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THE ROLE OF HYDROGEN IN THE DECARBONIZATION OF ZERO FARE PUBLIC TRANSPORT IN MARICÁ

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Abstract: The use of fossil fuels, as the main energy vector of economic activities since the Second Industrial Revolution, caused a significant increase in the concentration of greenhouse gases in the atmosphere, causing environmental impacts in several places on the planet. In this sense, the greatest motivation for addressing this topic comes from the socio-environmental need to reduce the use of fossil fuels, due to the risk of compromising future generations, due to the high emission of greenhouse gases (GHG), caused by fuels. derived from finite sources. Therefore, we warn about the urgency of energy transition, recommending a change from the current matrix (predominantly polluting) to a clean and renewable matrix. The use of hydrogen has gained notoriety as an energy vector in the urban public transport scenario, as a cleaner alternative that adds environmental and social quality. In this work, the current panorama of the economic and environmental viability of using hydrogen as a potential energy vector for the urban public transport sector in the municipality of Maricá (RJ) is investigated, through an exploratory bibliographic review. This way, it was possible to attest that hydrogen can be considered a promising energy source, classified as a green fuel, burning cleaner and more efficiently. It is noteworthy that the topic involves technological, social, economic, environmental and political factors, and requires investments in research, development and innovation for its implementation and expansion. Even so, the importance of the energy transition is evident, as it is necessary to abandon fossil sources and prioritize renewable sources, enabling the popularization of hydrogen in distributed generation.

Keywords: hydrogen, energy vector, public transport.

INTRODUCTION

The Paris Agreement indicates the stabilization of the global average temperature, in search of a balance between emissions and removals of greenhouse gases (GHG) from the atmosphere. To keep the temperature, increase below 2°C, this balance must be achieved in approximately half a century. Therefore, the energy, transport and industrial sectors, which are mainly responsible for global GHG emissions, must necessarily be transformed during this period, by replacing current sources and processes with low-carbon alternatives.

Hydrogen as a potential energy vector has become one of the main objectives of governments and companies around the world. It is believed that, with the post-pandemic economic recovery, an energy transition can be accelerated, mainly due to the policies announced by European Union countries (EMPRESA DE PESQUISA ENERGÉTICA, 2021).

Among these alternatives, hydrogen (H2) stands out for its versatility, both in consumption and production. Thus, its use can make it possible to reduce emissions, including in sectors where decarbonization is considered challenging, while its production can be based on a set of routes suited to the resources of each region.

According to the International Energy Agency (IEA), in 2020, the transport sector was responsible for 24% of direct CO2 emissions from the burning of fuels. At the same time, there was a 40% growth in the purchase and sale of these vehicles according to IEA (2021a), driven by the search for increasingly cleaner transport, as well as the use of these vehicles linked to public transport. Although its main demand is still focused on the industrial sector, the so-called "hydrogen economy" aggregates the world market, estimating a growth in trade aimed at energy use. In terms of end use, hydrogen as an energy vector is already a reality in the urban public transport sector.

Maricá seeks to include hybrid units using hydrogen cells to generate energy in its fleet of public transport vehicles. By developing its local hydrogen policy, the municipality can become a strategic hub in the production and use of low-carbon hydrogen, through the production route (whose main raw material is natural gas). Turquoise hydrogen has solid carbon (carbon black) as a by-product, the use of which can allow added value and prevent the release of carbon as CO2 into the atmosphere. This way, the objective is to generate a flexible and clean energy flow, from natural gas, providing opportunities for the gas chain to play an essential role in low-carbon energy and industry, in addition to expanding the role of transition fuel.

This article was prepared in the context of the Technological Order (ETEC) or the Development and Innovation Research Project (PDI), conducted by the Institute of Science, Technology and Innovation of Maricá (ICTIM). ICTIM's institutional mission is to carry out projects and research, both basic and applied, of a scientific or technological nature. Furthermore, the institute is dedicated to developing new products, services or processes that promote Science, Technology, Innovation and the Culture of Maricá.

