POLITECNICO DI MILANO

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Study for the electrification of naval transport systems
Case study: Venice naval taxis

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Ringraziamenti

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千里の道も一歩から
“*Sen ri no michi mo ippo kara*”,
che tradotto diventa
“Anche una strada di mille Ri comincia con un passo”

七転び八起き
“nana korobi ya oki”
Che tradotto diventa
“Cadi sette volte, rialzati otto volte”

Summary

ABSTRACT

This study deals with the electrification of water cabs in Venice, a widely used means of transportation in the lagoon city.

In order to carry out a correct and in-depth analysis, it was necessary to better understand how the cab service is delivered and the very role that it takes on within the city; for this reason, in addition to an in-depth bibliographic analysis, it was necessary to carry out inspections and meetings with the municipal managers of the service, which allowed for a well-detailed and defined picture of how the cab service works. Then, as it is possible to read within the paper, a study on the most requested routes and the actual feasibility of electrification of the cab service was carried out, taking into account the needs and peculiarities of the craft and the city itself.
To do this, several analysis tools were used, leading to estimated results.

This paper proves that, while for shorter routes electrification is feasible in a short period of time, longer routes require technological advancement in terms of batteries.
In addition, in order to ensure continuity of service, a suitable charging infrastructure, both power grid and charging stations, needs to be established to allow vessels to stop quickly and affordably.

1. MARITIME TRANSPORT

1.1 GLOBAL SCENARIO

The maritime sector plays an increasingly important role in the transport economy worldwide. More than 80-90 %of global trade by volume and 70 % by value is carried out by ship, and these values are always increasing.
With regard to the transport of people, the trend is similar: according to the 2017 estimates the maximum growth index was 2.2% [1] with about 24 million people choosing to move by sea. However, the number is now increasing, reaching 30 million people who in 2024 will opt for this transport system.

The COVID-19 pandemic has had a major impact on the maritime trade sector as well: in 2020, global production registered a 3.5% decrease, and merchandise trade declined by 5.4% resulting in sea shipments dropping by 3.8%, with 10.65 billion tons of goods traded. [2]
Although the short-term trend is very optimistic and upward, the long-term consequences are yet to be estimated; while the growth index in 2021 recorded a 4.3% recovery in global trade and a 2.4 percent increase in commodity volume, factors such as rising transportation costs, disrupted supply chains, and changing global trading partners make the long-term outlook unclear. In addition, the current geopolitical situation makes estimates of a global economy severely affected by price increases in oil, food, and energy supplies difficult. [3]

In this scenario, one-third of international trade occurs among countries with a developed economy, a second third takes place among these countries and countries with a less developed economy, and the last third takes place among economically less advanced countries.
The most important route in the global market, with 25 million containers traded in 2019, is the transpacific route between East Asia, which takes on the role of the world's largest exporter, and North America, which is instead the world's largest importing country. The second route is the Eurasian one, with about 23 million containers moved, with a flow coming mostly from Asian countries, and, finally, the trans-Atlantic route, between Europe and North America with 7.4 million containers exchanged. [4]

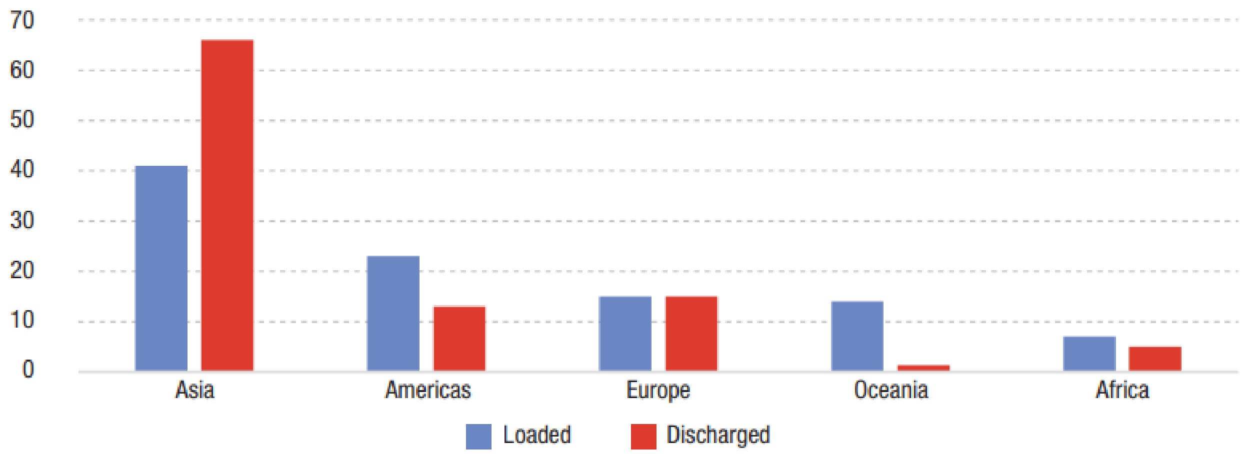

Fig. 1.1 - International maritime trade in percentage, 2020. [1]

Fig 1.1 shows the percentages of goods traded in tons. As can be seen, Asia monopolizes both the inbound and outbound markets, with a substantial dominance in world exports.

The impact of this growing trend can be approached from two different points of view, one global and one local; on a large scale, the effects of emissions are concentrated during navigation, while on a local scale the emissions are focused on port maneuvering. [5]
In this chapter, the attention will be focused on a large international and continental scale, while in the next chapters the focus will be directly on the city of Venice, the scenario of our study.

1.1.1 GLOBAL ENVIRONMENTAL IMPACT

Gas emissions caused primarily using fossil fuels from waterborne vehicles cause only 2.89% of the global greenhouse gas (GHG) emissions, according to the report of the International Maritime Organization (IMO) [6].
The largest source of GHG emissions in maritime transport is caused by large ships making longer journeys, both internationally and intercontinentally, and the amount of these emissions depends in part on imported fuels, of which 72 % is HFO (Heavy Fuel Oil), 26% is MDO (Marine Diesel), and the last 2% is LNG (Liquefied Natural Gas).
Although LNG is found to have a more efficient energy performance and to lead to lower GHG emissions than HFO and MDO, disadvantages such as handling and difficulty in storing methane have made this solution less attractive as a fuel. However, a study comparing LNG and HFO shows that LNG can reduce SOx, NOx, and CO2 emissions by 98%, 86%, and 11% respectively. [7]

As said before, international maritime traffic is the largest contributor of CO2 emissions, if not virtually the only contributor as seen in the following table.

Year	Global anthropogenic CO_2 emissions	Total shipping CO^2	Total shipping as a percentage of global	Voyage-based International shipping CO_2	Voyage-based International shipping as a percentage of global	Vessel-based International shipping CO_2	Vessel-based International shipping as a percentage of global
2012	34,793	962	2.76%	701	2.01%	848	2.44%
2013	34,959	957	2.74%	684	1.96%	837	2.39%
2014	35,225	964	2.74%	681	1.93%	846	2.37%
2015	35,239	991	2.81%	700	1.99%	859	2.44%
2016	35,380	1,026	2.90%	727	2.05%	894	2.53%
2017	35,810	1,064	2.97%	746	2.08%	929	2.59%
2018	36,573	1,056	2.89%	740	2.02%	919	2.51%

Fig. 1.2 - Total voyage-based and vessel-based international shipping CO2 emissions 2012-2018 (million tons). [6]

In addition, the same report shows that forecasts through 2050 have several scenarios in which the sector's emissions could increase moderately or remain about constant:

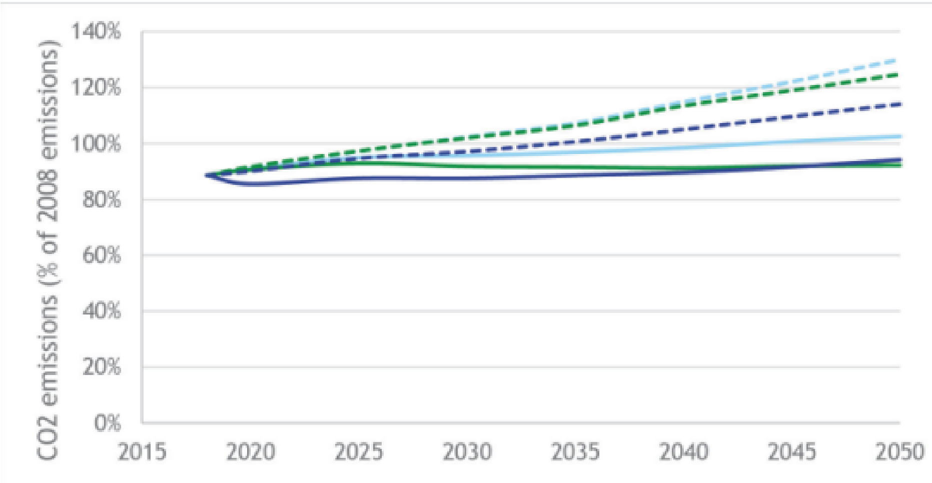

Fig. 1.3 - Marine vessel emissions projections as a percentage of 2008 emissions. [6]

Carbon dioxide CO_2, various ozone precursors, nitrogen oxides NO_x, and sulfur oxides SO_x[1] are the main substances introduced into the atmosphere by the various vessels, and a 2008 study [8] found the parameter "Global Temperature Change Potential" (GTP), which quantifies the effect of these substances on global temperature increase, to be close to zero over the next 50 years, due to the cancellation of the warming action of carbon dioxide and the cooling action of sulfur and nitrogen oxides. In the study, it is stated that the cooling effect has so far significantly exceeded the warming effect, but the gases with a cooling effect remain in the atmosphere for a shorter time than CO2, and it is possible, with a high margin of uncertainty, that this trend will be reversed with the decrease of the latter, rightly implemented given their extremely harmful impact on people's health (data found at national level but with a trend presumably comparable with the rest of the world).

One of the most important and well-known consequences of GHG is the global warming caused by CO2, which accounts for about 30% of the total effect, and which, being the most damaging greenhouse gas, contributes to increasing the atmospheric temperature; in fact, it is estimated that between 2007-2012, global shipping consumed an average of about 250 million to 325 million tons of fuel per year, resulting in about 740 to 795 million tons of CO2 emissions. [9]

The global shipping industry is making many changes to the fuel oil (FOC) to be used in terms of environmental sustainability. In fact, from 1st January 2020 the IMO has stipulated a MARPOL treaty in which it will be required that all fuels used in ships do not contain more than 0.5% sulfur in order to prevent pollution from ships [10]

The goal of this treaty is a significant reduction in the presence of sulfur from 3.5 percent to 2.5 percent.
Accordingly, any FOC that does not comply with the new regulations is prohibited.
The only exception to these regulations is the presence of an exhaust gas cleaning system called scrubber that allows for a reduction in the sulfur emission limit.

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[1] Substances that contribute to increased O_3 formation in the atmosphere.

According to a study conducted by the IMO's Marine Environment Protection Committee (MEPC) in 2016, it is estimated that failure to reduce the limit of sulfur SOx emitted by ships starting in 2020 would contribute to approximately 570,000 deaths worldwide between 2020-2025.
Also, to reduce GHGs, the United Nations (UN) agency has agreed to cut carbon emissions from the shipping sector by at least 50% below 2008 levels by the year 2050.

In addition to substantially reducing pollution problems, the agreement is expected to attract investment in green ship technologies, including fuel cells, biofuels, and advanced sail design.
In this investment perspective, the path of electricity and renewable resources is becoming increasingly popular; in fact, the latest innovations in the naval sector aim at the installation of electric motors powered by photovoltaic panels on board or energy generators to reduce consumption, as they consume lighter fuels. [9]

Following this vision, in addition to the technological advancement that represents an important turning point in the maritime industry that would allow to upgrade and improve performance and reduce pollutants, possible solutions to eliminate or reduce air emissions, as previously described, are the use of alternative marine fuels and the electrification of propulsion, as it is already happening in other transport sectors, introducing ships both with hybrid propulsion or, implementing the complete transformation, with the use of full-electric vessels.

In recent years, the technological advancement in the naval field has allowed a significant reduction of emissions with several innovations such as IEM (internal engine modification), exhaust gas recirculation (EGR), systems for the recovery of heat generated to use like heating, and the above-mentioned sulfur scrubber; however, the installation and use of these new inventions have a considerable weight both in operations and installation costs and in the maintenance of the ship.
Although technological advancement has reduced emissions by creating increasingly low environmental impact solutions, the solution that can have the greatest positive impact in this direction may be the change of propulsion, transitioning from diesel fuels to electric or hybrid propulsion.

1.1.2 HYBRID PROPULSION IN THE NAVAL SECTOR

The most important technological advances in terms of more sustainable transport come from the use of electric propulsion. Although wheeled transport has long since adopted this type of operation, the naval sector still has many steps to take [7]; the difficult sailing conditions they can face, the long distances, and the lack of such an efficient energy storage system make the total conversion to electric propulsion more difficult.

On the other hand, the adoption of a hybrid system has been experimented with for a long time also in this sector with the use of both batteries and fuel cells; in fact, the hybridization of ships allows for a significant reduction in emissions, with data showing a reduction of 2-45 percent of CO_2 and consumption, with a saving of 3 percent, of the vessels and allows to have optimal performance in all weather conditions. [7]

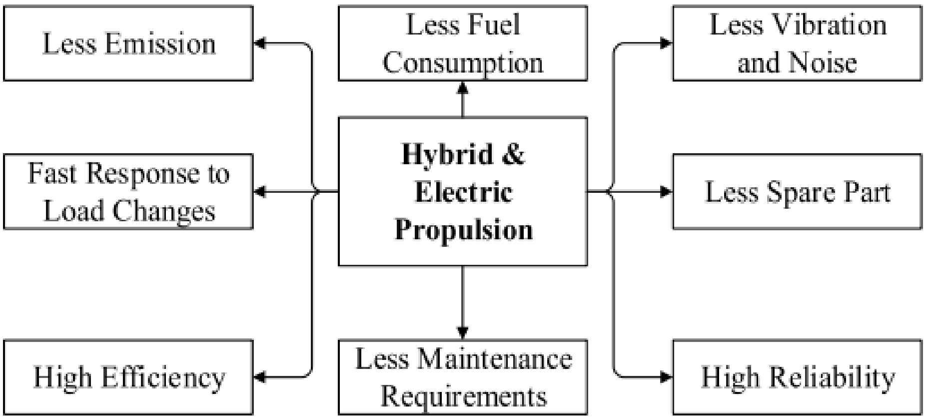

Fig. 1.4 - Advantages of hybrid and electric propulsion. [7]

In the hybrid configuration, the distribution of energy is mainly done using electrical systems that allow different configurations based on the confirmation of the system and the mode of delivery of electricity to the ship's propeller.
Before going into the details of the different configuration modes, it is necessary to specify that now, the marine sector uses a fixed frequency alternating current electrical system, however, the development and technological innovation in the field of electronics allows the introduction of direct current systems.

Generally, hybrid power is obtained from the combination of different energy sources, such as renewable sources, and energy storage systems, such as batteries, supercapacitors, and fuel cells, allowing for a diversity of choice in the manufacture of the vehicle, based on both the navigation and energy needs of the boat itself.

1.1.2.1 HYBRID CONFIGURATIONS AND ADVANTAGES

As previously specified, the diversity of hybridization typologies allows making the most of this technology, and creating a system that is suitable for each different type of boats and for the purpose for which they are built.

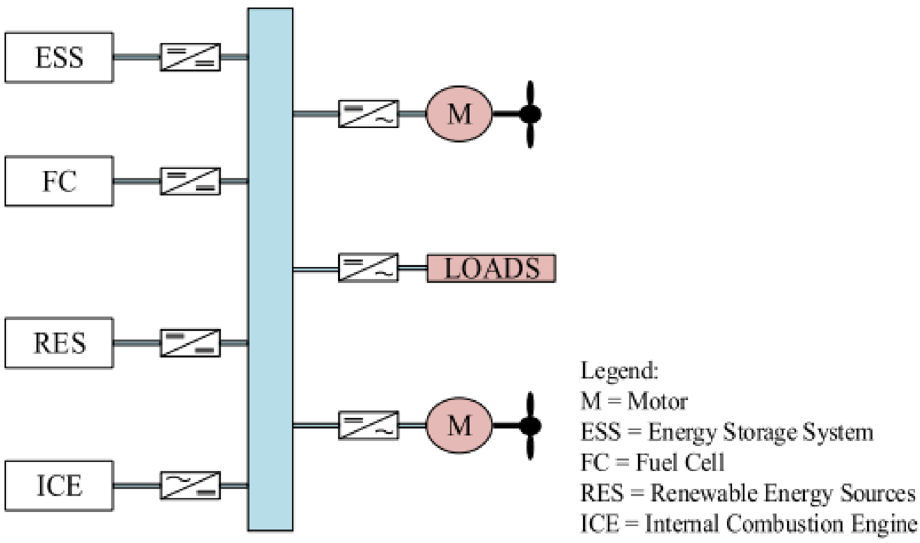

Fig. 1.5 - Series configuration of the hybrid boat.

The first type of hybrid configuration is the series type, in which both the propulsion system of the boat, or the electricity generators, such as fuel cells (FC) or renewable energy sources (RES), and the propulsion with engines ICE, generally diesel, and the various sources of energy storage (ESS), such as batteries or supercapacitors, are connected, through suitable converters, to the vehicle's electrical network, as shown in Fig.1.5.
The electric propulsion systems are connected to a DC busbar together with the ICE propulsion, the generated energy of which is first converted by a dedicated AC / DC converter. The energy present in the busbar subsequently feeds two motors into alternating current, converting the generated current back into AC, which feeds the boat's propellers.
In addition, the electricity generated goes to power the various loads of the ship, such as the air conditioning systems, the electrical navigation systems, and the general electrical network used for the needs of the crew.

As can be deduced, it is possible to have different combinations of production and accumulation of the energy necessary for propulsion that allows a variable and specific design for the different types of ships, which is why they have made it into a type that has been widely used for a long time.
The main advantage is due precisely to the different choices of operating modes; since the total electrical energy of the system converges and is distributed by a common bar, it is possible to use more working modes, choosing to power the propellers with different modes that will be explained later, allowing for greater versatility.
On the other hand, the energy generated by the various electrical systems, such as ESS, FC, or RES, allows the ICE system to operate in their highly efficient operating area, allowing for lower consumption and higher performance [7]

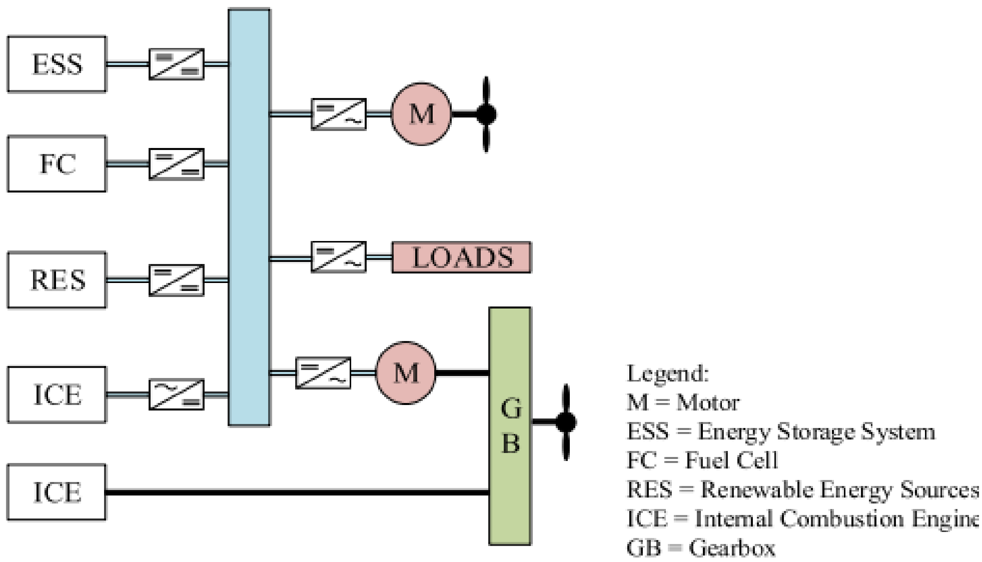

Fig.1.6. - The parallel configuration of the hybrid boat.

The second configuration is the parallel one which differs from the series in that there is a direct connection between the ICE and the propellers, as shown in Fig.1.6.

The generation and storage of the electrical part remain compared to the previous configuration while there are some structural differences on the load and propulsion side. Consequently, the presence of an electric motor, withthe respective sources of energy storage, allows to improve performance and provide part of the necessary power, reducing the load of the ICE with the consequent decrease in consumption and emissions from the boat.

The advantage of this mode of propulsion is the presence of double propulsion, electric and thermal, with the respective advantages. It is possible, in case of need such as blue port areas, to navigate with the electric motor only or, on the contrary, with a thermal motor only, saving fuel and avoiding emissions; furthermore, precisely this different possibilities of navigation make it possible to design the propulsion system differently, choosing, according to one's navigation needs, loads and generators of different sizes, reducing the installed power of the ICE in favor of the electric motor or vice versa.
If, instead, as is now well known from what has been previously said, the boat is powered by a double propulsion system, it is possible to work with high efficiency and low consumption. [7]

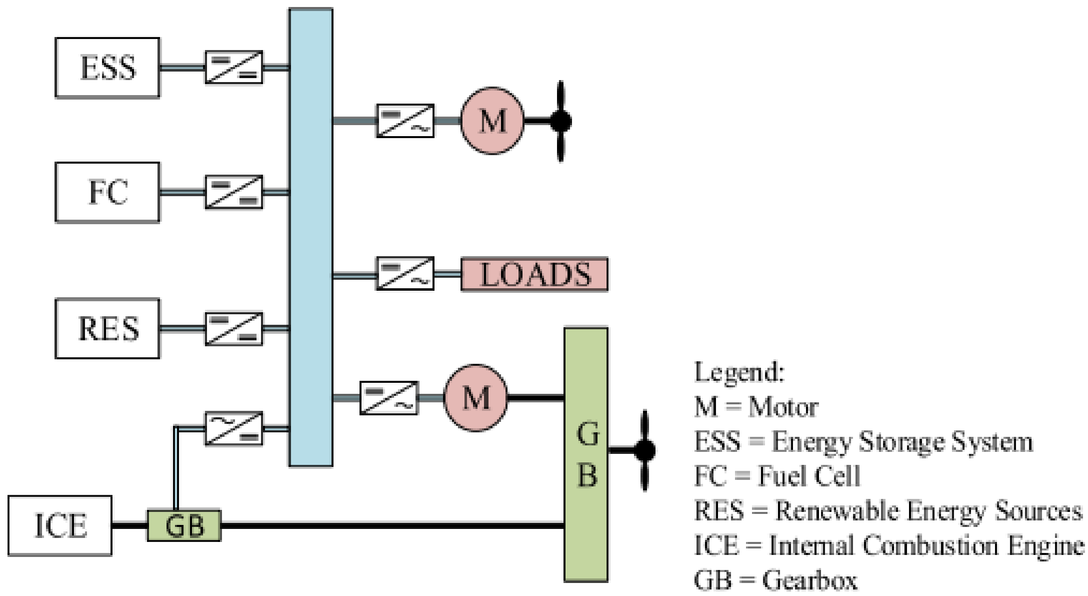

Fig. 1.7 - series-parallel configuration of the hybrid boat.

