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Fueling the Future With Green Economy: An Integration of Its Determinants From Renewable Sources

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Fueling the Future with Green Economy: An Integration of Its Determinants from Renewable Sources

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Abstract

Green hydrogen energy is a clean alternative fuel that can help developing economies to increase energy security. This study assesses possible solutions for Pakistan's energy scarcity based on a renewable source of green hydrogen generated through wind, solar, biomass, and geothermal energy. For this purpose, four main criteria: economic, commercialization, environmental, and social acceptance, have been assessed. The study used two-step models, the Fuzzy-analytical hierarchal process, and the Data Envelopment Analysis techniques to evaluate hydrogen energy production through available renewable energy sources. According to the fuzzy-led analysis's empirical results, wind energy source optimization is best suited to produce hydrogen energy in Pakistan for all four criteria (economic benefit, environmental impacts, commercial potential, and social acceptance). At the same time, solar is the second-best option in all the given criteria. The DEA-led analysis also considers wind energy as the most efficient source to produce hydrogen energy in Pakistan. This study can help policymakers develop fact-based hydrogen energy projects in their respective areas, especially in developing economies, as most share the same characteristics.

Keywords: Multi-Stage model; Renewable energy; Pakistan; DEA; Green Hydrogen Production (GHP); Fuzzy-AHP

1. Introduction

The energy demand is expected to increase by around 30% globally during the next twenty-five year between 2015 to 2040, while developing Asia may demand 50% more energy sources than currently. Nearly 13% of the world population (940 million) are suffering from finding necessary energy consumption (electricity), and Sub-Saharan Africa and South Asia account for 89% (840million) of the total electricity shortage (Iqbal et al., 2019). It has been estimated that 40% (more than three billion) of the world population must bear the health cost of indoor air pollution due to dirty energy sources for cooking and heating. The consumption of solid fuel for this purpose has been reported very high in sub-Saharan Africa (77%) and South Asia (61%). Therefore, increasing energy demand has become the primary reason to invests in safe, green, efficient, and sustainable energy sources (Hou et al., 2019). The world is spending sufficient time and money on renewable energy sources. There is a 28% share of renewables in global electricity generation in the first quarter of 2020 against 26% in 2019 (Iqbal et al., 2020). The primary sources are hydropower, wind, and solar. However, this renewable energy production is taking place in high economic growth countries. Most developing economies (except China) suffer from converting dirty energy sources into clean and green ones due to some similar constraints.

These constraints' most common characteristics are lack of finance, innovative technologies, and unskilled human capital at labor and policymaking levels. Like other developing countries of the South Asian region, Pakistan is also facing the issues of high energy demand, the high share of fossil fuel-based energy consumption, the high share of import-based energy consumption, and high environmental and economic cost in term of health issues due to solid & dirty energy usage for commercial and domestic use. Pakistan's per capita energy consumption reported 460.23kg oil equivalent in 2014, out of which 61.59% is fossil fuel- based energy and 24.12% imported (Wu et al., 2020). Only 43.32% of the total population has access to clean fuel and technologies for cooking and heating. Thus, during the last two decades, Pakistan has been facing an energy crisis, where more than 145 million people suffer from accessing electricity. Still, 28.91% population has no access to electricity in Pakistan, while the electricity deficit was nearly 6500 MW in 2018. Due to this, there were 6-9 hours per day average load shedding has been observed. It is exceptionally high in the rural areas (12 to 14 hours daily power shutdowns), and it has the worst implications on the country’s economic growth (Akhtar et al., 2018). For example, due to this calamity, almost five million daily paid workers have lost their jobs.

Pakistan is considered one of the least renewable energy-producing countries (only 4.2% out of 26 GW of total energy), while hydrogen energy production is near to none (Akombi et al., 2017). The world has shifted towards hydrogen production due to high fuel cell technologies, and it is likely to replace fossil fuel as a source of energy. Technology innovation is expected to replace oil-based vehicles soon with hydrogen fuel-based vehicles (Klitkou et al., 2015). In this context, hydrogen energy is the best option to boost the country’s economy and reduce the energy crisis on an emergency basis. Pakistan has sufficient hydrogen energy resources to drip water and fuel from renewable energy, produce the hydrogen energy system, and meet various sectors' energy needs, such as transport, agriculture, and electricity. Furthermore, the production process uses chemical energy from hydrogen and converts it into electricity without burning any fuel. Therefore, it is termed the green hydrogen energy economy. This study aims to establish a structure for the choice of the best viable hydrogen production in Pakistan.

The recent literature survey emphasized that green renewable provides the best alternative to fossil fuel energy in a better environment for human health (Khan et al., 2020). A potential agreement of 81 countries in 2020 focuses on increasing the green hydrogen economy for globalization and energy transition to boost the hydrogen fuel cell industry. Sectors, such as transportation, are already using this source of energy fueling (Rehman Khan et al., 2018) . Various hydrogen energy resources provide higher efficiency as compared to fossil fuel sources. Furthermore, sustainable and efficient hydrogen production from clean energy sources is a few renewable energy approaches such as wind, biomass, and solar. An increase in global warming and environmental degradation gives rise to a need for sustainable and environmentally friendly alternative energy sources, such as renewable energy sources. Several technological innovations for hydrogen production have been studied in the literature. Categorized hydrogen energy as a sustainable and clean energy source like solar, biomass, wind, wastages, and small hydro energy. Environment friendly and economically sustainable with higher technical and social benefits is a few of the reimbursements of hydrogen energy (Diriba Guta, 2012) . In this context, developed an intuitionistic fuzzy set theory for optimizing hydrogen energy by using wind, nuclear, coal, and natural gas energy to determine socio-economic performance and government support. It suggested that nuclear energy is the best approach to optimize electricity for hydrogen production. Similarly, (Khan et al., 2020) used the multiple-choice decision analysis (MCDA) technique to develop performance-based sustainability indexing for economic, social, and market factors by applying four hydrogen systems, such as feedstock, H2 consumption and production, and electrical energy. Furthermore, (Turcanu et al., 2007) used the MCDA with a fuzzy multiplication actor to measure wind power potential feasibility. For this purpose, the study developed criteria based on the approach's economic, environmental, social-political, and technological aspects.

It proposed the possibilities to contain conventional gasification, pyrolysis, fermentative, and supercritical gasification. (Dasappa, 2011) proposed a fuzzy- analytical hierarchal process (F-AHP) method for Turkey's hydrogen production. According to this study, two (wind and solar) renewable energy sources were efficient for hydrogen production. (Avikal et al., 2021) proposed the MCDA methods and F-AHP methods to assess the hydrogen production process, including gird, solar PV system, wind, and nuclear energy. It was studied based on four main criteria: social, economic, environmental, and technical criteria, and it found that gird sustainability is more efficient than the other production processes. The literature mentioned above suggested that the multi-criteria decision analysis technique for selecting the best hydrogen generation among the available energy recourses can be the right decision. On the same note, (Shukla et al., 2014) applied the AHP method to analyze the hydrogen production source selection from alternatives, such as biomass, coal, steam methane reforming, and partial oxidation for the hydro-carbons combination of wind energy, hydro energy, and solar PV system. It has been observed that most of the above literature carried out one or two primary objectives to view the possible production of hydrogen energy in different countries. We applied two-step MCDA, F-AHP, and DEA to evaluate four criteria: environmental impacts, commercial potential, social acceptance, and economic benefits. It suggested that the implementation of renewable energy for the production process of hydrogen is the clean option.

From a decision-making perspective, this study has several contributions to the evidence based on exploring the least cost and an uninterrupted system that supplies 100% renewable energy by focusing on developing economies. For this purpose, this study used a Fuzzy TOPSIS simulation model based on renewable energy sources. Further, the paper contributes to integrated modeling to assess renewable energy and deep decarburization targets collectively for the methodological purpose. Without the analytical framework, the analysis of renewable energy may be inconsistent and limited due to the scenario of deep decarburization, which leads to suboptimal policy decisions. Governments and decision-makers of developing economies face difficulties selecting the optimum electricity sources among the renewable energies (wind, solar, biomass, solid municipal wastages, small hydropower, and geothermal energy). In this context, this study aims to provide an MCDA-based approach for measuring the optimum renewable energy through green hydrogen production.

The weights criteria of F-AHP are considered the output of the DEA method with the development cost as its input. The relative efficiency of the given renewable energy source for hydrogen energy is calculated based on their respective ranks. This study's outcomes can be generalized for policymaking in developing economies, mostly from South Asia, which owned the same environment, climate, economic, and energy characteristics. 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. The study is organized as follows: section two highlights the background of renewable energy sources with context to Pakistan, followed by methodological issues in the third section. The fourth section presents the results with discussion, while the final section briefly describes the study's conclusion and policy implication.

Rest of this paper as follows: Section 2 Discusses the Background. Section 3 The methodology. Section 4 Results and analysis. Section 5 discusses the results. Section 6 Discussion and final Section 7 conclusion and policy implication.

2. Background

The possible renewable energy sources for green hydrogen generation in Pakistan are wind, solar, biomass, small hydro, geothermal, and municipal solid waste energy. These renewable energy resources are vital for the green economy in Pakistan with innovative conversing technologies.

2.1 Solar energy

According to the report of the Pakistan meteorologist department, Pakistan is an ideal country for solar energy due to its long summer season sunny days nearly three hundred days in a year (Xu et al., 2019). Many solar energies are planning resource-based projects running with the help of the United States, World Bank(The World Bank, 2015a) and Asian development banks(Haas, 1974). The USA based laboratory (NREL) and Aerospace Center Institute (ACI) German department shows its report that Pakistan has long hour sunshine of between 8 to 10 hours a day. Which are annual equals to the solar radiation of 15×1014 kilowatt-hours? These radiations produce a maximum of 1600 Giga solar energy (Solangi et al., 2019). The World Bank launches the assessment program called Energy Sector Management Assistance Program, which is the main goal to assess a solar resource mapping in Pakistan. In Figure 1. Shows the solar assessment results, which is total annually globally horizontal irradiance 2000 kWh/$m^{2\ it}$ is (90 %) in Pakistan areas.

