

# Green Hydrogen Supply Chain Design Towards Social Sustainability: A Case Study in Brazil

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## ABSTRACT

When designing and planning Green Hydrogen Supply Chains (GHSCs), sustainability considerations are increasingly recognized as essential, particularly in light of decarbonization goals and climate policy targets. Existing research has largely focused on economic and environmental however, social sustainability aspects remain significantly underexplored. This work aims to develop a mathematical programming model to design a GHSC, considering simultaneously economic and social aspects. Solar PV, wind power, and PPA (wind) as energy sources are integrated, while transportation options include the construction of new pipelines, compared to the use of existing highways for trucks carrying liquefied or compressed hydrogen to deliver hydrogen to an oil refinery. The model is applied to a case study conducted in the Brazilian state of Bahia, where different social indicators will be explored, characterizing the case study context while allowing generalization to other contexts. Results allow us to establish a trade-off analysis between economic and social concerns, offering valuable insights for both policymakers and companies, supporting strategies that strike a balance between economic competitiveness and regional social development.

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**Keywords:** Supply Chain, Hydrogen, Optimization, Social Sustainability, Brazil case study

## INTRODUCTION

Green hydrogen produced without CO<sub>2</sub> emissions, namely electrolytic hydrogen, has emerged as a key enabler for the decarbonization of hard-to-abate sectors [1]. It is widely recognized in literature as a promising solution to support the achievement of the United Nations Sustainable Development Goals (SDGs). However, despite its potential, the large-scale deployment of green hydrogen still requires policy support and subsidies to overcome cost barriers and enable market uptake [2]. In this context, national hydrogen strategies and roadmaps have been proposed and continuously updated to facilitate the development and deployment of green hydrogen supply chains (GHSCs) [3].

Nevertheless, the design and planning of GHSCs must go beyond purely techno-economic considerations and explicitly account for sustainability metrics. Although several studies have proposed mathematical programming models for GHSC design, relatively few have critically examined how environmental, economic, and social

dimensions are jointly addressed within these frameworks [4]. In particular, a significant gap persists in the assessment of social sustainability, as social aspects remain largely underrepresented in optimization-based formulations, often treated qualitatively or excluded altogether [4, 5].

This gap is especially concerning given that the development of green hydrogen is explicitly framed as a pathway toward sustainable and inclusive energy transitions. Beyond reducing greenhouse gas emissions, such transitions must also proactively address potential social risks, including neocolonial patterns of resource extraction, uneven distribution of economic benefits, exclusion of local communities, water scarcity, and land-use conflicts. Recent studies emphasize that the integration of energy justice principles is essential for the equitable and socially robust development of GHSCs [6].

Accordingly, socio-economic factors, encompassing income levels, employment generation, fiscal contributions, subsidies, and broader social development indicators such as the Human Development Index, have

emerged as critical elements in sustainability assessments [7]. Despite their relevance, these dimensions are rarely incorporated explicitly into optimization-based HSC design models, remaining largely disconnected from strategic planning and investment decisions [4].

In the context of a developing country such as Brazil, the inclusion of a social sustainability assessment is particularly important. While Brazil seeks to position itself as a competitive producer of low-cost green hydrogen, decision-making processes must also account for regional inequalities and development needs [8]. These objectives are often conflicting, highlighting the need for integrated modeling approaches. To address this challenge, this study proposes a bi-objective mixed-integer linear programming (MILP) model for the strategic design of a GHSC in Brazil, explicitly integrating economic performance and location-dependent socio-economic indicators into the decision-making process.

## LITERATURE REVIEW

Kim and Moon (2008) were the first to address a social criterion for HSC design using MILP, by considering cost and safety in the design of hydrogen infrastructure [9]. Since then, the models normally use safety to access the social aspects of the HSC, optimizing risk-related factors. This risk-based interpretation of the social dimension has become the dominant perspective in the literature [4].