The third, and last, type of hybrid configuration is a combination of the previous two, the series-parallel system, which combines the characteristics and advantages of each, such as offering different operating modes that use more flexible energy flow controls and optimize energy consumption.
Like the parallel one, this configuration allows to operate in different modes, such as with the aid of the ICE only , with the electric motor only, or with a hybrid system of the two, both in series mode and in parallel mode.
Although in configurations it resembles the parallel one, there is a mechanical connection between the electric busbar and the ICE system, through a suitable transmission, which reduces the power input to the propeller, as can be seen in figure 1.7., making it a more complex system than the previous ones.

For greater understanding and clarity, you can see each configuration's benefits and challenges in the following table. Each type has its pros and cons and, for this reason, when designing the boat model to be built, differences must be considered to obtain the right propulsion. [7]

Architecture	Benefits	Challenges
Serial Configuration	• Relatively long operational life • Mature technology, precise control • Engine downsizing and modular system • Zero noise and emission availability • Less fuel consumption and emission	• Multiple energy conversion • Loss of energy during conversions and relatively lesser efficiency • Only electrical propulsion is available
Parallel Configuration	• Zero-emission operation availability • Both mechanical and electrical propulsion availability • ICE can operate at a higher efficiency zone and reduced fuel consumption • Sizing optimization available • Reduced electrical chain and motor size	• Complex propulsion • Power and torque repartition rules • Additional mechanical links • Hard dynamic switching according to operational need • Need of robust control for higher efficiency
Serial-Parallel Configuration	• Relatively flexible control • Increase of DOF in operation modes • Zero-emission operation option • Higher efficiency at lower loads and higher loads • Both mechanical and electrical propulsion availability	• Complex system architecture • Higher cost • Same challenges as for the serial configuration

Fig. 1.8 - Comparison table of three different hybrid configurations.

The hybrid propulsion system implemented in boats has another two possible subdivisions: the first is a direct motorized propeller and an electric motorized propeller, which have different advantages and disadvantages and have two different types of operation and two different applications that also depend on the boat itself.

Although they have different uses, both modes contribute to improving energy efficiency and safety as, for example, an alternative to propulsion in emergency conditions or breakdowns. As previously explained the hybrid propulsion is obtained by combining the direct drive of each propeller by the thermal engine and the electric one separately as can be seen in the following figure Fig 1.9a, while more complex and advanced systems can be created that combine the power and transmitting it to the propeller in a combined way, as in Fig 1.9. [11]

One of the advantages of this mode of propulsion is the diversity of conduction of the vehicle in general: according to the type of vehicle manufacture and the driving need, it is possible to have three different options for supplying electrical power:

-the first option consists of a “full electric” and can be used in some maneuvers, such as docking, in which, if sufficiently available, energy can be carried out without emissions and great fuel consumption, or it can be used during navigation in case of failure of the ICE heat engine.

-the second mode is combined propulsion, or boost mode, in which the electric motors are activated to have more power available to obtain more speed or more power available in case of adverse navigation. In this case, the use of the heat engine is limited to a specific interval and can only be used if the ship's energy reserves allow it.

- the third mode is the combined one, in which the use of the electric motor is coordinated with the thermal one during the entire navigation. In this case, we will have a division of the propellers that are powered by the two engines separately as in Fig 1.9b, optimizing consumption and performance, as in a normal vehicle. [12]

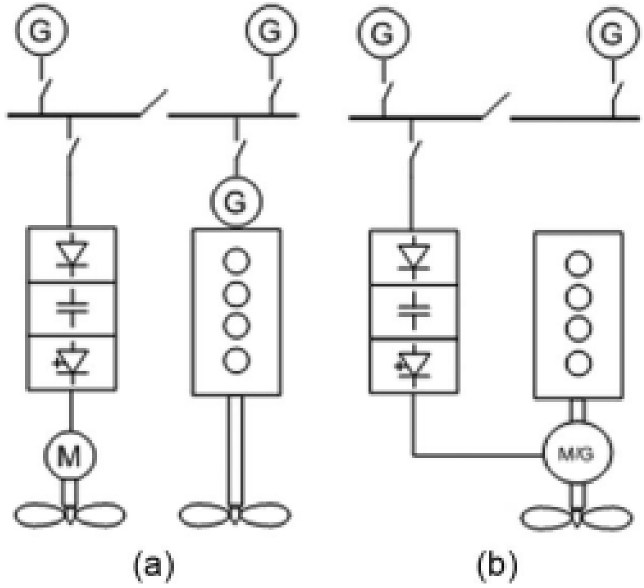

Fig. 1.9 - Different choices of Hybrid solutions.

However, the installation of a hybrid engine on boats certainly brings benefits to propulsion, but it lacks the advantages that are highlighted in other applications on-road vehicles; in fact, for wheeled vehicles we have a Power Take In and Poker Take Out management, due to a supply of energy during the march and recovery during the moments of braking, in the case of boats this value is less because the maneuvers ports are carried out not by braking the vehicle, but by activating the motors to counteract the slippery motion of the boat itself on the water, consuming and using large quantities of power and fuel.

1.1.3 RENEWABLE ENERGY SOURCES

One of the points in favor of the use of hybrid propulsion is the design and installation of renewable energy sources (RES) that allow producing energy during navigation, such as solar energy, wind energy, wave energy, and biofuels, as it is possible to see in Fig. 1.10.

The use of solar energy is a very advantageous solution considering the auxiliary power requirement of the ship. however, considering the driving system, the output power is very limited as the solar energy efficiency is not able to satisfy large energy needs. Furthermore, the different conditions of irradiation, latitude, and meteorological conditions do not allow a continuous and safe supply, causing power fluctuations that do not make the power supply stable.
For these reasons, solar energy has a greater need for energy storage systems onboard ships.

Fig. 1.10 - Solar panels installed on a cargo ship.

However, a different speech is about wind energy, which can take different forms to generate auxiliary power during navigation, reducing and optimizing consumption. Wind energy exploits the airflow present which, by turning turbines, produces electrical energy.

Over the years various types of turbines or rotors for energy generation have been invented. One of them was adopted in the early 1900s: the Flettner rotor is a rotor that is placed on the boat and uses the thrust of the wind, which passes through the rotor perpendicularly, to generate electricity, as shown in Fig. 1.11.
The peculiarity of this type of turbine is the possibility of generating energy and operating even at higher wind speeds, since, unlike the usual wind turbines, the rotation is activated by the direction of the wind, not by its speed.
This allows to have remarkable results as evidenced by a study carried out on the E-ship project implemented in 2010 which mounts 4 Flettner rotors together with hybrid propulsion with diesel engines can obtain a fuel saving of 20 percent. [13]

In addition to the solution described above, other equally effective and much better-known applications exploit the wind present such as kites and wing sails, in a similar way to sailing boats, as can be seen in Fig.1.12, thus having the advantage of not taking up space in the structure of the boat.
In this case, however, the presence of constant and intense wind is necessary for the operation of the system, but it can guarantee a saving of 50%, according to the study of R. Leloup et all. [14]

Fig. 1.11 - Flettner rotor installed on E-ship 1 project.

Fig. 1.12 - Kite solution installed on a cargo ship.

1.2 EUROPEAN SCENARIO OF MARITIME TRANSPORT

The global scenario highlights the main problems related to this sector, which, even considering a more local sample, do not change; rather they diversify according different situations both in terms of pollution and in terms of the solutions adopted. In fact, the European scenario is very varied, based on the sensitivity that each country has towards a problem that affects everyone.

Along the European coasts, ship emissions contribute to an important share of air pollution: as far as greenhouse gases are concerned, Europe contributes to about a quarter of the global pollution [15], while pollutants in the air contribute to between 1 and 7 %for PM10, 1 to 14 %for PM2.5, and, finally, 11 %for PM 1 levels; While the incidence of NO2 in the air is wider with a range between 7 and 24%, with peaks in the northern countries such as Denmark and Holland.
To reduce pollution and complete the decarbonization process renewable energy is an important, if not the only, solution for European marine transport, but with significant repercussions on the management of European energy production and needs, which has already been severely tested by both the attempt at decarbonization and the current unstable geopolitical situation.
The complete decarbonization, of the related shipping sector, would require 11-53% of additional renewable electricity generation, by 2050, over the 2015 levels, as is seen in Fig. 1.13. [15]
It is therefore essential and imperative to have a policy, both regulatory and economic, which enables all countries to be able to support change, by making available funds, recently approved by the European Commission, Next Generation EU, and Horizon 2020 funds [16], and also by imposing rigid regulations to avoid conflicts or inconsistencies on the part of member countries, setting objectives that can be pursued by minimizing environmental, energy and economic impacts.

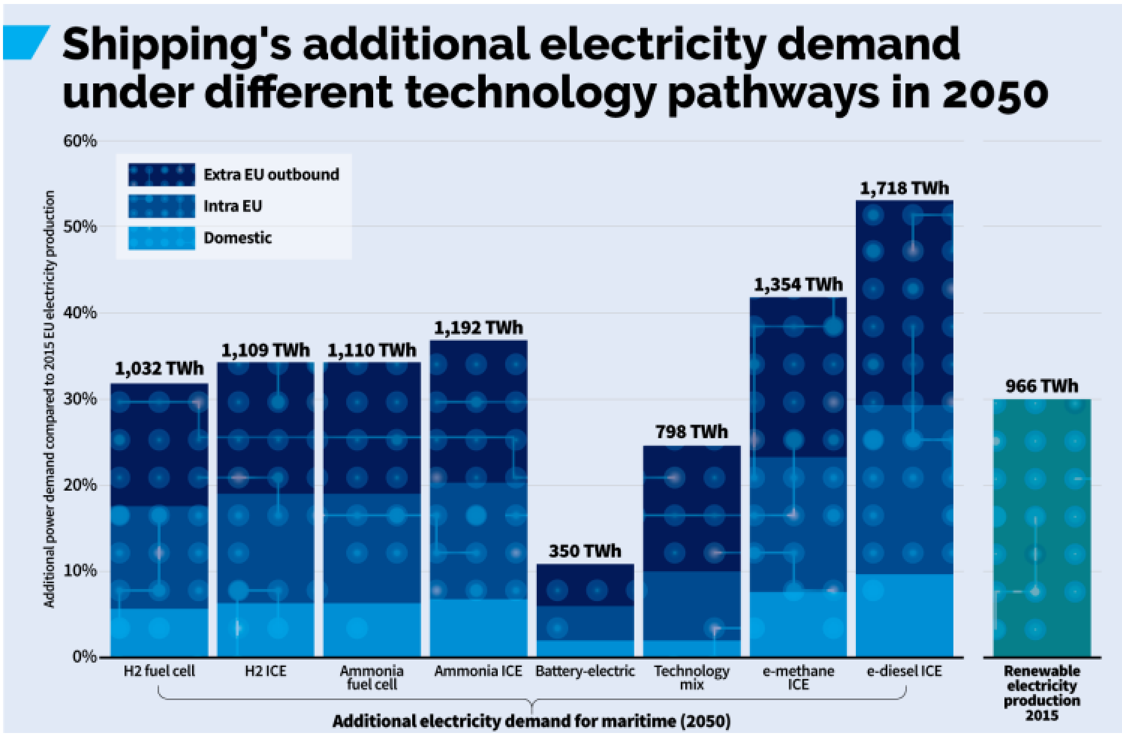

Fig. 1.13 - Shipping's additional electricity demand in 2050.

1.2.1 ALTERNATIVE SOLUTIONS

The transition to the nautical sector, according to the European vision, assumes various aspects and options; although the priority remains the study and improvement of technologies related to the electrification of boats, with multiple investments made to obtain improvements regarding the development of batteries and the production of green energy, solutions related to the development of e- fuels, such as hydrogen and ammonia, appear to be the optimal solution at the moment, due to the difficulties associated with batteries and the low productivity of RES.

Ammonia (NH_3) is a gas at normal temperature and atmospheric pressure which liquefying, -33 °C at atm or 24 ° C at 10 bar, obtains a higher energy density than the carbonated form, and it is an ideal energy vector for a low-carbon term. It is considered an e-fuel because it does not produce CO_2 from combustion, as it does not contain carbon molecules. The products that it generates are nitrogen and water vapor, and it can also be used as a carrier of hydrogen in fuel cells[2]; having 16 times as much the volumetric density that liquid hydrogen has, it contains more than 50 percent of hydrogen ions of the same volume, and the conversion to hydrogen would allow storage of hydrogen at nearly 18% by weight compared to 5% for hydrogen gas under pressure.
An important point in favor of the use of ammonia is its possible conversion into hydrogen through processes that allow its use as a catalyst for combustion, or as a fuel, for the exchange of protons in the membrane of the fuel cell.
The two main drawbacks of ammonia are its low energy density, compared to traditional fuels, and its toxicity. Both shortcomings have hindered the development of ammonia as a fuel for transport systems, especially for small vehicles such as automobiles.
With research and studies on eco-sustainable fuels and new technological advances in the energy field, making ammonia a competitive renewable energy source, also obviating the problems related to its toxicity, adopting a management and a synthesis of the already consolidated matter. [17]

However, the use of this material is more difficult and more complex technology as it requires much more energy, and higher temperatures, to split, incapacitating current fuel cell systems. Furthermore, the fuel cells themselves do not tolerate high concentrations of ammonia which, therefore, must be purified to be used. [15]

Hydrogen, on the other hand, is a fuel that can be obtained either from renewable sources, such as through the electrolysis of water or from solar panels, or from hydrocarbons, which are currently the most used in production, with a moderate impact. at the environmental level. Of course, to define Hydrogen e-fuel, its production must be made using RES to have not any type of environmental pollution. But this will not be discussed in this paper.

The greatest difficulty in using this gas as a fuel is, like any kind of green energy, storage, due to the costs and management of storage technology; in fact, the gaseous hydrogen must be stored at a pressure higher than the atmospheric one and stored in pressure pipes, while the liquid one must be stored only at cryogenic temperatures. [18]
It follows that management costs vary a lot, and the application of this technology is not It follows that management costs vary a lot, and the application of this technology is not recommended for all types of transport given the high flammability of the material.

[2] The industrial process for ammonia synthesis as followed: $N_2+3H_2 \Leftrightarrow 2NH_3$. [18]

Today's applications are related to the naval sector and a few elements on the transport of people on wheels.
However, for large vessels, this problem can be contained even if further technological developments are needed.
Anyway, the best way to store hydrogen is to transform it into liquid form through cryogenic tanks placed at temperatures close to 20 K, as shown in figure 1.14.

The use of this fuel has been the protagonist of technological progress over the years.
In the beginning, its use, in pressurized gaseous form, was limited to just starting the engine but, following problems related to both uncontrolled NOx emissions and loss of power, they led to the development of engines capable of managing high density. The intrinsic power of the liquid form of fuel, with the creation of ICE engines powered by hydrogen, although difficulties have been encountered over time in managing the tanks suitable for maintaining the material in the liquid state. [18]
The latest developments in this field lead to the hybridization of hydrogen propulsion: the hybrid-electric version, placed in series or parallel, offers more advantages by improving efficiency and reducing emissions without the need for special treatments.

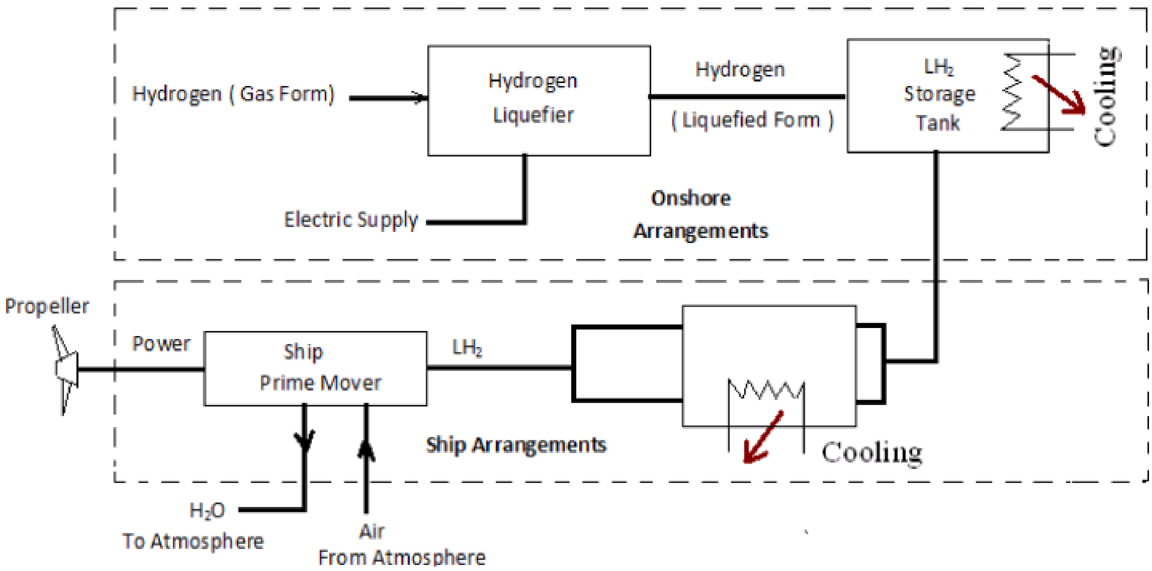

Fig. 1.14 - Hydrogen fuel storage system. [18]

Although the new generation of e-fuels offers ecological solutions that reduce emissions, costs remain very high both in production and indirect application to vehicles. For this reason, electrification is a very advantageous choice also in the naval sector.
it is necessary to specify a priori that the current state of the batteries does not ensure applications on large boats, as discussed so far, while for boats such as private motorboats or public travel the advantages, the object of the study of this thesis, are many and will be further explored in the next chapter.

Battery-powered electric propulsion is the most efficient technological path from an energy point of view, and this is demonstrated by the ever-increasing number of electric boats built and the investments made to encourage and enhance this propulsion system. According to the analysis carried out by T&E (transport and environment), it shows that electric propulsion is more convenient for small boats, such as RO-RO (roll-on / roll-off) routes, or boats used for short-range coastal or lake routes. [15]

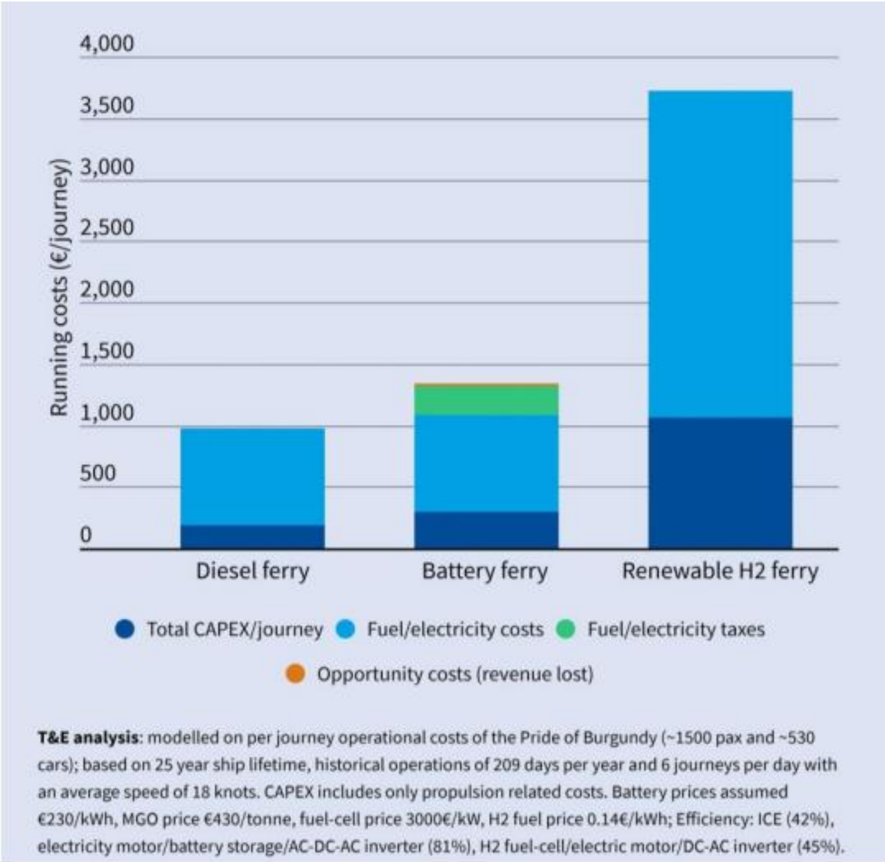

Fig. 1.15 - Comparison of short-range shipping running costs using different propulsion.

Furthermore, as shown in figure 1.16., if we compare the costs of a car using three different types of propulsion, ICE with diesel, electric, and hydrogen, it is possible to see that, under the same conditions, the costs of an electric car are very close to the costs of a diesel ferry, while benefiting from pollution, while the costs for a hydrogen ferry are more than double.

This difference in costs is due to three different factors: the first is due to the high efficiency and efficiency of the electric propulsion, which is 80 percent higher, and consequently, the amount of energy needed to complete the same journeys is significantly lower. compared to the diesel equivalent.
The second factor to consider is the cost of the fuel used; to date, the costs related to liquid hydrogen are very high, on the contrary, the cost of electricity is very low.
Finally, it is necessary to take into account the costs related to energy conversion technology. While electric motors have a well-established technology and economy, combustion cells are still in an evolutionary phase, and consequently, the costs are still very high. Furthermore, the useful life of fuel cells is shorter than that of other types of engines.

Although they are more convenient, electric ships are currently limited by the current technology of batteries that do not allow them to sail great distances and under many adverse conditions, in fact, the boats currently inactivity, as explained above, to cover large distances make use of the " help of the electric motor in case of need and to optimize the trip. However, it must be stated that there are continuous improvements in this area, and it cannot be excluded a priori that in the long run, this may be the propulsion that will have the greatest following, provided that a more efficient and advantageous solution is discovered.

1.2.2 EXAMPLES OF ELECTRIC SHIP

An innovative and interesting application of the technologies seen before is offered by Energy Observer, who built the first zero-emission boat capable of self-generating the energy necessary for operation using multiple renewable resources, such as wind, water, and solar panels, and storing them in batteries or hydrogen tanks.

