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Development of a Hydrogen Production from Solar Thermal Energy Application Model for The United Arab Emirates

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ABSTRACT

The application of large-scale renewable energy projects, especially solar thermal, in the Middle East region and the Gulf Cooperation Countries, leveling with the region's high potential, is facing many challenges, concerning the feasibility of a huge investment. One way to motivate policy makers is to use the excessive energy to produce Liquid Hydrogen for export to needed countries, making the investment profitable and helping reducing CO_2 emissions levels worldwide. In this study the surplus electricity from, from different scenarios of Concentrated Solar Plants application, is used for Hydrogen production using three different technologies (Alkaline, PEM and SOEC) for technical comparison. Another two scenarios are considered, with different locations for the Hydrogen production sites, between CSP sites and ports, using Geographical Information System GIS, to assess the pathways for Hydrogen production.

Keywords: Concentrated Solar Plants, Hydrogen, Pathway, The Middle East Region, United Arab Emirates.

1. INTRODUCTION

The United Arab Emirates and the Middle East are facing a surge in energy demand and growing CO_2 emissions [1], directing the region into seeking new sources of energy with low carbon footprint.

Solar energy presents a suitable fit to the region's climatic advantage [1], from sunlight abundance to the vast open areas of desserts. Few projects and plans are already on foot, such as Concentrated solar plants (CSP), to exploit the UAE's solar potential, but addressing it's full capabilities is still far to achieve, due to the large economic investment that doesn't yet prove feasible compared to the current traditional applied technologies.

In this paper we consider using the excessive energy from two different scenarios of large-scale CSP application in the UAE, for liquid Hydrogen production and using it for export, using the profits as an incentive for CSP large application, and keeping the UAE and Gulf Cooperation Countries (GCC) as a major energy export. Although few studies addressed the potential of renewable energy and hydrogen production of the UAE, along with their possible future cost, none fully compares different scenarios of CSP application nor investigates the ability of the current infrastructure to produce and deliver the produced H_2 to possible export areas.

2. METHOD AND DATA

In this study we investigate the technical potential of liquid hydrogen production from surplus electricity of two different scenarios of CSP application in the UAE based on our previous study [2], where the potential of solar thermal energy in the UAE in three different cases, depending on the distance from roads, electrical grid and water areas. The results show that, only two cases with the distances of 25 km and 40 km from mentioned parameters, can leave extra electricity for hydrogen production, after satisfying the future demand of the UAE for the year 2023.

Two delivery scenarios are pursued in this paper depending on the location of H_2 plants, the first one assumes they are at the same location of CSP plants, where 6 main spots are assumed for the location of the plants, covering all areas of UAE suitable for CSP application in both application scenarios, also with access to main roads and high voltage electricity grid of the UAE. In this scenario, the H_2 is to be delivered using trucks toward the main 6 seaports for export in the UAE [3], shortest distance from plants to ports are analyzed using Geographical Information System (GIS) to investigate the applicability of this scenario, where road