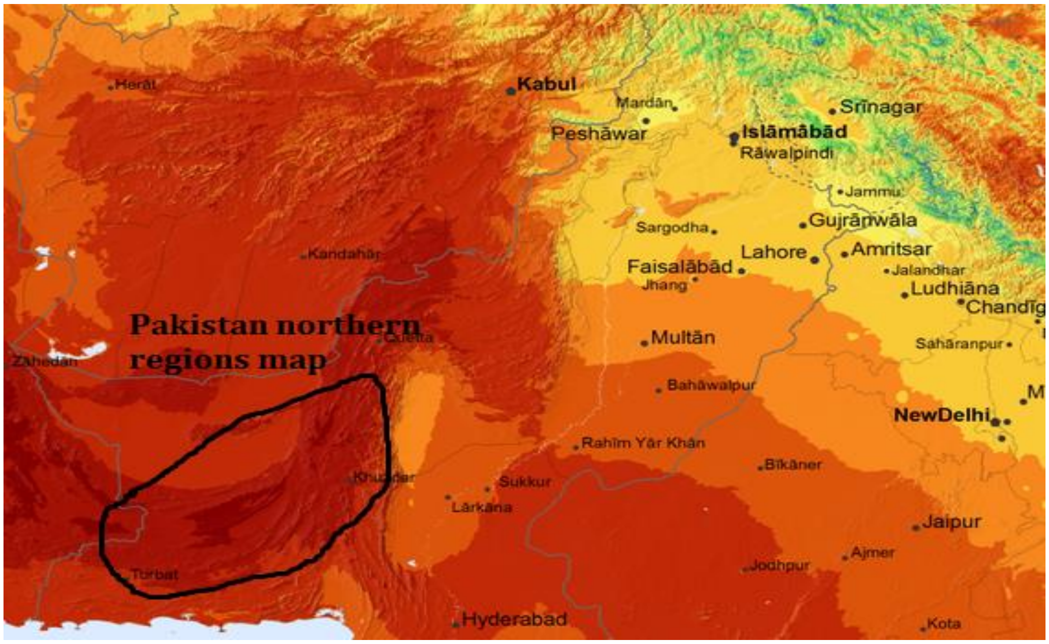

Figure 1. Global horizontal irradiance mapping of Pakistan Northern Region(Reno et al., 2012)

However, figure 2 showing high solar irradiance found in the northern region in Pakistan ,compared to other countries, Pakistan best solar irradiance is from sites location.(Stökler et al., 2016). The reports of surveys that the Pakistan has a massive amount of solar energy resources due to its vast land spaces available. These are zero air pollution, no cloud coverage, irradiance diffusion, and aerosol content (The World Bank, 2015b).

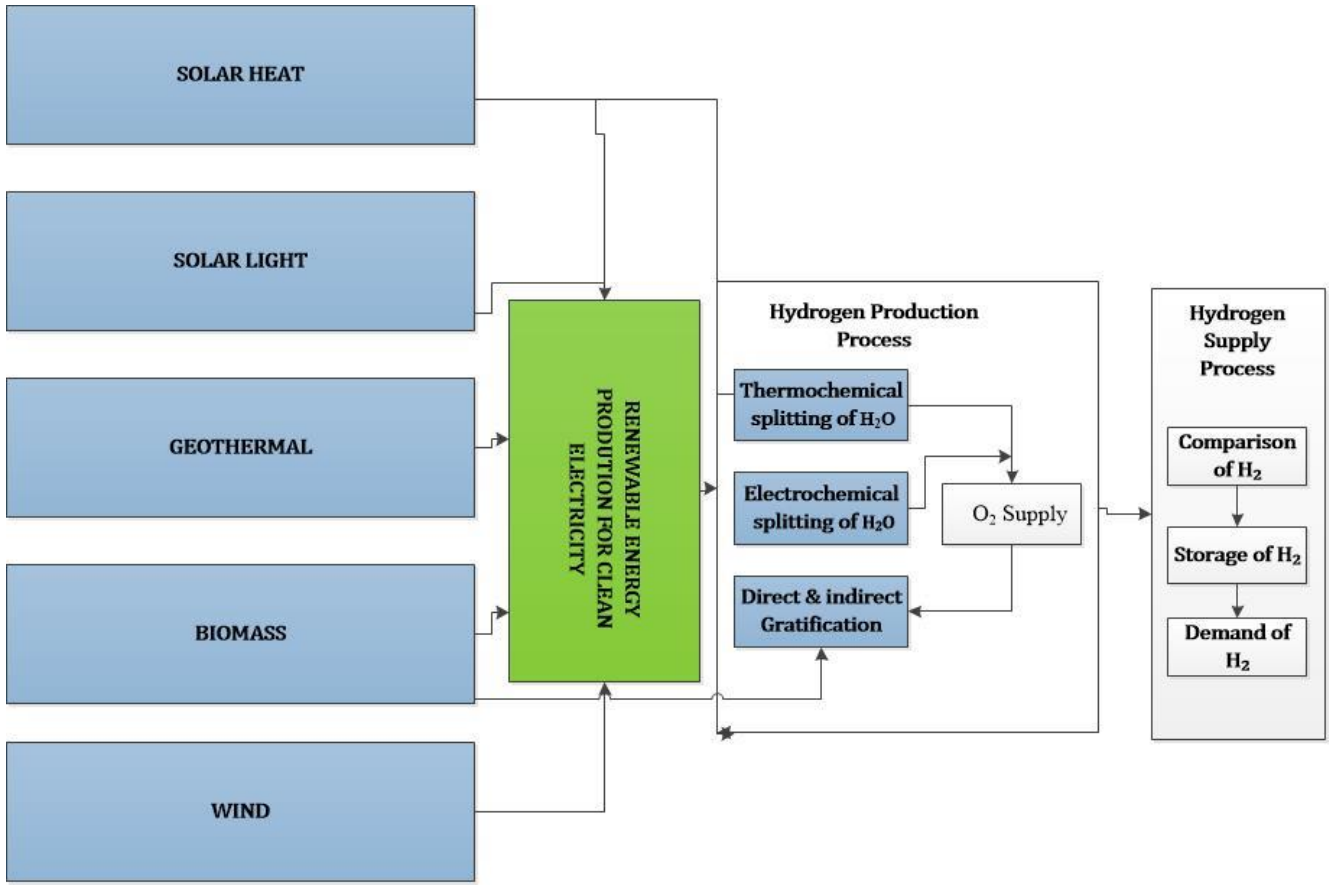

Figure 2. RES-based hydrogen production and supply

Pakistan has a variety of renewable energy sources including wind, solar, biomass, and geothermal energy. Such RES sources can be very suitable inputs for green hydrogen production using the new conversion processes. Therefore, this paper complete reviews and estimates potential of the renewable energy sources for hydrogen production from available RES resources. Our main objective of estimation to the select optimal renewable energy sources (RES) for increase the green hydrogen production for country wide. Table 1. Represent minimum and maximum solar radiation values, and also Table 2, the area-wise Solar radiation %, these data collected from NASA atmospheric and meteorology center.

Table 1. Show the values of minimum and maximum solar radiation (Tahir and Asim, 2018).

Mini or Max Solar radiation	**Values (kWh/m^2/day)**

Minimum	5.2275
Maximum	7.0016

In Table 2. Statistics show the accessibility of solar radiation of 150,000 square kilometer area, and these are best for maximum green hydrogen production. Based on the above estimate, less than 2 percent site available for the one hundred solar plant installation, from these small areas generated 20GW energy in the system (Duffie and Beckman, 2013). Moreover, the statics of green hydrogen production more according to solar energy availability (Melaina et al., 2013). These studies suggested that one-megawatt solar energy generation needs nearly 20.5 to 20.7 acres aera (Gondal et al., 2018). Therefore, we need to advance renewable technologies more to generate more green energy in the system.

Table 2. Solar irradiation in Pakistan areas (Tahir and Asim, 2018).

Solar Insolation (kWh/m^2/day)	**%**
5 to 6	69.31
> 6.0	30.69

2.2 Wind energy

Pakistan has abundant wind power energy resources, also has a high energy generation ability for hydrogen production. United states-based departments NREL, AEDB, and Pakistan Meteorological Department (PMD) assessment of the Pakistan wind power sources to create the wind energy mapping of the country. In Figure 3. Show the Map of the potential wind sites in Pakistan regions. The Sindh and Baluchistan region are more suitable for wind energy production, and only some areas of country have favorable wind energy potential for hydrogen generation. According to assessment, we will be able to utilizable more wind energy from high potential wind sites are as nearly 346 gigawatts. Pakistan has many suitable sites for wind power production connection projects. In between other sites, the Sindh region namely Gharo and Keti Bandar, was the best site for wind energy. These sites potential windy areas, which was calculated, seven(m/s) at about 50 meter air above the ground level(Shah and Solangi, 2019).

