OPTIMIZATION OF GREEN HYDROGEN SUPPLY NETWORK: MILP MODELING FOR CASE STUDY IN MINAS GERAIS

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ABSTRACT

This work aims to present a new computational tool, based on mixed integer mathematical programming, to assist the decision-making process in the choice of location and technologies present in the production of green hydrogen, aiming to minimize the total annualized cost. Its applicability was tested in a case study, considering the state of Minas Gerais, in which 15 different cities located in the state of Minas Gerais were considered. The results suggest that the hydrogen network is strongly influenced by production and transportation costs, and that decentralized production may be more suitable for the evaluated context. In addition, the results can serve as a basis for further studies.

Keywords: Green hydrogen, MILP-base superstructure, Supply network optimization.

Introduction

The search for more sustainable energy sources is motivated by the increasing global demand for energy and its possible impact on the environment. In this context, green hydrogen production is highlighted as one of the main alternatives for developing a low-carbon economy. Despite the development of new technologies for production, storage and transport, its use is still limited due to its high production and transport costs. In this sense, the increase of scale and the development of an optimized transportation network integrated with its production chain can be strategies to reduce its production costs and thus improve its competitiveness. However, the development of this network is a very complex task, given the technologies available for its production, the modes of transport as well as the location where its production can take place. In this sense, the development of a computational tool using Mixed Integer Linear Programming (MILP) would help in the decision-making process, and it is possible to find in the literature different formulations that address this issue, like Li et. al [1], that developed a formulation for hydrogen (H_2) production and transportation, and Potrc et al. [2] for different biofuels. When looking at studies on the production of green hydrogen, few consider the sizing of the solar panel system, as well as the local climatic characteristics in the efficiency of the solar panels. In Brazil, the production of green hydrogen has received a lot of attention, especially in the state of Minas Gerais, which produces the most electricity from photovoltaic panels. This work therefore aims to present a superstructure for the development of a hydrogen distribution network, encompassing the production and transportation of the resources needed for hydrogen production in the state of Minas Gerais.

Methods

A. Superstructure Description

The superstructure proposed in this study aims to represent a green hydrogen production and distribution network in Minas Gerais, to satisfy the demand of 15 locations distributed throughout the state. Its objective function, stated in equation (1), aims to minimize the total annualized cost (TAC), that considers Annualized Investment Cost (I), Acquisition resources cost (CC) and transportation cost (CT), in addition to revenues from Product sales (RP) and Carbon Credit sales (RC), which are calculated by eq.(2) - (7). $\mathrm{VC}_{\mathrm{u,l}}$ and $\mathrm{FC}_{\mathrm{u,l}}$, are parameters that represents the process variable and fixed costs, while fa, MC, OC and LC represents annualization factor, maintenance cost, operational cost and labor cost, respectively. $B_{p,r}$ represents the purchased amount of a resource r in a place p, and OC_r is the cost of resource. $S_{p,r}$ represents the amount sold of that resource, and HP_r is its market price. The transportation cost (eq. 5) is determined by the amount of a resource transported by a modal mo from a place p1 to p2 ($TFSM_{p1,p2,r,mo}$), its distance ($d_{p1,p2}$) and modal cost ($MCo_{r,mo}$). The superstructure resource balance is performed by equation (8), where $Pr_{p,u,r}$, $C_{p,u,r}$, $TFE_{p2,p,r}$ and $TFS_{p,p2,r}$ are the quantity produced and consumed of a resource by a unit in a place, the transported resource that from p to p2, and the resource that enters p2 from p, respectively. The resource produced and consumed by a process is determined by equations 9 and 10 respectively, where $IR_{u,r}$ and $OR_{u,r}$ is the consumed and produced resource by the process, while f is the operational time in a year. For solar panels, the produced energy is determined by equation 11, where G_p and e_p represents the global horizontal radiation and the local efficiency conversion of the panels respectively, these parameters mean that the presented formulation considers local climatic characteristics. The process selection is performed by equation (12), which has its capacities divided into levels (l), intervals limited by a maximum ($CapMax_{u,l}$) and minimum value ($CapMin_{u,l}$). $y_{u,l}$ is a binary variable that represents the existence of that unit in that level, $wl_{u,l}$ is a continuous variable responsible for the process scale adjustment into that level, while w_u is a continuous variable that represents the scale adjustment for that process. The transportation are performed by equations 14 - 16, where $TFEM_{p1,p2,r,mo}$ is the resource transported by a modal from p1 to p2, and $fp_{r,mo}$ is the resource loss factor.