Almaraz et al. (2013) was one of the precursors to the proposal of sustainable HSC, highlighting the importance of considering the triple bottom line in sustainability in the strategic stage of any new design to ensure system efficiency. However, the social aspects are restricted to the risks linked to the activities of each stage of the HSC [10].

Fazli-Khalaf et al. (2020) implemented in their modeling the maximization of social responsibility, considering among their criteria the generation of employment opportunities, reduction of health damage, and promotion of sustainable and balanced development between regions. Despite this broader interpretation of social sustainability, the adopted indicators remain highly aggregated and are not explicitly linked to regional socio-economic conditions or location-specific vulnerability [11].

In the Brazilian context, recent MILP-based studies on HSC optimization, such as da Silva et al. (2024), Santana et al (2025), and Camelo et al. (2025), focus primarily on economic and technical performance, without explicitly incorporating social or socio-economic criteria [12-14]. This highlights a persistent gap in the integration of location-dependent social indicators into strategic HSC design models.

To address this gap, the present study incorporates four socio-economic indicators into a bi-objective MILP

framework, explicitly linking regional socio-economic conditions to strategic supply chain design decisions.

## PROBLEM STATEMENT

As a deterministic capacitated facility location problem, this work aims to design optimal investments that consider both economic and social aspects in the GHSC to meet the demand of Bahia's oil refinery, as shown in the superstructure in Figure 1.

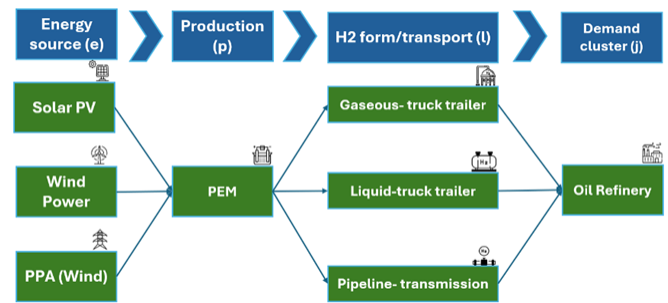
### Given:

- (i) A predefined hydrogen demand cluster  $j$  (representing the refinery).
- (ii) Possible facility locations  $i$  (12 locations in Bahia).
- (iii) Scenarios involving energy sources  $e$  (solar, wind, or PPA), production technology  $p$  (PEM), and transportation methods  $l$  (liquid tanker, tube trailer, or pipelines).

### Determine the optimal:

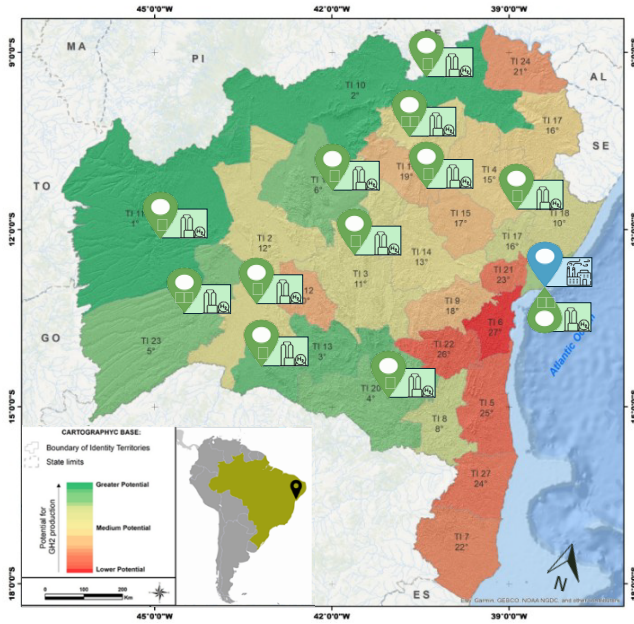
- (i) Hydrogen production plant location.
- (ii) The transportation method for the production plant to the demand cluster.

**Objective:** Minimize the Levelized Cost of hydrogen (LCOH) while maximizing social impact (SOCimp) for different social indexes.



