Towards Sustainable Maritime Transportation in the Galapagos Islands with green hydrogen

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Keywords

Green Hydrogen, Input-Output Analysis, Maritime transport, Environmental assessment, CO2 emissions, Galapagos Islands

Executive Summary

In this study, the feasibility of transitioning from diesel to green hydrogen to power the maritime transport sector in the Galapagos Islands is analysed. The plan is to study the environmental factors that may arise on the islands with the introduction of this new technology and its interaction with other sectors. This will enable the development of a plan that facilitates the transition and adapts to the environmental needs of the ecosystem. Four comparison scenarios were devised, where the first includes 100% hydrogen with 50% solar energy and 50% wind energy, the third 100% hydrogen with 100% solar, and the fourth 100% hydrogen with 100% wind. At the end of the study, it was found that the scenario generating the highest emissions is the one with 100% wind generation, and the one with the lowest emissions is the solar scenario. Additionally, it was discovered that the construction, equipment manufacturing, and land transport sectors experienced an increase in emissions. However, these increases do not surpass the 20k-ton reduction in CO2 emissions in the maritime transport sector. At the study's conclusion, it was understood that the collection of information and data should be expanded to extend the model and encompass a greater number of environmental and social analyses, yielding more precise results.

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1. Introduction:

Purpose and Scope

Green hydrogen has gained widespread recognition as a clean energy source with the potential to decarbonize the transportation sector, as it is an alternative that eliminates emissions and minimizes the risk of fuel spills in the environment. Beyond its sustainability benefits, its high energy density and ability to provide sufficient power over extended periods make it an attractive option for maritime operations. The production of green hydrogen comes from entirely renewable energy sources and is carried out through electrolysis, a process involving the use of electricity to decompose water. Systems operating with hydrogen can achieve emission-free operations, as the only byproduct of hydrogen is water vapor.

While the transition to hydrogen presents various challenges, it also unveils significant opportunities. One challenge lies in sizing the plant for hydrogen production, storage, and distribution. Additionally, potential social, environmental, and economic barriers that may arise in this process need to be addressed. Nevertheless, technological progress in fuel cells and storage systems is turning it into a viable option for commercial use. This advancement is positioning the future of green hydrogen as a practical reality and has motivated private organizations and institutions to invest in ambitious projects that accelerate the adoption of this clean technology.

The Galapagos Islands constitute a biological paradise that shelters species of native endemic flora and fauna. This archipelago was declared a World Heritage Site in 1976. It is composed of 13 main islands covering an area of over 10 km^2, six medium-sized islands, and another 215 smaller islands (according to UNESCO).

Currently, this province relies heavily on fossil fuels, which not only produce greenhouse gases but have also contaminated the waters on several occasions due to shipwrecks, jeopardizing the integrity of its natural environment. In 2018, only 16% of the electric generation structure came from renewable sources (wind and solar), while the remaining 84% was thermal electricity from facilities operating with internal combustion engines [2].

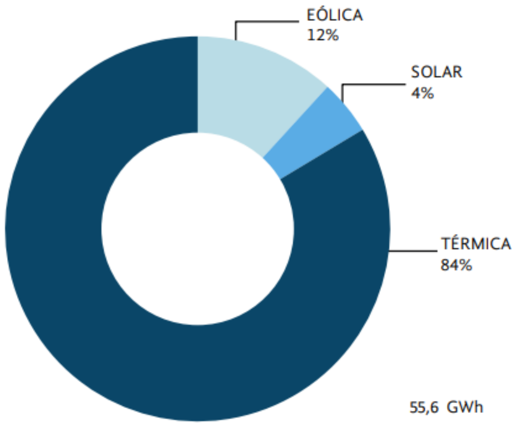

Figure 1: Electric generation of Galapagos in 2018 - Instituto de Investigación Geológico y Energético

In 2018, a total of 11,613,341 gallons of diesel were consumed on the islands, with the transportation sector accounting for 69% of this consumption. Within transportation, maritime activities contributed to 57.7% of the total [1]. In 2008, the Ecuadorian Government introduced the Zero Fossil Fuel Initiative, aiming to achieve zero fossil fuel usage in the islands by 2040. This ambitious goal requires a comprehensive transformation of the islands' energy and transportation sectors, with the transportation sector being a critical component to investigate.

This proposal assesses the feasibility of transitioning from fossil fuels to green hydrogen as the primary energy source to propel maritime transport in the Galapagos Islands. It incorporates an inclusive approach that considers the environmental impact of the system. The project aims to formulate a study with the goal of facilitating an understanding of the potential regional consequences associated with transitioning to this alternative and facilitate the formulation of a transition plan. This is achieved by mitigating economic and environmental barriers that may arise with the introduction of this new technology. This transition is presented as a significant step towards decarbonizing the islands' energy system.

