to the reduction of diseases in the population. Furthermore, the silent running of the electric motor will minimize underwater noise pollution. This will have fewer negative effects on the marine life in the Bosphorus (fish, dolphins, etc.). This is of paramount importance for the protection of the marine ecosystem.

For the sake of discussion, the environmental footprint of battery production and recycling is another factor to be taken into consideration while assessing the sustainability of the entire project. With the evolution of battery technologies and advancements in recycling techniques, the environmental footprint of battery recycling can be minimized. It is evident that the project contributes to the mitigation of the carbon footprint of Istanbul.

## 6. CONCLUSIONS

In the Istanbul Metropolitan Area, where population density and urban mobility are constantly increasing, replacing old and traditional ferries with modern, efficient, and environmentally friendly platforms using the latest engineering practices in the field is a historical and ecological necessity. In this graduation project, a 37-meter-long double-ended fully electric-powered passenger ship design is developed for the Küçüksü-Bebek route, in accordance with the basic principles of the Naval Architecture and Marine Engineering discipline, as proposed in the literature as a holistic concept to overcome operational challenges during transit routes passing through the Bosphorus. With its optimized propulsion power of 400 kW and 450 kWh capacity battery system with fast charging times, this design reduces operating costs significantly, especially in comparison to traditional fuel-powered alternatives, in terms of energy costs related to ship operation.

The double-ended symmetrical hull form of the ferry, along with the integrated azimuthing propulsion systems, will allow for superior maneuverability as well as efficient operation in the special environment of the narrow waterway of the Istanbul Bosphorus. This design approach will allow for the minimization of the time losses as well as the energy consumption usually incurred during pier maneuvers for conventional single-ended vessels. This will provide the potential for increasing the transport capacity of the route. Hydrodynamic analyses have confirmed the efficient operation of the vessel in both directions. The vessel will be able to operate safely even in adverse conditions due to the dynamic positioning capability. This is of vital importance for the provision of uninterrupted rapid transport services, particularly during peak passenger hours.

From the environmental point of view, the use of the fully electric propulsion system is the most significant outcome of the project. The exhaust emissions-free operation of the ferry will result in a significant improvement in the quality of the environment of the special ecosystem of the waterway of the Istanbul Bosphorus. This is perfectly in line with all the global environmental agreements made worldwide, including the United Nations Sustainable Development Goals and the Paris Agreement. Moreover, the quiet running of the electric motor will minimize noise pollution in the water, thus ensuring that the marine life is not harmed in any way. This is a clear demonstration of the fact that the project is not only a technological success but a strategic investment in the betterment of society as a whole. The environmental assessment carried out in the study is a clear demonstration of the potential of the proposed vessel to contribute to the global decarbonization goals of the maritime industry as set out by the International Maritime Organization. It is estimated that the vessel will save 960 tons of carbon dioxide from being released into the atmosphere every year through the use of the electric motor. This is quite significant since no particles or sulfur dioxide will be emitted.

With the complete elimination of the use of fossil fuels and the lower maintenance cost of electric motors, there are considerable cost savings on operational expenditure (OPEX). With these cost savings, the project is able to amortize itself within a certain period and has a lower cost of ownership during its operation compared to conventional vessels, making it an attractive model for investment for the public and private sectors.

In conclusion, it is safe to say that the conceptual design of the 37-meter double-ended electric-powered passenger ferry is technically feasible, environmentally friendly, and economically viable for the Küçüksu-Bebek route in the Istanbul Bosphorus. This project can be a major contributor to the modernization of the transportation infrastructure in Istanbul, making it more environmentally friendly and enhancing the passenger experience. It is important to note that future works should include engineering analyses and the construction of a prototype of the conceptual design of the 37-meter double-ended electric-powered passenger ferry. Moreover, it is important to keep an eye on the development of new battery technologies and innovations in charging infrastructure to enhance the success of the project. This type of innovative project not only solves transportation problems in the region but also sets the pace for the global maritime industry in terms of electric and autonomous vessels.

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