Assessing The Economic Viability And Fueling Capacity of Renewable Hydrogen: A Way Forward For Green Economic Performance And Policy Measures

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Abstract

Energy security and environmental measurements are incomplete without renewable energy therefore there is a dire need to explore new energy sources. Therefore, the aim of this study is to measure the wind power potential to generate the renewable hydrogen including its production and supply cost. We used first order eneginnering model and net present value to measure the levelized cost of wind generated renewable hydrogen by using the data source of Pakistan metorological department and State bank of Paksitan. Results shows that the use of surplus wind and renewable hydoregn energy for green economic production is suggested as an innovative project option for large-scale hydrogen use. The key annual running expenses for hydrogen are electricity and storage cost, which have a major impact on the costs of renwable hydrogen. Also, the results indicates that project has the potential to cut CO_2 pollution by 139 million metric tons and raise revenue for wind power plants by 2998.52 million dollars. The renewable electrolyzer plants avoided CO_2 at a rate of 24.9–36.9 $/ton under baseload service, relative to 44.3 $/ton for the benchmark. However, in the more practical mid-load situation, these plants have a significant benefit. Further, the wind generated renewable hydrogen deliver a 6–11% larger than annual rate of return than the standard CO_2 catch plant due to their capacity to remain running and supply hydrogen to the consumer through periods of plentiful wind and heat. Also, the measured levelized output cost of hydrogen (LCOH) was 6.22$/kg$H_2$ and for the PEC system, it was 8.43 $/kg$H_2$. Finally, its mutually agreed consensus of the environmental scientist that integration of renewable energy is the way forward to increase energy security and environmental performance by ensuring uninterrupted clean and green energy. Further, this application has the potential to address Pakistan's urgent issues of large-scale surplus wind and solar-generated energy, as well as rising enegry demand.

Keywords: Energy security; Energy efficiency; Renewable hydrogen, Green economic indicators; Renewable energy

1. Introduction

Pakistan has severe electricity crisis; for example, the energy demand-supply deficit in Pakistan is roughly 5500-6000 MW, and full blackouts occur 12–18 hours per day. The Pakistani government spent $9 billion in 2008 and 2009 to close the troubling difference between electricity demand and availability, which placed a strain on the country's economy (Iqbal et al. 2019b),(Anh Tu et al. 2021). Furthermore, emerging countries are affected by climate change problems correlated with global warming; for example, Pakistan's temperature has risen dramatically in recent decades (Chien et al. 2021). Because of the detrimental impacts of global change, such as drought, increasing sea levels, and decreased crop yields, as well as the resulting impact on health and poverty, these issues are worth investigating. In comparison to fossil fuel oil, several energy sources include high-productivity hydrogen energy with a significant amount of energy, efficient hydrogen production are biomass, solar, and wind (Jahangiri et al. 2020). Currently, conventional energy sources have the majority of Pakistan's energy, contributing to global warming and climate change (IEA, 2016). One of the main environmental threats of the twenty-first century is climate change caused by anthropogenic greenhouse gas (GHG) pollution. The Intergovernmental Panel on Climate Change (Zhao et al. 2019) proposed a variety of options for rapidly reducing GHG pollution. CO2 emissions responsible for 75% of anthropogenic GHG emissions (Khan and Tariq 2018), but lowering them has the biggest impact on mitigating global warming. Any of these guidelines, such as the use of intermittent green energies, are on target to keep global warming below 2 degrees Celsius. (VRE) (Wang et al. 2020) and (Nawaz et al., 2021; Hashemizadeh et al. 2021).

Since Pakistan is the world's sixth-largest nation and has a rapidly increasing population, the negative consequences of climate change may be extreme. Increased energy demand has resulted from increased population and better living conditions (Iqbal et al. 2020). More than

140 million Pakistanis suffer regular power shortage of 12–18 hours or do not have connections to the national power grid, resulting in an annual candle and kerosene spending of approximately US$2.3 billion. Many experts have called for the use of sustainable and indigenous resources to meet expected energy demand; for example, wind and solar have become essential. Researchers (DellaValle and Sareen 2020) concluded in the literature that rising energy demands could encourage environmental laws that support sustainable energy use, since continued use of carbon-based non-renewable sources. Coastal storm waves, warm summers, unpredictable and flooding are only some of the examples. As a result, a variety of mitigation measures have been implemented to mitigate the impacts of environmental destruction (Babar and Ali 2021) which ranks as the world's 12th most endangered country.

Pakistan is also at the peak of a country-by-country ranking of climate danger. Climate change has already claimed the lives of thousands of Pakistanis. This amounted to 1.1% of overall GDP (Alao et al. 2020). As a result, quantifying and qualifying the potential economic and environmental benefits of generating sustainable hydrogen solely from wind power is significant (Dhiman and Deb 2020). Many research have investigated the architecture and application of sustainable hydrogen systems using different quantitative and computational methods in an effort to establish an optimum energy balance. According to (Bamisile et al. 2021a), hydrogen can outperform necessitate the carbon-free energy systems. Estimation of power and equipment capability and economic assessment. During the construction phase, equipment costs, especially electrolyser costs, are the most significant.

Wind generated renewable hydrogen, sources is adopted for 100% renewable integration. It will help developing countries improve their energy self-sufficiency and stability, as well as reduce carbon emissions, by systematically broadening their energy portfolio and reducing their dependence (Iqbal et al. 2019a). Hydrogen dioxide, like all natural gas and oil outlets, does not occur in nature. Water (Tolliver et al. 2019), wood, coal , methane, and biological sources (Taghizadeh-Hesary et al. 2020) may all be used to extract hydrogen. In order to produce hydrogen from these current supplies, the resources expended must be abundant and sufficient on a continuous basis. Fuel cell-powered applications, on the other hand, have been produced but are currently prohibitively costly(Hou et al. 2019). However, with further research and development, these inventions are expected to reach a cost-effective spectrum. When fossil resources become scarce, hydrogen fuel-cell cars are anticipated to supplant conventional gasoline vehicles. Currently, hydrogen processing using wind energy in the electrolysis phase is thought to emit the least amount of greenhouse gas pollution of any hydrogen production method. Furthermore, of all green energy sources, wind-generated power has the lowest cost per kWh (Sun, et al., 2020).

The contribution of this paper lies in the following aspects, (i) Our key aim is to identify the most cost-effective method for producing sustainable hydrogen from electricity produced by wind turbines. We have measured the wind power potential and economic viability of wind generated renewable hydrogen to initiate the feasibility of clean fuel (Mohsin, Kamran, Nawaz, Hussain, & Dahri, 2021). (ii) We have also measured electrolysis cost of wind generated reenwable hydrogen. We have also measured the relative efficiency of the given renewable energy source for hydrogen production which is calculated based on their respective variables. (iii) This study's outcomes can be generalized for policymaking in developing contries such as Paksitan, which owned the same environment, climate, economic, and energy characteristics of economic and environmental vulnerability. As there is a considerable gap in the literature of hydrogen energy feasibilities for developing economies, the current study will fill the literature gap regarding methods, techniques, and evaluation processes of hydrogen energy project feasibility from different angles. (iv) The wind generated renewable hydrogen production and levlized cost of reenwable hydrogen production has been evaluated since it is the only near-term choice in the scale considered. The study measures the production and supply cost of wind generated reenwable hydrogen. The net costs of the delivery chains was estimated in the viability report. The costs of delivery are often compared to on-site hydrogen development through water electrolysis, which is an alternate method of supplying hydrogen to industrial hydrogen consumers. The distribution costs are limited by the expense of on-site development.We have proposed a policy framework for policy akers and decision makers based on achieved outcomes.

Rest of the paper is organzised as follows, section 2 provides the wind power potential, section 3 explains the methodlogy, section 4 decribes the results and discussion while section 4 concludes the study.