Figure 2 . a) Shows the marine fauna of the Galapagos Islands and its vulnerability to the negative effects of fossil fuels and their spills. b) Illustrates a spill incident that occurred near Santa Cruz Island after the shipwreck in 2022 and highlights the environmental risks of using fossil fuels in the Galapagos Islands. c) Represents the proposed energy transition system that uses clean sources to generate hydrogen, such as solar energy, widely available on the islands, and wind energy, complementary to solar energy at different times of the day. d) Sea Horse tourist boat powered by hydrogen fuel cells.

Objective and aims.

The study aims to assess the environmental implications arising from the transition to green hydrogen within the maritime sector of the Galapagos Islands. Specific aims include:

1. Conducting an Input-Output analysis to examine the incorporation of the green hydrogen sector and its interactions with other industries on the island.
2. Performing an emissions analysis that compares the introduction of green hydrogen with the island's initial situation.

3. Evaluating the overall system to comprehensively understand the impact and potential benefits of the transition.

2. Methodology

Modelling Approach/Tool Implemented

This study employed an Input-Output analysis, a model that provides a detailed description of economic relationships between goods and services. This type of analysis allows for the representation of interdependencies between sectors and is useful for conducting regional or multiregional comparisons regarding potential interactions between different industries when introducing new technology. This model enables the evaluation of environmental, economic, and social effects resulting from changes in the industry, identifying critical points and improvement scenarios for comprehensive transition planning.

When addressing models of this nature, it can be assumed that they involve large amounts of data and complex calculations. Therefore, it is important to include a software to simplify user interaction with the tables. This is where MARIO comes in, a tool developed by the Department of Energy at Politecnico di Milano. MARIO is a Python-based tool that facilitates working with IO tables, simplifying aggregation, scenario creation, and model calculations [4]. In this study, MARIO will be used to model a scenario where the variation in greenhouse gas emissions will be analysed when replacing all diesel used to fuel marine transport with green hydrogen.

A model was devised to represent a hydrogen plant in the Galapagos Islands with the capacity to generate the necessary amount of hydrogen to completely transform the maritime transportation sector, currently entirely powered by diesel. In this analysis, it is proposed that the hydrogen be produced on Baltra Island and then transported by truck to Puerto Ayora (50 km trip), where a national cargo ship will be used to distribute it to other ports. Fuelling stations will be installed at these ports to distribute hydrogen to various ships, as shown in Figure 3.