**Figure 1.** Superstructure of the Green Hydrogen Supply Chain Model.

The demand cluster requires 200 MW (29 kt/year) of hydrogen, according to a previous study [14]. The geographic disposition of the candidate site productions and the demand cluster is shown in Figure 2. Energy sources include solar PV, Wind power, and purchase power agreements of wind farms (PPA-wind). A hub-based configuration is adopted, in which a single production site is selected to supply the entire demand cluster. This assumption reflects the economies of scale and allows isolating location-dependent trade-offs between cost and social performance, which is essential for assessing the influence of regional socio-economic indicators in strategic decision-making.



**Figure 2.** Geographic Location of Candidate Production Sites (green) and Demand Cluster (blue) in Bahia, Brazil.

## METHODOLOGY

The study follows three main steps. First, a bi-objective MILP model is formulated to represent strategic decisions on hydrogen production site selection and transport mode selection, minimizing economic costs and maximizing social impact. Second, the model is parametrized using local socio-economic data from the Green Hydrogen Atlas of Bahia and complementary statistical sources [15]. At the same time, technical and cost coefficients are obtained from peer-reviewed literature. Finally, the optimization problem is implemented in Python and solved using the Gurobi solver, applying the  $\epsilon$ -constraint method to generate discrete Pareto fronts.

## OPTIMIZATION FRAMEWORK

### Mathematical modeling

A basic mathematical formulation of this work is based on previous models by Santana et al. (2025), was developed just to test the social component of such networks. The social objective is inspired by the work of Mota et al. (2018) [16, 17].

#### Sets:

- $i$ : Production site location
- $j$ : Demand cluster location
- $e$ : Energy source type
- $p$ : Production technology type
- $l$ : Transport mode

#### Parameters:

$a^{p,l}$ : Literature parameter for production technology  $p$  and energy source  $e$ , or transport mode  $l$ .

$b^{p,l}$ : Literature parameter for production technology  $p$  and energy source  $e$ , or transport mode  $l$ .

$c^{p,l}$ : Literature parameter for production technology  $p$  and energy source  $e$ , or transport mode  $l$ .

$d^l$ : Literature parameter for transport mode  $l$ .

$EP^e$ : Electricity price of energy source  $e$

$L_{ij}^l$ : Distance between production plant  $i$  and demand cluster  $j$  per transport mode  $l$ .

$FTE^{e,p,l}$ : Full time employment per energy source  $e$ , or production technology  $p$ , or transport mode  $l$ .

$SV^{si}$ : Regional social index value for index  $s$

$SV^{s,ref}$ : Reference social index value for index  $s$

$\mu_i^s$ : Regional factors based on social indexes  $s$

#### Variables:

$x_i$ : Plant capacity of production plant  $i$  (MW)

$Y_i$ : Binary variable, 1 if the site  $i$  is activated, 0 otherwise.

$T_{li}$ : Binary variable, 1 if the transportation mode  $l$  is activated at location  $i$ , 0 otherwise.

In this specific case study, as only one production location may be selected among all candidates, variable  $x_i$  becomes  $x_i = 200Y_i$ .

#### Equations:

The model considers that the flow between production site and demand cluster is equal to the plant capacity  $x_i$ , thus the levelized cost of hydrogen for producing at site  $i$  and transport to demand cluster  $j$ , are:

$$LCOH^p(x_i) = \sum_{i=1}^n (a^p x_i + b^p EP^e Y_i + c^p Y_i) \quad (1)$$

$$LCOH^l(x_i) = \sum_{i=1}^n (a^l L_{ij}^l T_i + b^l T_i + c^l x_i + d^l T_i) \quad (2)$$

Regional social factor definition:

$$\mu_i^s = \frac{SV^{s,ref}}{SV^{si}} \quad (3)$$

Social impact of installing a production plant in a location  $i$ :

$$SOCimp_i = \mu_i^s x_i (FTE^e + FTE^p + FTE^l L_{ij}^l) \quad (4)$$

#### Constraints:

Hydrogen production from all selected plants must equal the supply chain demand:

$$\sum_i x_i = D \quad (5)$$

**Table 1:** Regression Parameters for Levelized Cost of Hydrogen (LCOH) Calculation.

|                 | <b>a</b> | <b>b</b>                 | <b>c</b> | <b>d</b> | <b>Ref</b> |
|-----------------|----------|--------------------------|----------|----------|------------|
| $p$ (PEM)       | -0.0249  | 13.3604                  | 2.1039   | 0        | [17]       |
| $l$ (Pipeline)  | 0.2176   | $-7.105 \times 10^{-15}$ | 0        | 0        | [12]       |
| $l$ (Liq truck) | 0.0006   | 0.1203                   | -0.0078  | 3.5535   | [18]       |
| $l$ (Gas truck) | 0.0031   | 0.3231                   | 0        | 0        | [18]       |

**Table 2:** Employment Factors (FTE) for Different Supply Chain Echelons [19].

|                 | <b>Employment factor (FTE)</b> | <b>Unit</b> |
|-----------------|--------------------------------|-------------|
| $e$ (Wind)      | 0.4                            | FTE/MW      |
| $e$ (Solar)     | 0.12                           | FTE/MW      |
| $e$ (PPA-Wind)  | 0.0                            | FTE/MW      |
| $p$ (PEM)       | 0.9                            | FTE/MW      |
| $l$ (Pipeline)  | 0.04                           | FTE/km      |
| $l$ (Liq truck) | 2                              | FTE/(GW*km) |
| $l$ (Gas truck) | 0.3                            | FTE/(GW*km) |

**Table 3:** Candidate Production Sites: Characteristics, Distances, and Socio-Economic Indicators [15;20-21].

| Site ( $i$ )                             | Location   | Energy source ( $e$ ) | Transport mode distance (km) |      | GDP (kBRL per inhabitant) | IFDM          | SoVI         | Salary (BRL) |
|--|------------|-----------------------|------------------------------|------|---------------------------|---------------|--------------|--------------|
|  |            |                       | Pipe                         | Road |                           |               |              |              |
| 1  | Irecê      | Wind                  | 407.4                        | 443  | 10.011                    | 0.534         | 0.436        | 1652         |
| 2  | BJ Lapa    | Solar                 | 553.35                       | 743  | 10.095                    | 0.533         | 0.467        | 1652         |
| 3  | Seabra     | Wind                  | 364.35                       | 430  | 10.466                    | 0.546         | 0.459        | 1790         |
| 4  | Serrinha   | Wind                  | 130.2                        | 149  | 9.348                     | 0.536         | 0.465        | 1652         |
| 5  | Juazeiro   | Wind                  | 438.9                        | 472  | 15.551                    | 0.525         | 0.427        | 1790         |
| 6  | Barreiras  | Solar                 | 735                          | 828  | 37.867                    | 0.593         | 0.352        | 1937         |
| 7  | Guanambi   | Wind                  | 508.2                        | 640  | 13.946                    | 0.608         | 0.379        | 1652         |
| 8  | Jacobina   | Wind                  | 283.5                        | 305  | 10.842                    | 0.513         | 0.447        | 1790         |
| 9  | VConquista | PPA                   | 360.15                       | 481  | 15.124                    | 0.550         | 0.396        | 1790         |
| 10                                       | SM Vitoria | Solar                 | 644.7                        | 832  | 18.674                    | 0.547         | 0.405        | 1790         |
| 11                                       | S Bonfim   | Wind                  | 319.2                        | 349  | 12.213                    | 0.532         | 0.434        | 1937         |
| 12                                       | SF Conde   | PPA                   | 0                            | 0    | 30.8183                   | 0.653         | 0.3536       | 2522         |
| <b>Reference value (Bahia's average)</b> |            |                       |                              |      | <b>19.54</b>              | <b>0.5564</b> | <b>0.419</b> | <b>1865</b>  |

Hydrogen production is an integer variable:

$$x_i \in \mathbb{Z}^+, \forall i \quad (6)$$

Hydrogen production is constrained by its maximum capacity and is dependent on whether the plant is selected:

$$x_i \leq D Y_i, \forall i \quad (7)$$

Binary decision variables  $Y_i$  and  $T_{li}$  indicates whether a specific production site and transport mode is selected:

$$Y_i \in \{0, 1\}, \forall i \quad (8)$$

$$T_{li} \in \{0, 1\}, \forall i \quad (9)$$

Only one transportation mode may be selected if a location is active:

$$\sum_i t_{il} = Y_i, \forall i \quad (10)$$

**Objective functions:**

Minimize the Supply chain's LCOH:

$$\text{Min } LCOH = LCOH^p(x_i) + LCOH^l(x_i) \quad (12)$$

Maximize the Supply chain's social impact:

$$\text{Max } SOCimp(x_i) = \sum_{i=1}^n x_i \mu_i^s (FTE^e + FTE^p + FTE^l L_{ij}) \quad (13)$$

**Multiobjective optimization strategy:**

The bi-objective problem is solved using the  $\epsilon$ -constraint method. The economic objective is minimized to obtain the minimum economic cost and the corresponding social impact. Then, the social objective is maximized to obtain the maximum attainable social impact. So, a set

of  $\epsilon$  values is generated between these two extremes, and the economic objective is minimized subject to:

$$SOCimp \geq \epsilon_k \quad (14)$$

In this study, a discrete Pareto frontier is constructed using five  $\epsilon$  values uniformly distributed between the economic and social extremes.

### Model parametrization

The literature parameters:  $a^{p,l}$ ;  $b^{p,l}$ ;  $c^{p,l}$ ;  $d^l$ , are displayed in table 1. The production parameters are derived from Santana et al. (2024), which quantified the impact of various variables on the levelized cost of hydrogen (LCOH) for different plant capacity scales [17]. This parameter set incorporates costs associated with electricity, water pre-treatment, PEM electrolyzer system, initial compression, and gaseous storage buffering.

Based on the published data, a bilinear function was regressed to estimate the LCOH as a function of two key variables: plant capacity (MW) and electricity price (US\$/MWh). This formulation captures the main influencing factors identified in the reference study. In the present model, the electricity price is an exogenous variable, fixed and defined specifically for each location  $i$ .

The parameters for transportation and subsequent conditioning costs (gaseous or liquefied form) were sourced from the meta-analysis by Santos (2024) [18]. This work provides a comprehensive review of hydrogen production, storage, and transportation technologies, detailing their cost and greenhouse gas emission profiles. Given that initial compression costs are already internalized within the production parameters, the transportation and conditioning costs applied here refer to subsequent logistical steps. Originally, non-linear or scale-incompatible parameters were adapted and linearized where necessary to align with the scope and structure of the current model.

The employment parameters were sourced from Ganter et al. (2024), who synthesized the job creation potential for each echelon of the hydrogen supply chain. Their synthesis was based on a combination of data from academic publications, industry sources, and anonymous industry surveys and is presented in table 2 [19]. For PPA-wind is assumed to have no Job creation once the energy production isn't in the same region of hydrogen's.

The selection of potential plant locations  $i$  was based on the results of the Green Hydrogen Atlas of Bahia study [15]. This study applied an Analytic Hierarchy Process (AHP)-based multicriteria analysis to rank the most suitable regions within the Brazilian state of Bahia for green hydrogen production. The selection of the energy source type  $e$  for each locality  $i$  was performed by integrating data from the Atlas with information from the Brazilian National Electric System Operator [20].

Due to budget constraints, a single plant installation

is to be considered in this case. Also, the technology to be installed is a single one, and it will be an electrolyser.

The distances between production locations  $i$  and demand points  $j$  were calculated as follows: for pipeline transport, straight-line distances were obtained via Google Earth, with a 5% markup applied to account for potential route deviations. For truck transport (liquid or gaseous), road distances were acquired using Google Maps, and the electricity price is based on literature data, being \$0.05 per kWh for solar PV; \$0.03 per kWh for on-shore wind power and assume as premised by Mughal and Sajid, 2025 the electricity cost of PPA-Wind equal to solar PV (\$0.05 per kWh) [21, 22].

The data for social indices were either directly obtained or calculated from the values presented in the Green Hydrogen Atlas for the Municipal Development Index (IFDM), Social Vulnerability Index (SoVI), and Gross Domestic Product (GDP) [15]. Income data, however, were sourced directly from the Superintendency of Economic and Social Studies of Bahia (SEI) [23].

Table 3 presents the selected plant locations, distances, and social indices.

## RESULTS AND DISCUSSION

The results highlight a trade-off between economic efficiency and social sustainability in the design of a GHSC in Bahia. Using an  $\epsilon$ -constraint multi-objective MILP formulation with a single-sourcing structure, the resulting Pareto fronts are inherently discrete, with each non-dominated solution corresponding to a specific combination of production site, energy source, and transport mode.

Table 4 presents the trade-off between levelized cost (LCOH) and social impact when the Municipal GDP is used as the social indicator. The Pareto-efficient solutions range from the cost-optimal site (4-Serrinha) to the socially optimal one (6-Barreiras), illustrating the additional cost associated with investing in municipalities with lower economic activity to boost local development.

**Table 4:** Pareto-Optimal Solutions for the GDP-based Social Indicator.

| Site ( $i$ ) | Energy source ( $e$ ) | Transport mode ( $l$ ) | LCOH (\$/kg) | Social impact (GDP) |
|--------------|-----------------------|------------------------|--------------|---------------------|
| 4            | Wind                  | Gas truck              | 1.92         | 128                 |
| 5            | Wind                  | Liq truck              | 3.54         | 357                 |
| 6            | Solar                 | Liq Truck              | 6.42         | 1037                |

For the Municipal Development Index (IFDM), Table 5 summarizes the Pareto-optimal solutions obtained when maximizing its social impact. The sequence of selected sites demonstrates how the model shifts

investment towards locations with greater infrastructural and social needs as the social constraint is tightened, with a corresponding increase in LCOH.

**Table 5:** Pareto-Optimal Solutions for the IFDM-based Social Indicator.

| Site ( <i>i</i> ) | Energy source ( <i>e</i> ) | Transport mode ( <i>l</i> ) | LCOH (\$/kg) | Social impact (IFDM) |
|-------------------|----------------------------|-----------------------------|--------------|----------------------|
| 4                 | Wind                       | Gas truck                   | 1.92         | 259                  |
| 8                 | Wind                       | Liq truck                   | 3.44         | 352                  |
| 3                 | Wind                       | Liq Truck                   | 3.51         | 424                  |
| 7                 | Wind                       | Liq truck                   | 3.64         | 564                  |
| 6                 | Solar                      | Liq Truck                   | 6.42         | 571                  |

In turn, Table 6 details the compromise solutions identified when the optimization incorporates the minimization of Social Vulnerability (SoVI). The results show a progression towards sites with higher social fragility, underscoring the potential role of green hydrogen projects in addressing regional vulnerabilities, although at a higher production cost.

**Table 6:** Pareto-Optimal Solutions for the SoVI-based Social Indicator.

| Site ( <i>i</i> ) | Energy source ( <i>e</i> ) | Transport mode ( <i>l</i> ) | LCOH (\$/kg) | Social impact (SoVI) |
|-------------------|----------------------------|-----------------------------|--------------|----------------------|
| 4                 | Wind                       | Gas truck                   | 1.92         | 298                  |
| 8                 | Wind                       | Liq truck                   | 3.44         | 408                  |
| 3                 | Wind                       | Liq truck                   | 3.51         | 473                  |
| 2                 | Solar                      | Liq truck                   | 6.37         | 559                  |

Finally, the Pareto-optimal configurations for the social indicator based on the local Average Salary are presented in Table 7. The solutions reveal a trade-off where selecting sites with lower average wages (aiming to improve local income) leads to higher supply chain costs, highlighting a key equity-efficiency tension in strategic planning.

**Table 7:** Pareto-Optimal Solutions for the Salary-based Social Indicator.

| Site ( <i>i</i> ) | Energy source ( <i>e</i> ) | Transport mode ( <i>l</i> ) | LCOH (\$/kg) | Social impact (Salary) |
|-------------------|----------------------------|-----------------------------|--------------|------------------------|
| 4                 | Wind                       | Gas truck                   | 1.92         | 238                    |
| 8                 | Wind                       | Liq truck                   | 3.44         | 366                    |
| 11                | Wind                       | Liq truck                   | 3.46         | 415                    |
| 6                 | Solar                      | Liq truck                   | 6.42         | 555                    |

Across all social indicators, the economically optimal solution consistently selects Serrinha (site 4), supplied by

wind power and connected to the refinery via compressed hydrogen trucks (Gas truck), achieving the lowest LCOH of 1.92 USD/kgH<sub>2</sub>. This configuration benefits from short transport distances and low electricity costs but yields the lowest social impact. These results indicate that, in the case of Bahia, cost-minimizing strategies tend to concentrate investments in already consolidated regions, offering limited contributions to broader regional social development goals.

As social requirements become more restrictive, the model shifts the production location and systematically adopts liquefied hydrogen transport (Liq truck), despite its higher cost, due to its significantly higher FTE factor per distance. Intermediate Pareto-efficient solutions, such as Juazeiro (site 5, Table 4), Jacobina (site 8, Tables 5, 6, 7), and Seabra (site 3, Tables 5 and 6), present LCOH values between 3.4 and 3.6 USD/kgH<sub>2</sub>, while delivering substantially higher social impacts.

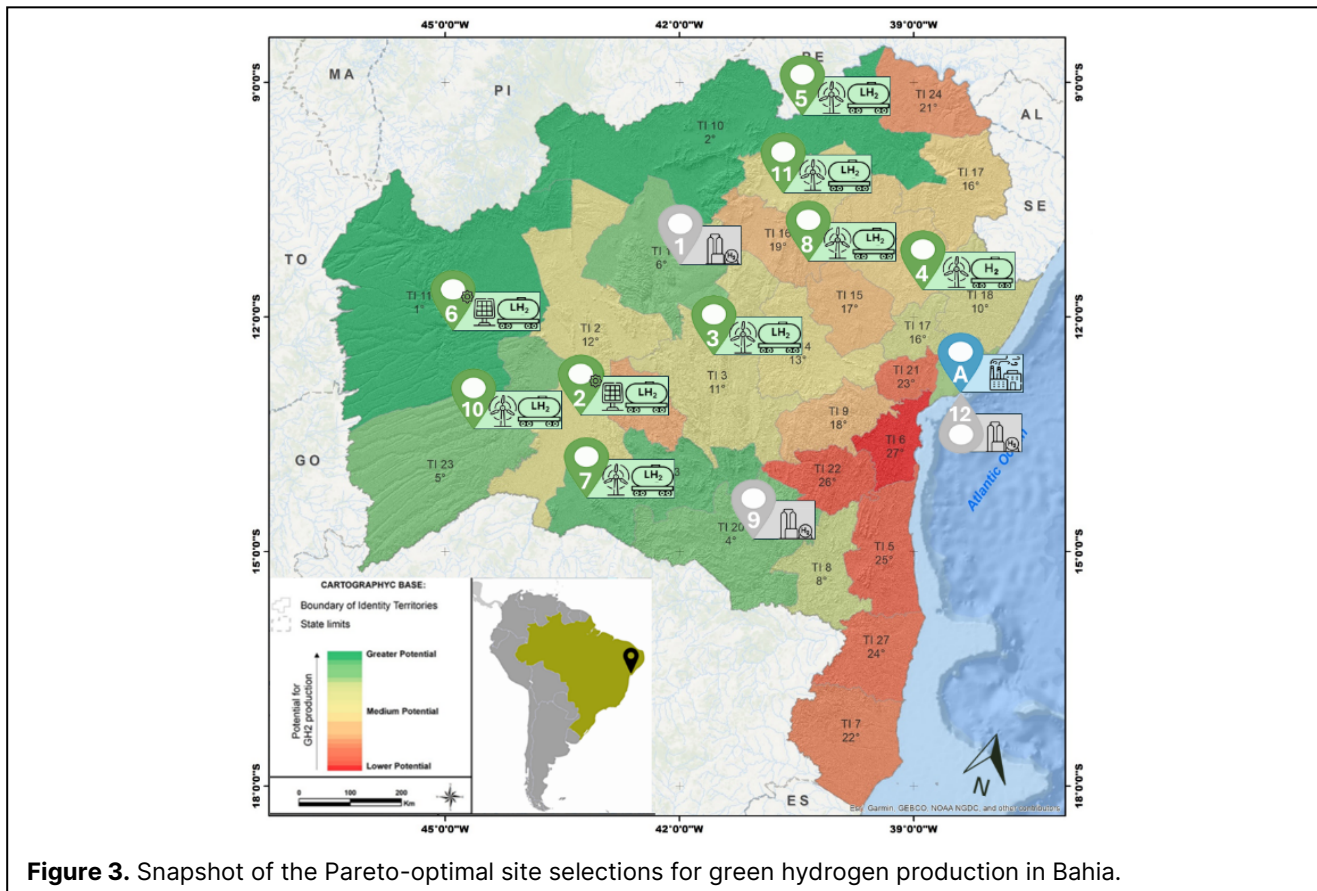
On the other hand, the socially optimal solutions for indicators like GDP, IFDM, and Salary are consistently associated with Barreiras (site 6, powered by solar PV and relying on Liq truck), achieving the highest social impact scores (Tables 4, 5, 7). However, these configurations present the highest LCOH, approximately 6.4 USD/kgH<sub>2</sub>, reflecting longer transport distances and higher electricity costs. This outcome reveals a structural tension: regions with the greatest potential for social benefits are often those facing logistical and energy cost disadvantages, limiting their competitiveness under purely market-driven conditions.