2. Wind Power Potential and Energy Security

The increased usage of green energy would help to establish a carbon-free energy zone while also reducing the volatile existence of the clean energy market, which faces the greatest obstacle to ensuring a constant supply due to its erratic nature (Nasir et al. 2020) and (Chien et al. 2021). Wind energy generation has recently been the cheapest of all alternative energy sources. Around a decade earlier, (Khodabandehloo et al. 2020) concluded that photovoltaic energy generation is normally more costly than wind energy systems. However, there hasn't been much research in this region. The ability to produce hydrogen solely from wind energy through electrolysis has gotten a lot of attention around the world. Despite possessing a large amount of resources, Pakistan has made little attempt, which prompted the current study (Sha et al. 2020).

Pakistan is a South Asian country with wind speed is nearly constant in certain parts of Pakistan, and the proportion of windy region is determined using the total land area. The average installed energy per square kilometer of wind power field is projected by traditional calculations to be 5 MW in order to assess the output of wind power (Duc Huynh et al. 2020).

Table 1 shows the cumulative capacity of wind resource evaluation in numerical terms. As a result, the overall ability of wind energy generation in this area is estimated to be about 349 GW.

Table.1 Wind resource classification

Wind Class	1	2	3	4	5	Total
Resource Potential	Moderate	Good	Excellent	Excellent	Excellent	
Wind Area (km2)	43,265	18,219	5320	2514	545	69,863
(%) of Total Area	5.61	2.36	0.69	0.33	0.07	9.06
Installable Capacity (MW)	216,325	91,095	26,600	12,570	2725	349,315

Pakistan has favorable offshore wind power capacity in addition to onshore wind energy potential and its use could account for a significant portion of electricity generation. Furthermore, using offshore resources will help Pakistan tackle air pollution. Renewable technology holds a lot of promise and has piqued people's attention. Renewable energy networks reduce economic risk factors and are unaffected by variations in fuel availability and costs (Anser et al. 2020), (Baloch et al. 2020). Geographically, renewable energy are more uniformly spread. To avoid expensive transmission delays, certain solar energy programs may be installed in small units near customer bases. Furthermore, federal legislation in the US power grid have resulted in significant progress and incentives for clean energy production and implementation (Pan et al. 2019). Renewable technology is projected to receive potential consideration in the domestic energy market as our awareness of the environmental effects of fossil fuel combustion grows. The largest impediment to large-scale clean energy deployments right now is the high upfront capital costs compared to traditional power sources. Any renewable energy systems only generate electrical energy, which has a higher value than heat (Babar and Ali 2021). Hydro, wind, photovoltaic, tidal, and ocean resources are among them. Nonetheless, biomass systems that can produce both heat and energy, as well as geothermal and solar systems (Yumei et al. 2021) are all in the research and development stage.

Renewable electricity is more evenly spread across the world than fossil fuels, and it is usually less sold in the market. Renewable technology encourages the introduction of various renewable energy sources, decreases energy imports, lowers the economy's market sensitivity, and offers ways to improve global energy security (Khokhar et al. 2020). Renewable energy sources may also help to improve the efficiency of energy supplies, particularly in areas where grid connectivity is often limited. (Sueyoshi and Yuan 2017) found that a varied energy mix, as well as good management and device architecture, will help to improve security (Jahangiri et al. 2020). Renewable electricity sources including solar and wind are inherently sporadic. Instead of burning fossil resources, renewable energy sources absorb energy from the atmosphere (such as coal, oil, natural gas, uranium). The sun is the ultimate provider of green resources accessible to humanity (Wang et al. 2019), (Yue et al. 2017). The overall radiant energy flux it intercepts from the planet is far greater than existing green energy solutions capture power. Although the theoretically significant volume of energy available, collecting and using this energy in a cost-effective manner remains a challenge. Electricity is becoming a more strategic asset as technical change accelerates and certain industries, such as agriculture and manufacturing, become more mechanized (Bortoluzzi et al. 2021). A systematic evaluation of the use of wind and alternative energy in developed countries is one such solution. Such analyses may be carried out in the framework of a green energy viability study in order to entice prospective investors to invest in the renewable energy market.

2.1 Brief Literature Review

(Chien et al. 2021) in China measured the capacity for wind energy production revealed that this area had a peak annual average wind energy density of 429 W/m2, indicating that it was an excellent investment prospect. (Bortoluzzi et al. 2021) conducted an economic-technical study in Taiwan to assess the right wind turbines for wind power ventures. They looked at things like annual electricity production, financial metrics, fossil fuel usage reduction,

CO_2 reduction, and turbine power factor for this. Finally, the VestasTMV60-850 KW model turbine was recommended as the best choice for the country's central regions. Hydrogen generation capacity from clean energy sources is being investigated (Wu et al. 2021). Renewable resources such as solar energy, geothermal energy, oil palms, and biomass have been identified as potential sources of hydrogen energy. Solar energy production costs are normally 6 to 18 times higher than comparable renewable energy and wind turbine systems, according to the report (Alvarez-Herranz et al. 2017) and (Wu et al. 2021).

As a result, it's critical to assess the potential for renewable hydrogen generation from wind energy (Seker and Aydin 2020).Hydrogen dioxide, like all natural gas and oil outlets, does not occur in nature. Hydrogen may therefore be derived from a variety of natural resources, including water, wood, coal, methane, and biological sources. As a result, we developed a novel statistical evaluation of renewable energy indicators in off-grid and remote regions, including wind-generated renewable hydrogen, in order to improve energy security and reduce continuous emission levels in the field. In order to produce hydrogen from these current supplies, the resources expended must be abundant and sufficient on a continuous basis (Tolliver et al. 2019) and (Kakoulaki et al. 2021). The aim of this research is to look at the techno-economics of sustainable hydrogen production utilizing wind energy in various windy locations in Pakistan's Sindh province. The levelized cost of wind energy was also estimated to determine the cost of hydrogen output (Bamisile et al. 2021b) and (Ozturk and Dincer 2021).

3. Data and Methodology

Hydrogen production from water electrolysis is also a suitable way to maintain efficiency performance of 80–90%, demonstrates considerable potential in a variety of hydrogen-production technologies (Bhattacharyya and Bhattacharyya 2019) and (Awaworyi Churchill et al. 2020). The amount of renewable hydrogen produced from wind energy is provided in the following equation .

$$h = \frac{\eta_{el} E_{out}}{ec_{el}} \tag{1}$$

Where h is the amount of hydrogen generated, E_{out} is the wind electricity input to the electrolyzer for hydrogen production, ec_{el} is the electrolysis process performance, which ranges between 80 and 90%, and η_{el} is the electrolyzer energy consumption, which is normally 5–6 (KWh/Nm3). ΔH = 286 kJ mol-1 is needed for the decomposition of water (H2O) to produce H2. The ultimate chemical reaction of water electrolysis can be written as:

$$H_2O \rightarrow H_2 + \frac{1}{2} O_2 \tag{2}$$

The charge transfer and enthalpy shift of the reaction determine the thermoneutral voltage V_{TH}

$$V_{TH} = \frac{\Delta H}{2F} \tag{3}$$

F shows molar charge constant, which is measured in efficiency. In relation to V_{TH} of n number of cells, electrolyzer process performance (η_{el}) can be measured almost precisely by electrolyzer voltage (V_{el}),

$$\eta_{el} \approx \frac{1.48n}{V_{el}} \tag{4}$$

Overvoltage is caused by a variety of failure factors, including physical, electrochemical, and transmission-related losses, which increase in proportion to current density (Ogura 2020). When attached to a wind turbine, the electrolyzer can run at a variety of current and power speeds.