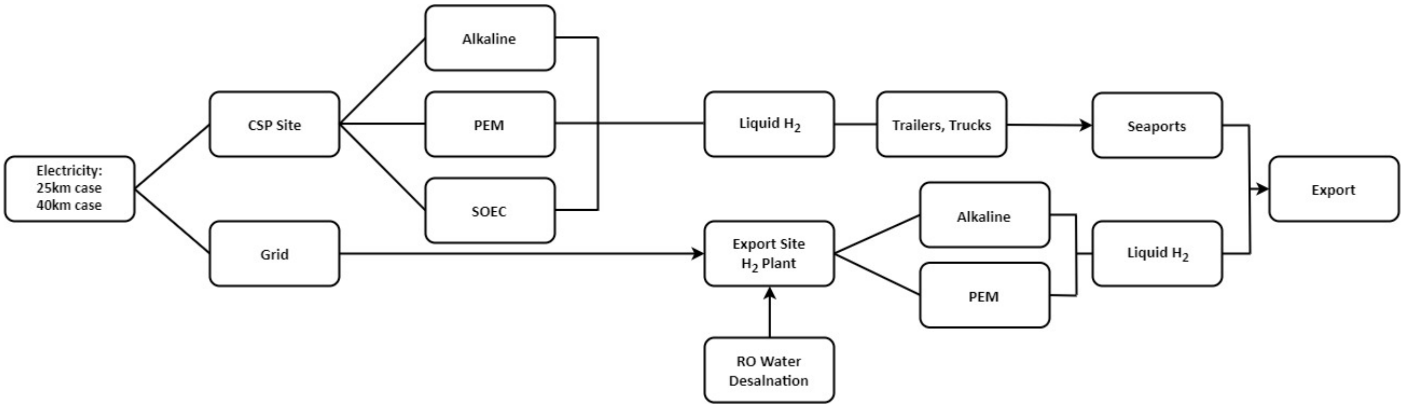

Fig 1 Scenarios layout

network data from OpenStreetMap [4] is used, and the truck speed is set to 80 km/h.

The second location scenario, assumes hydrogen production plats be placed at the ports, where excessive electricity from CSP plants are transmitted through the electrical grid of the UAE towards export ports, presuming that 3% of electricity is lost in the grid for every 1000km traveled [5]. The shortest routes of electrical grid are analyzed with GIS to ensure the least loss of electricity possible in the network in this scenario. The layout of study methodology is shown in Fig 1.

We assume 6 main points for CSP plants located on main roads and high voltage electrical grid. Then we include the 6 main ports for export in the UAE [3], shown in Fig 3.

We compare three different water electrolysis technologies for hydrogen production, the first is alkaline electrolysis, which is the most common technology [6], it's been used by industry for nearly a century, there for the most mature way to produce hydrogen. It uses potassium hydroxide (KOH) [6], which adds extra expenses for the production process. The second technology is Proton exchange membrane electrolysers (PEM), where the electrolyte is a polymer membrane which is only permeable for hydrogen ions, today they are commercially available. The last technology is Solid oxide electrolysers (SOEC) the electrolyte is a solid ceramic membrane. All electrolysers assumed are higher heating value (HHV), where alkaline and PEM work temperatures between 60° C to 90° C, while SOEC elctrolyser high temperature steam electrolysis (HTE) at temperatures in the range of 700° C to 800° C, this technology could be coupled with CSP plants, but it still at development phase. Chosen efficiencies for each technology are explained in Table 1.

For the second scenario where the hydrogen plants are located at the ports, only alkaline and PEM are considered, since SOEC would require extra energy consumption at the ports. Also, the water source for electrolysis in this scenario, is assumed to come from desalinated seawater using reverse osmosis (RO) desalination, and electricity used for water desalination is added to the energy demand of the electrolysis process, The energy needed can be determined by multiplying the energy need per cubic meter with the amount of water that is necessary which is [6]:

$$m_{\dot{H}_2O} = \frac{\dot{m}}{M\times\eta}\times M_{H_2O} \qquad (1)$$

Where $\dot{m}$(kg/s) is the production rate of hydrogen, M is the molar mass of hydrogen, η is the efficiency of water use and M_{H_2O} is the molar mass of water.

Table 1. Electrolysers efficiencies [7-9].

Elctrolyser	Efficiency	Efficiency
Alkaline	53.5 kWh/kg-H_2	73%
PEM	49.8 kWh/kg-H_2	78.9%
SOEC	39.4 kWh/kg-H_2	82%

3. RESULTS AND DISCUSSION

3.1 Hydrogen plants at the same site as CSP Scenario

Based on the assumptions mentioned in the previous section, in this scenario we first calculate the hydrogen for all different technologies for the two energy supply scenarios we have. SOEC has the biggest amount of hydrogen in both energy cases, as shown in Table 2.

For a better understanding Fig 2 shows a comparison between the amounts of hydrogen produced.

Table 2. Produced hydrogen from different technologies in the first scenario in both energy cases (kg x 10^6).