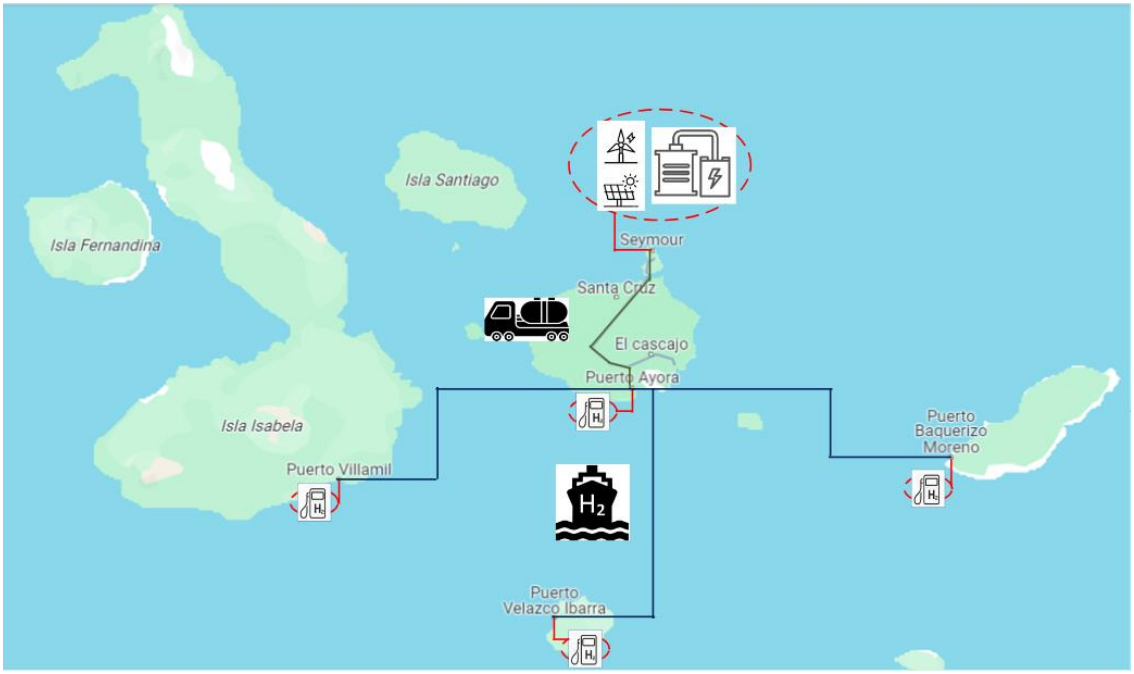

Figure 3: Distribution Map of hydrogen from the plant to the fuelling stations

Data source

To simulate the scenario in the Galapagos Islands, an input-output table developed by Robert Miguel Rosero, an economist from Ecuador, was used. He found it essential to quantify the impacts of productive activities on the natural resources of the islands. So that it could enable different economic agents and policymakers to base their decisions on the sustainability of the Islands [3]. The table was compiled using data from the year 2015 and is denominated in USD.

The table divided the sectors of electricity and fuels to encompass the necessary industries for the study. Fuels such as LPG, gasoline, and diesel were considered, and for electricity, both renewable and non-renewable energies were included. To perform this division, information from the energy balance of the Galapagos province [2] was utilized.

To present emissions for each sector, data for Ecuador was used but was reconfigured using coefficients specific to the Galapagos province. To size the hydrogen plant in Galapagos, a technical model was developed using Excel.

Assumptions

- To keep the analysis solely focused on the study of direct consequences on the islands, it was established that 100% of the hydrogen should be produced on the islands, with no importation of H2 to the archipelago.
- All plant equipment (electrolyser, compressors, storage tanks) is imported from other countries into the island.
- The manufacturing or entry cost of a new fleet of ships with the characteristics to run on hydrogen fuel is not included.

• The analysis will focus on the direct emissions from the construction of the hydrogen plant structure, the installation of production equipment, and the transportation of hydrogen.

Scenarios or sensitivity analysis

In this study, four scenarios were analysed. The first presents the base scenario and the current situation of the archipelago, where 100% of maritime transportation is powered by diesel. The second scenario introduces hydrogen into the energy matrix as a replacement for 100% of the diesel used in maritime transport, proposing that hydrogen be produced using 50% solar energy and 50% wind energy. For the third scenario, variations in the contribution of the renewable energy matrix are considered, specifically analysing the impacts generated by implementing 100% wind energy. Finally, the fourth scenario involves the use of 100% solar energy.

Table 1: Scenarios analysed in this case study

Scenario Label	Scenario Description	Key Assumptions
Diesel	Diesel is imported to the islands and delivered to the main ports to be used by ships.	- Diesel is imported in the islands
Hydro_50S_50E	Hydrogen is produced on the islands using renewable energy. For this scenario, 50% wind energy and 50% solar energy will be used.	-All plant equipment (electrolyzer, compressors, storage tanks) are imported to the island. -The direct emissions that this transition will have will be analyzed (Construction of the structure of the production plant, transportation, installation and import of plant components)
Hydro_100E	Hydrogen is produced on the islands using renewable energy. For this scenario, 100% wind energy will be used.	
Hydro_100S	Hydrogen is produced on the islands using renewable energy. For this scenario, 100% solar energy will be used.	

3. Results

The results were obtained using MARIO and Excel. To highlight the environmental impact of the system on the islands, emissions of CO2 produced by each sector were analyzed after each scenario. Figure 4 depicts the system diagram that will be studied.