The total cell reaction response can be said to be the number of the two half reactions while voltages of the reduction (E^{o}_{red}) and oxidation (E^{o}_{ox}). half-reactions.

$$E^{0}_{cell} = E^{0}_{(ox)} + E^{0}_{(red)} \tag{5}$$

The capacity of an isolated half-cell cannot be calculated explicitly. As a comparison, the normal hydrogen half-reaction was chosen and given a standard reduction potential of exactly 0.000 V,

$$2H^{+}_{(1M)} + 2e^{-} = H_{2(1atm)} \quad (E^{o}_{red} = 0.00V) \tag{6}$$

And

$$\text{(Anode)} \ Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^{-} \ (oxidation)\, E^{o}_{Zn/Zn^{2+}} = 0.76V \tag{7}$$

$$\text{(Cathode)} \ Cu^{2+} + 2e^{-} \rightarrow Cu_{(s)} (reduction)\, E_{Cu^{2+}/Cu} = 0.34V$$

Therefore,

$$\begin{aligned} E^{o}_{cell} &= E^{o}_{(ox)} + E^{o}_{(red)} \\ E^{o}_{cell} &= 0.76 + 0.34V \\ E^{o}_{cell} &= 1.10V \end{aligned} \tag{8}$$

The levelized cost of energy is a useful metric for comparing the unit costs of various technologies over their economic Levlized cost of electricity (LCOE). The LOCE approach is often used as a benchmarking technique to compare the costs of various electricity production technologies. Wind power economics are determined by a variety of factors, including net construction costs, energy generation, repair and operating costs, location selection, and wind turbine characteristics. The ratio of increasing NPV of total costs (PVC) to total energy (E tot) generated through the device is used to estimate the wind per unit cost (C W).

$$C_{W} = \frac{PVC}{E_{tot}} \tag{9}$$

3.1 Electrolysis Cost

Many previous studies have suggested an electrolyzer economic model, in which the electrolyzer expenditure consists of three major costs: cash, operational, repair, and replacement. The overall cost of the electrolysis cell is determined by the amount of hydrogen that can be generated. The electrolyzer capital cost is determined by the necessary rate of hydrogen supply (Kazmi et al. 2019). The efficient electrolyzer performance and the average real capital cost per kWh at nominal output are calculated as,

$$C_{ele,u} = \frac{M_{H_2} K_{el,th}}{8760.f\eta_u} \tag{10}$$

$$C_{ele,u} = \frac{M_{H_2} K_{el,th}}{8760.f\eta_u} \tag{11}$$

where ($C_{ele,u}$) is the electrolyzer unit rate, f is the power factor, and $K_{el,th}$ is the electrolyser's energy requirement. The comparison case assumes that the electrolyzer unit cost is $368/kWh, which is the goal amount. We believe that annual maintenance costs and repair costs electrolyzer has a seven-year operating period. We must measure the running costs of the chosen locations in order to investigate their economic evaluation. The per-unit expense ($/kWh) of wind power production must be estimated for chosen locations. Table 2 presents the component involves the wind turbine's explicitly specified power cost (C1), as well as miscellaneous costs (C2), construction costs (C3), operating and repair costs (C4), (C5) shows inverter costs and (C6) shows battery bank costs,

Table.2 Rated power costs of wind turbine

Pt(kW)	Caspec ($/kW)	Average (CASPEC) ($/kW)
>200	1150	700–1600
20–200	1250–2300	1775
<20	2600	2200-3000

It can be determined using the following formula,

$$PVC = I + C_2\left(\frac{1+i}{r-1}\right)\left[1-\left(\frac{1+i}{1+r}\right)^L\right] - S\left(\frac{1+i}{1+r}\right)^L \tag{12}$$

The total cost can be measured as,

$$C_T = \mathrm{PVC} + C_5 + C_6 \tag{13}$$

The expense of operating and maintaining a wind turbine is estimated to be 25% of the annual investment cost. Scrap is thought to be worth ten % of the annual investment expense (Shahzad et al. 2020). The investment expense (IC) is calculated as follows:

$$\mathrm{I_c} = \mathrm{C}_{\mathbf{ASPEC}} + \mathrm{P_r} \tag{14}$$

where $C_{\mathbf{ASPEC}}$ shows an average cost of per unit kW and P_r deterrmine the rated power cost of a wind turbine (Bangalore and Patriksson 2018).

$$C_{cu} == \frac{\text{Total cost}}{\text{Annual average yield}} \tag{15}$$

Table.3 Selected wind turbine specifications

Wind Turbine Model	Rated Power (KW)	Hub Height (m)	Cut in Speed (m/s)	Cut Out Speed (m/s)	Rotor Diameter (m)	Swept Area (m2)
GW-109/2500	2500	50	3	25	109	9516

The hydrogen production cost C_{H_2} is a major economic indicator has been taken as follows,

$$\boldsymbol{C_{H_2}} \frac{C_W + C_{ele}}{M_{H_2}.T} \tag{16}$$

where C_W and M_{H_2} represents the energy cost ($) and per year green hydrogen production respectively. Internationally, the constraint on green hydrogen production, particularly through wind energy from electrolysis, has gotten a lot of attention. Pakistan, on the other hand, just makes use of a small portion of this potential, ignoring the resource's usability. In the light of the topic above, this evaluation adds to a reduction in non-renewable energy source reliability (Cook et al. 2019). This investigation examines the atmosphere in almost every part of Pakistan while also serving as a condensed study of domestic demand for green wind-produced hydrogen.

$$Z = max_{e,h} \sum_{t\in 0}^{T} (P_t^e \, e_t^{grid} + P_t^h h_t)\tau \tag{17}$$

$$W_t = e_t^{grid} + e_t^h \,, \forall_t \in \mathrm{T} \tag{18}$$

$$h_t = a.e_t^h, \ \forall_t \in \mathrm{T} \tag{19}$$

$$h_t, e_t^{grid}, e_t^h \ \geq 0 \ \ \forall_t \in \mathrm{T} \tag{20}$$

$\boldsymbol{P_t^h}$ ($/kgH2) and $\boldsymbol{P_t^h}$ ($/kWhe) are the negligible hydrogen and consumer power costs, respectively. The $\mathbf{h_t}$ ($/kg$H_2$/h) hourly hydrogen production and power supplied from wind energy provided to the national lattice, ht grid, duplicate these costs (kWe). With the set T, t displays a certain period and includes the time interval (60 minutes). (2) At time t,

$\boldsymbol{e_t^h}$ grid(kWe), the power generated from wind energy provided to the national grid, $\boldsymbol{e_t^h}$ (kWe) , and the power spent for renewable hydrogen production at e th grid (kWe) have been divided (kWe). At time t, limitation (3) depicts the production of green hydrogen using wind energy. The option considerations, according to limitation (4), are non-negative genuine numbers and the day-ahead market power price. $\boldsymbol{P_t^h}$ grid energy is being provided to the K.E., ht hourly hydrogen production, $\boldsymbol{P_t^h}$ and the low hydrogen cost, and $\boldsymbol{e_t^h}$electricity scavenge deal is planned. The space-time-yield (STY) is a measure of how much output can be generated per unit of volume and time. This number is used to figure out how much each LOHC's reactor costs. It is determined by equation (21).

$$STY = \frac{n_A \chi_A M_A}{V_{A0} t_R} \tag{21}$$

With n_A = Maximum mole flow of the target product (A) per mole of source material (A_0)

χ_A = Equilibrium conversion

M_A= Molar mass

V_{A0} = Volume of one mole source material, including solvents

t_R = Reaction time

3.2 Methodology for Calculating Supply Cost of Reneable Hydrogen

The amount of deliveries expected each day would be determined by the hydrogen demand and the truck's payload:

$$required\ deliveries\ per\ day\ (day^{-1}) = \frac{Hydrogen\ demand\ (kg\ day^{-1})}{Net\ hydrogen\ payload\ (kg)} \tag{22}$$

The total trip time will be determined by the following factors: unloading/loading (drop-off/pick-up) times, transportation size, and average speed:

$$total\ trip\ time\ (h) = \frac{2 \times one-way\ distance\ (km)}{average\ driving\ speed\ (km\ h^{-1})} + loading\ time\ (h) + unloading\ time\ (h) \quad (23)$$

Theoretical maximum number of trips for each truck per day can then be calculated:

$$max\ \#\ of\ trips\ per\ day\ per\ truck\ (day^{-1}truck^{-1}) = \frac{24h}{total\ trip\ time\ (h)} \quad (24)$$