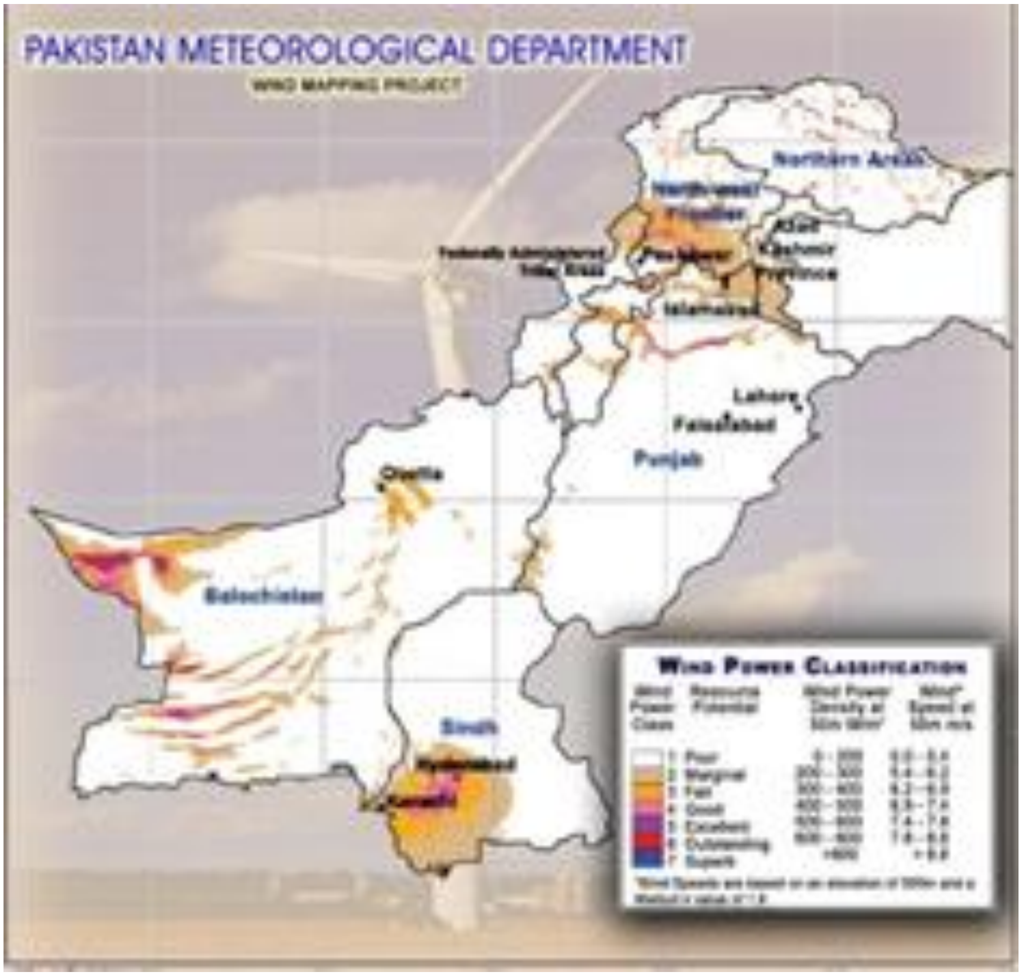

Fig 3. Pakistan wind resource assessment map(Simões and Estanqueiro, 2016)

Pakistan wind source sites 1 to 7 classes. We measure country wind power potential based on universal units. The Class 4,5,6,7 are best and high potential wind farm installation system for green hydrogen production, those area class between 3 or above, it means have high wind power installation capabilities. Table 3, Shows Classes from 1 to 7 of wind energy potential in country, these classes are well-defined at10 to 50 meters up length and parameters from above ground level. According to results that the approximately 9 percent area in Pakistan, highly potential for wind energy installation. Derives class 4 to 7 levels that can provide economic and practical wind power production.

Table 3. The wind energy potential resources in Pakistan (Shah and Solangi, 2019).

Wind energy class	Wind potential	10 meters		50 meters	
		Wind speed	Wind Energy density	Wind speed	Wind Energy density
Class 1	Very Poor	0–4.4(m/s)	0–100(W/m^2)	0–5.4(m/s)	0–200(W/m^2)
Class 2	Marginal	4.45.1(m/s)	100–150(W/m^2)	5.46.2(m/s)	200–300(W/m^2)
Class 3	Moderate	5.15.6(m/s)	150–200(W/m^2)	6.26.9(m/s)	300–400(W/m^2)
Class 4	Good	5.66.0(m/s)	200–250(W/m^2)	6.97.4(m/s)	400–500(W/m^2)
Class5	Excellent	6.06.4(m/s)	250–300(W/m^2)	7.47.8(m/s)	500–600(W/m^2)
Class 6	Outstanding	6.47.0(m/s)	300–400(W/m^2)	7.88.6(m/s)	600–800(W/m^2)
Class 7	Superb	>7.0(m/s)	>400(W/m^2)	>8.6(m/s)	>800(W/m^2)

See Table 4 Provides the potential of hydrogen energy from wind recourse in Pakistan. Based on the estimation, we produce (45,000 tons) of hydrogen energy, which is equals to 53,Kwh per kilogram. (Ivy, 2004). Pakistan was producing a total 900 MW wind energy that can be the ability to produce 360 tons of hydrogen energy.

Table 4. Estimated hydrogen generation using wind energy(Ivy, 2004).

Potential	Unit	Ten h - Aval	Conversion	Unit (rate of 53)
86,875	MW	868,750	16,610898	(KWh/kg)
87752.5	MW	877525	16,778680	(KWh/kg)

60812	MW	608,120	11,627533	(KWh/kg)
235,439.5	MW		45,017112	(KWh/kg)

2.3. Biomass energy

Pakistan has been categorized fifth-biggest sugarcane producer worldwide. The residual from this crop (sugarcane) can produce 18 Mt of biogas per year, which could be a good source of hydrogen energy production. The livestock sector is another source of biomass energy in Pakistan, where the animal population is growing at around 8 % annually. More than 35 million rural people are generating their 30%-40% income from livestock. Between, 2012-2013, Pakistan generated 1140 Mt of muck and 338 Mt of urine from its 72 million livestock. This considerable quantity of musk and urine objects can produce around 19,125 million cubic meters (m3) of biofuel every day. Moreover, bio-fertilizer and nitrogen-enriched produce nearly 57.4 Mkg per day [20]. 23 kg of a dry crop can produce one kilogram of hydrogen energy. Therefore, Pakistan has a total potential of 6633 thousand tons of hydrogen power from biomass energy resources. Table 5 presents the estimated hydrogen energy production from numerous varieties of crop residue in the country.

Table 5. Show each crop residue estimation for hydrogen energy production.

Kind of Crop	Crop residues	Existing Residue (1000 MT)	Potential of Hydrogen generation (1000 tones)
1.Cotton	Stalks	3300	254
	Cobs	11,900	915
	Husk	3300	254
2.Barley	Stalks	110	8
3.Bajra	Husks	152	12
	Cobs	950	73
	Stalks	142	11

4.Dry Chilly	Stalks	285	22
5.Wheat	Stalks	7200	554
	Husks	36,000	2,769
6.Maize	Stalks	600	46
	Husk	90	7
7.Rice	Boll Shell	10,400	800
	Stalks	1400	108
	Straw	10,400	800
Total		86,229	6633

2.4. Small hydropower

The first small hydropower canal, built by Sir Ganga Ram in 1925 at Punjab (Lahore).it is the total capacity of 1.1 megawatts and that hydro still generating energy. Pakistan has 0.2 to 40 small-hydro potential from different sites and varies from the site by sit estimated data can be 3100(MW) from country numerous river sites and waterfalls sites(Kamran, 2018). According to reports of Pakistan departments such as WAPDA and AEDB . The total micro-hydro potential from country different sites measurement shows in table 6.

Table 6. Represent the micro hydropower in Pakistan(AEDB, 2007)

Province	Potential Sites	Potential Range	Unit	Total Potential	Unit	Source Type
1.Sindh	150	5-40	Megawatt	120	Megawatt	Canal
2.KPK	125	0.2-32	Megawatt	750	Megawatt	Natural/Falls
3.Punjab	300	0.2-40	Megawatt	560	Megawatt	Canal
4.Azad Kashmir	40	0.2-40	Megawatt	280	Megawatt	Natural/Falls
5.Gilgit-Baltistan	200	0.1-38	Megawatt	1300	Megawatt	Natural/Falls

All operational small-hydro projects under provincial administration are taking with the help of the Asian Development Bank (AEDB).In 2018, the KPK government had announced the new six small hydro projects with a total volume of 118 megawatts.(AEDB, 2007). Additionally, with the capability of provinces, start various renewed hydro projects with the capacity of 2500 megawatt in different stages. Likewise, the Government of Punjab has started four hydro projects with a capacity of 20 megawatts (see table 7). After completed, these projects then the country will be getting more hydrogen production in the system.

Table 7. Represent entire small-hydro projects in Pakistan and these maximum generating power 98.41MW.

S. No	Site	Province/District	Volume
1	Daragai, Malakand	Khyber-Pakhtunkhwa province	20
2	Pehur, HES, Swabi	Khyber-Pakhtunkhwa province	18
3	Reshun, HES, Chitral	Khyber-Pakhtunkhwa province	4.2
4	Rsishi, HES, Chitral	Khyber-Pakhtunkhwa province	1.2
5	Nandipur, Upper Chenab Canal	Punjab province	13.8
6	Rasul, Upper Jhelum Canal	Punjab province	13.8
7	Shadiwal, Upper Jhelum Canal	Punjab province	13.5
8	Cichocki, Upper Chenab Canal	Punjab province	13.2
9	Renala, Lowr Bari Doab Canal	Punjab province	1.1

2.5. Municipal solid wastage energy

Municipal solid wastage too viable and affordable with renewable hydrogen production in Pakistan. Countries' main cities yearly produce 30 million tons of municipal solid wastage (Korai et al., 2017). Municipal solid wastage is increasing with the high rate this could, Speedy increasing urban population of country. But still, developing country Pakistan not proper management to recycling method of municipal solid wastage to convert as the valuable material. When, use the conventional way of wastage disposable this can affect the environment, socio-economic and public health (Khan et al., 2012), (Korai et al., 2016). It is promoting waste to energy on time. It is helpful for the government to tackle the challenge. This could be managed by increasing municipal solid wastage in the country. The municipal solid wastage increasing amount is beneficial for the production of hydrogen. Modern technologies are municipal soil wastages to hydrogen technologies that can be techno-economic viable amount of hydrogen energy producing. Energy from wastage with high population density areas. Mostly urban areas of Pakistan, whereas urban areas highly densely populated where a waste convert to hydrogen can be reached 1 million tones. Only Karachi city produces 13,000 tons of municipal solid wastage reaches per day.