DIAGNOSIS

The term atmospheric pollutant is any matter or energy with intensity and quantity, concentration, time or characteristics that are different from established levels that may make the air unsuitable, harmful or offensive to health; harmful to public welfare; harmful to flora and fauna; implying security issues for the enjoyment of property and normal community activities (CONAMA, 2023).

Maricá is a city in the metropolitan region of the state of Rio de Janeiro, with a population of 197,300 inhabitants (IBGE, 2022) and an area of 361,572 km². Public transport plays a fundamental role in the city and has a structure of bus lines operated by the Public Transport Company, which offers citizens zero fares on their journeys.

The municipality's current fleet has 39 lines, 135 vehicles and a network length of 498.91 km (EPT, 2023).

Number of bus fleet	135 vehicles
Average speed in urban centers	30Km/h
Useful life of buses	10 years
Passenger boarding number	122 thousand/day
Number of daily trips	1.300
Approximate fleet diesel consumption	5,581,716 L/year
Annual cost of diesel consumed by the fleet	R$ 32.094.867,00
Total fleet cost (vehicles)	R$ 97.200.000,00

Table 1 – Average data referring to the diesel bus fleet in the city of Maricá

From an environmental point of view, Maricá's urban transport system is unfavorable, as it is the main cause of air pollution in the region. Air quality problems arising mainly from emissions of atmospheric pollutants cause harmful effects on public health and the environment.

The burning of fossil fuels causes adverse externalities. Air pollution, in addition to causing damage to health, causes environmental costs through the loss of biodiversity and ecological systems, representing a social cost that, in general, is not easily noticed. Measuring these calculations is relevant, as it allows comparison with other costs and supports decision-making through cost-benefit analyses, allowing public authorities to decide on alternatives that result in greater benefits.

It is worth noting that, when estimating the cost of urban transport according to the price of all its inputs that make up the system's operation, social costs such as increased morbidity, hospital expenses and mortality associated with air pollution are disregarded. However, when comparing the cost of a diesel bus with a hydrogen bus, it would be necessary to take into consideration, the social costs generated by atmospheric pollution (PALADINO, 2013).

When analyzing the pollution generated by diesel buses in large urban centers, negative externalities are observed classified into three categories (Knight and Young, 2006):

- local effects such as reduced visibility, fog and acid rain;
- global environmental effects, such as climate change and global warming, which occur through the emission of CO_2 and other gases;
- harmful effects on human health, through exposure to particulate matter at high levels causing premature deaths and respiratory system diseases.

The main air pollutants emitted by the burning of diesel from the urban bus fleet in Maricá are: inhalable particles, sulfur oxides, nitrogen oxides, carbon monoxide, carbon dioxide, hydrocarbons and ozone.

To quantify the pollutants generated by diesel buses, a methodology is used that calculates the emissions of the main compounds directly from the amount of diesel consumed. As stated by Oliveira (2011), the emission of each pollutant when burning diesel oil can be quantified depending on the amount of oil burned. Table 2 presents the emission rates of the main pollutants causing both the greenhouse effect and the local effect, generated when burning diesel as fuel in grams per MJ (Oliveira, 2011).

Effects	Pollutant	Diesel (g/MJ)
GEE	CO_2	74,06670
	CH_4	0,00500
	N_2O	0,00060
GEL	HC	0,20000
	CO	1,00000
	NOx	0,80000
	SOx	0,31389
	MP	0,02778

Table 2 – Emission index of pollutants generated by burning diesel oil

Source: Oliveira, 2011.

With data from TAB. 2, pollutant emissions can be calculated using the equation:

$$E = (C\ P_{cal}\ E_{gas}) / 10^{15}$$

Where *E* is the pollutant emission in Mt/year, *C* is the zero consumption of diesel by the fleet in the city of Maricá (5,581,716 L/year), P_{cal} is the calorific value of diesel (38,376.21 MJ/m_3) and E_{gas} is the emission rate of pollutants from burning diesel. The results obtained are shown in TAB. 3.

Effect types	Pollutants	Emission (Mt/year)
GEE	CO2	0,016
	CH4	1,07103E-06
	N2O	1,28523E-07
GEL	HC	4,2841E-05
	CO2	0,000214205
	NOX	0,000171364
	SOX	6,72368E-05
	MP	5,95062E-06

Table 3 – Emission of pollutants by the diesel bus fleet in the city of Maricá.

The economic value of atmospheric air degraded by pollutant emissions released by burning diesel in urban buses in the city of Maricá is made up of a portion considering the value of air degradation by local pollutants and greenhouse gases.

The calculation for local effect is used based on the direct costs of pollution by type of pollutant as shown in the table below TAB.4.

These costs come from studies by the Institute of Applied Economic Research (IPEA) and the National Public Transport Association (ANTP) based on international sources adapted to the Brazilian reality, being reduced according to the approximate relationship of Brazilian *per capita* income (Lascala, 2011).

Pollutant	US$/t
NOx	1.289,91
HC	1.312,95
CO	218,82
MP	1.048,05

Table 4 – Direct cost of air pollution by type of pollutant

Source: Lascala, 2011.

Multiplying the amount of local pollutants emitted, provided in the TAB. 3, with the cost of pollution we arrive at the value of air degradation caused by pollutants with local effects emitted by the consumption of diesel in the city of Maricá presented in table 5.

Pollutant	Value (US$/t)	(Quantity ton/ year)	(US$/ year)
NOx	1.289,91	17,1364	22104,42
HC	1.312,95	4,284102108	5624,81
CO	218,82	21,42051054	4687,2361
MP	1.048,05	0,595061783	623, 6545
		Total:	33040,13

Table 5 – Annual cost of air degradation due to pollutants with local effects

This way, it is possible to see that analyzing only the environmental and social cost due to the emission of pollutants with local effects, a cost of US$ 33040.13 per year is estimated. With the municipality's total fleet of 135 diesel vehicles, the annual cost is approximately US$4,460,417.55. It must be noted that this cost must be evaluated when analyzing the feasibility of replacing the diesel bus fleet with hydrogen.

PROPOSITIONS

To analyze the economic viability of replacing the diesel bus fleet with hydrogen, an analysis of the costs of producing, storing and transporting hydrogen must be carried out. Then, the installation costs of the hydrogen factory and fueling stations, the estimated price of hydrogen vehicles and the cost of fuel consumption are analyzed. To evaluate production costs, it is based on data from technical literature, as explained by Yan and Hino (2011).

TAB.6 only presents factory installation costs and production costs, excluding storage, transportation, compression and distribution costs, as they are complex to measure as they involve factors such as equipment and distances to be covered.

In the case of hydrogen production to replace the bus fleet in the city of Maricá, energy technology must be considered, in favor of a healthy environment, in order to reduce pollutant emissions as much as possible. The municipality presents efforts to overcome the transition barriers from fossil fuels, focusing on the hydrogen economy, so that all phases of the hydrogen cycle are viable, including its production and final use.

The model developed in the municipality by Coppe has some characteristics, such as:

- Clean exhaust: considering that during its operation the fuel cell only produces water vapor, CO2 emissions and other potentially polluting gases are not released during the operation of the vehicle.
- High efficiency: one of the challenges for electric vehicles is to match the power of combustion engines; however, fuel cells combined with an electric motor are twice as efficient as gasoline vehicles (MIRANDA, 2019).
- Quick and noiseless filling: the tank

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Capacity cost					Cost of hydrogen production (US$/kg)			
Technology and fuel	Capacity 1000 kg/day	Million dollars	Dollars per 1000 kg/day	Capacity factor (%)	Installation	Feed stock	O&M	Total
Centralized natural gas reform	379.387	181	477	90	0,18	1,15	0,14	1,47
Distributed natural gas reform	1500	1,14	760	70	0,40	1,72	0,51	2,63

Table 6 – Estimated costs of natural gas production technology

Source: Yan and Hino (2011)

of a fuel cell vehicle takes around five minutes to fill. In May 2021, the Toyota Mirai broke the record for distance traveled with just one tank of hydrogen, covering 1,003 km. On that occasion, as part of the demonstration, the tank took less than five minutes to fill, at a pressure of 700 bar at the recharging station (TOYOTA, 2021). It is a minimum time and can be compared to the time it takes to fill up gasoline cars; and, as the engine is electric, these vehicles are practically silent (MIRANDA, 2019).

According to studies developed by the Municipality of Maricá through the contracting of a technological order for hydrogen hybrid buses with Coope, the average production cost of these vehicles is around R$1,800,000.00. They have the same passenger transport capacity as diesel buses, with the same number of vehicles. Therefore, the total fleet replacement cost would be around R$243,000,000.00. This cost is overestimated as it does not consider series production.

The prototype under development will enter the testing phase in 2024, where indicators and metrics will be determined considering local geography, number of passengers, climate, and number of stops that directly influence fuel consumption. Considering studies presented by Paladino, in 2013 hydrogen consumption would be 45 kg per 300 km. Thus, to cover the total covered by Maricá buses, which is 1,460,726 km/month on average (EPT, 2023), 219,109 kg of hydrogen is needed. According to studies by the International Energy Agency (IEA), the cost of blue hydrogen costs an average of US$ 2.30/Kg, so the monthly expense would be around US$ 503,950.70, converting into Brazilian Real the average is R$ 2,484,476.00. Comparing with diesel consumption considering a monthly consumption of 465,143 L and also, the average cost of diesel in the State of Rio de Janeiro is R$ 5.95, the current monthly expenditure on fuel is R$ 2,767,600.00.

The country can become a protagonist in the development of technologies that guarantee the demand for the use of nationally produced hydrogen, by adding technological and industrial value from the new energy matrix that is emerging worldwide, surpassing the Brazilian fate of supporting GDP from *commodities*.

Still on the use of hydrogen, Brazil is trying to develop its technologies, market and local uses, evaluating export possibilities, mainly through decarbonized products with this element.

Through the diversity of production methods that explore characteristics specific to renewable and low-carbon hydrogen, sovereignty and technological diversity are evident in business development and the creation of internal demand, these being priority premises for achieving the desired protagonism.

CONCLUSIONS

Hydrogen is the most abundant element in the universe, however, it is necessary to understand how to expand its use for energy purposes and the use of this significant portion of the planet's necessary demand as an energy transition unfolds. It will be a considerable change in the nature and pattern of how energy is used in the country and around the world, with the gradual decline of the fossil energy industry and the growth of the renewable energy industry. This is a transition that demands time for the emergence, acceptance and development of new technologies and procedures. It is necessary to scale and disseminate technological development for the energy use of hydrogen in its multiple production routes.

Diesel-powered buses generate social and environmental costs that were analyzed together with the economic feasibility of replacing the fleet. Maricá is in favor of the gradual replacement of the fleet, because although at first it seems more expensive, its environmental costs are zero. Furthermore, the service life of hydrogen buses is longer than that of diesel buses. Also noteworthy are the comfort offered by these vehicles and the zero emission of polluting gases, which must attract more users to the public transport system.

Despite the applications already developed, including in the urban public transport sector, there are still technological, economic and regulatory limitations for an energy transition. Like all strategies regarding the energy issue, the topic involves technological, social, economic, environmental and political factors. The solution, mainly in the financial sphere, is associated with the establishment of partnerships between the private and public sectors, industry, academia and governments, with a focus on investment in research, development and innovation to disseminate and expand an economically and environmentally viable infrastructure.

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