The wind is used to drive two vertical axis wind turbines for energy production and through a sail for greater thrust and energy savings, while the photovoltaic system, installed along with the entire boat as it's possible to seen in Fig.1.16b, allows the production of both electricity, about 5.6 kW, both of hydrogen during the entire navigation.
The boat is equipped with 8 watertight tanks, positioned in the hulls of the catamaran, capable of both serving as a tank and containing 332L of H2, for an imagined power of 1 MWh and as a balancing tool for the weight of the boat, which proved to be the biggest problem at the design stage.
Onboard there are two storage systems, the batteries, for the electrical part, and the tanks for the hydrogen part.
The co-management of these two resources is decisive in the design phase due to the important forces involved: in fact, the 112kWh battery set weighs about 1400 kg, while the tanks and fuel cells used for the use of hydrogen weigh 1700 kg on the balance of the boat but can offer 1000 kWh. In total, the boat has a power/weight ratio of approximately 1kWh every 12.5 kg for the electric and 1.7 kg for the hydrogen. [19]

Fig. 1.16 a) external view of Energy Observer, zero-emissions vessel.

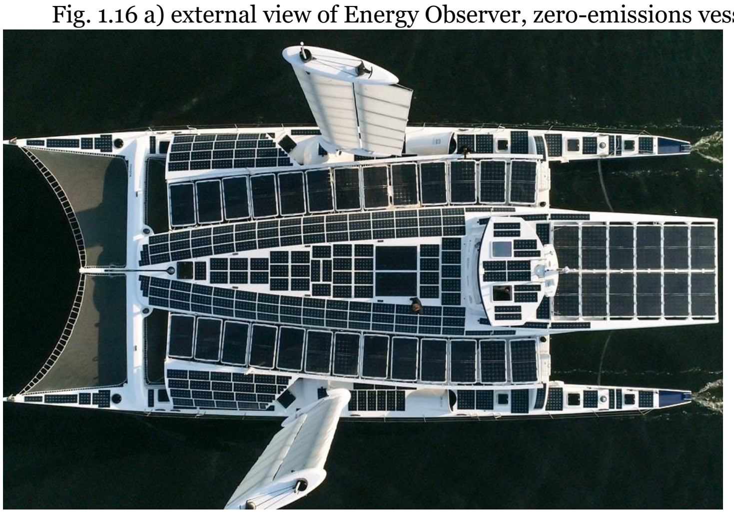

Fig. 1.16 b) photovoltaic installation along the vessel.

In support of what has been said so far, in Europe, it is already possible to find electric ships used for the transport of people, in particular, the examples below are boats built in the Nordic countries, known for their sensitivity to the environment and at the forefront of technology.

The first example of a boat is a scenic boat called Future of the Fjords, built-in 2018 by a Norwegian company and used to transport passengers along the fjords, a UNESCO World Heritage Site and a popular stop for tourists every year.[3]

Fig. 1.17 - Future of the Fjords, first full-electric vessel.

The catamaran, 40 meters by 15 meters wide and capable of carrying up to 400 tourists along the Norwegian fjords, was built with special lightweight materials, such as carbon fiber, to reduce consumption and optimize weight by reducing about 50 percent of the weight that would be obtained with the use of classic materials, this allows designers to choose batteries of lower capacity, always in favor of optimization, and to use lower powers by reducing consumption by installing propulsion loads on the starboard side[4].
a system consisting of two electric motors capable of supplying 450kW of power to a Servogear propeller system was chosen as the propulsion system created specifically for the boat, which gives the boat the right maneuverability and optimal management of the power generated by the installed batteries, allowing navigation at speeds close to 16 6 knots for 30 nautical miles. [20]

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[3] For this boat, which supports the previous model in service since 2016, about 17 million dollars have been invested, 60% more than its predecessor, but in support of the design there have been huge funding from the Norwegian government by donating more than 10 percent of the expenses incurred.

[4] Definition of starboard side: “in the marina, indicates the right side of the ship or boat in general, with respect to those looking towards the bow, and everything on that side”. [48]

There has also been a careful and accurate study both on the design and on the installed technology; the profile of the catamaran was designed to decrease the profile in favor of the aerodynamics of the boat and to reduce the wave motion generated by the boat in order not to negatively impact the rocky shores of the fjords, allowing passengers to have a wide view of the surrounding landscape. Additional care has been used in the interiors that transmit relaxation and tranquility, even to passengers who are not at ease sailing the waves, offering also a technological contribution with digital services available to all.

To complete the picture of the excellent work carried out, a charging station was installed at the docking point of the ship, capable of recharging the batteries in 20 minutes, delivering power of about 800kWh, currently one of the highest powers on the market of charging systems for an electric vehicle.

The second example that shows the goodness of electrification is the E-ferry, a fully electric ferry that promotes the efficiency of electric transport on the water with zero GHG and Co2 emissions, which is in use in the waters of the Baltic Sea.
The objective of this project is precisely to show that the application of a medium-sized full-electric ferry has the same capacity and efficiency as a ferry with ICE propulsion, both in terms of power and work done and in terms of service efficiency offered, carrying about 40 cars and about 200 passengers.
This boat can complete stretches of more than 10 nautical miles crossing the seas at a speed of about 14 knots, thanks to the capacity of the batteries that offer 4 MWh of available energy. Furthermore, unlike other electric boats, they can operate even in ice conditions up to 15 cm thick. [21]

The ferry has installed a DC charging system mounted in the front entrance ramp for cars, which is the optimal solution to reduce the weight of the boat and facilitates charging during the loading and unloading of the cars on board.

Fig. 1.18 - e-ferry render.

2. VENICE

After analyzing the global and European panorama, I will now move onto the scenario of this dissertation, the lagoon city of Venice, the capital of Veneto.
The city, which has more than 250,000 inhabitants, is one of the most important and oldest cities in both Italy and Europe, being both UNESCO heritage and considered one of the capitals of European cinema with the Venice film exhibition that attracts tourists from all over the world thanks to the presence of numerous movie stars who spent those days on the Venetian red carpet.
Although the history of Venice has pre-Roman origins, the importance of the city arose only towards the tenth century thanks to the rise of maritime republics, in which Venice assumed more and more power in the trade routes of the peninsula and the Mediterranean and reached the apex of its power in the thirteenth century.
The city offers its unique cultural landmarks to the thousands of tourists who visit it every year.
Venice is famous for being the city that rises above the waters of the Adriatic Sea with its stilts that serve as foundations for the many buildings in the city, so much so that it is imitated all over the world.
The historic center rises in the middle of the lagoon surrounded by many islets that surround it, with the multitudes of canals and canals that are navigable even today; the most famous is the Grand Canal, which cuts the historic center into two sides, and the Giudecca Canal which separates the city from the island of the same name, today the nerve center of the city's commercial traffic.

Another singular aspect, and a symbol of the city, is the transport system. Since the dawn of the city, every type of movement has been carried out along the canals of the city, with boats that have undergone more and more improvements and innovations over time. Even today a large part of the economy is driven by movements by sea, so much so that the famous and beautiful canals of the city have become very busy, creating many troubles both for movements and for nearby buildings. Today the city is facing the challenge of keeping intact the immense patrimony it bears, both environmental and architectural, looking for solutions to the many problems that arise.
One of the major problems linked to the excessive lagoon traffic is the wave motion generated by the boats that undermine the stability and compactness of the foundations of the buildings, as well as contributes in a negative way to the safety of the navigation of the canals. The source of this problem is to be traced back to both poor and inefficient circulation regulations and too many motorboats that can navigate along the canals. While for the current regulations only the competent bodies can intervene, the problem related to boats can be solved with the application of new technologies.

With a view on improvements and an eco-sustainable transformation in line with European directives, various incentives, and loans of about 1 million euros have been allocated in 2020 alone[5] intended for city residents to encourage the replacement of current thermal engines, both onboard and, outboard, by switching to the electric motor.
Furthermore, the same decree-law makes further funds available to the municipality of Venice for the replacement of the fleet of public transport on the water by adopting the new

[5] of decree-law n ° 34 of 2020, incentives for each resident of age. The contribution can be granted within the limit of the authorized resources and until they are exhausted; it is equal to 60 percent of the expenditure incurred, from 19 May 2020 to 31 December 2020 and cannot exceed the maximum amount of 500 euros. [49]

technologies available on the market, to incentivize and promote environmental protection and promote zero-pollution travel, in a city that according to Istat data is one of the cities with the most polluted air in Italy, seen cap 2.3.1.

In support of these investments already in 2016, with the Legislative Decree, 16 December 2016, No.256, after careful assessments of the need for electricity to the charging infrastructures along with the seaports and inside the city, a plan[6] was approved which aims at the installation and supply of an electricity network along the coasts, with priority on TEN-T areas such as the Giudecca island, to create a charging infrastructure for electric nautical vehicles to comply with environmental constraints.
Chapter 2 of the subsection has precisely as its theme the incentive for the electrification of the quays, stating that the marine transport system contributes, in significant quantities, to the pollution and emission of harmful substances, such as the various PM particulates, and gases. pollutants, such as NO_x, and SO_x, in the air, create both public health and image problems.

The 2016 decree[7], following some European directives in which it was stated that the installation of electric charging infrastructures along the coasts, or along navigable canals, can guarantee a green energy supply also for naval transport, reducing the rate of air pollution and the surrounding environment, as well as solving problems deriving from the noise pollution of ships.
This Directive asked the individual member states to evaluate the possibility of an electricity supply along with the coastal, lagoon, and marine sections, for the naval transport of people, and this installation must be completed by 31 December 2025, giving priority to the TEN-T corridors. And subsequently to the other ports, where electrification can contribute positively to the protection of both the environment and public health and can also bring economic benefits to companies in the sector.
These infrastructures must comply with the technical specifications present in the aforementioned decree and the use of such systems must have a tariff plan with dedicated tariffs, as always established by Article 48, paragraph 7-bis of the Legislative Decree n. 76/2020; for the supply of electricity for the operation of these systems, it provides for a nominal installed power of more than 35 kW, to offer all boats an efficient and quality service to be able to spread the electrical technology to as many areas as possible, to a tariff plan of 0.0005 euro / kWh[8].
Finally, in the last year, further investments have been made by the European Union[9] which, looking to the future, encourages the conversion to electricity, now well underway in the automotive sector, also in the naval sector, believing in the formation of a more eco-sustainable system and having at heart the environment that surrounds it.

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[6] subsection of the National Strategic Framework (QSN) also approved by the law decree 256.

[7] According to the Directive 2014/94 / EU of the European Parliament and of the Council, of 22 October 2014, on the construction of infrastructure for alternative fuels, the so-called" DAFI Directive.

[8] Legislative Decree no. 504/1995 under the heading" Electricity ": for the supply of electricity supplied, from land plants to ships moored in port equipped with electrical systems with rated installed power exceeding 35 kW: € 0.0005 for each kWh

[9] The decree-law n. 59 of 2021, relating to the complementary fund to the National Recovery and Resilience Plan (PNRR), allocated 700 million euros for the electrification of the docks (80 million euros for the year 2021, 150 million euros for the year 2022, 160 million euros for the year 2023, 140 million euros for the year 2024, 160 million euros for the year 2025 and 10 million euros for the year 2026

2.1 TRANSPORT ON LAGOON

One of the peculiarities of Venice is precisely the mode of transport that is used the most, namely the naval transport.
Since the early development of this city, citizens have invested in maritime transport, and, although technology has changed, the Venetians still use public or private boats every day.
Along the canals of the city, it is possible to find different types of boats used for different uses; first, there are the citizens' boats, therefore private boats, often motorized with low displacement engines, necessary for everyday travel. These are often also one of the types of boats that encounter more difficulties in navigating along the canals, which are usually very busy in the city. Another category of boat that can be defined as more fragile and more at risk than other types of boats is precisely one of the symbols of this city, the Venetian gondolas, that number is decreasing more and more in number[10].
The gondola has very ancient origins[11] that are intertwined with the history of the city: In the past, each family had their gondola, with or without a gondolier, in accordance to their social class, as, in order to move along the canals, travelling on water was the quickest choice. Over the centuries this boat has also changed: while the first boats were very short, narrow, and flat, now the model of the boat has been embellished and made iconic, even with very accurate details.

Fig. 2.1 - the iconic gondola along Canal Grande.

Nowadays, the gondola has very specific characteristics[12] and a very particular shape, based on a longitudinal asymmetry, which has a slight deviation of about 24 cm to the right to compensate for the movements due to the rowing style of the gondolier, who performs all the maneuvers with a single oar.

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[10] Just think that in 1500 were more than 10000 and now there are just over 400 boats left.

[11] According to the decree issued by Doge Vitale Falier in 1094, the term “gondola” was official, from the Latin “cymbula”, meaning small boat, to indicate the iconic boat of Venice. [50]

[12] 11m long and 1.42m wide has a height of 1.65m for a total weight of 500kg.

Although the large dimensions suggest a difficult and not very controllable maneuverability, the gondola is very versatile and very agile and fast in maneuvers, even along the narrowest canals of the city.
A further feature of this boat is the immense care taken in its construction, made with more than 280 pieces of precious types of wood, more than 8, which give both resistance and elasticity; each type of wood is used for different purposes due to the intrinsic characteristics that give the result a unique boat of its kind. Lastly, the decorations give a recognizable and precious physiognomy to the boat.

In the next two sub-chapters, the two large categories of public transport present in the city will be described. As later shown, these two categories create greater inconvenience to navigation along the canals of the city and contribute to most of the air pollution.

2.1.2 PUBLIC SERVICE

The most used means of transport in Venice, with 100 million passengers a year, is the Vaporetto, also called the water bus, able to embark about 200 people, that sail along the largest canals of the city or it is used in long-haul transport.
Its large size makes it the vehicle most used by citizens and tourists, also thanks to the reduced costs compared to water taxis, for everyday travel.

Fig. 2.2 -Vaporetto.

To move a boat of a similar size it is necessary to use an engine with a certain power available, even if the navigation is carried out mainly in calm waters, they mount 200 horses; consequently, fuel consumption is high and emissions contribute significantly to air pollution, according to the latest data, 40 percent of emissions are due to this type of movement. As evident to each passenger using this service, most of the emissions it generates occur during the docking and departure maneuvers of the Vaporetto, as the boat requires great power both in moving the large mass and in managing to brake. That, although the regulations and the driver's common sense would lead to gradually braking, causes abrupt maneuvers that drivers make every day as, to avoid hitting the mooring platform in a too conspicuous and risky way, they often brake too close to the dock of the stops creating large black clouds. These black clouds are due to the great efforts made by the

engine to counteract the inertia of the boat[13]. All the pollution that it generates during its countless runs contributes to making the air of Venice very polluted, a matter that next chapter will take in consideration
A further discomfort created by these boats concerns the wave motion generated following the passage of the vaporetti; the wake of water generated creates waves that impact both the buildings that rise along the canals and on small boats present in the canals, putting them in difficulty.

As explained above, most of the activities and travel takes place by the water, and many of the public services are no exception such as waste collection. Being a very important service for city life and as many boats are used to complete this purpose, not combining long journeys, in 2021 hybrid boats were introduced into the fleet of ships that manage the waste collection. [22]
The multi-utility group Veritas, in agreement with a local e-concept start-up, has put into operation two-hybrid waste collection boats and one fully electric.

Fig. 2.3 - First full-electric garbage boat. [23]

The first electric vehicle was designed to be able to carry out the door-to-door service with the right compromise of efficiency and eco-sustainability and the result of this work is a boat that allows you to perform the service in the best possible way while reducing both harmful emissions and reducing noise pollution of the boat; it also optimizes the boat's consumption and performance, allowing garbage collectors to do their work in an optimal and more comfortable environment.
As you can see in Fig.2.3, the boat is includes a space used for the maneuvers of the driver and a part that houses the compactor, and a mechanical arm or mechanical crane, which is always powered by the battery itself and which contribute to approximately the 25 percent of the boat's electricity consumption. [22]

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[13] unlike land vehicles which have a braking system connected to the wheels, for boats the maneuvers occur by operating the propeller in reverse to generate sufficient force to slow down and brake the boat.

The propulsion system is composed of an electric propulsion system part that works together with a hydrodynamic system for the management of the maneuvers that the boat must perform. The electrical power is managed by a low voltage system, about 270 V DC [24] and is powered by 3 lithium batteries capable of guaranteeing high performance and safety levels but also discreet management and battery life with many cycles. Charge and discharge are managed in two different ways: either by attaching the battery to a column or a charging system placed on the quay or with a set of generators, which directly charge the batteries, powered by Diesel that can supply power of about 19.4 kW [24]. These two modes can guarantee the vehicle great versatility and adaptability during the hours of service, ensuring the possibility of completing the assignment and returning to the base.

In addition to these two hybrid boats, an electric boat with a 50kW engine has also been put into service, with the task of collecting the waste of the city in a completely electric way and without polluting either the air or the water of the city. For the boat to be able to circulate, two e-dock columns have been installed in two different points of the city, one at Campo San Apostoli and one behind San Marco, which allow the boat to be quickly recharged in case of need during the service.
Another full-electric boat was made available, again by Veritas, for the collection of heavy waste as a traveling ecological platform.
These innovations show how much the city is becoming aware of the issue and wants to focus on eco-sustainable transport.

2.1.3 TAXI SERVICE

While the most famous boat in Venice is still the Gondola, another boat that is held in high regard by Venetians and tourists, this boat is the watertaxi.
The Venetian cab is the complete sum of elegance, cool, sophistication and beauty that has come to define Venice. [25]
The first boats to be used for taxi service in Venice date back to the period after World War I, around the 1920s, with the invention of the first engines suitable for the construction of small boats [26]; following the creation of this service, the first boatmen who believed in the possibility of innovation decided to found the first associations of taxi drivers, and the first authorizations for the performance of the service were issued. This service was mainly offered to tourists of the city, as the movement on the water had an already well-established network of boats such as ferries and gondolas, which allowed the movement in the canals of the city. Since 1920, the motorboat has undergone many structural changes to adapt to the needs and regulations that have come over the years; the first motorboats, as you can see in the photo below, had a very long and narrow hull, to be able to pass along the narrow canals of the city. The propulsion was obtained through a petrol engine with 100 horsepower and was able to accommodate up to 18 passengers. [26]

Fig. 2.4 - First boat used as a water taxi. [26]

During the early 1970s, following the technological progress and the needs both of an economic type[14], and of a regulatory type due to the problems that this type of boat created, (see chap 2.2.2), a switch to propulsion, always endothermic, but with Diesel, occurred. This change involves numerous adjustments to the boat, which have revolutionized its profile and maneuverability: the new Diesel engines are heavier than the previous ones and also noisier, so boats with a hull in the bow are now obsolete, with the bow too low and heavy, the waterline is affected, causing water to enter, both in the driver's seat and in the passenger cabin, and making the maneuverability of the vehicle difficult due to the poor draft of the ship's stern foot.
For these reasons, it was also decided to change the entire hull of the motorboats, to create boats with shorter bows, and to move the propulsion system to the stern, rebalancing the weights, creating a correct navigation position, and eliminating the noises generated by the

[14] During the years 1973-1974 an important energy crisis occurred due to an oil embargo proclaimed by Saudi Arabia, which caused the price of fuel, in particular that of gasoline, to increase significantly.

transmission. However, although the new specifications allow for an optimal navigation, the weight redistributions have a side effect on the boat's motion: the wider stern and greater draft means that the boat, moving, creates a wake of much larger waves and high compared to previous boats due to the greater volume of water moved.
Since then, in the shipyards of the builders, it has been decided to continue on this road, taking this new model of boats as a basis to study innovations that would increase efficiency and decrease the cost of production and maintenance, but over the years to the present day this became increasingly critical and subject to the opposition of small boat sailors and citizens, due to the consequences found on the buildings of the city, as will be shown in the next chapter 2.2.2.. [26]

Fig. 2.5 - Example of current water taxi.

Nowadays, in the Lagoon several Consortia offer Taxi service, allowing choosing the appropriate type of service between "standard" water cabs and extra luxury boats, varying the comfort and capacity of the vehicle itself. We will now focus on the case of a medium service motorboat capable of carrying 12 people, driver excluded. This model is built by Costruzioni Nautiche Giacometti and mounts a motor Volvo Penta D4 250 depotentiated to 150 hp, with 4 cylinders in line and 3400 cm^3 of displacement turbocharged, with 180L steel tank. According to the precise regulation in vogue, the hull has a length of about 900 cm and a width of 230cm [27].

Volvo has designed this type of engine tailored to the needs of Venetian taxi drivers, considering both the strict regulations to be followed and the need for a more efficient engine.

For this reason, the reverser system presents in the boat used for low-speed maneuvers, called stern foot, has been perfected to allow turning the engine propeller at lower revolutions than the limits of the engine. This leads to preserve the transmission system and keep consumption low.

According to an interview conducted by the naval documentary program "The Boat Show " [28] made by a local taxi driver[15] with 30 years of experience, this engine can provide at 2000 rpm an average consumption of 6 liters/hour against the 9 liters/hour declared by the company.
Estimating these data, the boat can travel for 20-30 hours after filling the tank.

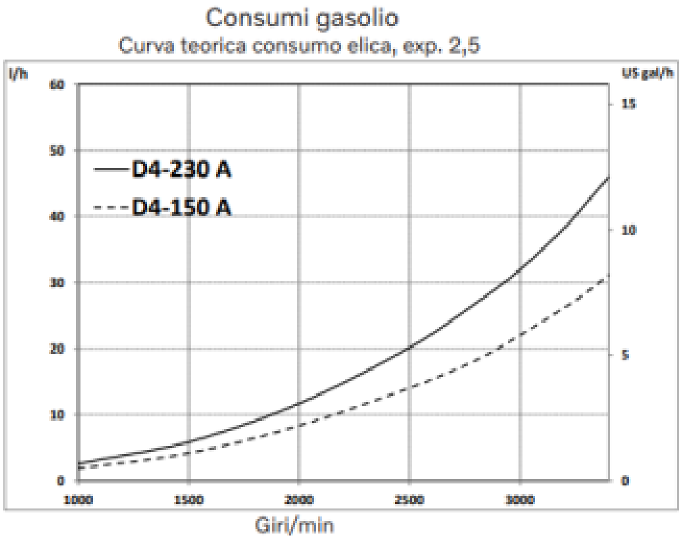

Fig. 2.6 - Theoretical diesel consumption curve. [29]

In addition to the classic models with ICE propulsion, in 2020 the first hybrid taxi able to accommodate 14 passengers us the driver was built by Cantieri Vizianello. This taxis a luxury hybrid motorboat capable of ensuring excellent performance and particular attention to pollution in the city, guaranteeing navigation electric-only along the canals of the Veneto capital. [30]

Fig. 2.8 - GV 30 Thunder Waterlimousine, Cantieri Vizianello. [31]

[15] Fabio Gianni, known as "the prince", license #18.

The propulsion of the boat, developed by Huracan Power, offers various power solutions from 25 to 28 kW of power capable of offering 128 Nm of torque to the propeller. As for autonomy, the boat is equipped with a battery pack with a capacity of 22kWh, guaranteeing 6 hours of autonomy at 4 knots, a speed suitable for internal city travel, while for movements in open water, such as travel to the airport, the boat uses the ICE engine with the support of the electric to optimize consumption and performance. [30]

A second hybrid model, the Love water limousine, was put into service in 2022, still by the Vizianello shipyard; this model is one of the most famous water limousines in the city, often used by Hollywood stars when they arrive in the city.