The required number of trucks was determined based on the number of deliveries required to satisfy demand, as well as the theoretical potential number of trips per truck would make in one day, taking into account truck availability,

$$required\ \#\ of\ trucks = \frac{required\ trips\ per\ day}{max\ \#\ of\ trips\ per\ day\ per\ truck * truck\ availability\ (\%)} \quad (25)$$

This number has been rounded to the next higher integer. Since rounding up, the lowest number of trips per day per truck that satisfies the hydrogen requirement is used in the study, which allows for non-integer amounts. For eg, a truck making 0.5 trips every day might deliver any other day. Three times as many trailers as trucks are needed for GH_2 distribution options. The trucks will wait until the tanker trailer is unloaded and then filled in the case of LOHC transport. As a result, LOHC base distribution necessitates the use of storage tanks. The cost of storage was included in the hydrogen production costs. The appropriate number of trucks and trailers, as well as their investment costs (IC) and capital recovery factors (CRF), were used to measure annualized investment costs for truck fleets (ICann,trucking),

$$IC_{ann,trucking} = (\#\ of\ trucks) \times CRF_{truck} \times IC_{truck} + (\#\ of\ trailers) \times CRF_{trailer} \times IC_{trailer} \quad (26)$$

Operation and maintenance costs (in \$/kg H_2) were calculated from the specified variable (VC) and fixed costs (FC) of the trucks and trailers (Tahir and Asim 2018) and (Gasser 2020):

$$SC_{trucking,O\&M} = \frac{(\#\ of\ trucks) \times VC_{truck} \times (annual\ drive\ distance) + (\#\ of\ trailers) \times (IC_{trailer} \times FC_{trailer})}{Delivered\ useful\ hydrogen\ per\ year} \quad (27)$$

Personnel cost for each kg of hydrogen delivered depends on the total trip time, hourly salary of the driver and delivered amount of useable hydrogen per truck:

$$SC_{trucking,personnel} = \frac{(total\ trip\ time)\times(hourly\ salary)}{Delivered\ useable\ hydrogen\ per\ truck} \quad (28)$$

Drive distance, fuel usage, fuel price, and delivered volume of usable hydrogen will all be used to quantify real delivery costs due to truck fuel consumption (Mohsin et al. 2018) and (Iqbal et al. 2019b):

$$SC_{trucking,fuel} = \frac{2\times(one-way\ distance)\times FuelConsumption\times FuelPrice}{Delivered\ useable\ hydrogen\ per\ truck} \quad (29)$$

The total specific hydrogen delivery cost from trucking then becomes:

$$SC_{trucking} = \frac{IC_{trucking}\times CRF_{trucking}}{Delivered\ useful\ hydrogen\ per\ year} + SC_{trucking,O\&M} + SC_{trucking,Fuel} + SC_{trucking,personnel} \quad (30)$$

The energy and hydrogen rates are set in the cases determining the worth of variable power and hydrogen supply, and the discount rate is determined to result in an NPV of zero at the end of the plant lifespan. This discount rate represents the anticipated return on investment from the construction and operation of the various plants.

$$NPV = \sum_{i=1}^{t} \frac{ACE_i}{(1+i)^t} \quad (31)$$

The method used to calculate the expense of CO_2 avoidance as seen in Eq. (31). (COCA). The levelized cost of energy is represented by LCOE, and the real CO_2 emissions of the plant is represented by E. The plant with CO_2 capture (Case 1) is denoted by the subscript CC, while the plant without CO_2 capture (Case 1) is denoted by the subscript ref.

3.3 Data

Wind speed data for various cites has been collected from metrological department of Paksitan, cost breakdown structure has been used from National Renwable Renewable Enegry

Laboratory USA (NREL) while the data for interestrate inflation and other economic indcators has been collcted from National Bank of Pakistan (NBP) and State Bank of Pakistan(SBP).

4. Results and Discussion

4.1 Green Hydrogen Production

In this experiment, we used an electrolyzer with a 5 (kWh/Nm^3) energy intake and a 90 % efficient rectifier. The formula for converting hydrogen formed by normal cubic meters into kilograms is 11.13 (Nm^3). Table.3 shows the findings of a study of annual hydrogen output at eight different locations and the capicity factor.

Table.3 Wind statistics

sites	Katti Bandar	Talhar	Gharo	Jamshoro	Baghan	DHA Karachi	Golarchi	Nooriabad
C.F	0.29	0.25	0.27	0.45	0.43	0.42	0.4	0.5
RE/kWh	21009552	16388043	16977724	22379630	20705733	20448179	19199308	3.05E+08
H2-Kg	393437	306892	317934	419094	387747	382924	359537	570524

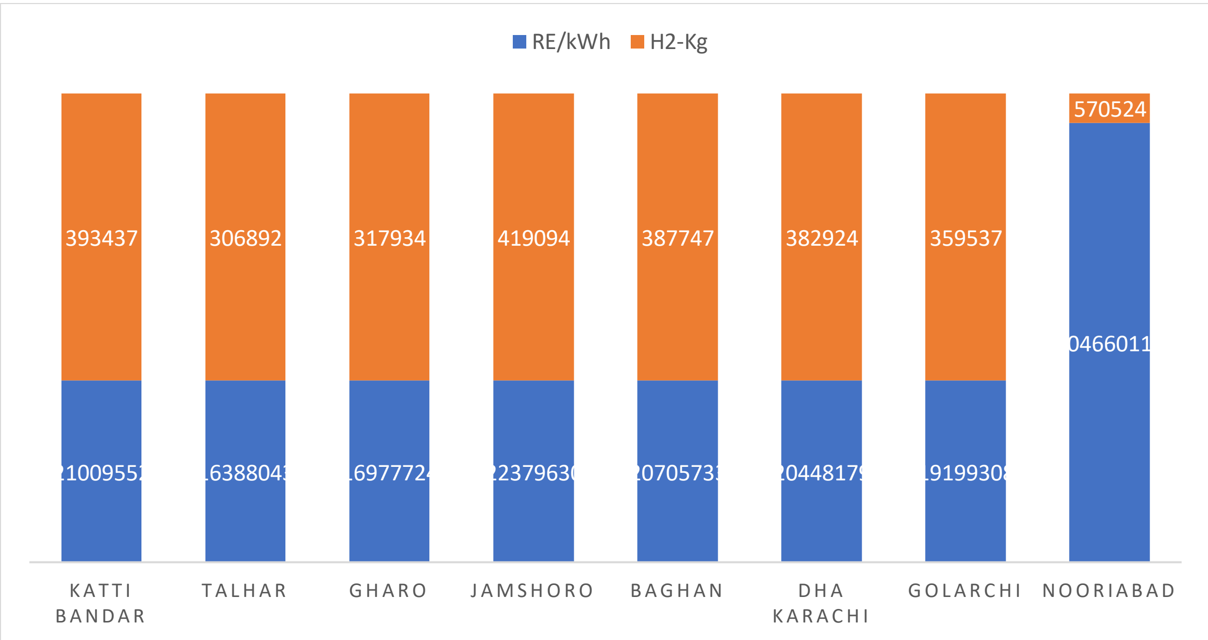

Figure. 1 renewable energy and hydrogen production

To generate energy, which is needed to create hydrogen, there must be a lot of wind. Annually, each car needs around 97 kg of hydrogen, (figure.1). Where, 9.5 kg of hydrogen is equivalent to 25 kg of gasoline by comparing the two energy sources. The explanation for this is because petroleum fuel has a capacity four times that of hydrogen fuel. Furthermore, Pakistan's cumulative wind-generated electricity capability is 119,410 MW. Additionally, transportation oil usage may be used to generate energy, alleviating fuel shortages.Total distribution costs for the 2.5 MW (1800 kg/day) and 10 MW (7200 kg/day) cases were determined to be 1.0–3.1 $/kg and 0.7–2.8 $/kg, correspondingly. For transport distances of 50–150 km, levelized cost of electricity and composite GH_2 are almost similarly efficient due to low venture costs for dehydrogenation reactors, whereas 300 km favors levelized cost of electricity. The cost of delivery using levelized cost of electricity should not escalate significantly as the distance traveled increases. In any case, delivery using 200 bar steel bottle containers is not the most cost-effective alternative, and the costs rise sharply with distance traveled. The expense of the fleet ranges from 0.3 to 1.0 million euros for levelized cost of electricity shipping, 1.8–7.8 million euros for steel bottle tanks, and 1.4–7.2 million euros for composite cylinders.