Moreover, rural areas generate more municipal solid waste; it is also beneficial for municipal solid wastage to hydrogen energy. As estimate, the rural areas can produce about 814 million kilograms of hydrogen energy per day (Zuberi and Ali, 2015). the biochemical method used for energy production of solid waste. Pakistan can reduce energy imports by 70 percent. Another essential process called the thermochemical process can generate enough energy that can completely replace imported energy. The thermochemical process of waste also decreases 1.86 percent burden from primary energy.

2.6. Geothermal energy

Pakistan is also suitable for geothermal energy due to the high number of tectonic plates available. According to the map, Pakistan can generate 100,000 MW of economical and clean electricity with its available geothermal resource. Table 8 presents the temperature of the potential hydrogen production areas from geothermal energy. Mostly urban areas, industrial zones of Sindh province, and dry rocks are the binding sites for hydrogen energy production. Based on the above-mentioned renewable energy source in Pakistan, the following figure 4 presents hydrogen energy through given resources.

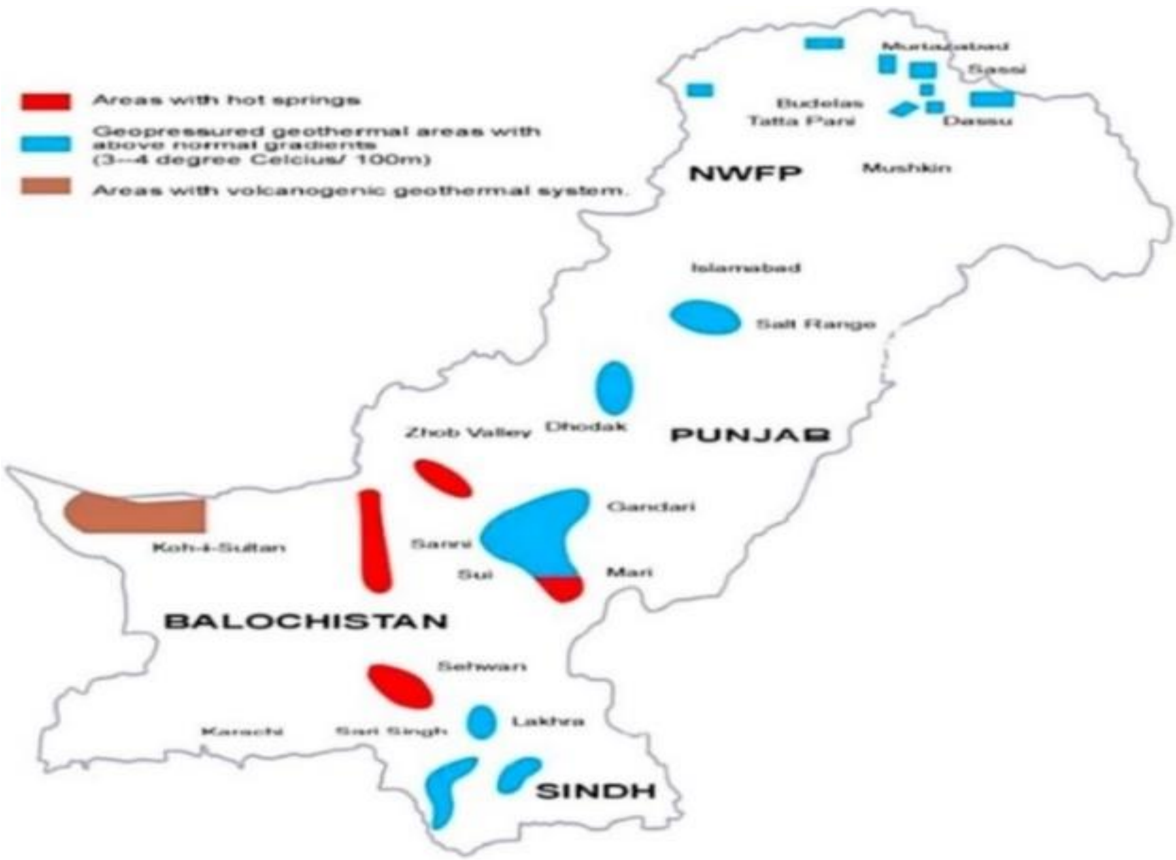

Figure 4. Map of hydro-geothermal resources in Pakistan(Yousefi et al., 2010)

Pakistan will generate 100,000 megawatts economical and clean electricity, with the following available geothermal resource. Table 8 present the temperature of the area with potential hydrogen production from geothermal energy in these mentioned areas. Mostly , urban areas industrial zones of Sindh province produce significant amount of hot, dry rock (Zaigham and Nayyar, 2010) which should provide high hydrogen energy production from these areas.

Table 8. Represent the Temperature. Areas and Application of geothermal energy in Pakistan

Areas	Maximum Temperature	Application
1. Karachi city	70 to 145 °C	Green housing Vegetable and fruits drying process

		Food processing site
		Pulp and paper processing
		Soft drink carbonation
		Concrete Block curing
2.Muzaffarabad	185 o 230 °C	Production of ethanol and Biofuels
		Binary Power plant
3.Chagai	200 to 300 °C	Hydrogen Production
		Dry and flesh steam power plan
4.Chakwal	60 to 90 °C	Heat Pump
		Aquaculture
		Biogas production
		Mushroom culture
5. Kolte, Tatta Pani, and Tato	100 to 200 °C	Binary power plant
		Fabric Dyeing
		Refrigeration & Ice making
		Cement & Aggregate Drying
		Pulp drying
		HVAC
		Lumber drying

3. Research Framework

In this section, we describe the research framework, which contains research methodologies. We are using the two-step proficient MCDA methods. Step 1, used Fuzzy-AHP, and step 2, used data envelopment analysis (DEA), to assess the optimal Renewable energy for hydrogen generation, based on different criteria. Firstly, we selected these criteria and further divided into the input and output criteria. These are the following: Four Output criteria contain (1. Technical potential,2. Economic benefits,3. Environmental implication and4.Social acceptance.), and Only One Input criteria include (renewable electricity production cost. Figure 5 below shows the research framework. Secondly, we obtain weights of Criteria using Fuzzy-AHP with the help of 10 experts. These experts including researchers, energy investors and academic professors. Later, we measure the efficiency score of renewable energy sources using input and output data criteria weights in the DEA model. Finally, ranked renewable energy sources with their efficiency scores.

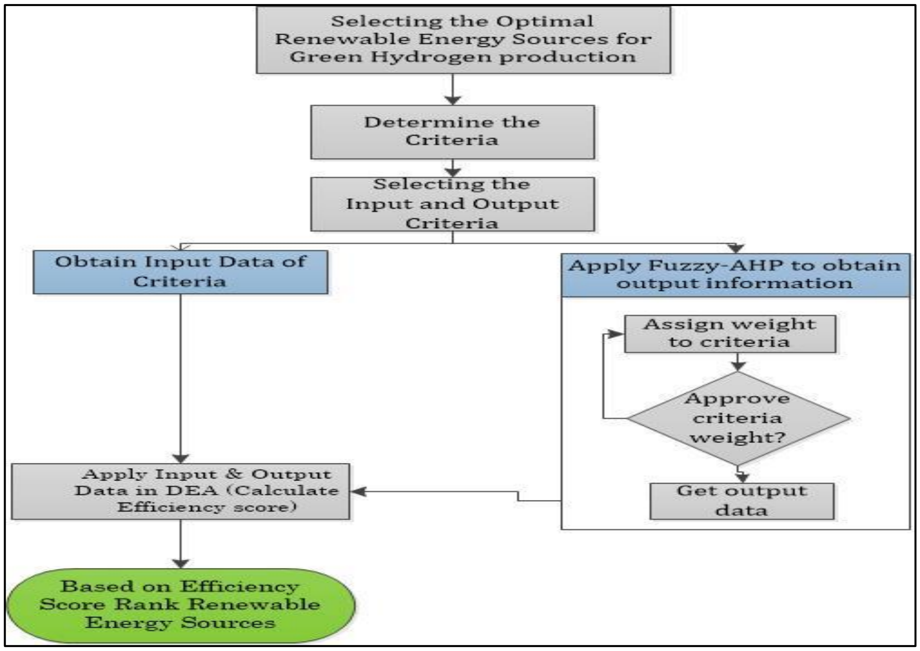

Figure 5. A Research Framework Diagram

4. Methods Description and Validation

4.1. Fuzzy Set Theory

It is tough to solve real-world problems without using appropriate measurement values. Therefore, decision-makers use crisp values because linguistic values have uncertainty data. The Fuzzy set theory potent tool to remove uncertainties, while decision-makers used for assessment decision-making when crisp values absent, as well as useful for linguistic feedback into crisp data for the decision making. In 1965, Zadeh developed a Fuzzy set theory, which is to minimize ambiguity into linguistic values with the help of the fuzzy triangular numbers (TFNs). We used the triangular fuzzy number (TFN) to rank Renewable Energy Sources (RES), which is best for ranking. Construct the Triangular fuzzy number Fij $= (a\text{ij}, \text{bij}, \text{cij})$; where middle number bij and aij,cij are left -side and right-side number of in TFN. Let's Suppose a fuzzy number divide in two numbers. Where Fuzzy1= $a1, b1, c1$, and Fuzzy2 = $a2, b2, c2$. We apply different math operation on fuzzy numbers, will be as follow:

Add :$(a_1, b_1, c_1) + (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$ **(1)**

Multiply :$(\mathrm{a}_1, \mathrm{b}_1, \mathrm{c}_1) \times (\mathrm{a}_2, \mathrm{b}_2, \mathrm{c}_2) = (\mathrm{a}_1 \times \mathrm{a}_2, \mathrm{b}_1 \times \mathrm{b}_2, \mathrm{c}_1 \times \mathrm{c}_2)$ **(2)**

Divide:$(a_1, b_1, c_1)^{-1} = (1/c_1\,, 1/b_1\,, 1/a_1)$ **(3)**

4.2. Fuzzy-AHP

Analytical hierarchal process (AHP) is a multiple-choice decision analysis (MCDA) method, which compares specific choices or alternatives and assigns weights to the criteria. The analytical hierarchal process levels are useful for converting complex problems into sub problems. Each sub-problem level contains the criteria and attribute. However, these criteria offer according to their relative importance and additive weighting process. Also, the AHP has been used in different areas for ranking purposes, which uses a pairwise comparison for calculating the importance of criteria in a hierarchical method. However, the AHP method has the following shortcomings:

- Unstable decisions
- Decision-making ambiguity judgments
- Inaccurate ranking subjectivity in judgment
- Decision-makers based on the AHP model results.