Fig. 2.9 – Water limousine Amore, Cantieri Vianello. [32]

The new boat, 9 meters long, is equipped with a hybrid diesel propulsion system managed by the Command integration system [32] which monitors and manages the electric and thermal propulsion.
For the electrical part, a 30kW electric motor and a 23kWh battery pack were installed, capable of guaranteeing an autonomy of just one hour at speeds of 6/7 nautical knots. The use of electricity is guaranteed only along the internal channels of the lagoon, while for stretches in the open sea the diesel engine is the master, allowing the batteries to recharge.

2.1.4 PROJECT'S BOAT
As a vehicle to be used to replace the current fleet, a full electric boat built by the Ecoline Marine shipyard was chosen, built with the taxi service in Venice in mind.

Following the canons of beauty of the lagoon, the boat is a classic launch, which is equipped with a 100 kW engine, necessary to navigate the lagoon safely, and capable of pushing a hull more than 9 meters long and 2.4 meters wide. , mandatory for navigation along the canals, capable of accommodating 12 passengers, plus the driver.

Fig. 2.10 - Eco Taxi 900 GRT Electric, built by EcoLine Shipyards.

The characteristics, and the related problems, are similar to current vehicles in that the model does not differ from them, but with the favor of the electric.
The choice of the engine fell on the Torqeedo company, which offers a propulsion kit that, together with the 100 kW motors, couples an 80 kWh battery pack, thus allowing a range of 110 km, traveling at 10 km/h.

2.1.5 FUTURE BOAT SOLUTIONS

As previously pointed out, electrifying a boat is not the ultimate solution to the many problems present in the lagoon, which is why this chapter was included to give further solutions in choosing the type of boat to adopt. Next, two types of foils-type boats will be proposed, which differ greatly from the boats currently in active use and which are not easily accommodated, as of today, due to certain aesthetic canons, and distrust, currently very much ingrained in Venice. However, because of the goodness of the study of this project, it is only right to introduce them as very interesting models due to their peculiarity.
Foil-type boats have the merit of creating a wave wake significantly less than classic boats, due to the fact that they fly over the water thanks to the foils; however, they need speeds in excess of 10 to 15 knots in order to take off, precisely making immediate adaptation to the city difficult as there are strict navigation rules explained in Chapter 2.3.1.

In contrast to this there are the positive aspects of using this kind of boat which are technical in nature but also economic; In fact, flying on the water these boats have very little resistance since the entire hull is not in contact with the water and therefore it benefits navigation, which is not at the mercy of the waves, consumption, which is significantly lower since one does not have to overcome the very large resistive force explained in later chapters. Consequently, the economic aspects are in favor of the foils-type boat since, inherently, it needs less maintenance and has lower consumption and greater range, compared to the electric boats considered as the project model.

Thus, it was positively evaluated, to introduce this chapter in a future perspective in order to take into account also the huge problem of wave motion present in Venice, taking into account that the models that will be shown, were not taken into account as a model for this study both for lack of data regarding navigation, being prototypes or boats just released, and for an obligatory adaptation to the thinking in vogue in Venice.

The first foils boat model is , the GerrisBoats model, a recent Italian start-up project, will be examined.

Fig. 2.11 – GerrisBoat Render. [33]

The GerrisBoats model is a design of a fully electric foil[16] boat designed specifically for the naval taxi service. GerrisBoats started from foil boat technology, reinterpreting it for the type of boat to be designed, paying close attention to the fact that it is not enough to simply install an electric motor with a set of batteries on an existing vehicle, but it is necessary to create an optimized model in every aspect of it for electric propulsion.

The technology with two movable side hulls allows the boat to have a multimodal configuration for three different navigation modes:

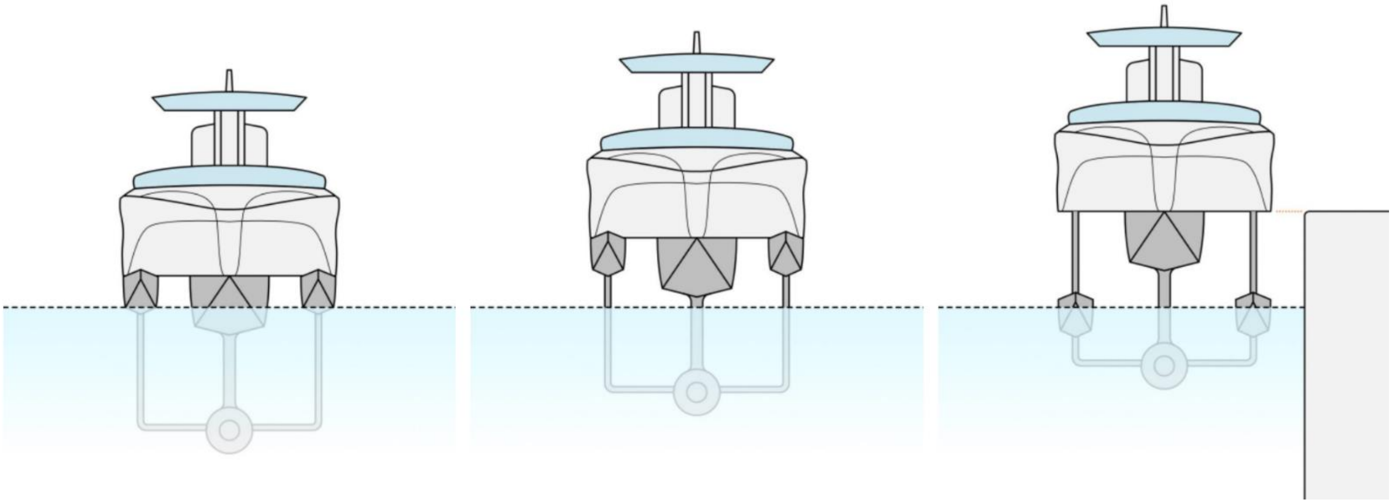

Fig. 2.12 - Multimodal variable configuration hull.

The first mode on the left allows the boat to function as a trimaran[17] and it is used when the boat is stationary or in case of rough water, as it makes the boat very stable thanks to the deep keel[18]. In-flight navigation on the foils, in the center, is the most efficient mode, thanks to the high reduction in hydrodynamic drag and it is used at higher speeds. The rolling[19] and pitching[20] motions are controlled, and in addition, the side hulls offer an additional measure of safety in the event of very high waves.
Finally, the last mode with raised boarding, on the right, makes it possible to ensure accessibility to the boat for everyone, including people with disabilities, thanks to the height adjustment of the hulls. It can also be used when navigating along shallow canals, such as those in Venice, whose average depth is around 1.3 m or to make the vehicle more stable.

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[16] The foils are appendages capable of producing a vertical thrust and making them lift in part or almost completely the boat from the water. In this way, the surface in contact with water is drastically reduced and therefore hydrodynamic drag, resulting in a significant increase in speed. For the foils to enter the
function, it takes a decent speed and that is why they are applied on motorboats or boats to particularly performing sail.
[17] Trimaran: a boat consisting of three hulls.
[18] Definition of Treccani. Keel: In shipbuilding, in wood or steel, the continuous fundamental element of the hull, runs longitudinally from stern to bow; in particular, in steel hulls
[19] Definition of Treccani. Roll: oscillating motion around its own longitudinal axis, caused by the alternate contrast of a heeling couple that tends to tilt the ship (e.g. due to wave motion), and a righting torque (stability torque) that tends to bring it back into its normal position, characterized by the amplitude (roll angle) and by the period, i.e. the time between the instant of maximum inclination on one side and the instant of the subsequent maximum inclination on the opposite side.
[20] Definition of Treccani. Pitch: Oscillating movement of boats around the barycentric transverse axis, which is normal to the longitudinal axis, generally because of the wave motion, so that the bow or stern are alternately raised on the crest or sunk into the hollow of the waves.

In designing this system, the founders considered two important characteristics of a naval taxi: the first one is the necessity to minimize the production of wave motion generated by the boat and, also, the second one is the need to respect very low-speed limits, required by municipal regulations. This has led to particular navigation adjustments, since to have positive effects compared to other modes, the classic navigation on foil requires higher speeds than a normal boat as it must be able to "fly" on the water.

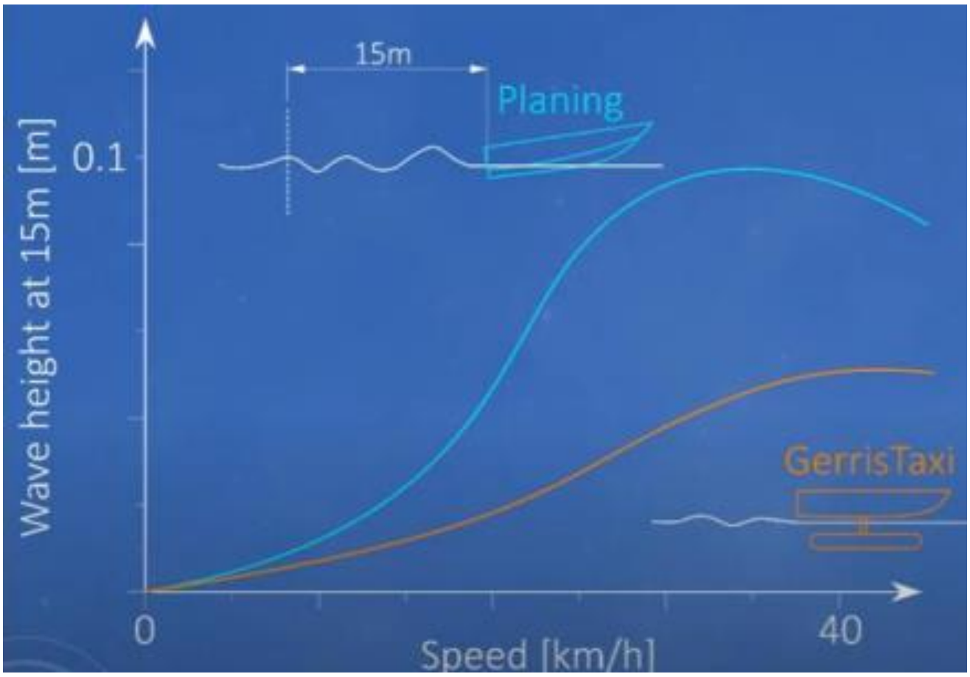

Fig. 2.13 - wave motion generated as a function of speed.

The possibility of lifting the boat for navigation on foil considerably reduces the movement of the water and the wave motion Fig.2.12, a very important problem felt by the Venetians. Even at low speed with operation from trimaran, this is guaranteed thanks to the torpedo present under the hull, which in addition to containing the batteries (and thus reducing the weight onboard) produces hydrostatic thrust with very low wave formation, as shown in Fig.2.13.

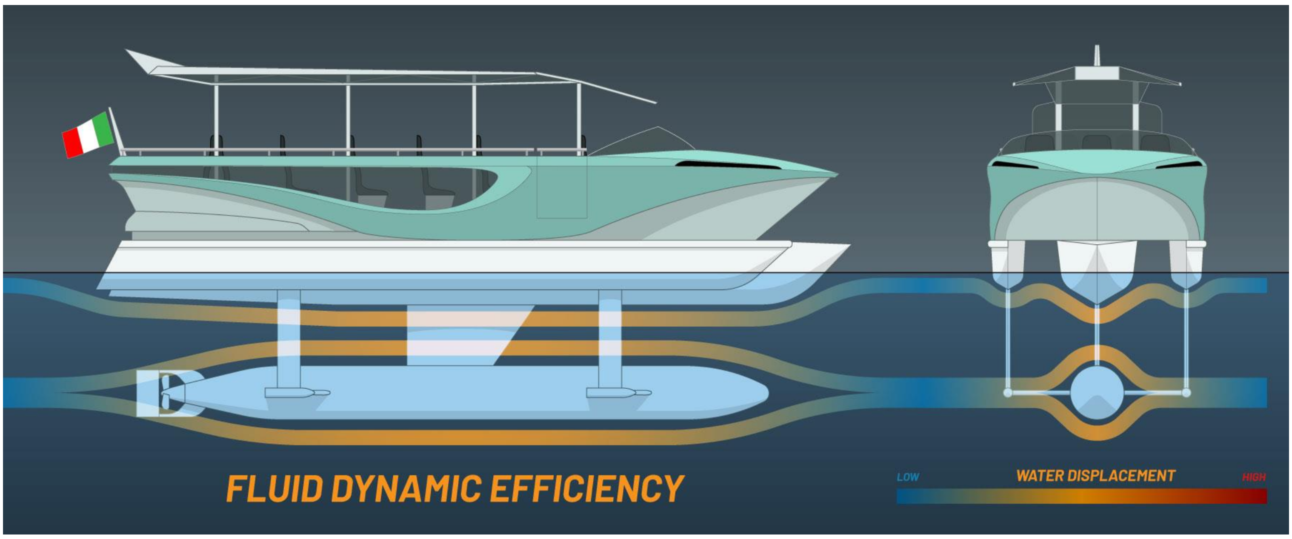

Fig.2.14 - Fluid dynamic efficiency of the boat.

The innovation and peculiarity of this boat are found underwater, to optimize the electric propulsion system, reducing the height of the waves generated and providing the boat with the stability it needs to meet the objectives of the project. Together with the foils technology they allow the boat to rise by reducing the movement of the water, not only generating little wake but also increasing its aerodynamics and decreasing the opposition to the motion it generally performs.

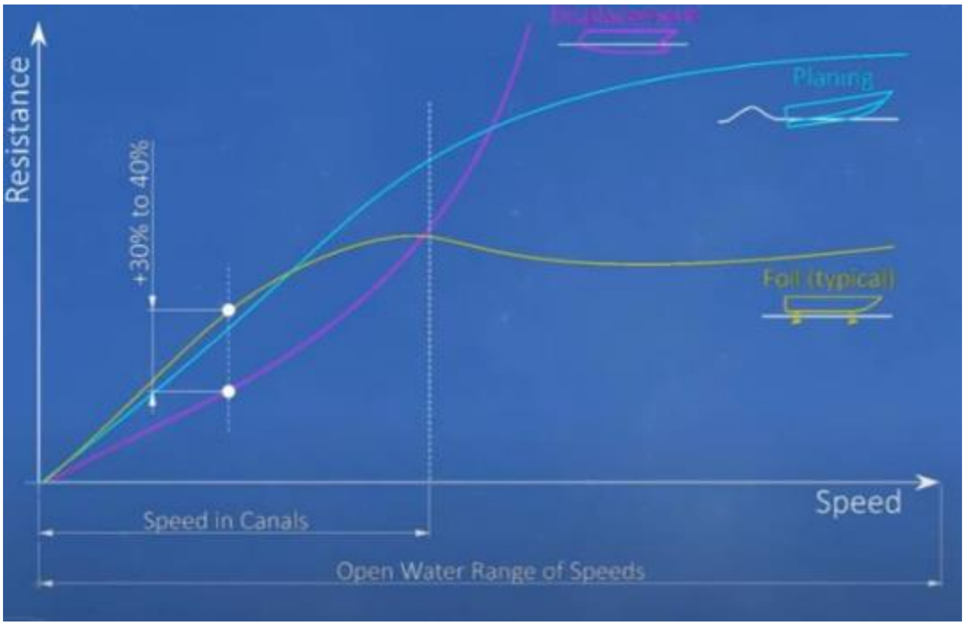

Fig 2.15 – Resistance of the boat in the function of speed.

On the other hand, water taxis operate in environments where speed limits are very low, as we will see in later chapters, depending on the canals of the city.
At these speeds, generally, the foils are not able to lift the boat, and they allow it to slide on the water; therefore, to overcome this problem a torpedo was inserted under the main body of the boat.
This particular solution allows the boat the necessary hydrostatic thrust which keeps the boat raised even at low speeds, allowing it to take off and navigate even in the lowest channels.
The aerodynamic aspect of the torpedo is not its main purpose of operation, since the entire propulsion system of the boat is concentrated in it, guaranteeing various advantages both in terms of space and navigation comfort and in terms of energy management of the boat.
The installation under the ship's keel allows you to take advantage of all the available space of the boat's hull, creating a spacious and comfortable environment for passengers.

Instead, as regards the propulsion of the boat, a 50kW motor is installed in the torpedo together with a 60kWh battery pack which, according to the manufacturer, allows autonomy of about 6 hours. This is also possible thanks to the poor resistance to water that the vehicle has which allows an energy saving of up to 60%, as can be seen from the Fig.2.14, In fact, the greater the hydrodynamic resistance and the dissipation of the energy of the boat, the lower it will be the autonomy of the vehicle, which translates, for a naval taxi service, into fewer trips and more time spent recharging the vehicle, reducing both the economic gains of the taxi driver and the attractiveness of switching to an electric boat which would not be able to guarantee the same service compared to current boats

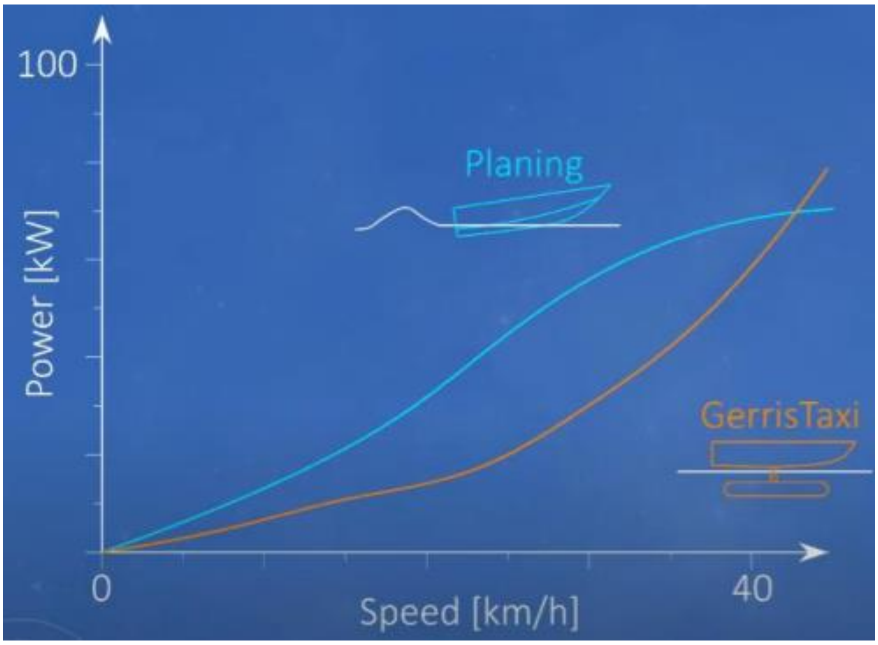

Fig. 2.16 – Power consumption in the function of speed.

As can be seen from Fig. 2.15 at about 5 knots, in trimaran mode the boat would absorb about 40% less than a traditional hull, consuming about 7-8 kW of propulsive power. On the other hand, at the maximum speed of 15 knots in "foiling" mode, 50 kW is needed.

The second model was presented by Candela, a Swedish shipyard, at the 2022 Venice Boat Show, as a replacement proposal for the current water taxis. This boat is similar to the prototype presented above, but there are some points of detachment, due to a different thought and interpretation of the foils, but also to the fact that it is not already a prototype but an affordable boat.

The model is C8 Voyager candle, and features a foil and a mobile propulsion torpedo, which allows adaptation to different speeds and different modes of navigation adaptation.

Fig. 2.17 - Candela c8 Voyager.

This model is equipped with a 50kW electric motor together with a battery pack of approximately 45 kWh that allows it to sail for 40 nautical miles at a cruising speed of 20 knots, 2-3 times longer than conventional electric speedboats with 300% bigger batteries. [34]

The retractable C-FOIL system makes P-8 Voyager an electric boat capable of adapting to all sailing conditions without compromise. In surface mode, the foils and Candela C-POD are protected by the hull. In extreme weather conditions that prevent foiling, the P-8 Voyager can be driven like a conventional boat, albeit with a reduced range. As can be seen in Fig.2.18 a), b), c), d) [35] the C-FOIL assumes 4 different positions that allow different navigation modes:

Fig. 2.18 a - Harbor mode, in which the foils are fully retracted.

a.

Fig. 2.18 b - Shallow mode, for low speeds and for navigating lower channels.

b.

Fig. 2.18 c - Planing mode, for navigation at cruising speed.

c.

Fig. 2.18 d - Foiling mode, which allows high efficiency navigation and to reach longer ranges.

d.

2.2 LOCAL PROBLEMS

The choice to electrify the naval taxi service in Venice comes from the need to both adapt to a technological context that sees more and more electricity taking part in the naval sector, and to try to solve some problems that grip most of the Italian cities and in particular Venice. The effects of the lockdown caused by the pandemic that arose in the first months of 2020 have had repercussions on many aspects of everyone's life, but also the environment; while for each person subject to these obligations, he assessed the effects of the lockdown negatively, both psychologically and economically, for the environment it was like taking a breath of fresh air, literally speaking. In fact, due to the many limitations, many cities in the world have had to stop and, therefore, the countless cars, boats, and planes that circulate every day emitting pollutants into the air, have temporarily stopped contributing to polluting the planet. This meant that not only the quality of the air benefited but also the various natural ecosystems, including the Venetian lagoon.

A study carried out by a professor of ITT Montani, Teresa Cecchi, highlighted how, precisely in Venice, thanks to the lockdown, pollutants in the waters of Venice were reduced by 40%, making them, even visually, more limpid, and cleaner, as can be seen in the following photo. [36]

To try to replicate these positive effects on the environment, it is good to take the right path that aims to defend the environmental heritage that the city of Venice has, looking for solutions with zero environmental impact.
So it is good to understand better what are the factors that have the greatest impact on the quality of the air and water in the Venetian capital.