4.2 Economic Analysis

The economic analysis is based on such assumptions, such as construction and operational costs accounting for 25% of annual wind turbine expenditure and a wind turbine's existence being 20 years. Though installation costs are 5%, investment costs are 10%. As a result, at the final supply stage for the provided proposed locations, average price increases with regard to the intent of consumption. Further considerations presumed that the capital expense of sustainable hydrogen production is $0.027/kg, which covers direct, secondary, and maintenance costs. For ease of comparison, the leveled water supplying rate is estimated to be about $4.1/ton of water. As a result, the electrolysis system's capital charging ratio ranges from 0.10 to 0.115 (figure 2).

Finally, the expense of green hydrogen output for the most effective and optimal device ranges from \$4.02/kg-H_2 to \$4.310/kg-H_2. Annualized capital investment is the main determinant of green hydrogen production prices as compared to annual expenditures such as raw material procurement costs and plant running costs. The literature on sustainable energy systems shows that the economic burden imposed by large capital expenditures. Also, through adapting, marketing, preparing, timing, and expanding markets and demand, a practical strategy for planning excess electricity will boost the economics of renewable energy production. Table.4 presents the results of cost of electricity and Renewable hydrogen generation. The economic incorporation of hydrogen reveals that the cost of production varies between \$4.9 and \$5.1 per kilogram.

Table.4 Cost of electricity and Renewable hydrogen

Sites	Katti Bandar	Talhar	Gharo	Jamshoro	Baghan	DHA Karachi	Golarchi	Nooriabad
C.F	0.29	0.25	0.27	0.45	0.43	0.42	0.4	0.5
Electricity ($/kWh)	0.084	0.086	0.085	0.081	0.081	0.082	0.082	0.08
H2 Price/kg-H2	4.304	4.315	4.31	4.221	4.221	4.221	4.221	4.002

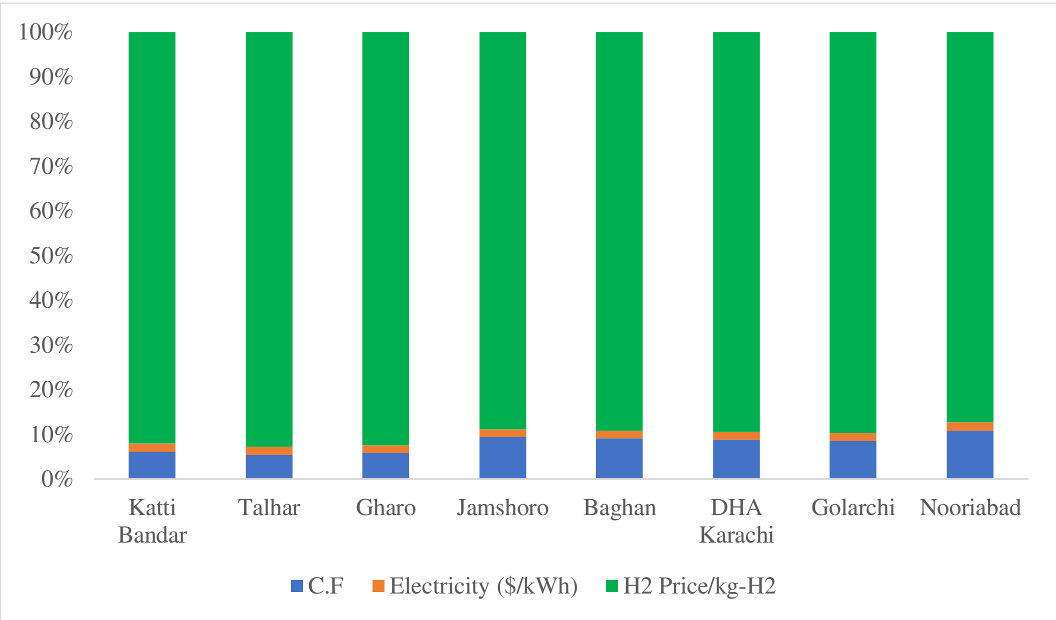

Figure.2 Capacity factor and electricity prices

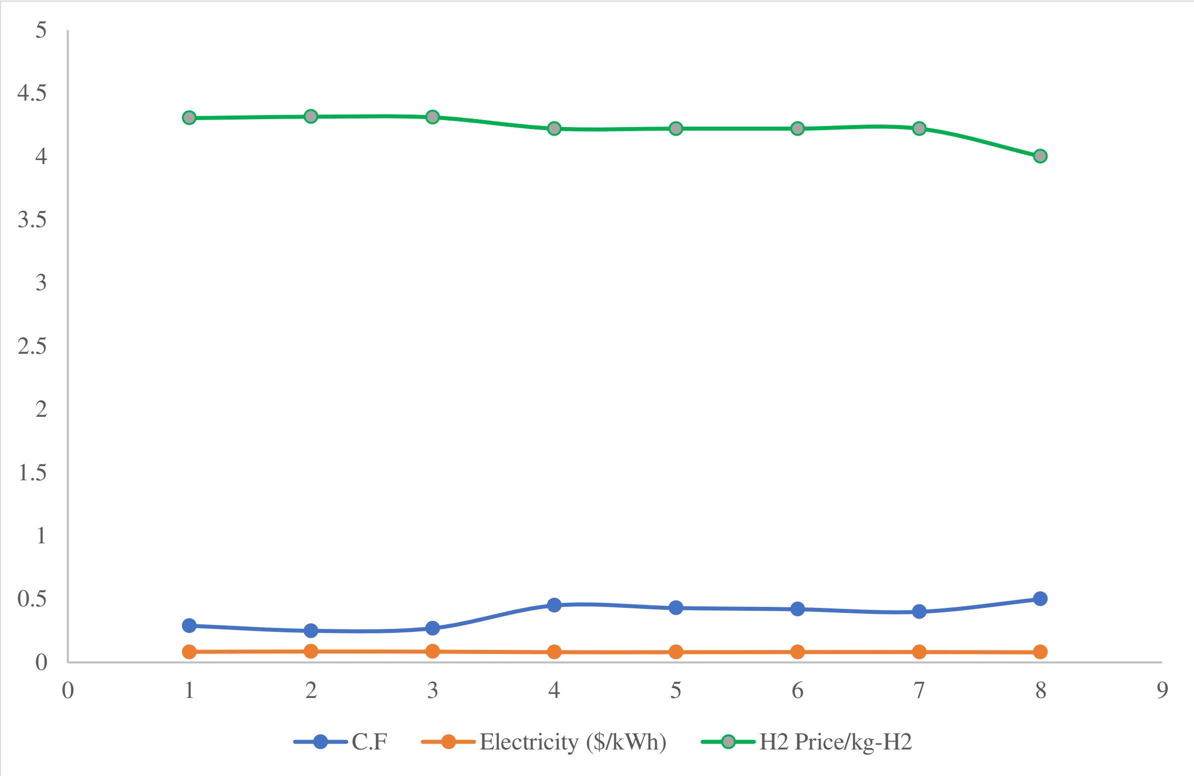

Figure.3 Capacity factor and price of H_2

Since all expenditures are the same, the priority process has little bearing on the system's CAPEX; it's just a separate scheduling technique. In terms of OPEX, there is a disparity in the volume of hydrogen sold and hence in the costs of transporting hydrogen. However, transportation charges for excess hydrogen are not included since they are distributed to third parties that choose to purchase this hydrogen. Because of this distribution, the OPEX and CAPEX for all priority systems are the same. The power rate, which includes prices for energy from the solar park and the grid, is the only factor that varies. The fuel costs in the Power-to-H_2 scheme with heat as a target are 260 k$ per year, although they have now increased to 360 k$ per year, since both heat and hydrogen are purchased from the grid.