According to AHP limitations, its qualitative analysis produces an absolute magnitude of decided evaluation while these linguistic outcomes cannot be converted into mathematical form. Due to these limitations, it is proposed to convert the linguistic outcomes of AHP into fuzzy numbers. Table 9 presents the Fuzzy measurement scale. Considering this, we applied each linguistic value as a fuzzy number as the reciprocal of each generic verbal value [23]. Thus, there are the following advantages of using fuzzy methodology:

- The Fuzzy set theory is a potent tool to remove uncertainties
- it equips decision-makers to apply this to assess better decision-making options in the absence of crisp values.
- The fuzzy set theory minimizes ambiguity into linguistic values with fuzzy triangular numbers (TFNs) [24].
- It is applied to rank renewable energy sources.

Table 9. Represent the Fuzzy measurement scale(Hu et al., 2010)

Measurement Scale	**Classification**	**Description**
(1, 1, 1)	All Equivalent preference	Two elements make equal contribution
(2/3, 1, 3/2)	Reasonable preference	One variable is significantly more favorable than others
(3/2, 2, 5/2)	Robust preference	One variable is extremely favorable
(5/2, 3, 7/2)	Quite robust preference	A variable is very highly favorable
(7/2, 4, 9/2)	Highest preference	One variable is the most favorable variable than others

This matrix represents the Fuzzy pairwise comparison as follow:

$\mathrm{B} = (\mathrm{b_{ij}})_{\mathrm{n\times m}}$. Let's have a say Triangular fuzzy number (TFN): $\mathrm{R_{ij}} = (\mathrm{x_{ij}}, \mathrm{y_{ij}}, \mathrm{z_{ij}})$.

A Fuzzy AHP also contains the following procedures:

1. Using Triangular fuzzy number (TFN) to build pairwise compression through pair according to hierarchical structure.
2. The value of ith Fuzzy synthetic set is as follows:

$$SE_i = \sum_{j=1}^{m} R_{ij} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij}]^{-1} \tag{4}$$

$$\text{s.t} \sum_{j=1}^{m} R_{ij} = \left(\sum_{j=1}^{m} x_{ij}, \sum_{j=1}^{m} y_{ij}, \sum_{j=1}^{m} z_{ij} \right) \text{for } i = 1,2, \dots, n \tag{5}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij} = \left(\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij}, \sum_{i=1}^{n} \sum_{j=1}^{m} y_{ij}, \sum_{i=1}^{n} \sum_{j=1}^{m} z_{ij} \right) \tag{6}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} z_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} y_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}}\right) \quad (7)$$

The equation number 4,5,6 and 7 measure the $\mathrm{SE_i} = (\mathrm{x_i}, \mathrm{y_i}, \mathrm{z_i})$.

3. Comparison of SE_i values and Calculate what's possible degree of $SE_j = (x_j, y_j, z_j) \geq SE_i = (x_i, y_i, z_i)$.

The formulation equivalent is as follows:

$$\mathrm{V}\left(\mathrm{SE_j} \geq \mathrm{SE_i}\right) = \mathrm{height}\left(\mathrm{SE_i} \cap \mathrm{SE_j}\right) = \mathrm{z_{s_j}}(\mathrm{d}) = \begin{cases} 1, \text{ if } \mathrm{y_j} \geq \mathrm{y_i} \\ 0, \text{ if } \mathrm{x_i} \geq \mathrm{z_j} \\ \dfrac{\mathrm{x_i} - \mathrm{z_j}}{\left(\mathrm{y_j} - \mathrm{z_j}\right) - \left(\mathrm{y_i} - \mathrm{x_i}\right)}, \text{ otherwise} \end{cases} \quad (8)$$

Where d shows the intersection between z_{s_j} and z_{s_i}; A comparison between the values is required of $V\ (SE_i \geq SE_j)$ and $V\ (SE_j \geq SE_i)$ with the values of SE_i and SE_j.

4. This step calculates minimum chances degree $d(i)$ of $V\ (SE_j \geq SE_i)$: where $ij = 1,2, \ldots, k$.

$$\begin{gathered} \mathrm{V}(\mathrm{SE} \geq \mathrm{SE_1}, \mathrm{SE_2}, \mathrm{SE_3}, \ldots, \mathrm{SE_k}), \\ \text{for } \mathrm{i} = 1,2,3, \ldots, \mathrm{k} \\ = \mathrm{V}[(\mathrm{SE} \geq \mathrm{SE_1}) \text{ and } (\mathrm{SE} \geq \mathrm{SE_2}) \text{ and} \ldots (\mathrm{SE} \geq \mathrm{SE_k})] = \min \mathrm{V}\left(\mathrm{SE} \geq \mathrm{SE_i}\right) \\ \text{for } \mathrm{i} = 1,2,3, \ldots, \mathrm{k} \end{gathered} \quad (9)$$

Assume

$\mathrm{d}'(\mathrm{B_i}) = \min \mathrm{V}(\mathrm{SE_j} \geq \mathrm{SE_i}), \text{ for } \mathrm{i} = 1,2,3, \ldots, \mathrm{k}$

We then define this latter vector as

$$\mathrm{W}' = \left(\mathrm{d}'(\mathrm{B_1}), \mathrm{d}'(\mathrm{B_2}), \ldots, \mathrm{d}'(\mathrm{B_n})\right)^{\mathrm{T}} \quad (10)$$

where B_1 $(i = 1,2,3, \ldots, n)$ represents n elements: This last step norms the weight of the vectors as follows:

$$W = \left(d(B_1), d(B_2), \dots, d(B_n)\right)^T \quad (11)$$

Here is a non-fuzzy number indicating W.

4.3. Traditional data analysis model

DEA is very (Tone and Tsutsui, 2009) famous MCDA approach used to measure the optimal efficiency of DMus, which is used the multiple inputs and multiple outputs. This approach has many applications from the 1978.For example, evaluation the performance of banks, education departments, airlines, health departments. (LaPlante and Paradi, 2015) , Sustainability assessment of networks supply chain (Tajbakhsh and Hassini, 2015), (Krmac and Djordjević, 2019), Techno-economic Solar Stills Assessment (Rufuss et al., 2018), assessment of energy efficiency improvement.

Data envelopment analysis (DEA) is a practical MCDA approach used to measure the decision-making unit (DMUs), which uses multiple inputs and outputs. Different researchers have applied this approach to measure the efficiency of different departments. For instance, (Wang et al., 2019), evaluated the performance of banks, (Peng Zhou et al., 2008), for education departments, and (P. Zhou et al., 2008), for airlines, health departments. (Cook et al., 2019) used this method for the sustainability assessment of the network supply chain. Simultaneously, (Kahraman et al., 2003) applied it for techno-economic assessment of solar stills, and (IRENA, 2014) utilized it to assess energy efficiency, improvement in environmental performance analysis, and benchmarking performance evaluation, respectively. Thus, fuzzy-AHP criteria weights are considered the DEA model's output data, and development cost is considered the input data. Charnes, Cooper, and Rhodes (CCR) planned DEA to assess the comparative efficiency or competence of specific DMUs [31]. It has the following generalized form: A set of “N” decision-making units will be examined with m outputs and l inputs. Thus let (k = 1,2,3, … , n) represent a DMU. In principle, the CCR model is categorized into two further models (i.e., CCR-I - input-oriented model and CCR-O - output-oriented model). CCR-I aims to minimize the input data for a given output data. Conversely, CCR-O models maximize the outputs at a given level of inputs. Since the objective of this study is to maximize the outputs, the following output oriented CCR model is proposed. Figure 6 provide the working of CCR model.