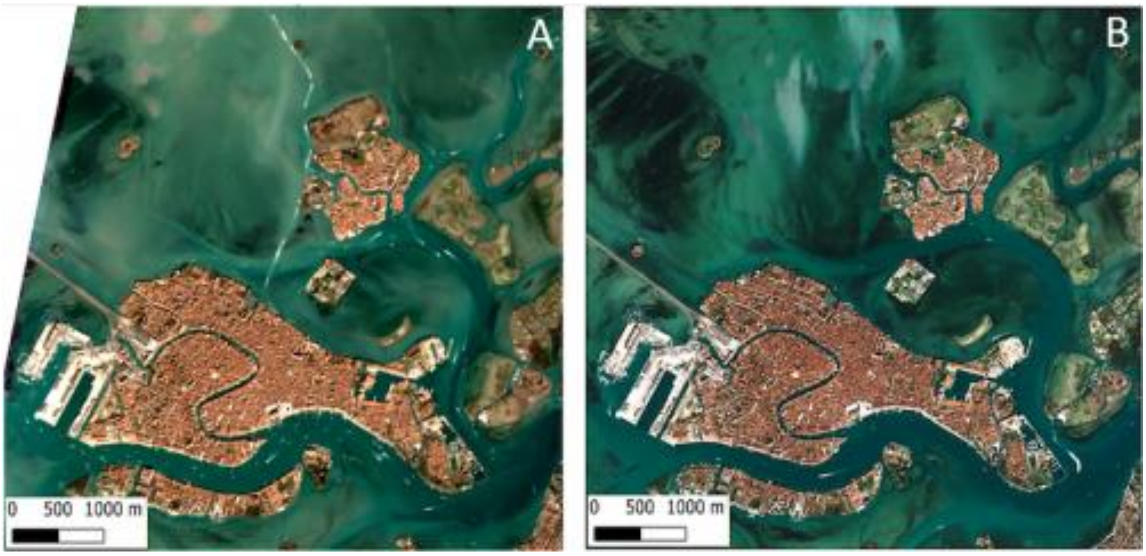

Fig. 2.19 - The waters of Venice before (A) and after (B) the lockdown. [37]

2.2.1 ENVIRONMENTAL PROBLEM

One of the most serious problems in Venice concerns air pollution, often underlined by the major Italian newspapers; confirm it is the ISTAT data for the year 2019 [38], the fixed air quality monitoring stations of the "traffic" type[21] have found that the Venetian capital has exceeded for 68 times the maximum limit to protect human health, prescribed for atmospheric particulate matter PM_{10} (50 µg/m3 daily average, exceed able for a maximum of 35 days in a year), the fourth-worst municipality in Italy while maintaining the annual average at 34 µg/m^3 and therefore slightly below the limit of 40 µg/m^3. As for the particulate matter $PM_{2.5}$, the annual average is 21 µg/m^3, within the annual limit of 25 µg/m3, but lower only than the municipalities of Andria and Rovigo.
As far as the presence of NO_2 in the atmosphere is concerned, the annual average of 51 µg/m^3 exceeds the maximum limit of 40 µg/m^3, another datum that confirms the heavy contribution of naval traffic. The analysis of the flow of transport activities in the Venetian canals, presented in the Plan for the Reorganization of Water Traffic in the Historic Centre of Venice [39], shows then that traffic develops mainly due to activities of prevailing public interest (90%) and only marginally derives from private movements, thus suggesting how an intervention to cut direct emissions from ship cabs could be effective to improve air quality. Therefore, the positive effect on air quality and noise pollution is a valid reason for the electrification of boat cabs, especially since the air in Venice is particularly polluted.

In support of the reading of the data, a study was carried out by the students of the School of Architecture of Venice (IUAV) who, together with the Open System group of the University of Barcelona and the participation of 4Sfera, collected data on air pollution installing detectors in 25 different sites in the city capable of measuring the concentration of NO2.

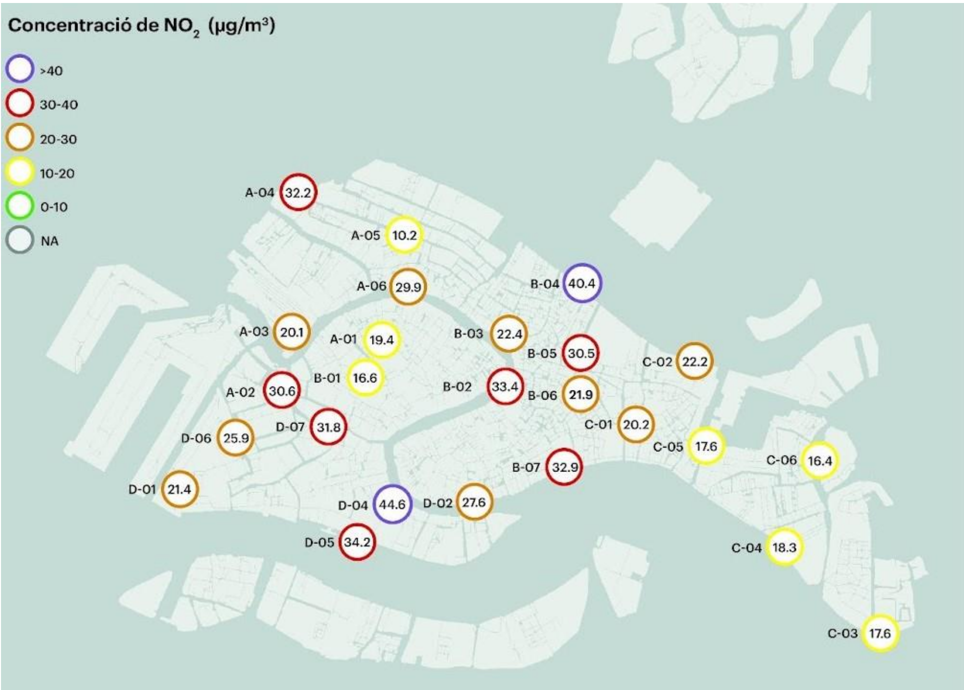

Fig. 2.20 - NO2 concentration detected in\ µg/m^3. [40]

[21] Is located in such a position that the level of pollution is mainly influenced by traffic emissions, coming from neighboring routes with medium-high traffic intensity.

As shown in Fig. 2.20, according to this study it was found that the concentration is, in every single site, higher than the values set by the WHO of 10 µg / m3, and they declared that the main source of NO_2 is combustion engines, as can be seen from the comparison of the levels before and after the closures imposed by the pandemic. [40]

2.2.2 WAVES MOTION

The wave motion phenomenon is a second problem that creates a lot of inconvenience to navigation. The first protests carried out by citizens dating back to the last decades of the 1800s when the first water buses began to circulate in the lagoon [41]. Over the years, with the increase in the number of boats circulating between the canals of the city, the protests increased, and, to date, no solution or remedy has been found, except limiting the circulation in the lagoon to only smaller boats, excluding access to mammoth cruise ships and large yachts from August 2021.
To better understand the associated effects, the origin of this phenomenon is explained below.
The resulting wave motion is a temporal and spatial combination of wave trains generated by boats of different types (length, immersion, width, hull shape) and speed [42].
The generation of currents occurs when a vessel moves on a navigable waterway, generating a reverse current parallel and opposite to the direction of movement of the hull, and due to the kinetic charge of the water moving laterally to the boat, a lowering area of the water level is created to keep the current line constant.
Therefore, the water level around the boat decreases depending on the geometric characteristics of the channel and the vessel, as well as on the boat's [42].
That is, the larger and heavier a boat is or the faster it is to travel, the greater the cone of wake and the lowering of the water level.
The surface oscillations are converted into a transverse wake and secondary waves at the bow level, and all these oscillations consist of transverse and divergent waves that combine to form interference combs. The interference combs propagate in a V-shape with an inclination of about 35° concerning the longitudinal axis of the boat.
The value of the wave height of the secondary waves depends mainly on the characteristics of the boat, the depth of the seabed, and the speed of movement of the boat. [42]

This phenomenon does not have the same effects along all the canals of the city the Giudecca Canal and the Grand Canal are more subject to the negative effects of the phenomenon due to their size and the high traffic of boats they host every day, and in these channels, the condition worsens due to the vertical walls of the banks which reflect the waves breaking on them.
It follows that the waves generated by the boats both negatively impact the foundations of the buildings, damaging them and accelerating the various erosive phenomena of the water, and creating inconvenience to the navigation of smaller boats, such as the famous gondolas.

2.3 MORPHOLOGY AND INFRASTRUCTURE AT VENICE

The city of Venice has a structure and nature unique in the world. It rises with a system of stilts on the waters of the lagoon, forming a network of internal canals that have allowed the movement and exchange of goods since the beginnings of the city.
In this chapter it will be possible to better understand the complexity of the design of an efficient transport system, considering the many regulations related to navigation and docking of ships.
The Ordinance on Water Circulation in the City of Venice was established to promote proper circulation of boats, taking into account the needs of urban, commercial, and tourist life, as well as the urban and environmental context of the city, to mitigate as much as possible, the harmful effects of water movements, explained in the previous chapter, caused by the movement of boats and propellers. Moreover, the application of these regulations preserves the environmental scenario of the city by limiting the pollution of water and air in Venice.
A final important point is the management of shipping traffic in the city. As already mentioned, the movement between the canals is the fastest way and is used by both citizens and tourists; therefore, it is necessary to limit and organize the numerous traffic carried out by motorboats, considering the reasons for each movement, and preserving the movements of the most fragile boats without engines.

2.3.1 CANALS AND RII

As widely said, moving by ship is always the solution most used by both citizens and tourists, and although it may seem easy to organize, there are many strict rules and regulations on the behavior to be adopted while driving a boat.
As happens on the road, where a vehicle is not the only one and must look after other vehicles around it, even along the canals it is important to be aware of the other boats that sail along the same route and to be aware of the difficulties that can be created. If we break the rules in place.
It is good to specify this summary, without going into details that would be useless for this discussion, as many of the regulations in force in Venice refer to how to behave in the vicinity of other boats, motor, or rowing, to facilitate circulation and not create problems.
However, although the regulations in force have the purpose of managing ship traffic, they have been modified also taking into account the aforementioned wave motion; in fact, the document mentions: "Within the maximum speed limits indicated in the previous paragraph, the drivers of motorboats must, in any case, navigate by limiting the speed, the production of" wave motion "and the movement of" reluctant "water in such a way as not to give rise to susceptible situations to cause damage to people and things " [43]

In the following Fig.2.21, it is possible to view the limits to be maintained in the individual channels; the various areas, delimited by different colors, show how in the internal canals of the city the boats must maintain very low speeds of 5 km/h, along the Grand Canal due to the high traffic that hosts the limit is set at 7 km/h, while the limits rise along the Giudecca Canal and in the open water area whose limits are respectively 14 km/h and 20 km/h. It is good to specify these limitations to understand the analyses carried out in the chapters.
Furthermore, it is necessary to specify that these limitations apply to every private boat or boat used for taxi services, while the ACTV public service boats have slightly higher limits. [44]

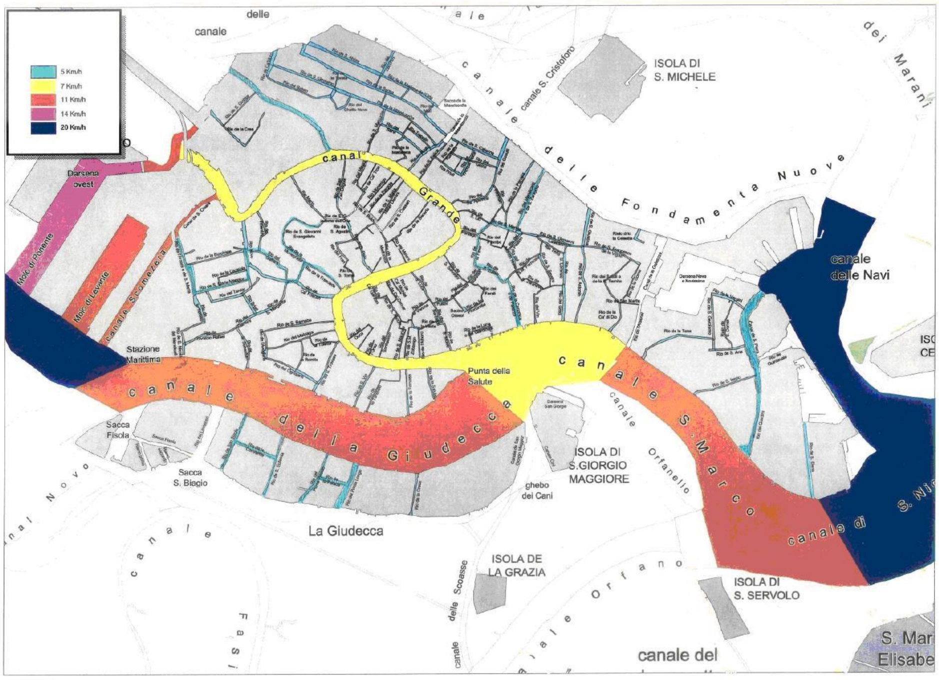

Fig 2.21 - The speed limit of canals and rii into Venice Lagoon imposed by order no. 158/14 of the Port Authority.

As far as the circulation along the canals is concerned, further limitations must also be taken into account as regards the depths of the smaller canals and canals and the draft of the ship, as shown in Figure 2.22; in fact, not all canals have the same depth and this limits circulation to those boats which, due to the too deep draft, would risk running aground or damaging the seabed or foundations of buildings, again due to the wave motion effect generated.
It is therefore essential to have a boat that allows me to adapt to every backdrop and every situation, and in this, the chosen prototype is a good choice.

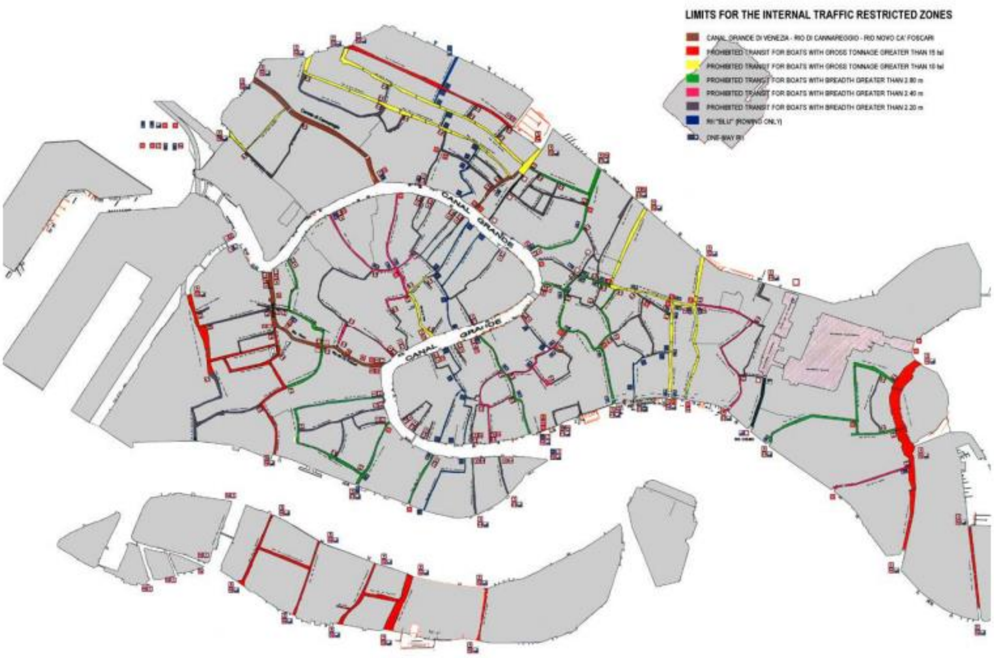

Fig. 2.22 - Limits for the internal traffic restricted zones.

2.3.2 STATIONS AND PIERS

To better manage and organize the taxi service, the municipality has set up and reserved well-defined spaces along with the city's docking points. As you can see in the following Fig. 2.23, in the city there are eleven areas where it is possible to use the taxi service, and, based on seasonal shifts, more boats are made available.

Fig. 2.23 - Map of the location of the taxi service stations in the city of Venice.

In addition to the stations highlighted in the figure, there are other stations outside the city canals that allow you to connect Venice with the islands of Murano and Burano, which are popular destinations for tourists every year, with the Venice Lido and Venice Airport, which represent a long and critical journey for the service.

Each station consists of a water area concessioned by the municipality and infrastructure of moorings and masts that allow both the embarkation and disembarkation of passengers and the mooring of the ship, as shown in Fig. 2.24 (a) and (b) for the example of Station 7 near the Rialto Bridge.
For this study, it is important to evaluate the feasibility of installing a recharging system that adapts to the existing structures and tries not to be architecturally and visually disruptive, to create a scenario that is completely removed from the city. As you will see in the next chapter, these small details were also taken into account when choosing the type of column to install.

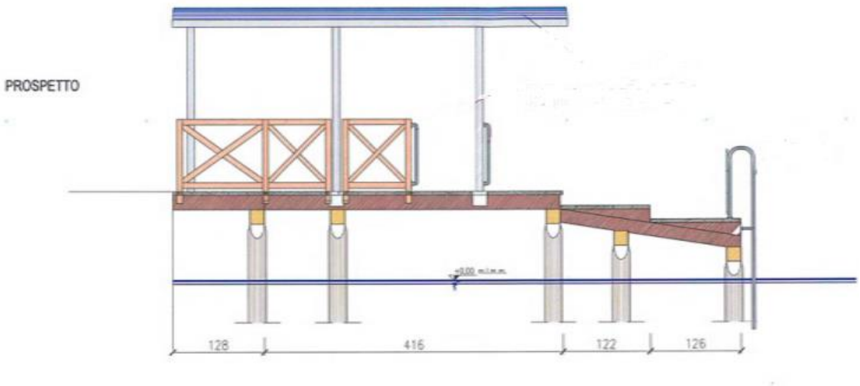

Fig. 2.24 a - Elevation plan of Rialto station 7.

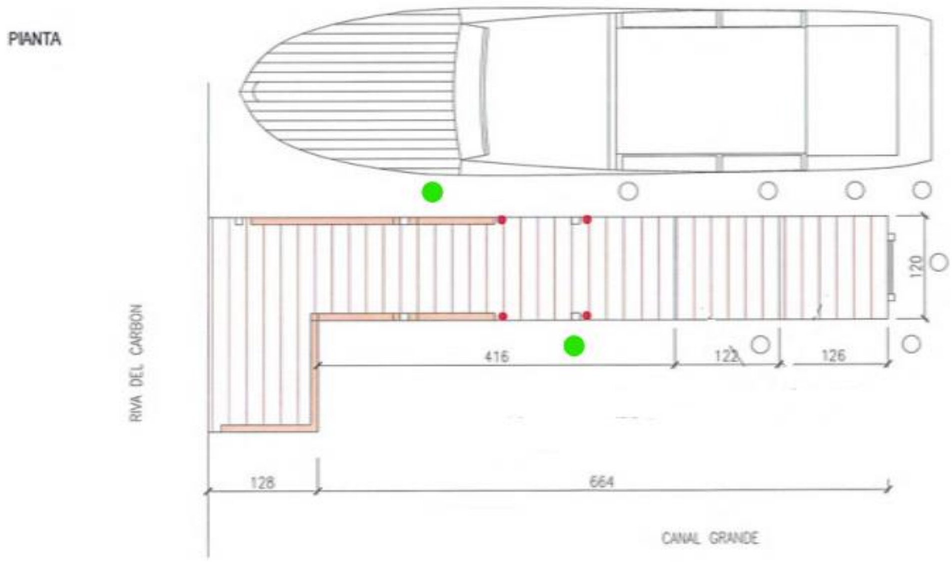

Fig. 2.24 b – plan of the plant of Rialto station 7.

Following this reasoning, the two poles highlighted in green in Fig. 2.24 b) were chosen as the installation point of the electric columns, and always taking this station as an example, the guideline will continue in all the other stations following the same idea.

2.4 CHARGING INFRASTRUCTURE

When it comes to electric vehicles, in addition to listing performance, an important point must be analyzed: recharging.
In recent years it has been possible to see how the growth in sales of electric vehicles goes hand in hand with the increase in charging stations, with many start-ups and large companies that have moved to install an increasingly widespread network to allow the circulation of vehicles not only in the city but also in rural areas where electric traction struggles to take off precisely due to the scarce availability of recharging infrastructure. The latter has had a significant improvement in efficiency over the years, from recharging in DC to ultra-fast recharging in AC, significantly halving the time taken to recharge the vehicle.
In the naval sector, recharging is mainly carried out during the stay in the port, or in small-sized docks, thus taking advantage of conductive recharging, however, there is also, in some cases, the possibility of recharging through auxiliary generators presents in large ships for the transport of goods. [45]
There are further charging possibilities, such as wireless mode and battery swapping, which can potentially have many benefits, especially for wheeled vehicles, but they encounter more problems in the nautical sector.
As for the type of boat of the study, the wireless mode, with today's technology, was discarded as the applications found do not ensure the right performance and the right safety standards, while the possibility of battery swapping will be examined, in the light of the specifications. techniques of the chosen boat that facilitate this recharging method.

2.4.1 CONDUCTIVE CHARGING

Conductive charging is the method in which the electric vehicle is directly connected to the charging infrastructure or power supply device, using a power cable to supply power.
In the charging architecture AC, shown in Fig. 2.25, the currents and voltages are transmitted from the power grid to the socket in the ship through the electric vehicle's socket at an electric frequency of 50 or 60 Hertz.
The battery located in the storage system still requires DC current, so the AC current and voltage must be converted by a system onboard the ship. The socket of the ship is immediately connected to a solid-state transformer, AC / AC converter, which consists of three blocks: the first block consists of a rectifier and a filter that convert the waveform AC to DC, the second is an inverter that again converts to AC but at a higher frequency, and the third block is a transformer that provides galvanic isolation in the electrical path between the grid and the battery for safety reasons and, thanks to the increase in frequency, can be smaller than a power supply with grid frequency. After the transformer follows a rectifier with a special filter from the high-frequency AC to DC, which finally supplies the ship battery with the desired voltage. [46]

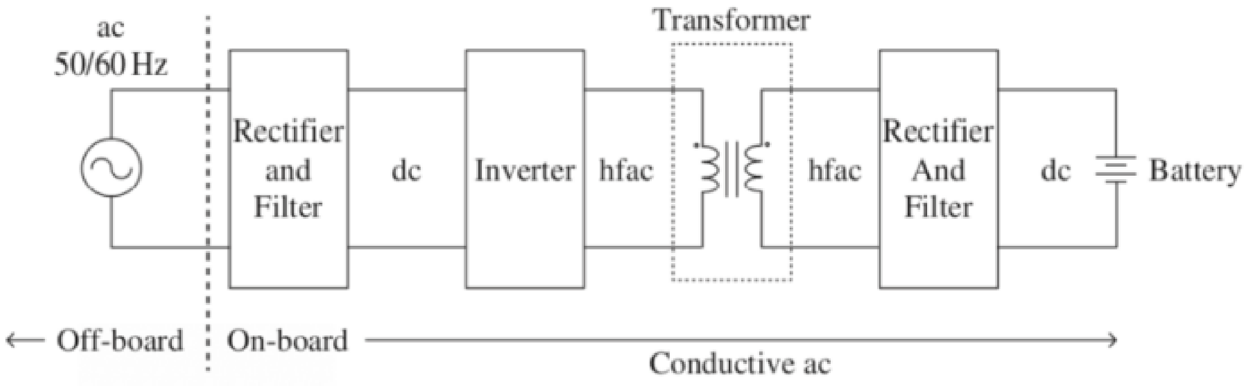

Fig. 2.25 – AC conductive charging scheme. [46]

As for DC charging, generally, the architecture of the DC fast charging station, in Fig. 2.26, includes the entire system of converters and connection cables, allowing all this to remain overboard. As well for AC charging, the battery voltage depends on the state of charge (SOC), so it must always be necessarily controlled through the converters. The battery power supply of electric vehicles from the grid can reach power levels of 240 kW [46].