In the hydrogen case, the output prices for heat and hydrogen shift. Since the heat system's reliability has reduced and more energy from the grid is purchased at a higher price than from the solar park, the heat price has increased by 1.1 $/GJ to 27.1 $/GJ. With the same investment costs, hydrogen demand grows from 90 to 125 tonnes a year. As a result, the price of hydrogen supply falls from 5.4 to 4.6 $/kg (figure 3). The price of water should not adjust significantly. When hydrogen is prioritized inside the system, gross annual costs per household are 1,715 $/year, vs 1,785 $/year when heat is prioritized. In terms of yearly costs per home, the favorable impacts on hydrogen production costs balance out the detrimental effects of higher heat production rates. The key explanation for the lower costs is that, with equal expenditures, more hydrogen is generated, resulting in a higher electrolyser ability factor.

4.3 Grid Electricty and wind generated renewable hydrogen prices

The wind generated reenwable electrolysis system's techno-economic study yields an LCOH of 6.22 $/kgH_2$. The costs are split down into the wind and electrolyzer sections for the first and second bars, respectively, to demonstrate the ratio of these two parts. The new global movement toward lowering GHG pollution, is focused on solid science assertions about the impact of an increasingly evolving atmosphere on natural, social, and economic sustainability. Experts are now warning of the dangers of global climate change caused by human-caused GHG pollution. CO_2 pollution increased by 4.2 % a year between 1999 and 2004. Furthermore, according to the same study, Pakistan is responsible for 0.2 % of global carbon emissions, or around 9.3 tons of CO_2 per human. As a result, Pakistan has the potential to enact measures to reduce greenhouse pollution, such as an emissions exchange scheme. To address the threat of climate change, well-defined emission-reduction strategies and environmental legislation are essential. Pakistan is among the world's poor largest oil producer and has seen a substantial increase in GHG emissions, especially CO_2, as a result of increasing petroleum output and related sales (which account for around 95% of export earnings and contribute more than 54% of Pakistan's GDP).

Pakistan's main contributors to GHG emissions are oil and cement production, which, like most other countries with large increases in greenhouse emissions, can be linked to both economic and industrial development. The usage of petroleum products as fuels in many refining, industrial, and transportation fields is one of Pakistan's major causes of air pollution. CO_2 is primarily generated through the burning of different fuels in the power generation sector (38%), transportation (20%), and industry (8%), with other industries accounting for the remaining 34%. Various toxic or toxic gases (primarily carbons, hydrocarbons, acid, and nitrogen oxides) are emitted from oil fields and refineries, and can have a negative impact on the local residential and marine areas. In 2010, two-thirds of the world's electricity was generated by burning fossil fuels, and Pakistan emitted around 60 million tons (Mt) of CO_2, up from 50 million tons (Mt) in 2002. This was mostly due to rising energy demand. Since the sum of CO_2 pollution per unit of energy differs based on the fuel type (coal, oil, or natural gas), the shift toward higher natural gas consumption should help to dramatically reduce CO_2 emissions in the long run. CO_2 emissions are projected to more than double in the coming years as a result of rising energy growth, hitting about 104 Mt in 2030. Over the forecast timeframe, annual average growth in pollution is estimated to be 3.3 %. However, because of the shift to gas-fired power plants, this is smaller than the initial estimate (3.6 % rise in demand).

Table.5 Grid electricity prices

Grid average electricity price	60 $/MW h
Mid-load price premium	10–40 $/MW h
Hydrogen sales price	$1.35/kg
Capacity factor	45%
H_2 capacity factor	45%
First year capacity factor	30%
CO_2 price	30–100 $/ton

Table.5 shows that the cost of the electrolyzer is higher than that of the wind device, at 3.92 $/kgH_2$ and 2.30 $/kgH_2$ respectively. Without maximizing the size of these two plant materials, the difference is much wider. More wind power deivices were introduced as part of the optimization process to reduce the amount of electrolyzer modules, resulting in a power factor rise from 28% to 31%. As a result, the photovoltaic panel's surface area rose by 4%, while the electrolyzer section's scale decreased by 11%. Since there is already demand for economies of scale and hence a substantial rise in output rate, it is possible that the electrolyzer's costs would drop significantly within the next several years. The third bar depicts the total device costs, demonstrating that module costs account for a significant portion of the total.

3.4 Comparitive Discussion

In some cases, the purpose of energy security is to protect the poor from fluctuations in commodity prices (Šprajc et al. 2019). Others have emphasized the importance of protecting the economy from disruptions in the supply of energy services by increasing commodity prices during periods of scarcity (Arminen and Menegaki 2019). For some, the goal of energy security is to reliably provide fuel, while the role of nuclear energy is to increase security (Amin and Bernell 2018). Results reveals that Sindh province has a potential demand for renewable hydrogen of 454, 192, 000 kg and that renewable hydrogen production ability is sufficient. Except for a few areas in Sindh province's interior, wind-generated renewable hydrogen. Furthermore, provinces with strong wind-energy capacity, such as Sindh's interior and the coastal areas of Sindh and Baluchistan, also have few options for a hydrogen mandate. Renewable corridors in Sindh and Baluchistan can be reconciled analytically to ensure renewable hydrogen generation and use (Liu et al. 2018). Sindh province is home to nearly all wind power schemes, and its geological characteristics make it ideal for producing green hydrogen for ZEVs and fuel cell electric vehicles.

Energy costs is increasingly making wind-generated renewable hydrogen more appealing. In addition, the impact of K-Electric-produced electricity rates are minor. Wind-generated green hydrogen already has a marginal price of US$4.30/kg-$H_2$. As a result, annual wind-generated renewable hydrogen demand rises with time, owing to improved sales, which enables additional wind power plants to be built, thus increasing the ability of wind-generated renewable hydrogen output. (Khan et al. 2018) and (El Khatib and Galiana 2018). Hydrogen could also be supplied by cryogenic tanker trucks, or it could be liquefied and transported by pipelines. Pipelines, , are only cost efficient for vast quantities or short lengths, but they are seldom used to maximize the efficiency of by-product hydrogen. Due to substantially complex cargoes (4000–4500 kg), liquefaction will allow renewable generated hydrogen to be trucked more effectively over long distances. The hydrogen liquefaction method, on the other hand, is both capital and energy intensive. Boil-off damages are often caused by the shipping and handling of liquid hydrogen (Roddis et al. 2018). Owing to the immaturity of the process, the investment costs for dehydrogenation and hydrogenation reactors are somewhat unpredictable. For "large-scale" green hydrogena production , (Krejčí and Stoklasa 2018) used costs of 260 and 40 $/kWH_2$,LHV, respectively. Basic costs for hydrogenation and dehydrogenation reactors for a MWH_2,LHV facility were 252 and 368 $/kWH_2$,LHV, respectively. As a result, cost estimates vary greatly.

In addition, there is considerable inconsistency in the prices of hydrogenation and dehydrogenation reactors. Teichmann, for example, calculated hydrogenation reactor costs to be slightly higher than dehydrogenation reactor costs, while xxx estimated reactor costs to be far closer together. (Al Garni and Awasthi 2017) thought the dehydrogenation reactor was more costly, although Reu thought the same. Pakistan might reduce its crude oil demand by 600 billion barrels a day if it implemented green hydrogen power production. It will be necessary to will the existing CO_2 emissions of 166298450 tons in this sense. Results shows the cost of carbon emissions at different constrained prices, which could be affordable as compared to the cost of ecological theft. Since the yield of green hydrogen is dependent on the nature of usable wind, which differs and is difficult to forecast, using the greater degree of wind output poses a suspension problem. The electricity market faces considerable inconsistency as a result of this variation, as it becomes difficult to balance supply and demand. In the case of traditional power terminals, shifting demand levels will render market power costs extremely volatile, posing additional difficulties for businesses who depend on transmitting it (Maleki et al. 2017) and (Valasai et al. 2017).