Energy case	Alkaline	PEM	SOEC
25km case	4,784.08	5,139.524	6,496.15
40km case	8,918.5	9,581.11	12,110.134

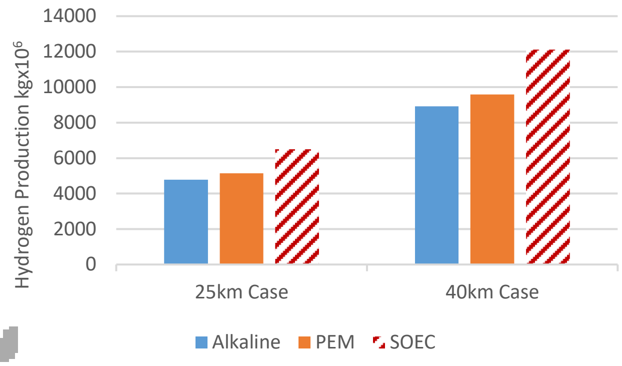

Fig 2 Comparison of hydrogen production in all technologies for 25km and 40km energy supply cases, in plants at the same location as CSP sites scenario.

SOEC results were shown in pattern style to express that only this technology is still at lab level, where the others at an industrial one.

The next step is the geospatial network analysis, to find the shortest routes for the hydrogen delivery from production sites to close ports. Fig 3 shows the shortest routes analyzed deliver the hydrogen to 4 ports, where two plants can deliver to Khalifa port, other two to Jebel Ali, one to port Rashid and the last to Fujairah port.

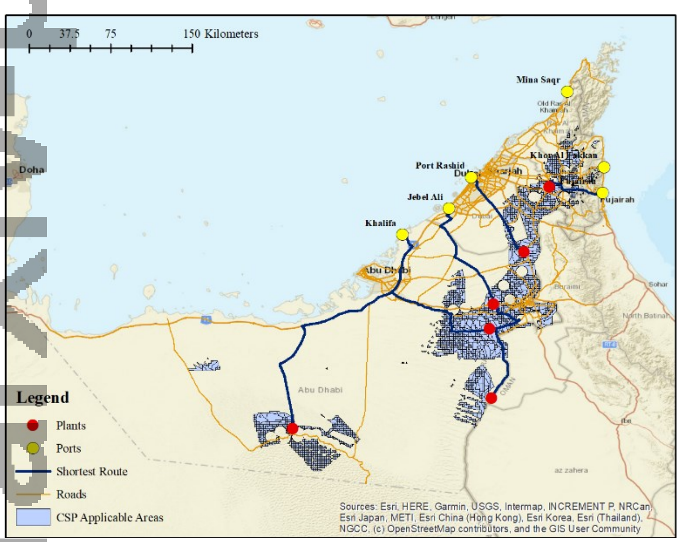

Fig 3 Shortest routes from hydrogen plants to export ports analysis by GIS in the 25km CSP case.

The distances calculated can be used in future cost analysis to compare scenarios feasibility.

3.2 *Hydrogen plats at Ports Sites Scenario*

For this scenario we first start with the network analysis to define the shortest distances of electrical grid, to deliver the surplus electricity in all cases from CSP plants to ports. Fig 4 shows the GIS results, where only two ports are chosen, five CSP plants are closer to Khalifa port, while only one can transmit the electricity to Fujairah port.

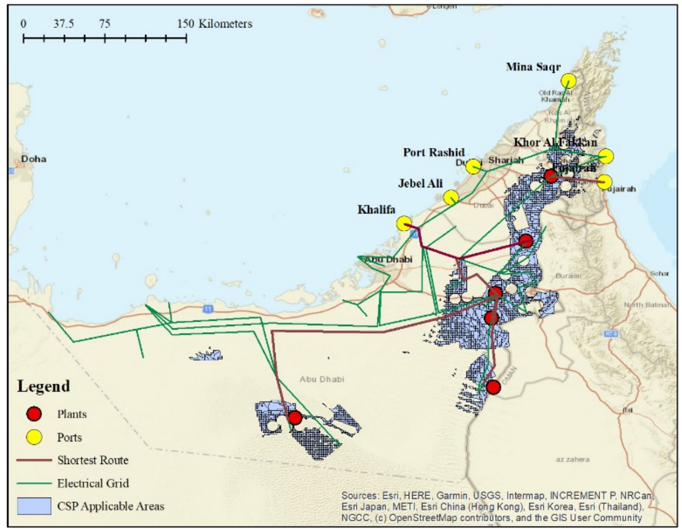

Fig 4 Shortest electrical grid routes from hydrogen plants to export ports analysis by GIS in the 25km CSP case.