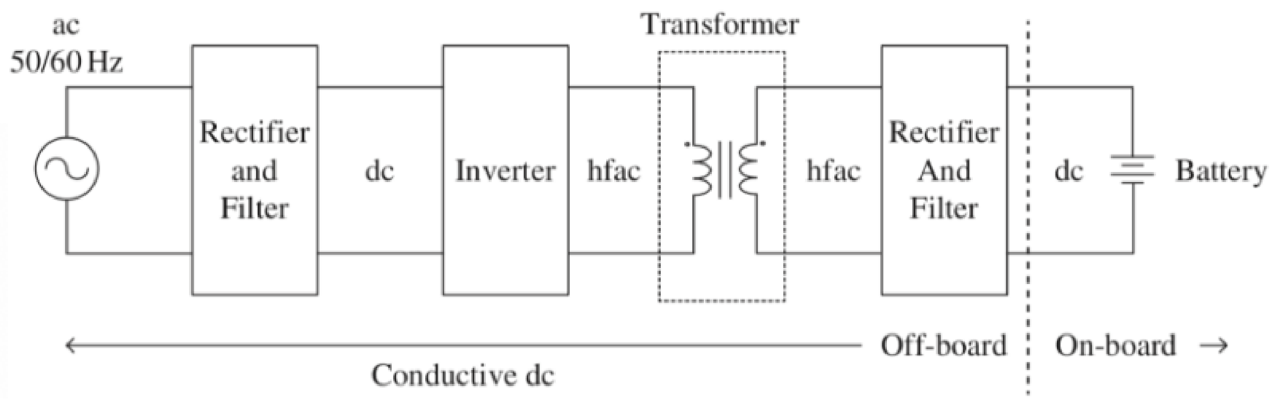

Fig. 2.26 - DC conductive charging scheme. [46]

2.4.2 BATTERY SWAPPING

This charging method allows you to replace the discharged battery of a means of transport with one that is the same but charged, to eliminate the often-long recharging times.
However, to take advantage of this mode, it is necessary to create an adequate infrastructure network and equip the vehicles with the same type of battery.
It follows that the adaptation to this mode is very complicated, while the creation from scratch service can be less demanding, as it should be standardized in the design phase allowing to have the same type of batteries and create an exchange and recharging of the batteries to optimize the service.

Unlike normal recharging, in which it is possible to use any column even if it is not linked to the manufacturer of the vehicle purchased, in this way there is a manufacturer-owner constraint; in fact, either globally we move to an adaptation to a single model of compatible battery, or we are bound to use the battery change only from a supplier. Furthermore, it is necessary to change the perspective of purchasing a vehicle, in which the battery is supplied by the manufacturer, who remains the owner and can lease it, so as not to create inconvenience to the owner of the vehicle, who will not have to worry about the actual state of health of the battery, but that may at the same time have the advantage, also in economic terms, of not having its battery.
In this charging mode, the agents in place in charging such as the owner of the electric vehicle, the station owner, and the power system itself are mutually connected to each other, both for the reasons mentioned above regarding the homogeneity of the batteries, and as an intrinsic quality of this system, making this process advantageous for everyone.

The vehicle owner has a number of advantages such as:
1. Reduction in the cost of the electric vehicle, which is currently very high due to the costs related to the batteries on the market.
2. The charging time is canceled, and the battery replacement time is comparable with the current refueling time (approximately 3 minutes for electric cars).
3. The owner does not need to install the charger on the place of him, reducing the initial investment for the vehicle.
4. Elimination of owner's range anxiety for long distance travel.

The station managers are equally advantaged as they can reduce the cost of managing the cost of electricity through forecasts on the periods and on data obtained daily, the cost of batteries will decrease due to the technological development of the new batteries, the reduction of space necessary for carrying out the activity and the reduction of the time necessary for the exchange maneuvers which will be reduced over time.
Furthermore, using RES, it is possible to reduce management costs by recharging the discharged batteries during the hours of sunshine. [47]

Although this charging method is a valid alternative to charging stations for wheeled vehicles, adaptability to naval vehicles encounters some critical issues of both practical and technical depth.
As for the practical aspect, battery swap maneuvers are less rapid and less simple than wheeled vehicles, thus losing the strengths of this charging system such as charging speed, or swapping.
These difficulties are due to the need to bring the boat into storage, take it out of the water and carry out the necessary exchange operations which, in addition to being very critical and

time-consuming, have the further criticality of where the battery set is installed and the need for the latter to be insulated in a workmanlike manner, to avoid water infiltration during travel.
In addition, the diversity of consortia and shipyards makes the management of this method more complicated, as can be seen from the study scenario, in which the difficulty further increases due to the multitudes of shipyards and consortia that offer the naval taxi service or that they set the different boats in motion.

These difficulties make it very difficult and not very advantageous to adopt this charging method for the service studied.

2.4.3 CHARGING COLUMNS

In choosing the settlement method in the present case, it should be taken into account that the installation of many models of columns with a futuristic appearance on the market may detract from the beauty of the Venetian landscape and cause a negative reaction from residents and tourists.
The importance of this aspect is confirmed by a project launched in 2020 by the company E-concept, which has signed a partnership agreement with Enel X, providing technological supply for the public and private charging system type 2, mode 3 according to the provisions of the IEC 61851-1 standard.

The project is called E-dock and consists of the construction of a charging pole in the form of a mooring mast, which can be easily confused with the poles scattered in the canals of Venice, as shown in Fig.2.27.
The identified solution integrates the electric charging technology into the mast, a characteristic element of Venetian moorings, overcoming the problems of visual impact in the delicate urban context of Venice. So, the design of the E-Dock is Made in Venice and is perfect to be used all over the world. It was built with 100% recyclable materials.

Fig. 2.27 - e-dock column installed.

The nautical column, so-called by the company itself, consists of two parts: the upper part, which houses the technical equipment, and the lower part for anchoring to the seabed. The positioning of the electrical components is optimal, as the equipment is elevated and does not run the risk of being submerged at high tide. In addition, the mast complies with the

strict regulatory requirements for mooring masts, which are attached to an existing mast in such a way that its structural characteristics are not altered.
The pole can accommodate one or two charging stations, as desired, and provides optimal service thanks to its ease of installation and use.
However, the electricity grid in Venice is not yet capable of handling this major change. For this reason, electric utilities have made modernization investments to install a comprehensive charging network in the city.

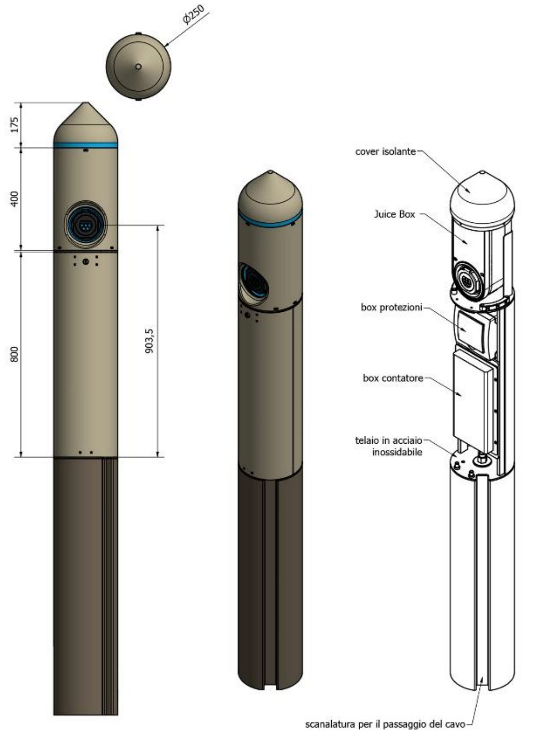

Fig. 2.28 - technical details of the e-dock column.

3. MODEL

Now that the scenarios in which we will operate have been shown, it is possible to move on to the explanation and study of this project, whose purpose is to verify the possible electrification of the naval fleet of water taxis in Venice, and studying its routes, timing, and consumption.

To do this, it was necessary to carry out first of all a study and in-depth research on the service, on the boats in action and on the needs and duties that the taxi service entails, both for drivers and for the municipality to which they belong. Subsequently it was necessary to research and understand the solutions to be implemented, since it is not enough just to assemble an electric motor and any battery; in fact, with regard to the vehicle, an ethical / environmental choice was made, as we did not opt for a launch-type boat model, but we followed the Gerris boat project that allows a reduction of wave motion in Venice. As explained above, and because we are using a prototype model, this has made it possible to adopt a 100kW motor combined with an 80kWh battery pack, unlike the one that has now been chosen, meeting the expectations that taxi drivers had.
In fact, following an interview with both the head of water transport in Venice and with the director of the RES Maritima company, it was possible to better understand the criticalities and needs of both the service that is carried out daily in the Venetian lagoon and of the water means that allow the correct development of the same, as will be specified in the chapter 3.2
Once this work was done, it was possible to create a study model using Anylogic, a simulation software, with the help of Google Earth and Excel.

3.2 ASSUMPTIONS

Creating a model to simulate identical to the current scenarios is not easy, as there are many factors to consider, especially regarding the scenario of this study.
First, the taxi service involves the unpredictability of a service on open water, subject to bad weather and atmospheric phenomena typical of the Venetian lagoon, and it also requires a better understanding of how the naval taxi service works in the lagoon.
The naval taxi service, managed by timetables and from positions assigned during shifts, turns out to be a 24-hour service in which the same boats are continuously in motion and are always ready to welcome new passengers. In order to manage these high rates, a single manager of a few boats hires several taxi drivers who alternate during working days without ever being out of service.

Each individual taxi has a seat assigned during its shift, as shown in Fig. 3.1, but it is not uncommon for individual boats to go around the lagoon in search of customers.
Only at the end of the day, the taxi driver goes to his colleague who will have to work the following morning to be able to leave the boat, which will be immediately ready to be active in the service. Therefore, as is easily understood, the transition from a boat with ICE propulsion to a full electric one encounters many difficulties, mainly due to the still underdeveloped technology that does not allow for large ranges.
For these reasons it was decided to carry out a study with a long-term perspective, with different scenarios that will later be expanded on, and which will allow an ever-greater use of electric boats both in terms of route lengths and in terms of number of ships in the fleet.

Tab.3.1 - Example of shifts of the water taxi service managed by the municipality of Venice. [48]

Fermata: FERROVIA (GALLEGGIANTE)	Orario: 8:00-18:00
LTA nr. 42 - 156 - 338 - 313	
Fermata: FERROVIA (GALLEGGIANTE)	Orario: 18:00-24:00
LTA nr. 2	
Fermata: FERROVIA (SANTA LUCIA)	Orario: 8:00-18:00
LTA nr. 297 – 44 – 354 – 260 – 226 – 135 – 339 – 40 – 136 – 140 – 233 – 169 – 3 – 319 - 39	
Fermata: FERROVIA (SANTA LUCIA)	Orario: 18:00- 24:00
LTA nr. 151 – 314 – 171	
Fermata: LIDO	Orario: 8:00-18:00
LTA nr. 123 - 145	
Fermata: LIDO	Orario: 8:00-20:00
LTA nr. 376 – 208	
Fermata: MURANO(COLONNA)	Orario: 8:00-18:00
LTA nr. 143 – 293	
Fermata: OSPEDALE	Orario: 8:00-18:00
LTA nr. 26	
Fermata: OSPEDALE	Orario: 18:00-24:00
LTA nr.259	
Fermata: P.ROMA(RAMPA)	Orario: 00:00-8:00
LTA nr. 179 – 352 - 265	
Fermata: P.ROMA(RAMPA)	Orario: 8:00-18:00
LTA nr. 245 – 141 – 308 – 249 – 300 – 206 – 41 -362 – 214 – 50 – 36 – 225	
Fermata: P.ROMA(RAMPA)	Orario: 18:00-24:00
LTA nr. 235 – 378 – 213 – 46 – 52 – 192 – 159	
Fermata: P.ROMA(RIO NOVO)	Orario: 8:00-18:00
LTA nr. 321 – 177 – 224 – 296 – 5 – 358 – 142	
Fermata: P.ROMA(NOVO)	Orario: 18:00-24:00
LTA nr. 372 – 347 – 150	
Fermata: RIALTO(CARBON)	Orario: 8:00-18:00
LTA nr. 43 – 167 – 318 – 37 – 16	
Fermata: RIALTO(CARBON)	Orario: 18:00-24:00
LTA nr. 131	
Fermata: RIALTO(CERVA)	Orario: 8:00-18:00
LTA nr. 253 - 216	
Fermata: RIALTO(CERVA)	Orario: 8:00-18:00
LTA nr. 309 – 263 – 132 – 210 – 199 – 158	
Fermata: RIALTO(CERVA)	Orario: 8:00-18:00
LTA nr. 353 – 29	
Fermata: SAN MARCO(CA' DI DIO)	Orario: 8:00-18:00
LTA nr. 255 – 18 – 304	
Fermata: SAN MARCO(DANIELI)	Orario: 00:00-8:00
LTA nr. 340 - 368	
Fermata: SAN MARCO(DANIELI)	Orario: 8:00-18:00
LTA nr. 247 – 356 – 371 – 251 – 258 – 298 – 264 – 125 – 175 – 236 – 49 – 27 – 373 – 346 - 234	
Fermata: SAN MARCO(DANIELI)	Orario: 18:00-24:00
LTA nr. 34 – 23 – 292 – 267	
Fermata: SAN MARCO(LONDRA)	Orario: 8:00-18:00
LTA nr.173 – 310 – 222 – 21 – 360 – 119 – 202 – 9	
Fermata: SAN MARCO(LONDRA)	Orario: 18:00-24:00
LTA nr. 252 - 31	
Fermata: SAN MARCO(MOLO)	Orario: 00:00-8:00
LTA nr. 138 – 239 - 320	
Fermata: SAN MARCO(MOLO)	Orario: 8:00-18:00
LTA nr. 128 – 366 – 218 – 6 – 205 – 14 - 262 – 4 – 133 – 350 – 17 – 232 – 254 – 178 – 375 – 266 – 203 – 348 – 19 – 174 – 361 – 351	
Fermata: SAN MARCO(MOLO)	Orario: 18:00-24:00
LTA nr. 25 – 121 – 367 – 32 – 35 – 200	

Fig.3.1 - Picture with the location of each station.

Having made this premise, in order to best adapt the study carried out with the available software, various assumptions were made in order to make the simulation more truthful and more fluid and to remedy some shortcomings dictated by the lack of information in possession and the lack of a predetermined model of boat, absent in the software used. These assumptions have valid arguments, which will be explained, and have not been made ignoring the possible consequences and shortcomings that could, consequently, follow one another.
The assumptions made concern the routes studied, the vehicle used, the shifts.

3.2.1 ROUTES

The assumptions regarding the sections were made both for a reason of interest and to adapt to the software; in fact, the chosen routes, show in the following figure, are the 4 routes most requested by tourists[22] to taxi drivers, and therefore the most accomplished and which must also be ensured with the change of propulsion; in addition to this reason, it was necessary to adapt the software, AnyLogic, which does not contain in its Libraries predetermined models of boats and movements on water, which does not make it possible to use the GIS map in an effective and optimal way[23] as the movements it supports concern only the sections on roads and for 4-wheeled vehicles. For this reason, the routes traveled have been drawn by hand[24], first using Google Earth and then in AnyLogic, causing some errors in the length of the route and in the distance.

Fig.3.2 - the chosen routes.

[22] This preference was confirmed during the interview with Dr. B. Carrera, responsible for the means and transport of the Venetian lagoon.
[23] GIS implementation allows to support OpenStreetMap maps.
[24] the modalities will be explained in detail in the explanation of the model.

Once the route had been drawn, given the lack of creating a true simulation of the journey and the motion that the boat makes, each single section was divided into further sections in which the vehicles moved with uniform rectilinear motion or uniformly accelerated motion, so to be able to calculate the timing, accelerations, and data regarding consumption. It is evident that such a motion cannot best represent a real scenario, which is why a percentage of error has been inserted which increases the results obtained by 20%. The accounts carried out will be analyzed and explained in detail in the next chapter.

As a second assumption, atmospheric phenomena, and scenarios in which the sea is very rough and creates problems for navigation have been ignored, as they are particular phenomena, and therefore not considered in the common scenarios.

3.2.2 CHARGING STOP

The assumptions regarding the necessary top-ups and the related times required are in contrast with the current taxi service system which, as explained above, very often does not stop for long, or it even skips stops during the shift. Obviously, speaking of electric vehicles, we cannot but talk about recharging methods and recharging times due to intrinsic properties of the type itself which, with current technologies, often requires times that are not comparable with the stop for refueling of ICE vehicles.
For this reason, you have to choose two modes, micro recharges as soon as the vehicle is stationary or micro recharges as soon as it stops to complete the recharge. This study focuses on the second mode for practical and theoretical reasons: first of all, this thesis takes into consideration the State of Health (SOH) of the battery, which is not conducive to repeated and complete cycles of charge and discharge, but it is more optimal to carry out continuous refills. However, it would be difficult to guarantee battery management in this way, and it was deemed appropriate to recharge while remaining in the range 25-80% of the State of Charge (SOC) of the battery itself.
Furthermore, in favor of the choice made, as will be explained in detail in the next chapter, the energy required to make the longest route is about 25% of the total charge[25].
And therefore, to ensure the complete development of the section, it is necessary to have at least the same amount of energy available.
Finally, it was considered more productive to carry out longer top-ups to ensure the correct performance of the service, allowing taxi drivers to leave immediately once they arrive if the SOC is sufficient to complete the route.

These assumptions are the result of the available technology, which does not allow autonomy close to the boats used now.
For these reasons, different scenarios will be analyzed, short, medium, and long term, in which the percentages of full electric taxis increase to the detriment of current vehicles or hybrid vehicles.

[25] Taking into account a battery pack with 80kWh available.

3.2.3 ELECTRIC BOAT

"No vehicle is in the wrong environment like a boat in the water, just as there is no resistance greater than that encountered by a boat while sailing." This quote, extrapolated from a speech explaining the resistances in a boat [49], is the main focus of the assumptions made regarding how a boat works. As I will explain, the drag resistance of a boat is a very important data regarding the consumption of the boat itself and it is not a fact that can be easily ignored unlike the accounts that can be carried out with viscous friction of the air, since the liquid in which it is immersed has a viscosity undoubtedly, and immensely, greater than that of air.
To corroborate what has been said, the engines of boats are replaced on average every 2000/3000 hours of navigation, while an engine of a car or vehicle on a wheel can last up to ten years and hundreds of thousands of kilometers without difficulty, precisely at due to the effort that is made to overcome these resistances during motion.

As for the assumptions made, and the reasons that led to them, on the study medium are the result, first of all, of a lack of data necessary for the creation of a model as similar as possible and the particularity involved in creating a boat model. In fact, during the research of the material to carry out this study, the peculiarity of how a model of a boat is born, which is not only the result of drawings and models, but there is the need for a study, in specific conditions and basins, of the resistances to which it is subject, which do not strictly depend on pre-established physical laws, but depend on the model and the surfaces in play. For this reason, the lack of studies carried out on a boat model makes it almost impossible to perform a correct simulation close to real behavior.

To obtain the resistance values of a boat, the shipyard carries out studies on scale models; the results obtained are very valid and close to the behavior that the boat will have subsequently, thanks to the studies carried out by Froude,[26] which affirm the similarity of the values obtained from the model of the boat with those of the real boat using a coefficient of Lambda simile, seen in Fig 3.3. This shows how the resistances involved in a boat are not the result of rigorous physical formulas, but of studies on models, and consequently are difficult to replicate in the absence of them.

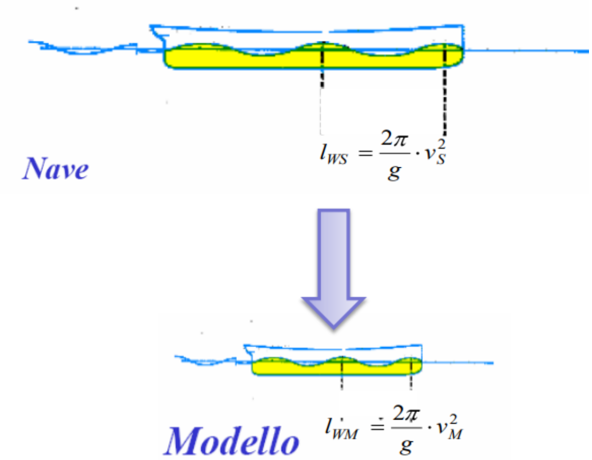

Fig. 3.3 - Explanatory slide of the similarity of Froude's method.

[26] Concepts argued and explained in these slides. Corso di Tecnica ed Economia dei Trasporti I, Trasporto Marittimo, UNIVERSITÀ DEGLI STUDI MEDITERRANEA DI REGGIO CALABRIA - FACOLTÀ DI INGEGNERIA.

In order to obtain the real values, according to Froude's method, we rely on the similarity dictated by the Lambda constant and the following conversion equations:

$$\lambda = \frac{l_{ws}}{l_{wm}}; \quad (1)$$

$$l_{ws} = \frac{2\pi}{g} * v_s^2; \quad (2)$$

$$l_{wm} = \frac{2\pi}{g} * v_m^2; \quad (3)$$

From which it’s possible obtain:

$$\lambda = \frac{v_s^2}{v_m^2}; \quad (4)$$

$$\frac{v_s}{v_m} = \sqrt{\lambda}; \quad (5)$$

Where l_{ws} and l_{wm} represent the length of the transverse waves generated by the model and the real boat, v_s^2 and v_m^2 are the two relative speeds and finally g is the gravitational acceleration.

Consequently, the resistances that were used are the result of a study obtained from bibliography[27], in which an analysis was carried out in a wind tunnel on a planing boat, like the one under consideration. The study, however, analyzed the model of the boat for speeds above 3 m / s and for this reason it was necessary to perform an interpolation of the data to have a forecast of the resistance trend as the navigation speed varies.
As a last step, since the motion of the boat has uniform sections, as described above, the average values of the resistances were obtained to be able to use them at the speeds necessary for this study.

The results that will be obtained will therefore be conditioned by this assumption, which however was made necessary due to the lack of replicable data and the lack of a predetermined model in the software that was used. To fix these errors, a 20% increase in the values obtained was used to try to compensate for the gaps obtained from these assumptions.