5.Conclusion and Policy Implication

The current study measured the wind powe power potential and economic viability of wind generated renewable hydrogen to initiate the feasibility of clean fuel. The study's outcomes can be generalized for policymaking in developing contries such as Paksitan. which owned the same environment, climate, economic, and energy characteristics of economic and environmental vulnerability. Different electrolyzer systems exist to generate effective hydrogen via the electrolysis phase. When the minimum price of hydrogen exceeds US$2.99/kg kg-$H_2$, green hydrogen demand rises as well. In the Pakistani energy sector, however, it is commercially beneficial since the marginal price of sustainable hydrogen is US$3.92/kg-$H_2$. Furthermore, due to the efficiencies of the hydrogen conversion mechanism, wind energy could generate approximately 0.85 billion kg of hydrogen in Pakistan, which could meet the country's 22% demand for hydrogen.

The findings show that the marginal prices of renewable hydrogen, respectively US$1/kg kg-H2 and US$4/kg kg-H2, have a considerable impact on annual hydrogen demand, and that a significant rise in renewable hydrogen production. The results have not been taken into account. Furthermore, lower renewable hydrogen prices (e.g., US$2/kg) have a relative impact on renewable hydrogen demand. Annual wind-generated sustainable hydrogen output is dependent. The performance of an energy conversion electrolyzer device will have a big impact on the amount of renewable hydrogen generated by wind. According to the findings, an electrolyzer device with a 75 % energy efficiency

In both the public and private sectors, Pakistan has a multi-tiered electricity Independent Power Producers are the main players in the supply chain (IPPs). WAPDA has four GENCO distribution entity since 2012 due to consolidation. There are three Rental Power Projects to choose from (RPPs). Pakistan's gross installed power generating capacity will exceed 3.4 GW in 2020, compared to a requirement of 2.5 GW from primary customers which can only carry out 2.2 GM energy during peak hours requirement, it would be unable to close the 3000 MW deficit difference. As a result of machine inefficiency, NTDC has 17.53 % line losses and KEL has 25.30 %. As a consequence, there is a significant difference between production and demand [41]. Furthermore, the majority of hydroelectric plants are operating at 50% potential and are affected by seasonal water supply. The working capability of thermal plants that contribute more than 60% of overall power production is a pitiful 65 %. Notably, increasing generating capability and relying too heavily on hydrocarbon supplies does not help to mitigate energy shortages where usable resources are underutilized or misused [42]. Increasing the country's power generating capacity by constructing new plants is an unworkable option for increasing availability. Repairing improperly run generation plants and dysfunctional transmission and dispatch networks, on the other hand, will accomplish the same goal.

Distribution losses ranged from 9.47 % to 33.40 %, and no DISCOs were able to hit NEPRA's loss goals, with some also seeing an improvement over the previous year. Another issue is the lack of long-term, organized, and integrated policymaking, as shown by the fact that programs were started. The schemes that were found to be infeasible in the middle of the project. Due to geopolitics, despite its significant hydropower capacity, it was not given priority. No technological adaptation abused local capital, and after signing the MOU for thermal plants, the China Pakistan Economic Corridor is now responsible for all projects.

The Pakistani government, on the other hand, wants to raise wind-generated electricity and has suggested many locations. Pakistan will meet its national demand and export clean electricity by converting its power system to wind and solar energy. Several pathways for hydrogen development, including thermal and reenwable hydrogen which is now the most widely utilized process due to its reliability and low cost. In comparison, hydrogen production using fossil fuels generated hazardous gases (e.g., GHGs) during the manufacturing phase.

Ethical Approval and Consent to Participate

N/A

Consent for Publication

We do not have any individual person's data in any form.

Authors Contribution

Wu Baijun: Conceptualization, Data curation, Methodology, Writing - original draft. **Bingfeng Zhai**: Data curation, Visualization. **Huaizi Mu**: Visualization, supervision, editing. **Xin Peng** : editing. **Chao Wang**: review. **Ataul Karim Patwary:** Final review & editing and software

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Competing interest statement

We declare that there is no conflict of interest.

Availability of data and materials

The data that support the findings of this study are openly available on request.