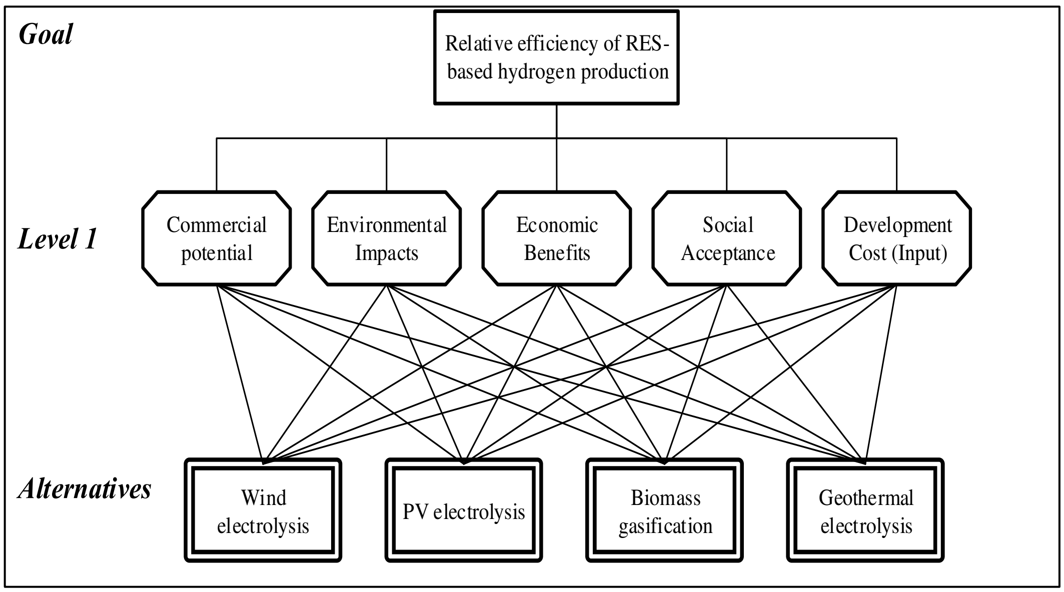

Figure 6. Output oriented CCR model

Charnes, Cooper, and Rhodes (CCR) proposed DEA for the first time in 1978. CCR designed DEA as a measure to compute relative productivity or efficiency of a particular DMUs (Charnes et al., 1978). we analyze a set of ns DMUs, and each DMU uses l inputs and m outputs. The formulation of DEA is as below:

Let $(k = 1,2,3,\ldots,n)$ represents a DMU, and the aim is to maximize the efficiency of that DMU then

$$\mathrm{Max}\ \mathrm{h_k} = \frac{\sum_{r=1}^{m} v_{rk} Y_{rk}}{\sum_{i=1}^{l} u_{ik} X_{ik}} \qquad (\mathbf{12})$$

$$\mathrm{s.t}\frac{\sum_{r=1}^{m} v_{rk} Y_{rk}}{\sum_{i=1}^{l} u_{ik} X_{ik}} \leq 1, \mathrm{for j} = 1, \ldots, n \qquad (\mathbf{13})$$

$$v_{rk} > 0, \text{for } r = 1, \ldots, m \tag{14}$$

$$u_{ik} > 0, \text{for } i = 1, \ldots, l \tag{15}$$

Where , v_{rk}represents the output weight, which is given to the rth DMU_k, u_{ik} show the input weight allocated to the ith DMU_k, v_{rk}, and u_{ik} these variables use to evaluate the relative efficiency of kth DMU, Y_{rj} shows the rth output of the jth DMU, and X_{ij} represents the ith input of the jth DMU. Here, Y_{rj} and X_{ij} both variables are positive value. h_k donates the efficiency score. Additionally, the value of h_k is less than or equal to one. If the value of $h_k = 1$, that is proved the decision-making unit (DMU) is performing on an efficient frontier.

Basically, CCR model further two categories models such as CCR-I, it means input-oriented model and CCR-O, it means output-oriented model. Input-oriented aims to minimize the inputs data for a given outputs data. Conversely, the output-oriented models maximize the outputs at a given level of inputs. The focus of this study is to maximize the outputs. Therefore, we used the below-given output-oriented CCR model:

$$\min px_0 \tag{16}$$

$$\text{s.t } qy_0 = 1 \tag{17}$$

$$\mathrm{qY} - \mathrm{pX} \leq 0 \tag{18}$$

$$\mathrm{p}, \mathrm{q}. \tag{19}$$

Here, x_0 and y_0 are respective inputs and outputs vectors of DMU_0. X and Y variables, in Eq. 18 refers to separate inputs and outputs matrices. Let (u^*, v^*) be an optimal solution for LP_0. Then, we can obtain the optimal solution from

$$\mathrm{p}^* = \mathrm{u}/\theta^*, \mathrm{q}^* = \mathrm{v}^*/\theta^* \tag{20}$$

It is clear that (p∗, q∗) is feasible for an optimal solution LP_0. Equation 21 computes the optimal solution as follows:

$$\mathrm{p}^*\mathrm{x}_0 = \mathrm{u}^*\mathrm{x}_0/\theta^* = \eta^* \tag{21}$$

$$\hat{x}_0 = x_0 - g^{-*} \quad (\mathbf{22})$$

$$\hat{y}_0 = \eta^* y_0 + g^{+*} \quad (\mathbf{23})$$

Here, g^{-*} and g^{+*} are respective input and output slack variables of DMU_0.

Now, g +∗ and g −∗ are output and input slack variables of $DMU0$. Thus, a first-order engineering model is used to measure gasoline consumption for each province of Pakistan. The prior studies found that by increasing the population density function, fuel consumption by transportation decreases sub-linearly. Consequences of geographical classification (e.g., urban vs. rural) have been scrutinized in-vehicle petrol consumption studies. Water electrolysis having an efficiency of 65 to 85%, use electricity from renewable energy generated from wind, and it has a more significant potential between various technologies that generate hydrogen,

$$A_{H2} = \frac{\eta_{el} E}{LHV_{H2}} \quad (24)$$

Where A_{H2} indicates the produced hydrogen quantity. E shows the input of wind electricity to the electrolyzer to produce hydrogen, ηel is the efficiency of the electrolysis process, and LHV_{H2} is the value of lower hydrogen heating. This study quantified the demand for renewable hydrogen generated by the wind for nationwide light-duty vehicles. The numbers of comparable units of electrolyzer are essential. Over an electrolysis system, the renewable hydrogen quantity H_{it} (kg/period) in the given period is measured as follows:

$$H_{it} = M_t N_{Jt}^{el} H_{Jt}^{el} \forall_J \in J^{el} \qquad t = 1, \dots, n \quad (25)$$

Where the elements electrolyzed in the system is denoted by N_{Jt}^{el} although Mt is the hours that measure in the electrolyzed system. Resultantly, by using this method, oxygen is formed for breathing and hydrogen for fuel. Both the electrodes are of metal (e.g., platinum) and are connected to electricity in water [32]. We have considered [33]as a base case study for cost evaluation. As we argued, annual wind-generated renewable hydrogen production is a function of marginal hydrogen prices and the electrolyzer system's energy efficiency. As the marginal price of the wind-generated renewable hydrogen increases, there will be an increase in hydrogen production until it levels off.

4.4 Power Plant Cost for renewable hydrogen production

We consider power producer technologies that compete against a large number of powers producing technologies such as flammable gas, coal, oil, uranium, and renewable and sustainable power sources such as hydropower, wind, and geothermal-warm procedures, with and without coal catch and capacity (CCS); including consolidated cycle steam plants (CC) and joined cycle installed gasification (IGCC); and sun-oriented methane (SOME). The rivalry between the various approaches is generally focused on Leveled power costs (COE, represented in \$/MWh), which are measured as follows:

$$COE = \frac{C_f}{n} + \frac{1000\ C_I}{8766\ CF}.i + \frac{C_{0\&Mfix}}{8766.CF} + C_{0\&Mvar} \tag{26}$$

Where C_f denotes fuel cost in \$/MWh, represents power plant performance, Ci denotes asset expenditure cost in \$/kW, and CF denotes calculation component, which denotes the proportion of operating hours exceeding the sum of 8766 per year. Here, i represent a fixed charge rate, $C_{O\&Mfix}$ represents a fixed O&M cost per year, and $C_{0\&Mvar}$ represents a variable O&M cost. In 2015, all costs are recorded in real USD. These uncertainties are meant to serve as a source of insight for strength framework models and, in particular, inserted evaluation models, as well as engage with GCAM's core assumptions about the power market. Two calculations are periodically collected to quantify more budgets realized by CCS systems: the cost of CO_2 gained and the expense of CO_2 prevented. Both are expressed in dollars per tonne of CO2. The suggested calculations take into account the costs from this analysis while excluding the transportation and power costs from GCAM. The cost of CO_2 capture is estimated by dividing the maintenance cost of generating energy by the volume of CO_2 generated by a CCS-ready office ($/kWh).

$$\text{cost}_{\text{capt}=}\frac{\text{COE}^{(\text{CCS})} - \text{COE}^{(\text{noCCS})}}{\text{CO}_{2-\text{capt}}} \tag{27}$$

Where COECCS denotes the power expense of a CCS-prepared plant in dollars per kilowatt-hour. COECCS relates to the cost of electricity delivered by a plant without CCS invention, with CO_2 per capita as the limit. In order to generate energy, it is important to develop a strategy of strategic petroleum reserves. In reality, renewables are one of the most important replacements for liquefied petroleum output in the first and second biofuel cohorts. Oil supply curves regulate how quickly they are disseminated. The market share of biofuels increases as oil prices rise at each point, capturing the rivalry between oil-based liquid fuels and biofuels in a clear way.

The operational cost per unit of energy generated by a wind energy conversion device is often assessed using a variety of methods. The ratio of cumulative net present value of total costs (PVC) to total energy (E tot) produced by the device is used to calculate the per unit cost (C W) of wind energy in this analysis.

$$\text{C}_\text{W} = \frac{PVC}{E_{tot}} \tag{28}$$

The electrolyzer capital cost is determined by the necessary rate of hydrogen supply. The efficient electrolyzer performance and the average real capital cost per kWh at nominal output are calculated as.

$$C_{ele,u} = \frac{M_{H_2}K_{el,th}}{8760.f\eta_u} \tag{29}$$

$$C_{ele,u} = \frac{M_{H_2}K_{el,th}}{8760.f\eta_u} \tag{30}$$

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 are equal to 2% and 25% of the initial cell expenditure, respectively, and that the electrolyzer has a seven-year operating period.

5. Analysis and results

5.1 Priority Weights of Criteria

The initial step in finding relative involves is the construction of the pairwise comparison matrix. The construction of the pairwise comparison matrix helps to find a relative relationship [34]. Therefore, the criteria' priority weights have been performed, and its pairwise comparison matrix is shown in table 10.

Table 10. The results of the fuzzy evaluation criteria.