[27] “CARATTERIZZAZIONE AERODINAMICA DI UN’IMBARCAZIONE PLANANTE mediante prove in galleria del vento”, D. Porzani, a.y. 2011/2012, Politecnico di Milano

3.3 ANYLOGIC SOFTWARE

AnyLogic is a simulation software based on object-oriented conception, which combines three main simulation methodologies: SD (system dynamics), DE (discrete events) and AB (agent-based modeling), that support different types of simulation i.e., by varying the parameters to be entered or by optimizing the production chain.
The main constituent element of the AnyLogic model is an active object that has its own unique functionality and interacts with its environment, containing attributes, methods, and behaviors, defined using state graphs.
Finally, a simulation model in AnyLogic consists of a set of active objects that function simultaneously and interact with each other.
The AnyLogic simulation environment can be used in different application problems, such as epidemic modeling, industrial development, complex system project evaluation, computer performance evaluation, military systems, transportation systems, supply chain management, and business process evaluation.
This system called COVERS (Concurrent Verification and Simulation) allows the analysis of graphic modeling and system behavior.
AnyLogic was developed with the intention of providing a new-generation software that would allow simulation, performance, behavioral optimization, and visualization analysis of stochastic systems

3.4.1 LANGUAGE AND OPERATION

AnyLogic's creation was inspired by Java, which is the ideal language for model makers. Java is the most used programming language on the planet and nowadays billions of electronic devices use Java technology because of itsmain features such as
1. the simple syntax, similar to that of C or C ++.
2. the fact that the code can be written using a notepad without paying for licenses.
3. the fact that the memory management mechanism is automatic. Moreover, the fact that the compiler is very strict and obliges the programmer to resolve all error situations ensures a greater possibility of program operation.
4. the fact that Java is a high-level language above all thanks to its standard class libraries documented in detail. This also allows those who approach Java for the first time to create complex applications.
5. the writing of the program in Java, which is independent of the platform for which it is intended;
6. the fact that this independence is made possible thanks to the Java Virtual Machine (JVM), a software that acts as an interpreter for Java applications.
After writing the Java program you must compile it, thus obtaining a file that contains the translation into a machine language called "byte code". Once this file is obtained, the JVM will interpret the byte code and the program will go into execution. The tools provided by Java require object-oriented programming, but the paradigms of such programming are easily appreciated and understandable as Java is the clearest and most schematic object-oriented programming language. [50]

The simulation through AnyLogic allows you to directly view the model created thanks to interactive 2D and 3D animation and therefore the availability of elements that can be viewed in 3D and 2D. The animation allows us to immediately observe in which direction our model is going and intervene by making changes if what we are achieving does not comply with what we had set for ourselves.

The processes are graphed through diagrams that are different depending on the type of model chosen.
The main ones in AnyLogic are the following

1. Stock & Flow Diagrams, used for modeling in System Dynamics.
2. State charts, used for Agent Based modeling.
3. Process flowcharts, used for modeling in Discrete Event.
4. The Process Modeling Library, used above all for modeling at Discrete Events, for the simulation of assembly lines, company logistics, hospitals thanks to the provision of elements such as vehicles, customers, products, resources that we can graphically represent and then observe in the simulation. The blocks representing the process include delays, files, services, resource usage and are arranged to structure a flowchart.
5. The Pedestrian Library, which is dedicated to the simulation of models that simulate a flow of pedestrians such as the subway station or security checks or roads.
6. The Rail Library, which supports modeling of railway stations.
7. The Fluid Library, that allows modeling of fluid storage and transfer processes. The elements available allow the representation of tanks, pipes, valves, and routing objects.
8. The Road Traffic Library, which allows you to simulate urban traffic allowing a detailed modeling of the vehicle. Each vehicle represents an agent with a behavior and moves within a road network that considers driving rules such as traffic lights, pedestrian crossings, movements of public transport.
9. The Material Handling Library, which allows modeling of processes within factories and warehouses. It has elements such as conveyor belts and trolleys for handling.

Another powerful tool made available by AnyLogic, and which has been widely used for the project it will later analyze, is the maps. As previously mentioned AnyLogic supports maps from free providers such as OpenStreetMap, they are mainly used for modeling geospatial paths for agents. [50]

3.4.2 AGENT

In AnyLogic, agents can have different representations, as they are the main building blocks; for this reason, it is possible to represent different scenarios simply by customizing the various properties.
Within an agent it is possible to define variables, events, state diagrams, flowcharts, and furthermore, it is possible to incorporate other agents by adding them with process flowcharts. You can define as many types of agents in the model as there are different types of agents. [51]
The design of an agent begins with the identification of its properties, behavior, and interface with the external world. In the case of many agents, it is possible to create an entire population of agents that have the same properties and behavior.
The internal state and behavior of the agent can be implemented in different ways, describing with the Java language every single step, or using state diagrams or flowcharts, also implemented with the use of special Modeled Libraries such as Pedestrian, Railway, Road traffic, etc.; the behavior can be say passive, i.e., performing the indicated actions upon receiving messages, timing or function calls, or active in the whole simulation dynamics, calling other agents itself.

3.4.3 PROPRIERTIES

Agents can have parameters, i.e., features that are used to represent some characteristics of the modeled object and are useful when instances of the object have the same behavior described in the class but differ in some parameter values.
All parameters are visible and editable during model execution, so that it is possible to modify the model by varying the parameters at runtime, but generally, it is a constant in a single simulation, and is changed only when it is necessary to adjust the behavior of the model. [51]

3.4.4 VARIABLE

The agent may contain variables, used to store model simulation results or to model certain data units or object characteristics, which change over time, that can be grouped into data collections, used to define data objects that group multiple elements into a single unit.
The variable, in AnyLogic, is a simple variable of arbitrary scalar type or Java class, with a value always assigned, but, when this is not specified, it takes on a value of type double null. Similar to other simulation tools, AnyLogic supports variables of primitive types: double, integer, Boolean, but in addition, variables of any Java class are also supported. [51]

3.4.4 STATE CHART

State chart is the most advanced construct for describing event- and time-driven behavior; this ordering of events and time of operations is so pervasive that it is best characterized in terms of a state transition diagram.
State chart is characterized by states and transitions. Transitions can be triggered by user-defined conditions such as timeouts, messages received from the state diagram, or Boolean conditions, while the execution of the transition can lead to a state change in which a new set of transitions becomes active. The states in the state chart can be hierarchical, that is,containing other states and transitions. [51]
In order to better understand, in the following Figure it is possible to observe the construction of a state chart and its components.

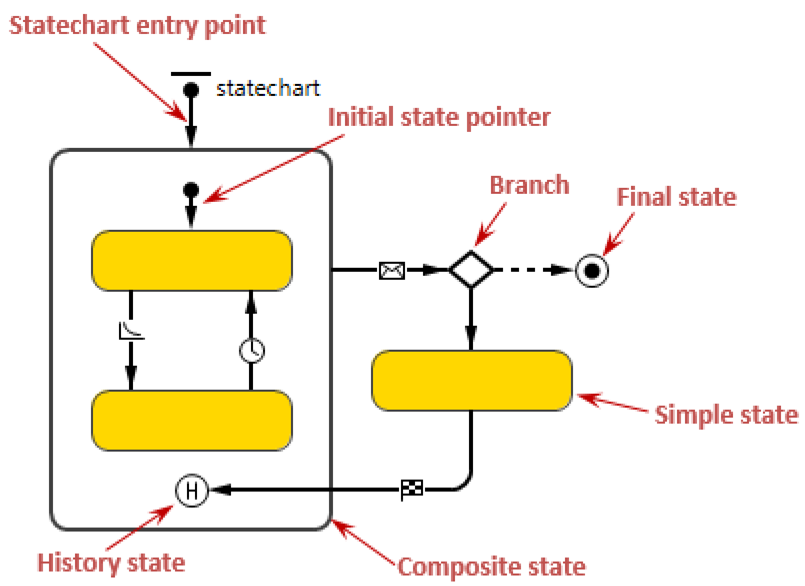

Fig. 3.9 - Statechart explanation. [51]

3.4 ANYLOGIC MODEL

As in any programming code, the created model begins with the creation of a Main, which will collect all the agents in the field.
Once the temporal unit of the model was defined, set in minutes, the simulation environment was created using the GIS map, as shown in Fig.3.10; although the software gives the ability to take advantage of the map to create routes automatically using various navigation libraries, the route I used was defined and drawn by hand, through special functions, due to the lack of ship routes in the software.

Before drawing the route, the agents StationSanMarco and StationAirport, described by their geographic coordinates, and the agent Yellow, which encapsulates the properties of the yellow route such as accelerations, velocities, resistances, etc., were defined.
The two stations will serve as the starting and ending points of the Yellow route and also as charging points for the arriving cabs, with available seats and power outputs defined, while the Yellow agent was created so that all of its properties are encapsulated in the simulation database, so that a fluid simulation code in which it is sufficient to call the individual variables specified in the agent itself can be created.

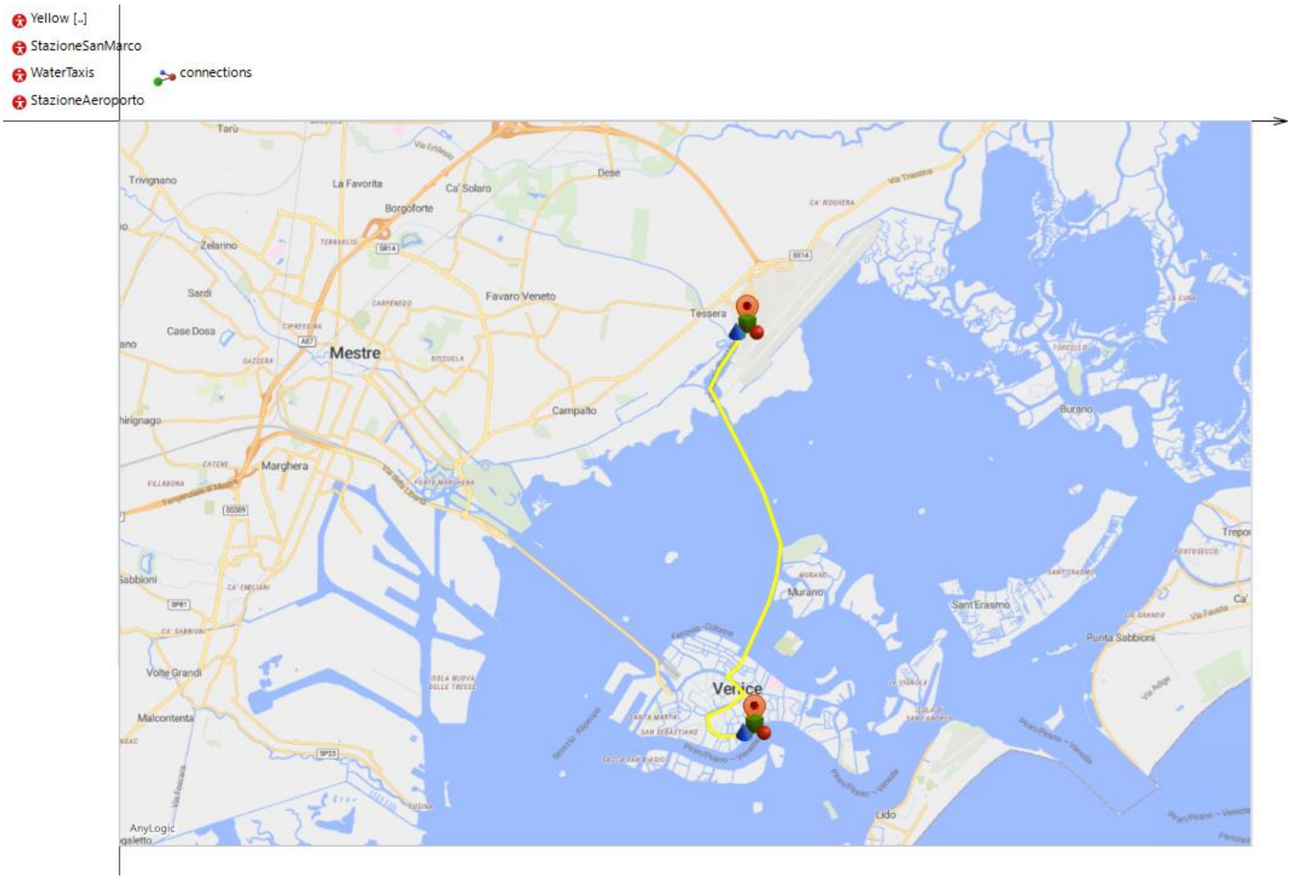

Fig.3.10 - Main and GIS maps of the model.

After describing the simulation environment, the Water Taxi population agent, which is the core of the simulation itself, was created, as shown in Fig. 3.11.
In order to recreate the desired simulation, the various specific characteristics of the agent (such as mass, engine power, battery pack capacity etc.) and the number of vehicles involved in the simulation were defined as first.

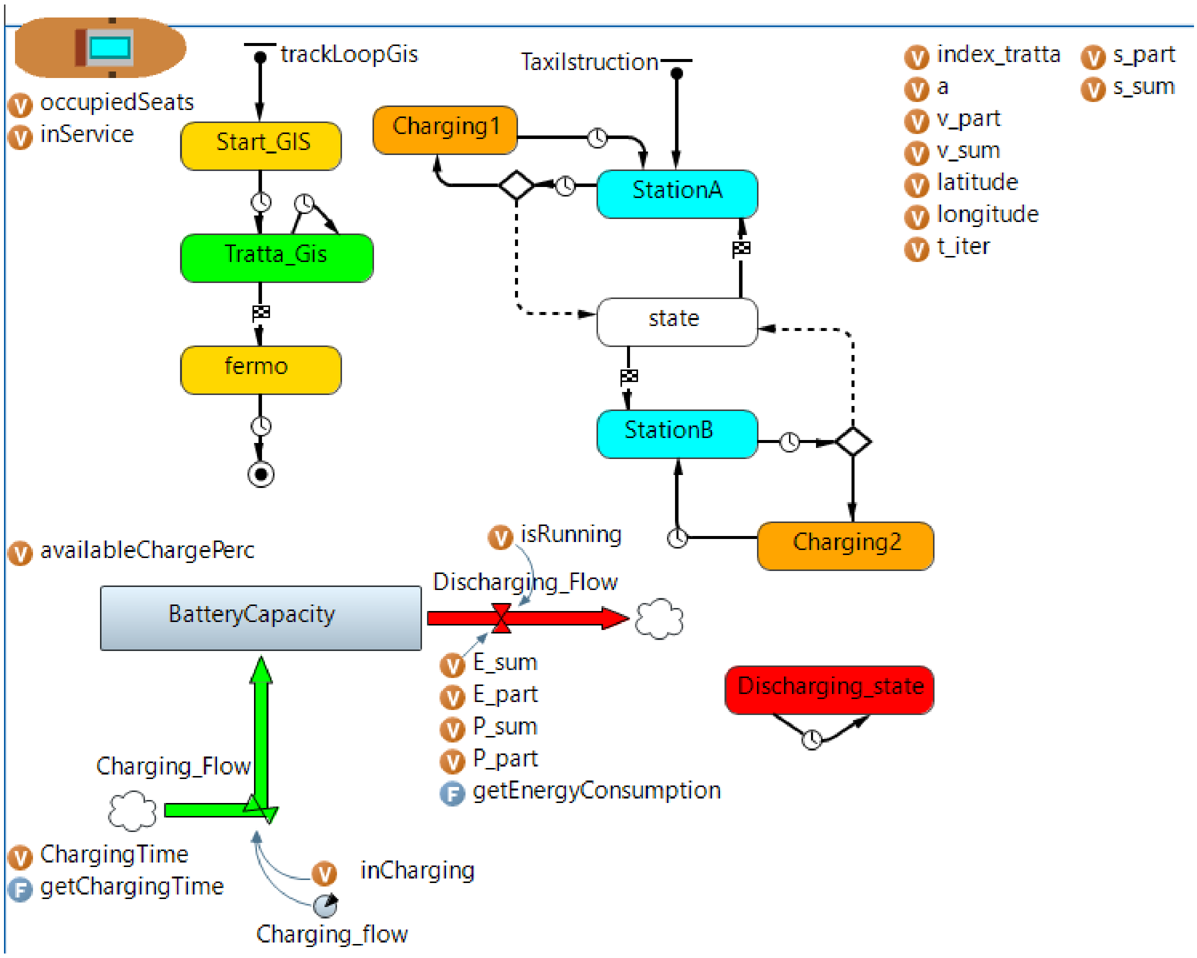

Fig. 3.11 - Water taxi's description.

After defining all the characteristics of the agent, its behavior was defined thanks to two state charts, one related to the departure and arrival inputs, called TaxiIstruction, and one related to the behavior to be adopted along the entire route, called TrackLoopGIS, and, finally, a flow chart that allows the simulation to manage the flow of battery charging and discharging.

Starting with the TaxiIstruction state chart, it encapsulates the basic commands for the simulation, such as departure, arrival, and charging of the vehicle; in the StationA and StationB states, the departure and arrival stations have been defined, which alternate based on the direction of the route, while through the two branches, the state of battery charge is analyzed and, based on the state itself, the vessel can either proceed to leave for another trip or stop at the station to recharge. This analysis is done in a loop every few arbitrarily defined seconds.

As can be guessed, these commands simply allow the movement from one station to another, but without taking into account the morphology of the route itself and without being able to give useful outputs for the simulation. For this reason, a second state chart dedicated to the description of the route and the energy management of the craft was created. It should be specified that this was a personal choice of the developer, since it was possible to create a single, more complex and articulated state chart, but the choice fell on two separate state charts to make both the creation of the simulation and any changes and modifications easier.

The TrackLoopGIS state chart, on the other hand, is the heart of the energy and travel management of the chosen stretch, in particular the pivotal state is the one called

Tratta_GIS, where with a code, shown in Fig 3.12 a and 3.12b, all the behaviors to be maintained in the stretch have been specified; to do so, the entire route has been divided into stretches, which are described by specific conditions, as specified in Section 3.3, in which the vessel must maintain constant acceleration or speed values.

```
//obtain taxi coordinations
latitude=getLatitude();
longitude=getLongitude();

if(latitude==45.43278 && longitude==12.3386)
    {isRunning=0;}
else{isRunning=1;
//ACCELERATION 0-7
if(v_sum<1.94)
           {index_tratta=0;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            v_part=a*t_iter;
            v_sum=v_part+v_sum;
            s_part=0.5*a*t_iter*t_iter;
            s_sum=s_part+s_sum;}
//COSTANT_7
else if(v_sum>=1.94)
           {index_tratta=1;
            v_sum=1.94;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            s_part=v_sum*t_iter;
            s_sum=s_part+s_sum;}
//ACCELERATION 7-11
else if(latitude==45.445 && longitude==12.337)
           {index_tratta=2;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            v_part=a*t_iter;
            v_sum=v_part+v_sum;
            s_part=0.5*a*t_iter*t_iter;
            s sum=s part+s sum;}
```

a.

```
//COSTANT 11
else if(v_sum>=3.056)
            {index_tratta=3;
            v_sum=3.056;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            s_part=v_sum*t_iter;
            s_sum=s_part+s_sum;}
//ACCELERATION 11-20
else if(latitude==45.460 && longitude==12.343)
           {index_tratta=4;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            v_part=a*t_iter;
            v_sum=v_part+v_sum;
            s_part=0.5*a*t_iter*t_iter;
            s_sum=s_sum+s_part;}
//COSTANT 20
else if(v_sum>=5.56)
           {index_tratta=5;
            v_sum=5.56;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            s_part=v_sum*t_iter;
            s_sum=s_sum+s_part;}
//DECELERATION 20-0
else if(latitude==45.490 && longitude==12.328)
           {index_tratta=6;
            a=main.Yellow.get(index_tratta).a;
            latitude=getLatitude();
            longitude=getLongitude();
            v_part=a*t_iter;
            v_sum=v_part+v_sum;
            s_part=0.5*a*t_iter*t_iter;
            s_sum=s_sum+s_part;}
//ARRIVE
else {isRunning=0;}
}
```

b.

Fig. 3.12 - Code to describe the course of the course.

From reading the code, one can infer the use of the database created in the Yellow agent, from which accelerations are called, using the index_tract variable to be able to choose which values to assign to each leg, while velocities are specified each time.
In addition, the conditions of the if loops are dictated by both the coordinates and the velocity; in particular, the acceleration strokes are defined by the geographic coordinates of the point on the path where the velocity can be increased, while the constant strokes are accessed by the velocity conditions to be used in the individual stroke.

Just as with the charging action, a loop cycle defined by a 2-second t_iter variable was created for this state, allowing the simulation to calculate the travel speed and the space traveled, updating the data every 2 seconds. In fact, two distinct variables for both speed and space defined as v_part and v_sum or s_part and s_sum are specified in the code, where v_part and s_part are the values obtained for each calculated loop cycle, while the v_sum and s_sum values are the summed values of each individual loop cycle.

Finally, the flowchart was used to handle the discharging and charging of the battery, which assimilates with the discharging_state to allow the simulation to calculate the energy consumed during the run. In order to handle this flow, two variables were needed to act as switchers between the two states Charging and Discharging, called inCharging and isRunning, which take values 0 or 1 depending on the conditions the boat is in.

To handle the Discharging state, the behavior was described through a code within the Discharging_state, as shown in Fig. 3.13.

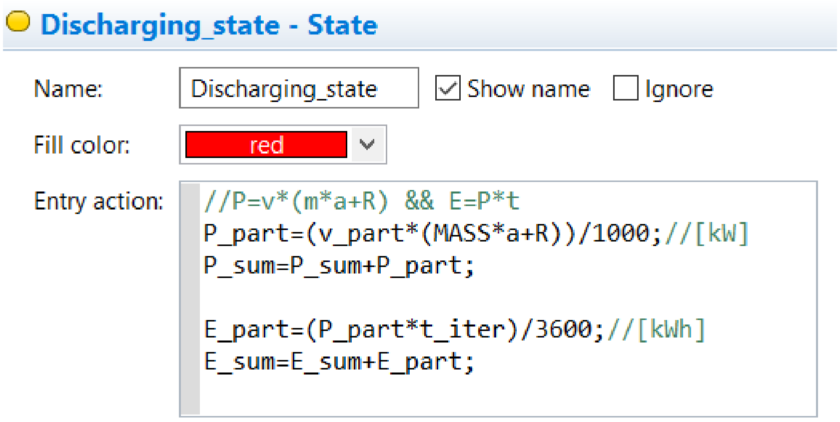

Fig. 3.13 - Discharging State code.

As previously done for space and velocity, it was necessary to introduce a loop cycle, every 2 seconds, in which the power P_part and energy E_part consumed in the accomplished stretch is calculated, which then, added together each time, return the values of P_sum and E_sum and allow to precisely calculate the consumption of the vehicle.

4. SIMULATION AND RESULT

Starting from the analysis of the territory and the taxi service thanks to Dr. B. Carrera it was possible to find out about the GEOSMA Geoportal[28] of the Municipality of Venice, accessible to all, where it was possible to see in detail every single taxi service station and all the shifts of licenses. In addition, the stations were analyzed in the best possible way in order to be able to design and organize the loading and unloading maneuvers of tourists and the loading and unloading maneuvers of the boats in service.