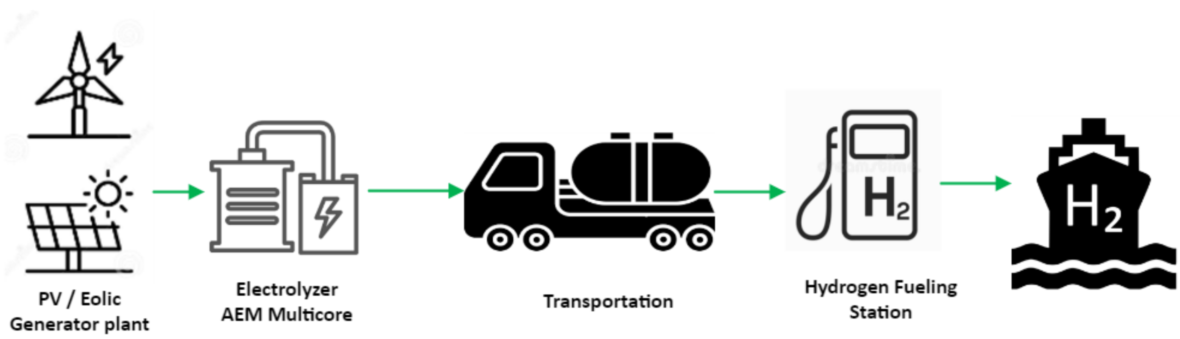

Figure 4: Flow diagram of the analysed plant

Figure 5 illustrates the emissions of each sector in the base scenario. It is observed that the food and beverage sector have the highest emissions, and maritime transport also significantly contributes to emissions. In this case, it accounts for 20,000 tons of CO2 emitted during a year of construction and operation. Figure 6 presents the CO2 emissions in scenario 2, where 100% hydrogen is used. Here, the transport emissions drop to 0, and there is an increase in emissions in the construction, equipment manufacturing, and land transport sectors. The other sectors also experience a minimal increase, though it can be disregarded due to their small size.

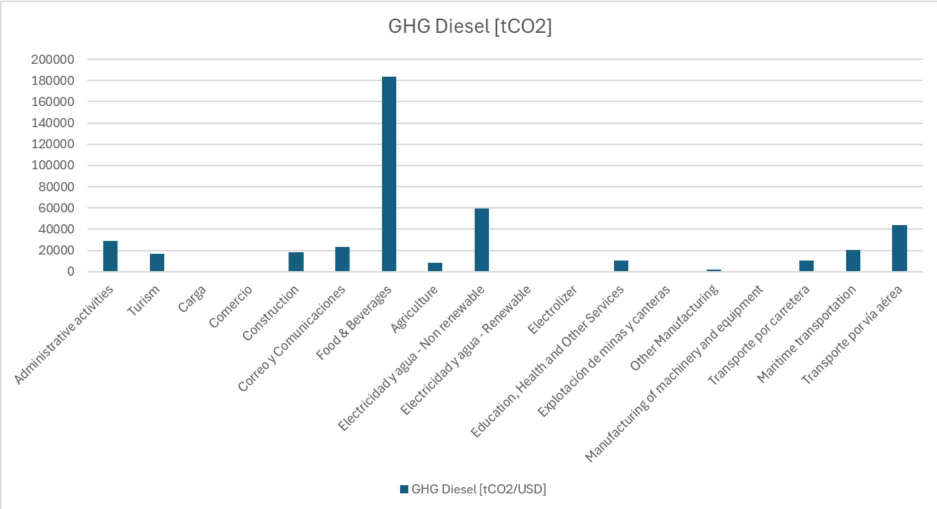

Figure 5: GHG graph in tCO2 for scenario 1

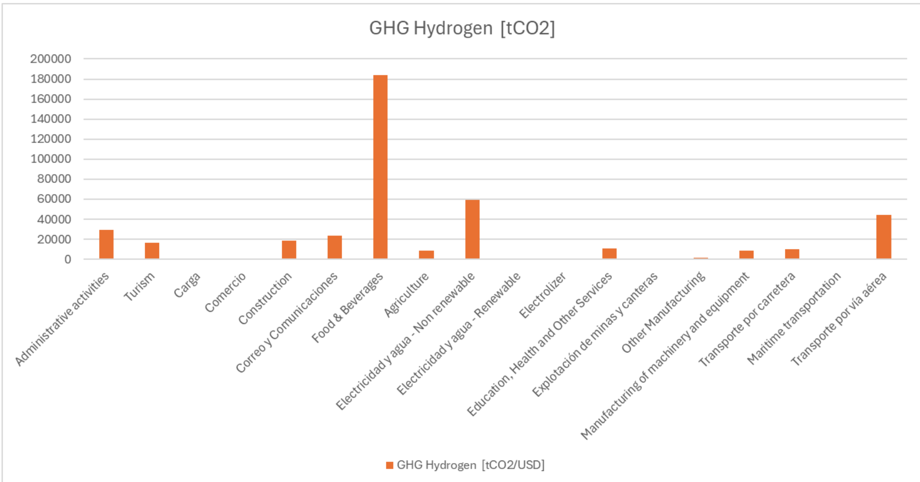

Figure 6: GHG graph in tCO2 for scenario 2

Figure 7 displays the total emissions for the four scenarios. It is important to note that only the sectors most affected by the technology and those directly related were included in the sum. It is observed that the highest emissions occur in the 100% eolic scenario, and the lowest with the 100% solar scenario. Figure 8 breaks down the emissions by sectors, showing that the variation introduced by each scenario mainly affects the manufacturing of machinery and equipment. It can be appreciated that there is an increase in emissions in the construction, equipment manufacturing, and land transport sectors. However, these do not surpass the reduction in emissions in the transport sector.