	Commercial potential	**Environmental impacts**	**Economic benefits**	**Social acceptance**
Commercial potential	1, 1, 1	1.09, 1.57, 2.13	0.46, 0.65, 0.95	0.58, 0.81, 1.2
Environmental impacts	0.47, 0.64, 0.92	1, 1, 1	0.88, 1.27, 1.76	0.83, 1.23, 1.72
Economic benefits	1.05, 1.53, 2.18	0.57, 0.79, 1.13	1, 1, 1	1.22, 1.77, 2.34
Social acceptance	0.83, 1.23, 1.72	0.58, 0.81 ,1.2	0.43, 0.56, 0.82	1, 1, 1
CR = 0.06				

The obtained results of priority weights of criteria can be used to estimate the TFN against the values of each criterion as follow:

We used these obtained results to calculate the TFN values of each criterion as follows:

$$SE_1(\textbf{Commercial potential}) = (3.13, 4.03, 5.28) \otimes (1/22.07, 1/16.86, 1/12.99)$$

$$= (3.13 * 1/22.07, 4.03 * 1/16.86, 5.28 * 1/12.99)$$

$$= (0.142, 0.239, 0.406)$$

$$SE_2(\textbf{Environmental impacts}) = (3.18, 4.14, 5.4) \otimes (1/22.07, 1/16.86, 1/12.99)$$

$$= (3.18 * 1/22.07, 4.14 * 1/16.86, 5.4 * 1/12.99)$$

$$= (0.144, 0.246, 0.416)$$

$$SE_3(\textbf{Economic benefits}) = (3.84, 5.09, 6.65) \otimes (1/22.07, 1/16.86, 1/12.99)$$

$$= (3.84 * 1/22.07, 5.09 * 1/16.86, 6.65 * 1/12.99)$$

$$= (0.174, 0.302, 0.512)$$

$$SE_4(\textbf{Social acceptance}) = (2.84, 3.6, 4.74) \otimes (1/22.07, 1/16.86, 1/12.99)$$

$$= (2.84 * 1/22.07, 3.6 * 1/16.86, 4.74 * 1/12.99)$$

$$= (0.129, 0.214, 0.365)$$

After calculated the values of SE_i, we compared them and computed possibility degree of $SE_j = (x_j, y_j, z_j) \geq SE_i = (x_i, y_i, z_i)$ by solving Eq. 8. Table 11 presents the values of $V(SE_j \geq SE_i)$. We have now obtained the TFNs of four main indicators. After obtaining the SEi values, the possible degree of $SEj = (x\ ,\ yj\ ,\ zj) \geq SEi = (xi\ ,\ yi\ ,\ zi)$ is computed and compared by explaining equation 8. As mentioned earlier, the respective indicator results based on the process are presented in table 11.

Table 11. Values of $V(SE_j \geq SE_i)$

$\boldsymbol{V(SE_1 \geq SE_i)}$	**Value**	$\boldsymbol{V(SE_2 \geq SE_i)}$	**Values**
$V(SE_1 \geq SE_2)$	0.97	$V(SE_2 \geq SE_1)$	1.00
$V(SE_1 \geq SE_3)$	0.79	$V(SE_2 \geq SE_3)$	0.81
$V(SE_1 \geq SE_4)$	1.00	$V(SE_2 \geq SE_4)$	1.00

$V(SE_3 \geq SE_i)$	**Value**	$V(SE_4 \geq SE_i)$	**Value**
$V(SE_3 \geq SE_1)$	1.00	$V(SE_4 \geq SE_1)$	0.90
$V(SE_3 \geq SE_2)$	1.00	$V(SE_4 \geq SE_2)$	0.87
$V(SE_3 \geq SE_4)$	1.00	$V(SE_4 \geq SE_3)$	0.68

After finding the values of $V(SE_j \geq SE_i)$, we calculated the minimum possible degree of $d'(i) = \min V(SE_j \geq SE_i)$, for $i = 1,2,3, \ldots, k$.

$d'(\textbf{Commercial potential}) = \min V(SE_1 \geq SE_2, SE_3, SE_4) = \min(0.97, 0.79, 1.00) = 0.79$

$d'(\textbf{Environmental impacts}) = \min V(SE_2 \geq SE_1, SE_3, SE_4) = \min(1.00, 0.81, 1.00) = 0.81$

$d'(\textbf{Economic benefits}) = \min V(SE_3 \geq SE_1, SE_2, SE_4) = \min(1.00, 1.00, 1.00) = 1.00$

$d'(\textbf{Social acceptance}) = \min V(SE_4 \geq SE_1, SE_2, SE_3) = \min(0.90, 0.87, 0.68) = 0.68$

We obtained the weight vector as follows:

$W' = (0.79, 0.81, 1.00, 0.68)^T$

In the final step, we normalized the weight vector as follows:

$W = (0.24, 0.25, 0.30, 0.21)^T$

The final weights of political, environmental, technical, and social are 0.24, 0.25, 0.30, 0.21, respectively. The preference of these four criteria is economic benefits > environmental impacts > commercial potential > social acceptance.

5.2. Priority weight of criteria for different RES

The steps followed in 4.1 have been applied for different renewable energy sources considered alternatives for hydrogen production to estimate the priority weights criteria. The fuzzy techniques' assessment matrixes of renewable energy sources have been used as substitutes under specific criteria Table 12 presents the results of the fuzzy evaluation matrix and shows the priority weights of RES alternatives under each criterion.

Table 12. Fuzzy assessment of renewable energy sources alternatives within commercial Criteria

	Wind	**Solar**	**Biomass**	**Geothermal**
Wind	1, 1, 1	0.77, 1.09, 1.5	0.9, 1.32, 1.8	1.01, 1.37, 1.8
Solar	0.66, 0.92, 1.3	1, 1, 1	0.88, 1.27, 1.76	1, 1.46, 1.96
Biomass	0.56, 0.76, 1.12	0.57, 0.79, 1.13	1, 1, 1	1.22, 1.77, 2.34
Geothermal	0.56, 0.73, 0.99	0.51, 0.68, 1	0.43, 0.56, 0.82	1, 1, 1
CR = 0.01				

This study compares four main criteria (commercial potential, environmental impact, economic benefit, and social acceptance) under the different criteria condition to see the second level's decision procedure. The outcomes of this procedure have been depicted in Table 13, 14,15 and 16.

Table 13. Fuzzy assessment of RES alternatives inside environmental impacts criteria

	Wind	**Solar**	**Biomass**	**Geothermal**
Wind	1, 1, 1	0.94, 1.33, 1.82	0.65, 0.94, 1.35	0.81, 1.09, 1.43
Solar	0.55, 0.75, 1.06	1, 1, 1	0.76, 1.1, 1.57	0.86, 1.26, 1.75
Biomass	0.74, 1.06, 1.54	0.64, 0.91, 1.32	1, 1, 1	0.6, 0.81, 1.16
Geothermal	0.7, 0.92, 1.24	0.57, 0.79, 1.16	0.86, 1.23, 1.66	1, 1, 1
CR = 0.01				

Table 14. Fuzzy assessment of renewable energy sources alternatives within economic benefits criteria

	Wind	**Solar**	**Biomass**	**Geothermal**
Wind	1, 1, 1	0.77, 1.15, 1.72	0.59, 0.89, 1.35	0.9, 1.38, 1.98

Solar	0.58, 0.87, 1.3	1, 1, 1	0.68, 1, 1.48	1, 1.64, 2.46
Biomass	0.74, 1.12, 1.69	0.68, 1, 1.48	1, 1, 1	1.1, 1.64, 2.34
Geothermal	0.51, 0.72, 1.11	0.41, 0.61, 1	0.43, 0.61, 0.91	1, 1, 1
CR = 0.00				

548 **Table 15.** Fuzzy assessment of renewable energy sources alternatives within social acceptance criteria

	Wind	**Solar**	**Biomass**	**Geothermal**
Wind	1, 1, 1	0.61, 0.91, 1.37	0.49, 0.72, 1.1	0.9, 1.23, 1.65
Solar	0.73, 1.1, 1.63	1, 1, 1	0.68, 1.06, 1.62	1.1, 1.74, 2.46
Biomass	0.91, 1.38, 2.05	0.62, 0.94, 1.48	1, 1, 1	1.2, 1.84, 2.56
Geothermal	0.61, 0.81, 1.11	0.41, 0.57, 0.91	0.39, 0.54, 0.83	1, 1, 1
CR = 0.00				

549 **Table 16.** Priority weight of criteria for various renewable energy sources RES

RES	**Commercial potential**	**Environmental impacts**	**Economic benefits**	**Social acceptance**
Wind	0.29	0.27	0.27	0.24
Solar	0.29	0.26	0.27	0.30
Biomass	0.26	0.23	0.28	0.31
Geothermal	0.16	0.24	0.17	0.16

550

551 ## 5.3. Alternatives criteria final weights for Renewable energy sources

552 Here, we multiplied the priority weights of criteria by priority weight of criteria for various 553 Renewable energy sources to obtain the final weights of each renewable energy sources.

554 Table 17. Provides the criteria weights of RES

RES	Commercial potential	Environmental impacts	Economic benefits	Social acceptance
Wind	0.29(0.24) equal to (0.070)	0.27(0.25) equal to 0.068	0.27(0.30) equal to 0.081	0.24(0.21) equal to 0.050
Solar	0.29(0.24) equal to (0.070)	0.26(0.25) equal to 0.065	0.27(0.30) equal to 0.081	0.30(0.21) equal to 0.063
Biomass	0.26(0.24) equal to (0.062)	0.23(0.25) equal to 0.058	0.28(0.30) equal to 0.084	0.31(0.21) equal to 0.065
Geothermal	0.16(0.24) equal to (0.038)	0.24(0.25) equal to 0.060	0.17(0.30) equal to 0.051	0.16(0.21) equal to 0.034

Table 17 explains the four leading indicators (commercial potential, economic impacts, economic benefits, and social acceptance) score of renewable energy sources (Wind, Solar, Biomass, and Geothermal) based on the criteria' priority weight. Here, the value of commercial potential for wind and solar energy is 0.29, biomass 0.26, and geothermal 0.16. Thus, wind and solar sources are equally crucial for the commercial potential of hydrogen energy in Pakistan. Wind energy scores highest (0.27), followed by solar energy (0.26) from the environmental perspective. Geothermal energy source scores 0.24, while biomass holds the last position in this lineup for environmental impact with a 0.23 score. The economic benefit of renewable energy sources by utilizing hydrogen energy led by biomass (0.28), followed by solar and wind energy for a 0.27 score. Here, geothermal secures the last position for economic benefit with just a 0.17 score. Biomass is the leading source of conversion into hydrogen energy for social acceptance after securing 0.31 points, followed by solar (0.30) energy sources. The wind and geothermal energy sources are relatively less important for social acceptance as both attained 0.24 and a 0.16 score. Here, the overall wind energy source of renewable energy is relatively more suitable for Pakistan's hydrogen energy production, followed by solar and biomass considering the four main aspects.