Later, Google Earth software was used to recreate the routes chosen for the study.

Fig. 4.1 - map of the routes studied.

As shown in Fig.4.1, the paths chosen are 4, highlighted with different colors:

a. Orange: this route connects the Santa Lucia railway station to the Lido station (bottom right). This route allows tourists arriving in Venice by train to reach the seaside area of the Lagoon.

b. White: this route connects the Santa Lucia railway with one of the most important attractions in Venice, the Rialto bridge, a must for all tourists who visit the city.

c. Yellow: this is one of the two most critical and most important sections of the taxi service, but also one of the most requested; in fact, it connects the Venice

[28] Website: https://www.comune.venezia.it/it/content/geosma

airport terminal (top left) to the most important square in the city, San Marco, which is home to many of the most important hotels in Venice nearby.

d. Purple: this route represents the longest route that a taxi driver has to take, but not the most frequent, which connects the square of San Marco to the islet of Burano (top right), a tourist resort known for its beauty and for being the most colorful city in Italy, thanks to its colorful houses.

As mentioned above, the highlighted routes were drawn by hand, using the "ruler" function in the Google software, allowing me to calculate the length of the route, following the guidelines obtained, and following an interview with the water transport manager. Obviously, being a route dictated by guidelines and reconstructed on the computer by hand, it will not be completely identical to what taxi drivers take every day, but it can be a faithful replica of the real one.

After having drawn them, it was possible, in an arbitrary way, to divide the individual paths into sections: they, in fact, contain acceleration sections, cruising sections with uniform speed and a deceleration section.

Tab 4.1 - Tables showing the data relating to the 4 routes in sectors.

ORANGE				
tratta A 0-7 km/h	tratta C 7 km/h	tratta A 7-11 km/h	tratta C 11 km/h	tratta D 11-0 km/h
200 m	3000 m	200 m	2370 m	500 m
t=30 s	1543 s	t=27 s	776 s	t=45 s
a=0,44 m/s^2	t=25 min e 42 s	a=0,3 m/s^2	t=13 min	a=-0,36m/s^2

WHITE		
tratta A 0-7 km/h	tratta C 7 km/h	tratta A 7-0 km/h
100 m	1288 m	188 m
t=20 s	t=662 s	t=27 s
a=0,5 m/s^2	11 min	a=-0,36m/s^2

YELLOW						
tratta A 0-7 km/h	tratta C 7 km/h	tratta A 7-11 km/h	tratta C 11 km/h	tratta A 11-20 km/h	tratta C 20 km/h	tratta D 20-0 km/h
200 m	2700 m	90 m	2015 m	315 m	2980 m	1400 m
t=30 s	t=1389 s	t=15 s	t=659 s	t=30 s	t=536 s	t=8 min e 24 s
a=0,44 m/s^2	23 min e 8 s	a=0,5 m/s^2	t=11min	a=0,5m/s^2	t=8 min e 56 sec	a=-0,011 m/s^2

PURPLE						
tratta A 0-7 km/h	tratta C 7 km/h	tratta A 7-11 km/h	tratta C 11 km/h	tratta A 11-20 km/h	tratta C 20 km/h	tratta D 20-0 km/h
200 m	2700 m	90 m	2910 m	315 m	3785 m	1200 m
t=30 sec	t=1389 s	t=15 s	t=952 s	t=30 s	t=681 s	t=7min e 12 s
a=0,44 m/s^2	t=23 min e 8 s	a=0,5 m/s^2	t=15 min e 52 s	a=0,5m/s^2	t=11 min e 21 s	a=-0,0128 m/s^2

As you can see in the table, the subdivision into sectors made it possible to calculate the acceleration and travel times, important data that will later be compared with the data that will be obtained in simulation.

In order to obtain the data in the table, the constituent equations of the motions examined (URM and UARM) were used:

For uniformly accelerated rectilinear motion:

$$s = \frac{1}{2}a\,(t - t_0)^2 + v_0(t - t_0); \tag{6}$$

$$v = v_0 + a(t - t_0); \tag{7}$$

For uniform rectilinear motion:

$$s = v(t - t_0) + s_0; \tag{8}$$

where s is space, a is the acceleration, t is time and v is the speed.

Once the data concerning the accelerations were obtained, the forces acting on the boat during motion were analyzed:

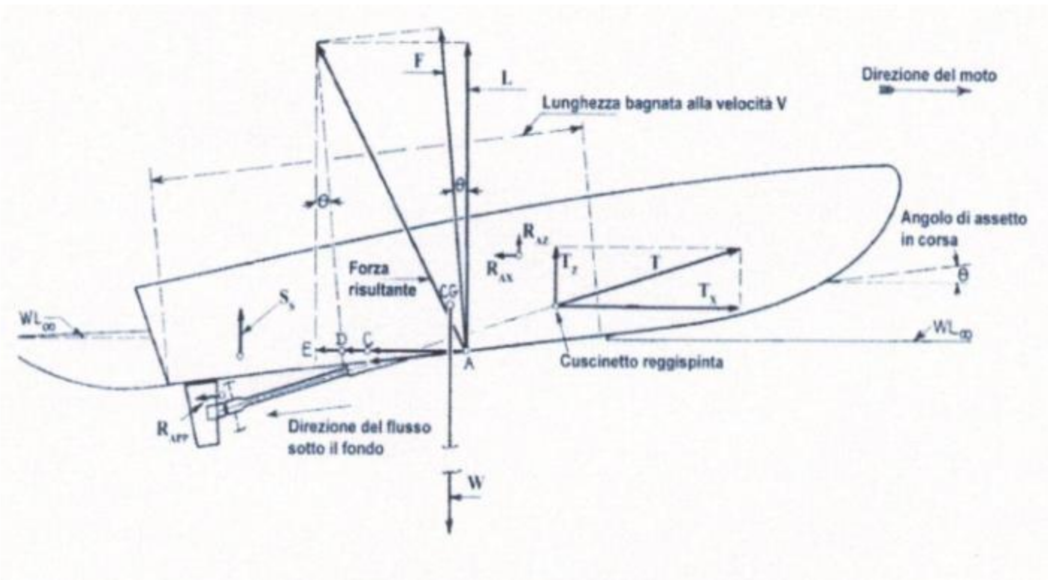

Fig. 4.2 - Diagram of the forces acting on a boat.

As can be seen in Fig. 3.5, the forces acting are broken down according to the angle of the boat it assumes during motion; The vertical forces, Archimedes' thrust and the force of gravity shown in Fig.3.6, are obviously equivalent, while the motion is due to the resultant of the longitudinal forces.

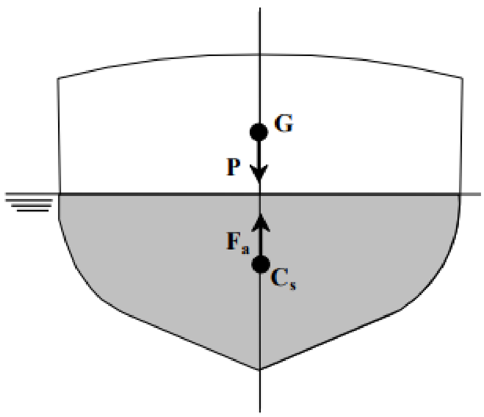

Fig. 4.3 - Diagram of the vertical forces in a boat.

Considering only the latter, the component to be won is that of resistance due to a viscous friction component of the water and, to a lesser extent, to the viscous friction of the air. Unlike wheeled vehicles whose frictional force is given more by the friction generated by the road, or rails, the resistances in a boat have different components and depend on different factors.

The force that opposes the motion is called resistance to forward movement RTS, and is equal to the component, in the direction of the motion of the resultant, of the dynamic forces exerted by the fluid, and, consequently, in order to proceed the boat must overcome this force, which however strictly depends on the speed of navigation.
The trend of RTS, for a boat used for the fast transport of people, is not linear, but has a curve that can be divided into two macro-zones, the first part of the curve in which resistance increases rapidly with speed, while a second part where the curve is flatter, as shown in Fig. 4.4.

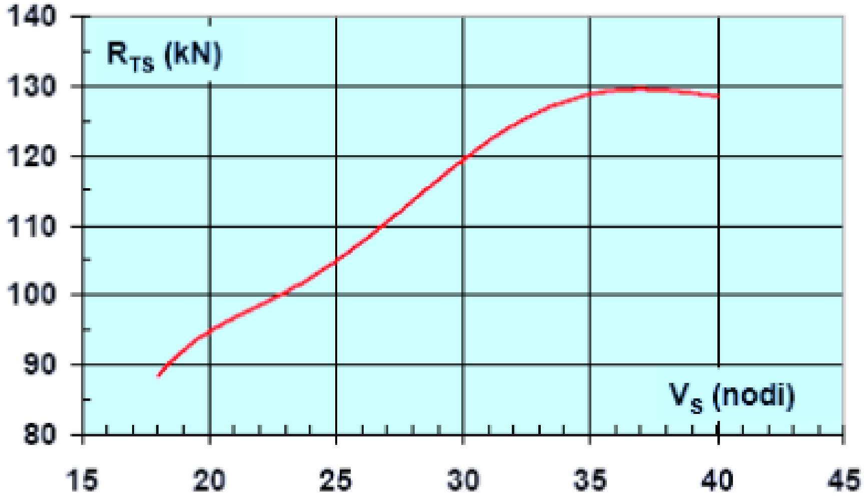

Fig. 4.4 - Example of the curve profile relating to the resistance to advancement of a boat for transporting people.

Furthermore, R_{TS} turns out to be a sum of several components that act on the boat:

$$R_{TS} = R_F + R_W + R_A ; \qquad (9)$$

where R_F is the viscous resistance of water, R_W is the wave resistance and, finally, R_A is the resistance of air.

RW is the force opposite to the direction of motion of the hull and corresponds to the energy transmitted by the hull to the wave formation it produces; the wave train generated includes two divergent wave systems (stern[29] and bow[30]) and two transverse wave systems (stern and bow) between the ship and the diverging waves, as shown in Fig.3.8.

[29] Stern: rear part of a boat.
[30] Bow: the front of a boat.

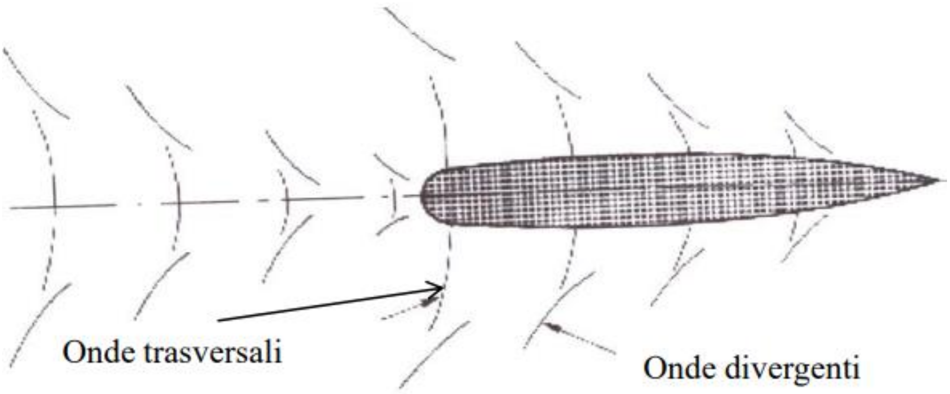

Fig. 4.5 - Depiction of the wave systems generated by a boat.

The air resistance R_A, on the other hand, depends on the speed of the ship, the viscosity of the air and is linked to the strength of the wind and the direction of the latter.

The contribution of each individual resistance varies from the type of boat being studied, but generally the greater contributions are dictated by the presence of wave resistance and friction resistance with percentages that vary greatly.[31]

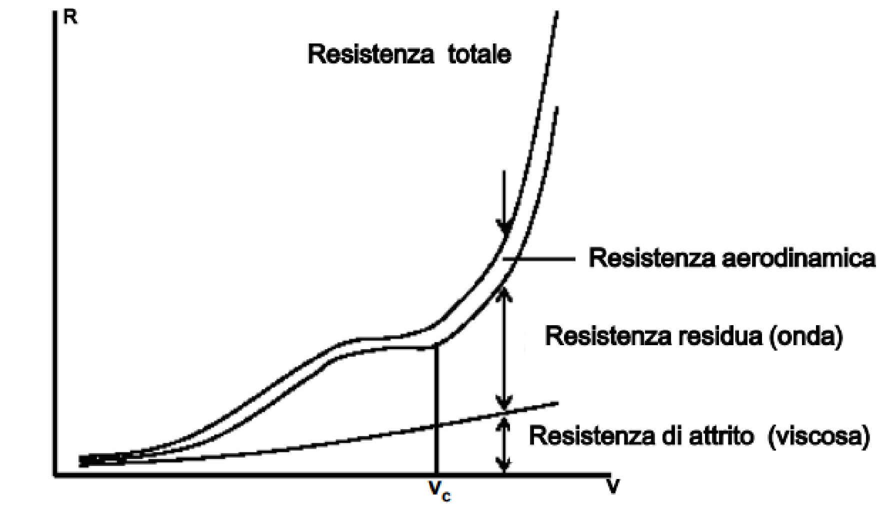

Fig. 4.6 - Example of the present components of the R_{TS} Total Resistance of a freight ship.

A further difference from wheeled vehicles, as far as the resistances acting in a boat is concerned, is the lack of a close correlation with physical formulas that can best describe the curve; in fact, although we have tried to find a formula, during the design of a boat, measurements are made on a scale model, in the wind tunnel and in special tanks to simulate the real functioning process that the boat will have once put into operation service.

These surveys, therefore, give empirical data and are made with reference to the method of Froude, a marine engineer of the 1800s, who developed this method to obtain the resistance values directly from a scale model, noting a correlation of behaviors between the boat and

[31] As for the wave resistance, the trend of which depends on the cube of the speed is about 10-60 percent of the RTS; while the Viscous Resistance Rf reaches 40-90 percent of the RTS.

its scale model. He noted that this bond depended on a simple ratio of magnitudes, called the Lambda coefficient which turns out to be equal to the ratio of the two lengths of the transverse waves drawn on the respective hulls.

As explained in chapter 3.2.3, in the absence of data regarding the resistances of the model examined, resistances calculated on a catamaran were considered in a thesis study carried out in the wind tunnel [52] and following appropriate adaptations due to the different dimensions of the two models it was possible to obtain resistance values.
Finally, in order to be able to use data in the sections in question at specific speeds, an average of the values was made, thus obtaining the following values used as resistances:

- V= 7 km/h → R_{TS}= 7,512E+3 kN
- V= 11 km/h → R_{TS} = 4,30E+3 kN
- V= 20 km/h → R_{TS} = 3,47E+3 kN

At this point, it was possible to obtain consumption forecasts taking into account the resistances.
From the second principle of forces:

$$\Sigma F = m * a; \tag{10}$$

the propulsion force necessary to perform the desired displacement at the required accelerations was obtained. Subsequently, the values obtained were multiplied by the travel speed thus obtaining the power required for advancement, obtaining the results in Tab.2.

Tab. 4.2 - Power and Energy consumption of each track.

	PowerConsumption	EnergyConsumption	EnergyConsPercent
Orange	92,769 kW	12,00 kWh	15,00 %
White	56,318 kW	3,63 kWh	2,90 %
Yellow	155.690 kW	16,64 kWh	20,79 %
Purple	155,668 kW	18,63 kWh	23,29 %

In order to reduce the measurement error made with the assumptions made, the values have been increased by 20 percent, a large margin of error, with the intention of getting closer to the real measurements, or at most exceeding them, guaranteeing greater certainty about feasibility of the project, thus obtaining the following data:

Tab. 4.3 - Power and Energy consumption of each track with error compensation.

	Power Consumption	Energy Consumption	Energy Cons Percent
Orange	111,323 kW	14,402 kWh	18,00%
White	67,582 kW	4,354 kWh	5,44%
Yellow	186,828 kW	19,963 kWh	24,95%
Purple	186,802 kW	22,357 kWh	27,95%

The values relating to Power and Energy consumption alone do not allow a clear picture of how much the sections are more or less expensive. For this reason, it has been reported in the table in terms of consumption in percentage terms, which are more understandable.

It is possible to make some initial considerations on the different routes, the white route, being the shortest one, is easily traveled by electric boats as it involves a very low consumption of the available capacity, while the longer ones, i.e. yellow and purple, involve a remarkable energy expenditure and, with simple calculations, it is possible to notice how carrying out the single round trip involves the discharge of the battery for about half of its capacity, always taking into account current technologies.

In fact, it can be understood that because the routes have different consumption, the service offered will not have homogeneity in duration and continuity of service; while the longer route, under current conditions, can make two trips, round trip, before having to stop and recharge, the shorter route turns out to be more continuous, having 6 times less consumption.
This result makes it immediately clear that while for the shorter routes and within the city canals electric is an excellent and applicable choice in the short term, for the longer routes the road to electrification is a long one, as today's batteries still do not provide the right performance that ICE boats can, although the costs are significantly lower.

4.2 CHARGING ANALYSIS

Once the results obtained are confirmed, it is possible to analyze how to sustain this service in terms of charging and infrastructure.
To do this, the white route was examined, which, being within the city's canals, is the one that is most relatable to real travel and is able to simulate any other travel within the city's "Fish [32]".

Taking into account the consumption calculated in Table 4.3, and allowing for a reserve of 10 percent of the total capacity[33], it is possible to estimate how many trips our boat can make, while also calculating how long it remains in service; in order to calculate how many trips it is capable of making, it is sufficient to make the following calculation:

$$\frac{90\%}{5{,}44\%} = \frac{72\ kWh}{4{,}354\ kWh} = 16{,}544; \qquad (11)$$

Considering precisely 90 percent of the battery capacity, i.e., 72 kWh the craft is able to make 16 complete trips, i.e., 8 departures from the Ferrovia Santa Lucia station and departures from the Rialto station.
For each trip, the cab takes about 12 minutes to perform the leg and consequently, we can say that multiplying by the number of legs it can do, the taxi driver has to stop and charge after about 3 and a quarter hour of service.
At this point, the taxi driver must stop at the charging station and wait for the battery to be fully recharged, which, considering an ultra-fast 55 kW of power installed in the electric charging station, the time taken to recharge will be approximately:

$$\frac{72\ kWh}{55\ kW} = 1{,}309\ h = 1h\ 19\ min; \qquad (12)$$

As a result, on a standard 8-hour shift, the taxi driver will only need to accomplish one recharge, but that is equivalent to about 16 percent of the service time, which is not an insignificant percentage for the service offered, both because of the waiting time and the lack

[32] Name attributed by the citizens of the lagoon city which, from above, takes the shape of a fish.
[33] Equivalent to 8kWh.

of revenue due to it. In order to solve this problem, one must, inevitably, wait for more competitive technologies both in terms of the battery pack and the powers available for charging.

A further analysis can be gleaned from this reasoning, namely the amount of power required to ensure daily service along this route.
Considering only the Santa Lucia Railway station and assuming that the station has a number of charging stations congruent to the service equal to 50 double columns, reasoning that we will address in the next chapter, the energy consumption E_C to ensure charging for all 100 vehicles, per shift, will be:

$$E_C = 72\ kWh * 100 = 7{,}2MWh; \tag{13}$$

And consequently, the necessary daily energy E_d will be:

$$E_d = 7{,}2MWh * 3 = 21{,}6MWh; \tag{14}$$

Therefore, for the Ferrovia Santa Lucia station alone, the daily energy requirement is approximately 22 MWh.

5. CONCLUSION

The results obtained show that this service is indeed electrifiable, especially if we take into account electric transportation for shorter routes, but also, once technology allows, for longer routes, thus ensuring an environmentally friendly service with little environmental impact.

In addition, we can draw from these considerations an important issue to be addressed, which is the excessive consumption for longer routes, which would not guarantee an efficient service and is a far cry from the continuous going of motorboats.
In order to run this service properly, therefore, it is clear that electric vehicles alone, in the immediate term, are not the optimal solution, which is why a gradual path toward electrification of the service must be taken.

For the creation of an application model that is feasible in both temporal and technical terms, it is necessary to introduce an appropriate time perspective, for this reason a scenario was devised that leads to the gradual integration of the full-electric fleet, flanked by hybrid vehicles, which are already present both in the market and, with some examples, in the current cab service.
The scenario prefigures 3 different moments, short term scenario 2022-2030, medium term scenario 2030-2040 and long-term scenario 2040-2050:

1. In this scenario, 100 electric vehicles, or 25 percent of the total, are introduced into the fleet of 400 units to replace the current Gasoline-powered boats allowing the city to have a service, along the inner canals, that is completely electric, reducing both environmental and noise pollution.
   While the remaining percentage will consist of a mix of hybrid and gasoline vehicles, with the number of the former still less than the latter.
   This combination makes it possible to run the longer routes more safely and also allows a gradual replacement of the vehicles to date.

2. The second scenario involves increasing electric vehicles to half the water cab fleet. With research at higher capacities and higher-performance engines, the boats will be able to regularly travel on the longer routes safely and will be able to rely on greater autonomies. Even with more advanced technologies, it is more optimal to have the longer routes, however, be done by vehicles powered by gasoline or hybrids, ensuring electric service on the short to medium length routes.

3. The third scenario envisions a predominant percentage of electric vehicles equal to 75 percent of the totals, while still leaving the presence of hybrid vehicles. This is also necessary during the periods and times when there are major events in Venice for which, due to the appeal of water cabs, it is in greater demand.

The introduction of these scenarios also allows the city the time it needs to evolve technologically; in fact, now the city is unable to be able to run a partially or fully electric service due to the low power and electrical energy deliverable through the electrical infrastructure to date. A very broad time frame allows all the agencies in charge to upgrade the grid so that what is analyzed and elaborated in this study is feasible, at least on paper.
In addition to upgrading the electric grid, a plan needs to be drawn up for the installation of electric columns both in cab stations and in areas used only for parking to recharge electric boats. Although it may seem trivial to mention this last point, it turns out to be, on the other

hand, a very delicate and non-trivial piece to implement because of the many, and strict, regulations regarding the concessions of water spaces and piers.
It is necessary, therefore, to focus on where we want to manage vehicle charging, aiming to enrich the present infrastructure for docking and landing or whether to create areas used only for charging electric boats, private and municipal.

Obviously, to be able to manage and implement this requires substantial funding and investment both in the short term and in the long term, and it is hoped that both the private and government sector can enable the creation of a naval electric service.
As mentioned in the opening chapters, this step is as crucial as it is morally obligatory in order to preserve the beauty and health of the Venetian lagoon.

These considerations lead one to say that the road to boat electrification is still a long one and needs steps forward in terms of available capacity and shorter recharging times in order to offer a very efficient service.
However, the adoption of a congruent number of electric vehicles for use in travel along the city's canals in the short term would allow for a significant improvement in the city's pollution to the benefit of both citizens and tourists, but also the lagoon waters.

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