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Figures

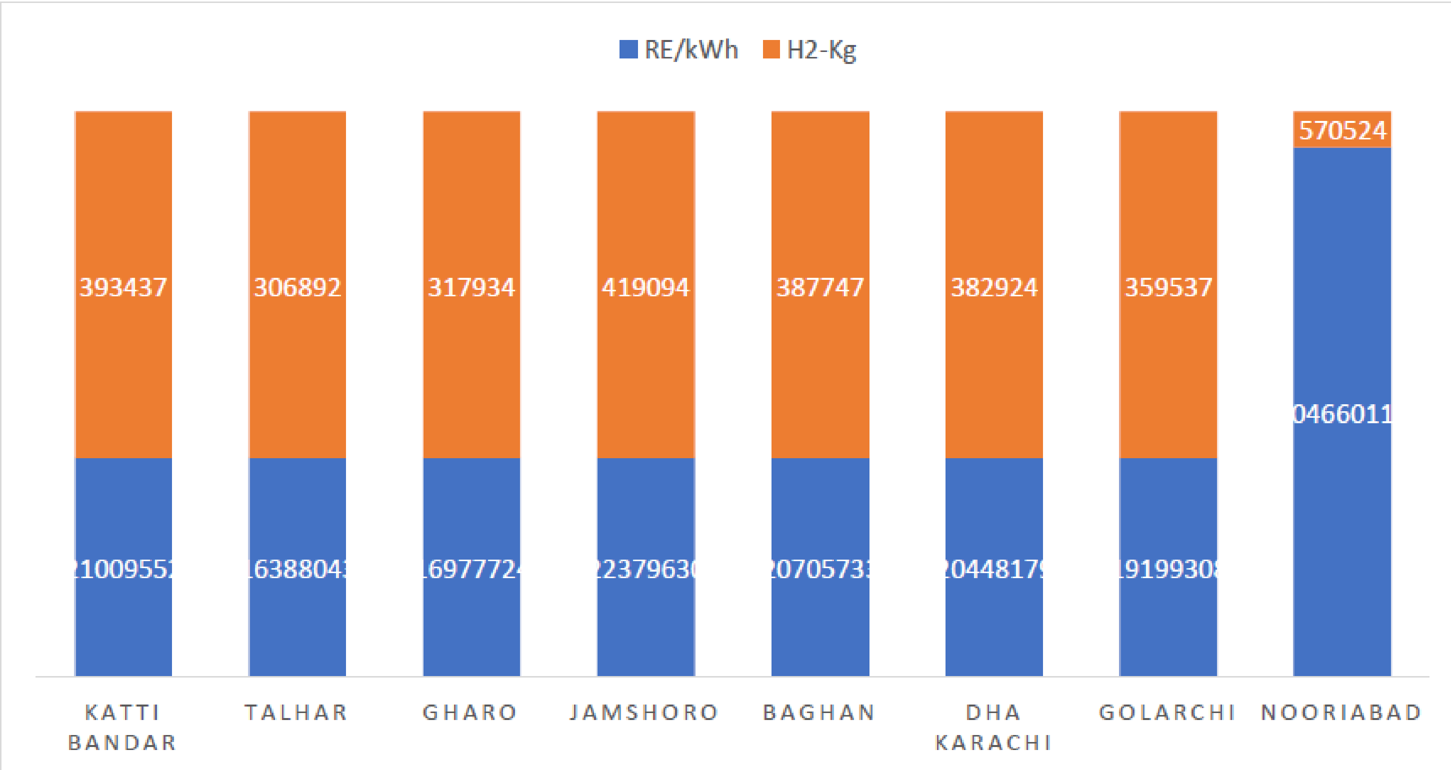

Figure 1

Renewable energy and hydrogen production

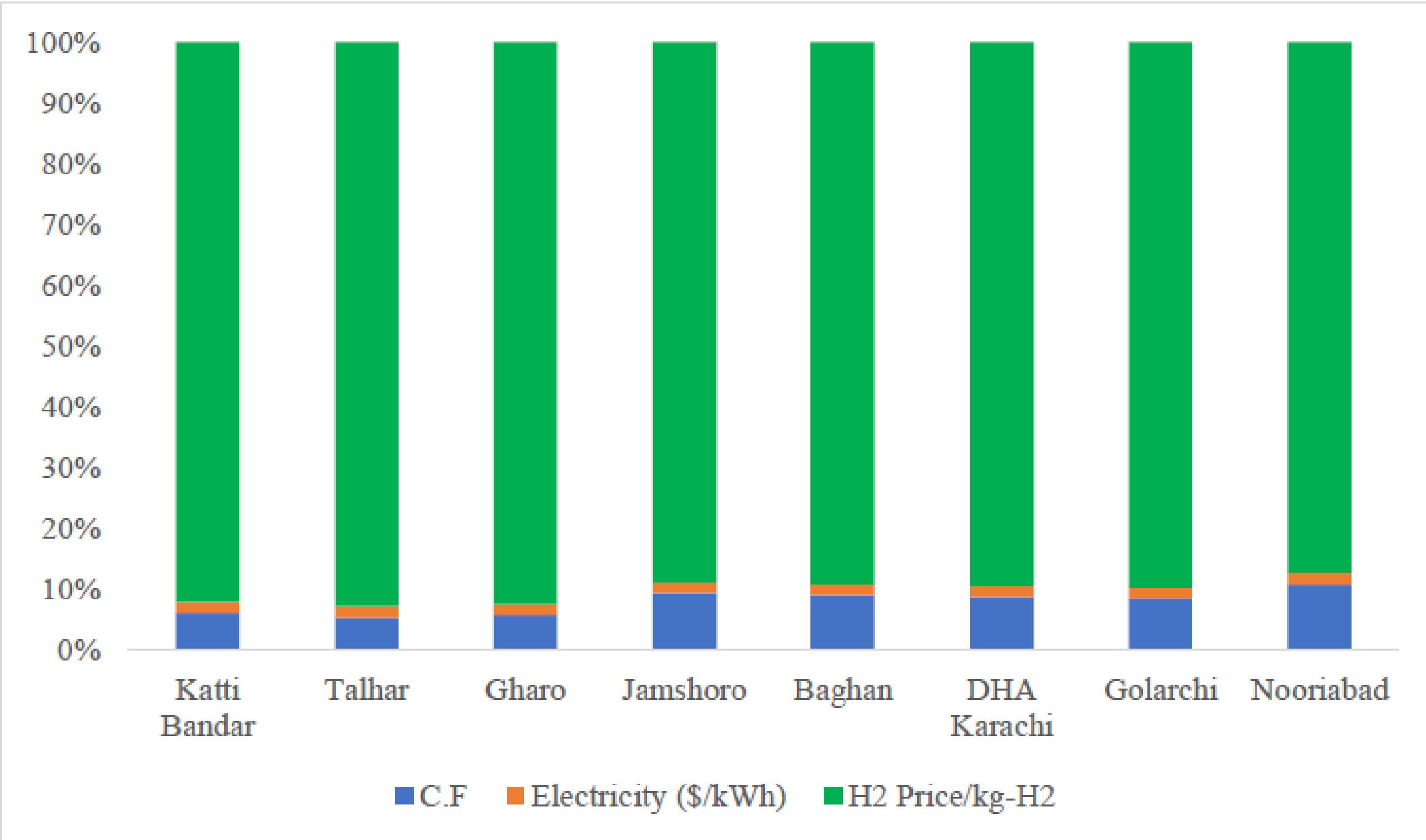

Figure 2

Capacity factor and electricity prices

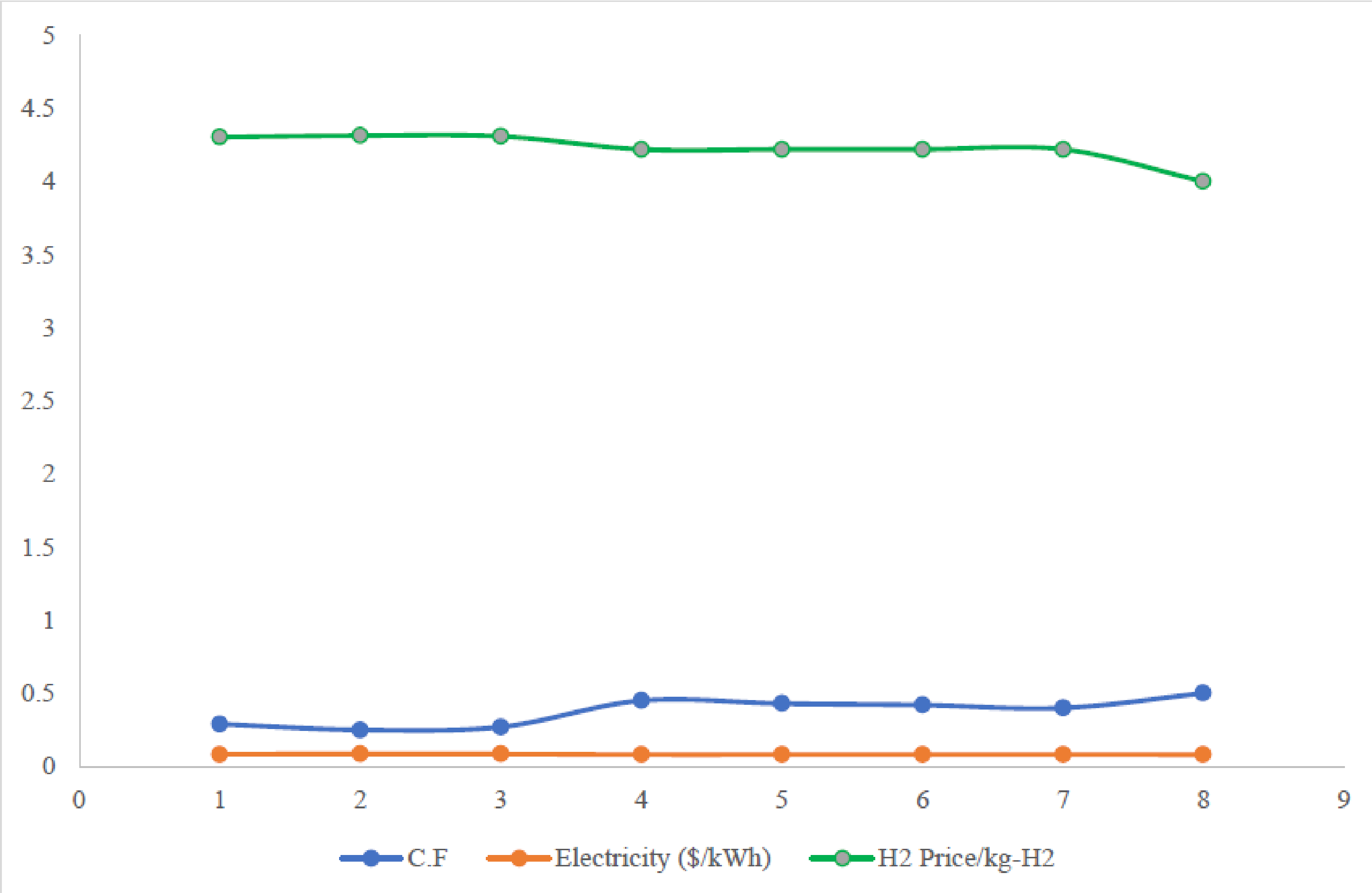

Figure 3

Capacity factor and price of H2