5.4. Renewable Energy Sources Ranking

In second stage, we assess the relative efficiency scores with help of DEA of renewable energy sources for hydrogen generation, after efficiency scores to rank available renewable energy sources. The final weights obtained by multiplying each renewable energy source (RES) with criteria priority weights are presented in table 18. According to the DEA results presented in table 18, the wind is ranked as one to be converted into hydrogen energy as it has a score of one efficiency level. Biomass is the second efficient energy source for hydrogen energy with 0.975 DEA efficiency, while solar is the third efficient (0.756) source for hydrogen energy conversion. The geothermal energy source is the least efficient for hydrogen production as it has a 0.662 efficiency score and is ranked four. According to DEA results, the wind is a highly efficient renewable energy source to be converted into hydrogen energy due to its efficient cost and benefit outcomes. Here, biomass is the second-best available option for this purpose.

Table 18. Presents ranking and relative efficiency scores of various renewable energy sources.

RES	**Inputs**	**Output**				**Efficiency score**	**Final Ranking**
	RE generation cost ($/kWh)	CP	EI	EB	SA		
Wind	0.06	0.070	0.068	0.081	0.050	1.000	1
Solar	0.10	0.070	0.065	0.081	0.063	0.756	3
Biomass	0.08	0.062	0.058	0.084	0.065	0.975	2
Geothermal	0.08	0.038	0.060	0.051	0.034	0.662	4

5.4 Techno-economic analysis of wind-generated renewable hydrogen production

There is no zero-emission vehicle in Pakistan when it has increased hydrogen demand for a vehicle of zero-emission. In contrast, all the provinces in Pakistan aggregate the rural and urban intensities of gasoline consumption. Table 19 shows a total demand of 14.6 billion kg of gasoline for all the provinces. Alternatively, the H2-demand (in billion kg) 4.88 billion kg renewable hydrogen is needed to the fleet the equivalent amount of vehicles fleet by 14.6 billion kg of gasoline in the country. Similarly, 6.63 billion kg is needed for LDV H2 Demand (kg/Annually). The price of renewable hydrogen fluctuates between USD0/kg to USD5/kg, having a growth of USD0.1/kg. There is an increase in hydrogen prices when there is an increase in renewable hydrogen production when the minimum price of hydrogen goes above the

USD2.99/kg kg-H2. Table 19 shows that for renewable hydrogen, the province of Punjab's potential demand is 4.54 billion kg. Moreover, provinces with high potential for producing wind energy have little possibility for hydrogen mandate, mainly coastal areas of Baluchistan and Sindh and interior parts of Sindh. In urban areas, gasoline consumption is nearly 3.2% lesser than the average consumption of gasoline, and in a rural region, the consumption of gasoline is nearly 6.66% higher than the average consumption. The following findings are in line with the conclusion drawn by (Chien et al., 2021). The prices of hydrogen range between 0-5$/kg, the site included in this study have an average price of USD4.3/kg, and the market prices of K-E (Mohsin et al., 2018) and wind power are from the potential data. In contrast, economically, in Pakistan, it is advantageous for electricity as the marginal price of renewable hydrogen is USD3.92/kg-H2. Moreover, hydrogen production is made through the efficient hydrogen conversion process through wind energy, about 0.85 billion kg in Pakistan, fulfilling Pakistan's hydrogen demand by 22%. It revealed that the outcome of the annual hydrogen production could be affected significantly by the marginal price of renewable hydrogen, namely, USD1/kg kg-H2 and USD4/kg kg-H2, and the lower prices of renewable hydrogen (e.g., US$2/kg) have a relative influence on the production of renewable hydrogen (He et al., 2020). The discrepancies between the different renewable cost curve sources indicate that focusing on renewable energy penetration is less cost-effective in carbon reduction than concentrating solely on decarbonization.

Table 19. Price of renewable hydrogen

Sites	Price in $
Price of electricity at Baghan site	$0.0864/kWh
Price of electricity at DHA K site	$0.0868/kWh
Price of electricity at Golarchi site	$0.0864/kWh.
Price of electricity at Nooriabad site	$0.0862/kWh
Price of hydrogen at all sites	$4.304/kg-H2
Supply price of hydrogen at all sites	$5.30–$5.80/kg

Other sites: DHA Karachi, Baghan and Golarchi.

In Pakistan, fuel rates vary from \$3.27 to \$4.80 per gallon (the maximum fuel prices are in Norway, at \$7.08 per gallon), and the world's average gasoline price is \$6.44 per gallon (www.globalpetrolprices.com) Though hydrogen supply costs range from \$5.30/kg to \$5.80/kg. Thanks to rising procurement costs, the average cost of green hydrogen has risen. Hydrogen can cost between \$4 and \$5 per kilogram in order to be a competitive fuel for electric cars. About the fact that owing to extreme electricity shortages and the most fragile atmosphere in the world, hydrogen use in Pakistan is possible at a higher cost (\$5.30/kg to \$5.80/kg).

According to table 19, when there is an increase in carbon reduction levels, the gap between the cost curves widens. In carbon mitigation, concentrating exclusively on renewable energy goals is more than 20% less cost-effective than focusing on high-ambition emissions reduction goals. For a different energy system costing equal to 1% of GDP, emissions under CO2 targets are decreased by 72%, but only by 45% when concentrating on renewable energy goals. Similarly, by relying on Hydrogen P MR HydrogenMC Qpc Qm Pcont Qc MRcontro sustainable targets, the energy system costs 80% carbon mitigation scenario lowers pollution by 55%. The environmental analysis shows that a CO2 emission of 645g is considered per kWh of electricity from the grid. In the national grid scenario, 3218 kg/year of CO2 emissions would raise the cost per kWh of energy and kg of hydrogen by considering the pollution penalty payments. In this scenario, there is no excess energy because the grid is accessible when needed. In the national grid/wind turbine situation, the highest excess electricity is generated by a wind turbine, which accounts for 35.2% of the total excess electricity produced and prevents 883 kg of CO2 emissions annually [38]. The renewable hydrogen and electrification pathways have comparable energy cost system. In 2050, both paths' overall cost will be around 29% higher than the national energy cost system's situation, and the gap between these paths is less than 1%. However, in these cases, the cost structure is substantially different. The pathway's dependence on crude oil is heavily dependent on the import of crude oil. Pakistan’s import dependency remained around 70%–72% until 2016. It fell to 70% in 2016 and 69% in 2017 due to the new gas field and wind energy increases. The system efficiency analysis at rated stack current showed that the electrolyzer system had 57% efficiency while the maximum alkaline system efficiency reached 41%. It noted that the hydrogen production was about 20% lower than the manufacturer’s rated flow rate, and if the rated flow were achieved, 50% system efficiency would be realized. Moreover, Pakistan is an oil-importing country and has a total oil import of 25% compared to total imports. If Pakistan’s energy imports become one-fourth ($7.13 billion) of the total imports ($27.34billion), it will save $5 billion per annum. This selection is justified by the comparative research results on alternative green hydrogen generation technologies focusing on their impacts on costs and the environment. In terms of greenhouse gas emissions, the differences become more noticeable. Only hydrogen production using solar energy offers similar GHG reduction potential to the water electrolysis, while the biomass-based methods generate significant emission levels. The paper covers the most actual initiatives addressing the combination of renewable hydrogen production with the possibility of hydrogen implementations for energy storage, transportation, and stationary applications such as combined heat and power (CHP) plants or fuel cell electric generators.

5.5 Discussion

This study is based on four criteria (commercial potential, economic impacts, economic benefits, and social acceptance) to identify optimal renewable energy sources (RES) for hydrogen production in developing economies such as Pakistan. The Fuzzy-AHP MCDA and DEA techniques used to measure the criteria weight and efficiency give renewable energy sources for hydrogen energy production. Empirical results based on fuzzy-AHP suggest that for economic benefit and commercial potential criterion, wind and solar are leading (equal) sources of renewable energy. At the same time, biomass is the third option in this regard. However, geothermal is not suitable for both the economic and commercial purposes of hydrogen energy production in Pakistan. The wind is the leading source for the environmental impacts to be converted into hydrogen energy, followed by a solar energy source. Here, biomass is the third suitable source, while geothermal is the least renewable energy source again. According to social acceptance, biomass is the leading source to be converted into hydrogen energy, while solar is the second-best option in this lineup. Here, the wind is the third suitable renewable energy source for hydrogen energy production, while geothermal is the last choice also here as well. These outcomes have also been found in recent studies [40], [41] The DEA model results showed that wind energy had the highest efficiency score of 1,000, the best optimum rank 1 for another RES like [42]. Therefore, Pakistan's wind sources are the predictable best renewable energy for Pakistan's green hydrogen energy production.

Next, biomass has the second-highest score of 0.975, while solar energy ranked third with a score of 0.756, which is consistent with (Mokhtari and Hasani, 2017). The efficiency score of geothermal energy in Pakistan was 0.662, indicating that it has the minimum efficiency as RES for hydrogen production. 5 Conclusion and policy implication Based on F-AHP, MCDA, and DEA method techniques, this study evaluates the possible sources for producing hydrogen energy in a developing country like Pakistan. