Economic and environmental viability of the production, storage, and distribution of hydrogen for the vehicle sector in the province of Córdoba (P-21H)

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1. Introduction

Large-scale energy production and its excessive use generate negative impacts on the environment that will affect the living conditions of future generations, as much of the global primary energy comes from fossil fuels.

Argentina, since 1983 when the replacement of liquid fuels was implemented, has become the leading country in the use of Natural Gas both, for the production of primary energy and in the transportation sector. Such is the case of the province of Córdoba, the second-largest in population in our country, which is representative of the development of the Compressed Natural Gas (CNG) industry at the national level [1]. In 2019 the Argentine transport sector was responsible for the emission of 54.2 million tons of carbon dioxide equivalent (CO_2eq) [2].

To limit global warming to 1.5°C, it is essential to study the transition from fossil fuels to renewable energies, and the application of new energy vectors. Along with electricity and the latest generation of batteries, one of the most important energy vectors is hydrogen (H_2) [3]. In recent years, it has been globally identified as a key element of the future clean energy matrix [4], as it is capable of providing safe, economically competitive energy that is free of carbon dioxide (CO_2) emissions [5].

Given this scenario, it is necessary to guide society towards safer, more durable and, above all, non-polluting energy systems. The role of public energy policies is essential to promote the expansion of renewable energy development. In the literature, several works highlight the economic and environmental benefits of hydrogen production [6-9]. Argentina has great potential for the exploitation of renewable resources, including solar power and wind power. This makes the province of Córdoba an excellent model case for the study of the rapid incorporation of hydrogen generation, transportation, distribution and usage of this fuel. Thus, in this work, the Levelized Cost Of Hydrogen (LCOH) and emissions associated with the production of hydrogen to replace CNG in vehicles is analyzed, using two different production sources, electricity from renewable energy and electricity from the Argentine electric grid.

2. Metod

Analyzing hydrogen supply chains is of paramount importance to properly understand Argentina's future energy systems. Two different scenarios are proposed and studied for the generation of Hydrogen and its subsequent use in a mixture with CNG at 20% v/v (HGNC) for the supply of CNG fueled vehicles in the province of Córdoba. The replaced volume corresponds to 62.05 million Nm^3 or 5575.38 tons of hydrogen per year. The production chain is shown in Fig. 1.

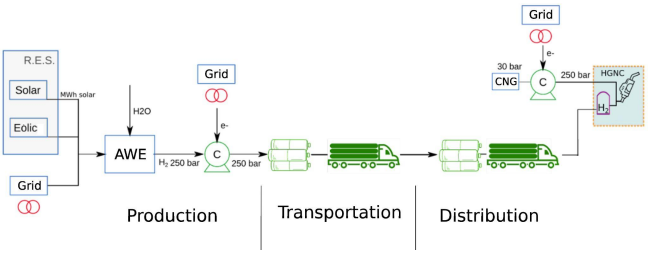

Fig. 1. Hydrogen production and delivery pathway.

Green H_2 production was devised using alkaline water electrolyzers (AWE) in three renewable energy generation parks in the province of Córdoba: (i) Achiras wind farm, (ii) Arroyo del Cabral photovoltaic park,and (iii) Villa María del Río Seco photovoltaic park. The capacity factor (CF) of the facilities are 57.40%, 23.00%, and 23.00%, respectively.

Hydrogen exits the electrolyzers at 10 bar and is compressed to 250 bar in tube trailers with a capacity of 1100 kg [9]. To carry out the substitution of natural gas, the current locations of the CNG refuelling stations are used, and eight distribution centers to deliver the hydrogen to the stations are proposed. The location of the deposits and the distribution paths were calculated using the Vehicle Routing Problem (VPR), a library extension of ArcGIS 10 [10], with the aim of minimizing the distance travelled. The location of the deposits and the distribution paths can be seen in Fig. 2.

Two scenarios are proposed: (i) production using only renewable energies, sizing the production facilities according to their respective CF, (ii) production supplementing the intermittency of the renewable parks

using grid energy to feed the electrolyzers at constant rated power.

To determine the viability of using this new energy vector in the CNG vehicle sector, the levelized cost of hydrogen, according to the method described in Ref. [8], and the emission of carbon dioxide equivalent (CO_2eq) were analyzed. For the levelized cost of hydrogen calculation, the cost of electrolyzers, their auxiliaries, trucks, tube trailers, civil works, and the costs of operation and maintenance were taken into account. For the emissions calculation, the emissions generated from the use of energy from the electricity grid and the emissions generated by trucks in transport and distribution were taken into account. These values were later compared with the savings in CO_2eq emissions from the volume of CNG replaced.

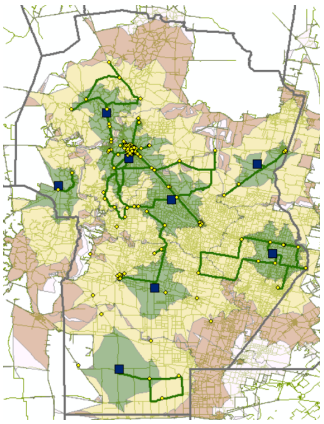

Fig. 2. Deposit locations and distribution routes in Córdoba province.

3. Results

Fig. 3 shows the breakdown of the levelized cost of hydrogen, for production using only renewable energy. The LCOH turns out to be 8.68 USD/kg-H_2.

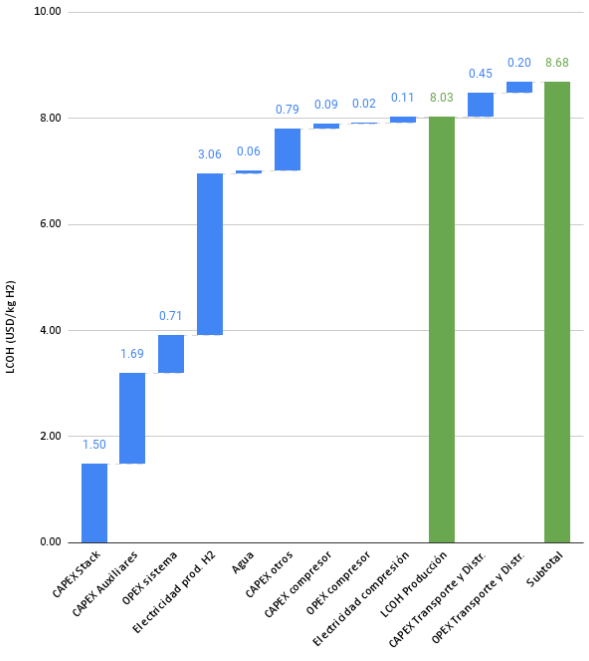

Fig. 3. LCOH breakdown for H_2 production from renewables.

Fig. 4 shows the different CAPEX of the project, where the CAPEX of the stack and its auxiliaries represents 67.8% of the total. This is because by using only renewable energy, the electrolyzer plant is underutilised.

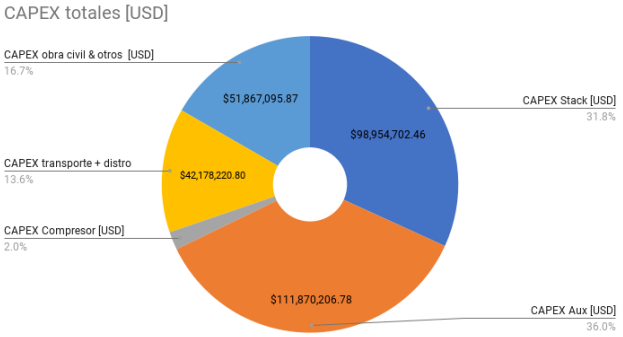

Fig. 4. CAPEX for H_2 production from renewables.

Fig. 5 shows the LCOH breakdown for production using renewable energy and energy from the electricity grid. The LCOH turns out to be 8.12 USD/kg-H2.

Fig. 6 shows the different CAPEX of the project, where the CAPEX of the stack and its auxiliaries in this scenario represents 60.3% of the total due to the electrolyzer plant size going from 135 MW to 39MW. Overall, in the second scenario the CAPEX decreased by 49%, from 311 MUSD to 159 MUSD.

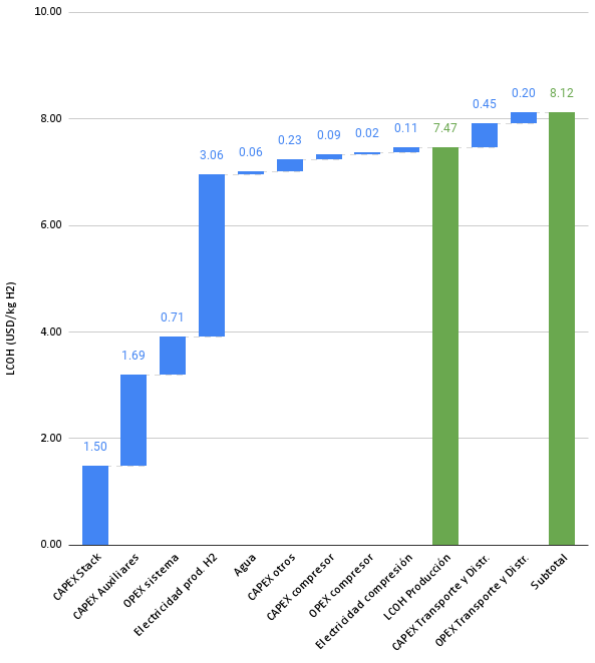

Fig. 5. LCOH breakdown for H_2 production from mixed sources.

In scenario (i), 3,053 tons of CO_2eq are emitted per year due to the transportation and distribution of hydrogen, while in scenario (ii), 79,140 tons of CO_2eq are emitted per year; the difference of 76,087 tons CO_2eq is due to the use of electrical energy. While in scenario (i) 100% of electricity comes from renewable sources, in scenario (ii) this value falls to 35.68%. Due to the fact that renewable energy is cheaper than that from the grid, the

cost of electricity is 208 MUSD for scenario (i) and 231 MUSD for scenario (ii).

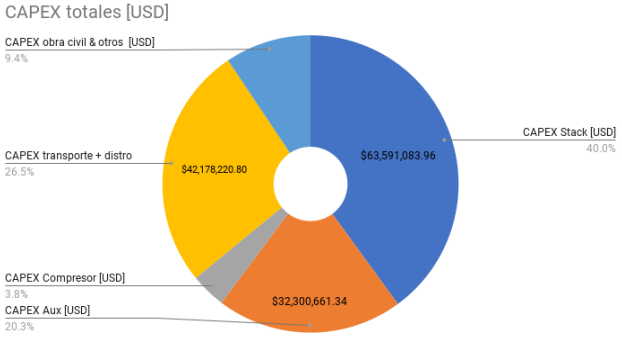

Fig. 6. CAPEX for H_2 production from mixed sources.

The CO2eq emission of the entire fleet of CNG vehicles in Cordoba amounts to 602725 tons per year. The new blend of HCNG with 20% v/v of H2, would yield a reduction of 117,693.93 tons of CO2eq per year for scenario (i) and 41,606.90 tons of CO2eq for scenario (ii). The proposed substitution would reduce that emission by 19.49% under scenario (i) and 6.87% under scenario (ii).

Taking the current CNG price in Córdoba 0.63 USD/Nm^3, the addition of 20% v/v of H_2 to the CNG mixture would change the price to 0.6626 USD/Nm^3 for scenario (i) and 0.6526 USD/Nm^3 for scenario (ii), increasing the price per unit of volume in 4.64% and 3.05% respectively. The lower heating value (LHV) per mass of the HCNG turns out to be 31.44 MJ/kg, lower than that of the regular CNG, which has a LHV of 36.6 MJ/kg. Taking this into account, the energy price of the CNG is 17.30 USD/GJ while the HCNG price turns out to be 21.07 and 20.76 USD/GJ, for scenarios (i) and (ii) respectively. an increment of 21.81% and 19.97% per unit of energy.

4. Conclusions

In this paper, the costs and emissions associated with the generation, transportation and distribution of hydrogen in the province of Córdoba were calculated using two production scenarios.

It was possible to verify that in both scenarios there was a reduction in CO_2eq emissions by replacing 20% v/v of vehicular CNG with Hydrogen produced using (i) renewable energy or (ii) a mix of grid electricity and renewable energy.

The LCOH found in both scenarios is at the lower end of the price range found in the literature, showing that the CNG substitution is favorable from an environmental point of view, on the other hand, the HNCG price would be higher yet affordable.

Finally, it is important to mention that this proposal is a fast technological transition pathway since current technical-economic data and currently available technologies in the market were used.

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