Although each social indicator emphasizes different dimensions of local development, consistent qualitative patterns emerge. GDP-based results favor municipalities with lower economic activity, while IFDM and Salary indicators shift solutions toward regions with greater development needs. The Social Vulnerability Index (SoVI) further reorients the Pareto frontier toward socially fragile municipalities, such as Bom Jesus da Lapa (site 2, Table 6), even at the expense of higher hydrogen production costs.

From a policy perspective, the results suggest that achieving socially inclusive GHSCs requires targeted interventions, such as regional incentives, subsidies, or infrastructure investments in inland regions. Without such measures, cost-driven solutions are likely to prevail, limiting the social benefits of hydrogen deployment. For supply chain planners and investors, the intermediate Pareto-efficient solutions detailed in the tables offer viable compromise strategies that balance economic competitiveness with measurable social contributions, aligning with emerging ESG-oriented investment frameworks.

## CONCLUSION

This work proposed a bi-objective MILP framework



**Figure 3.** Snapshot of the Pareto-optimal site selections for green hydrogen production in Bahia.

for the strategic design of GHSCs that explicitly integrates economic performance and location-dependent social sustainability indicators. By incorporating regional socio-economic metrics into the optimization process, the model enables a transparent assessment of trade-offs between cost efficiency and social impact. The case study in Bahia, Brazil, demonstrates that cost-minimizing solutions tend to favor already developed regions, while socially oriented solutions shift investments toward inland municipalities with greater development needs, at the expense of higher hydrogen costs. The resulting Pareto fronts provide actionable insights for policymakers and investors by identifying compromise solutions that balance competitiveness and social contribution. Although the analysis is restricted to a single production hub, the proposed framework is flexible and can be extended to multi-facility, multi-period, and uncertainty-aware formulations, supporting broader applications in sustainable hydrogen planning. The model proposed is a basic model that will be further developed to include further detailed characteristics of the GHSC, such as fugitive emissions and multiple demand clusters and technologies for hydrogen production.

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