Analysis shows that the sum of distance traveled in electrical grid is 1031.24 km, therefor the loss in the grid would be up to 3.1% of total energy transmitted, the remaining energy is used to desalinate water and produce hydrogen at the two chosen ports, electricity consumption for desalinating the water needed for one kg of H_2 from equation (1) is 1.8 kWh, which is added to elctrolyser's consumption. In this scenario only alkaline and PEM electrolysers are used, as SOEC works better coupled to steam source such CSP plants. Table 3 shows a comparison between the amounts of hydrogen produced in this scenario for all energy cases.

Table 3. Produced hydrogen from different technologies in the second scenario in both energy cases (kg x 10^6).

Energy case	Alkaline	PEM
25km case	4,635.77	4,806.471
40km case	8,642.018	8,960.23

In Fig 5 we compare these results to shows the differences between the amounts of produced H_2 in each energy case.

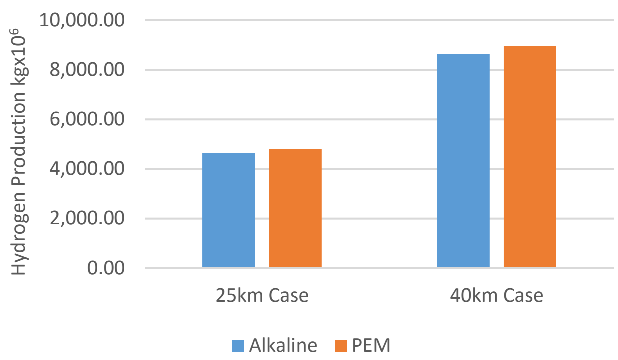

Fig 5 Comparison of hydrogen production in all technologies for 25km and 40km energy supply cases, in plants at port sites scenario.

3.3 Location Scenarios Comparison

Finally, we compare produced hydrogen in all scenarios for 25km energy case to have a better understanding of the results, as shown in Fig 6. The results for the 40km are similar with higher amounts of produced hydrogen.

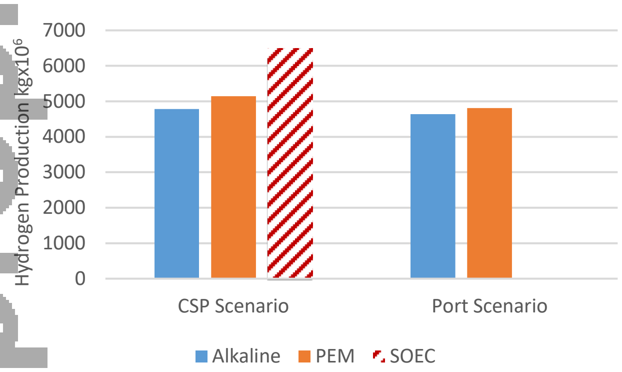

Fig 6 Produced H_2 for all location scenarios in the 25km case.

4. CONCLUSIONS

In this study we evaluate hydrogen production from different technologies, in two location scenarios, based on excessive electricity from two different energy cases of CSP application in the UAE. The produced hydrogen is planned to be exported as mean of profit to make the investment in large scale CSP application in the UAE and GCC feasible.

The resulted from the two delivery paths show that four ports can be used for export from various CSP plants, providing more flexibility to delivery options. While in the second scenario, only Khalifa and Fujairah ports are chosen as the closer option for electricity transmission and hydrogen production sites.

Production results show SOEC elctrolyser as the best technology for large scale H_2 production in the first scenario when coupled to the CSP plants, while PEM seems like the better fit for the port scenario, with using desalinated water using RO.

A future cost analysis is needed to provide a wider perspective and better understanding for what is a better scenario and delivery path.

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