$$Objective\ function = \min TAC \tag{1}$$

$$TAC = I + CC + CT - RP - RC \tag{2}$$

$$I = \sum_p \sum_u \sum_l (VC_{u,l} wl_{p,u,l} + FC_{u,l}\, y_{p,u,l}).fa.(MC + OC + LC) \tag{3}$$

$$CC = \sum_p \sum_r B_{p,r} OC_r \tag{4}$$

$$CT = \sum_{p1} \sum_{p2} \sum_r \sum_{mo} TFSM_{p1,p2,r,mo} d_{p1,p2} MCo_{r,mo} \tag{5}$$

$$RP = \sum_p \sum_r S_{p,r} HP_r \tag{6}$$

$$RC = \left(\sum_p \sum_r S_{p,r} AC_r - \sum_p \sum_r B_{p,r} EC_r - \sum_{p1} \sum_{p2} \sum_r \sum_{mo} TFSM_{p1,p2,r,mo} CM_{r,mo} d_{p1,p2} \right) CV \tag{7}$$

$$B_{p,r} + \sum_u Pr_{p,u,r} + \sum_{p2} TFE_{p2,p,r} = S_{p,r} + \sum_u C_{p,u,r} + \sum_{p2} TFS_{p,p2,r} \tag{8}$$

$$IR_{u,r} W_{p,u} f = C_{p,u,r} \tag{9}$$

$$OR_{u,r} W_{p,u} f = Pr_{p,u,r} \tag{10}$$

$$W_{p,u} G_p e_p = Pr_{p,u,r} \tag{11}$$

$$CapMin_{u,l} y_{p,u,l} \leq wl_{p,u,l} \leq CapMax_{u,l} y_{p,u,l} \tag{12}$$

$$\sum_l wl_{p,u,l} = w_{p,u} \tag{13}$$

$$TFEM_{p1,p2,r,mo} = TFSM_{p1,p2,r,mo}(1 - d_{p1,p2} fp_{r,mo}) \tag{14}$$

$$TFS_{p1,p2,r} = \sum_{mo} TFSM_{p1,p2,r,mo} \tag{15}$$

$$TFE_{p1,p2,r} = \sum_{mo} TFEM_{p1,p2,r,mo} \quad (16)$$

To represent the processes in the production and distribution of green hydrogen (H_2G), seven models were considered: Solar Production, PEM Electrolyzer, Alkaline Electrolyzer, Liquefaction (G2L), Compression (G2CG), Regasification (L2G) and Decompression (CG2G). Each of these units has input and output streams and plays the role of converting one specific resource into another. Figure 1 shows a representation of the developed superstructure.

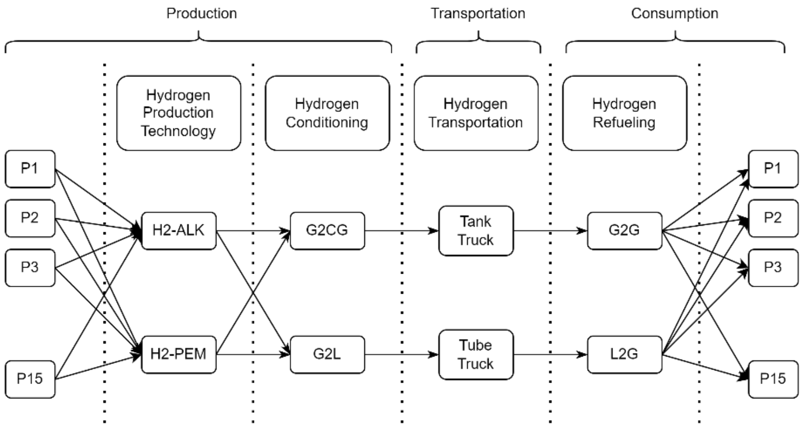

Figure 1 - Superstructure schematic representation.

The choice of locations was made to consider the heterogeneity in terms of radiation received, to analyze the impact of this parameter on the final network. The demand was based on the fuel consumption of these cities and the total mileage of popular vehicles, considering a conversion factor of 13.90 $km.l^{-1}$ for gasoline, 9.50 $km.l^{-1}$ for alcohol and 240.70 $km.kg^{-1}$ for H_2. The considered cities and it's H_2 demand are presented in Table 1.

Table 1 - Cities and their respective values of H_2 demand, photovoltaic efficiency, and Global Horizontal Irradiation, considered in this analysis.

City	H_2G Demand [$ton.y^{-1}$]	Photovoltaic Efficiency [-]	GHI [$kWh.m^{-2}.y^{-1}$]
Januária	467.43	0.1771	2,124.30
Montes Carlos	5,931.01	0.1713	2,098.75
Sete Lagoas	3,901.60	0.1736	2,000.20
Uberlândia	13,840.00	0.1729	2,007.50
Lavras	1,618.07	0.1822	1,898.00
Belo Horizonte	43,468.00	0.1796	1,941.80
Divinópolis	3,672.00	0.1741	1,963.70
Ituiutaba	1,728.06	0.1735	1,996.55
Pouso Alegre	3,174.21	0.1799	1,843.25
Teófilo Otoni	1,877.44	0.1786	1,832.30
Barbacena	1,941.98	0.1839	1,788.50
Muriaé	1,710.05	0.1768	1,843.25
Poços de Caldas	2,728.18	0.1699	1,843.25
Governador Valadares	3,439.32	0.1793	1,828.65
Juiz de Fora	8,020.63	0.1837	1,719.15

For electricity production, was considered a solar powerplant. Contrary to other works, a study was carried out with the parameters of radiation absorption and photovoltaic generation for each

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municipality in the Trnsys software, considering real data of solar panels, inverters, and climatological data of each city. Regarding the costs of purchase and sale of resources, 3.30 U$$.t^{-1} were assumed for the purchase of water [3] and 5,000 U$$.t^{-1} for the sale of H_2G. Previously, the cost of transporting liquid hydrogen by tube truck was 5.73 U$$.t^{-1}.100km^{-1}, while the cost of displacing compressed hydrogen was 612.20 U$$.t^{-1}.100km^{-1}[4] . The online simulator HyJack[5] was used for the costs of photovoltaic panels, PEM electrolyzers, alkaline electrolyzers, and hydrogen compressors.

Results and discussion

For this study, the green hydrogen distribution network is determined based on the minimization of the annualized production cost. Different cases have also been evaluated to verify the influence of costs and transportation losses. Considering all the costs and losses mentioned in the methodology, the optimization model presents as optimal configuration the formation of a predominantly decentralized network, which can be seen in Figure 2a. The centralized production in Belo Horizonte and Pouso Alegre can be justified by the good geographical location of the cities and the easy flow of H_2 to nearby cities. In addition, the centralized production in these locations can be advantageous due to the increase in economies of scale and the consequent reduction in production costs. In Case 2, to verify the influence of losses in energy transmission, they were assumed to be zero, and the most viable configuration presented a centralized production for electricity, with the installation of a single photovoltaic plant in Januária. For H_2G, as in the previous case, the network is predominantly decentralized, but with centralized production only in Belo Horizonte and Juiz de Fora, as can be seen in Figure 2b. For the latter case, we have not considered the costs related to the transportation of resources and the losses in the transmission of electricity. Unlike the previous configurations, in this case a centralized configuration was presented in Januária for electricity generation and in Belo Horizonte for H_2G production. These configurations are presented in Figure 3. When comparing the results obtained by the cases, it is possible to observe that for the state of Minas Gerais, there is a prevalence of decentralized production. Nevertheless, the results suggest that the city of Belo Horizonte can play a very important role in the development of an H_2G network in the state of Minas Gerais, since it has presented in all cases the role of producer and distributor of this resource. This characteristic can be justified by its high demand, which represents 44.50% of the total demand. In addition, the cities of Lavras, Divinópolis and Barbacena did not have the installation of a solar plant or electrolyzer in any of the cases evaluated.

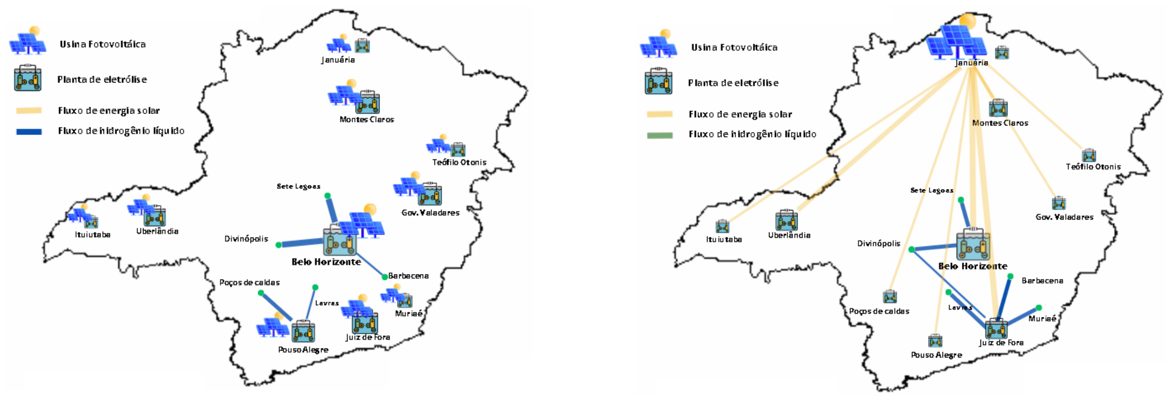

Figure 2 - Configurations for cases 1(a) and 2(b).

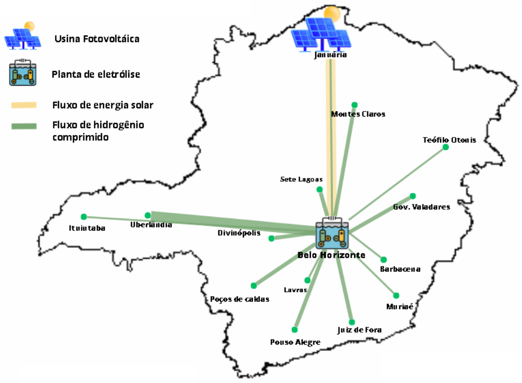

Figure 3 – Obtained configuration for the different cases.

Conclusion

The results obtained suggest that the configuration of the hydrogen network is strongly influenced by the factors considered. They also indicate that decentralized production may be the most appropriate, especially considering transportation costs and transmission losses. In addition, the hydrogen demand plays a crucial role in the network configuration. The results also demonstrate the effectiveness of the developed formulation, and it is important to emphasize that the expansion of the cities considered can lead to a better design and development of a network for H_2G production and distribution in Minas Gerais. In addition, the configurations obtained can serve as a basis for more in-depth and accurate studies.

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References

[1] L. Li, H. Manier, and M. A. Manier, "Integrated optimization model for hydrogen supply chain network design and hydrogen fueling station planning," *Comput Chem Eng*, vol. 134, p. 106683, Mar. 2020, doi: 10.1016/J.COMPCHEMENG.2019.106683.

[2] S. Potrč, L. Čuček, M. Martin, and Z. Kravanja, "Synthesis of European Union Biorefinery Supply Networks Considering Sustainability Objectives," *Processes 2020, Vol. 8, Page 1588*, vol. 8, no. 12, p. 1588, Dec. 2020, doi: 10.3390/PR8121588.

[3] "COPASA." www.copasa.com.br (accessed Jul. 07, 2023).

[4] IRENA, "Innovation landscape brief: Renewable Power-to-Hydrogen," 2019.

[5] "HYJACK," 2022. hyjack.tech/ (accessed Jul. 09, 2023).