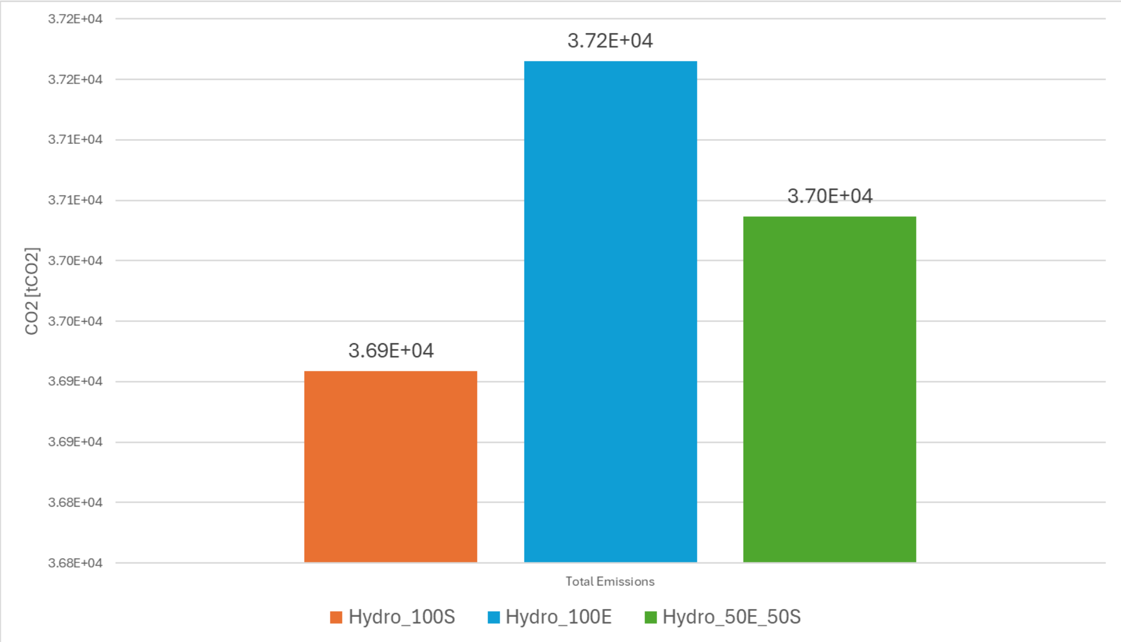

Figure 7: Graph for total emissions for scenario 2, 3 and 4

Figure 8: Graph for variation of emissions by sector for scenario 2, 3 and 4 with respect to baseline

4. Discussion

The results obtained after completing the study demonstrate that the transition from diesel to hydrogen has significant potential to reduce emissions resulting from the use of fossil fuels in the archipelago. As evidenced by the results, making this switch shows a reduction in CO2 emissions of up to 20,000 tons. Moreover, it eliminates the possibility of a spill that could contaminate the archipelago's water and damage the ecosystem. Even when considering the increase in emissions in other sectors, the reduction from using hydrogen remains evident. However, to quantify the true environmental, economic, and social impact of introducing the hydrogen plant, it is necessary to expand the analysis and involve sectors beyond the scope of this study. This would allow adjusting the obtained values to make them more realistic and identify critical points in the plant's implementation to propose improvements.

Currently, the study is limited by the lack of data and information needed to construct a table to model the Galapagos system. This suggests conducting an exhaustive search for information that can complement the model and provide results covering more environmental emissions as well as social aspects. It is recommended to include a technical study that analyses in-depth the limitations imposed by climatic conditions and available space when installing a solar or wind plant of such magnitude.

This model allows visualizing the advantages of implementing hydrogen as a replacement for fuels in activities that require high energy potential. However, hydrogen remains expensive, and its production and distribution processes are complex, requiring further studies to optimize the system. As a future study, it is proposed to conduct an analysis of the plant throughout its active life cycle, i.e., 15-20 years, where operational and maintenance costs can be included. These are crucial factors for effective implementation planning. Additionally, this would involve a financial analysis showcasing the associated costs of plant installation and potential gains.

5. Conclusions

Upon concluding the report, the versatility of the learned tool and its potential for application in studying the implementation of energy policies becomes apparent. This is evident in recognizing the extensive future work that can be accomplished using this tool. Which allows for a comprehensive understanding of the consequences of implementing technological changes. It can encompass the social, economic, and environmental aspects of altering the market behaviour of a sector. In the case of my project, it will continue to be used to complete the analysis and obtain results for the total island system. To maintain the accuracy of the results, it is recommended to work with high-quality data, as these are the elements that will shape the consequences of the model.

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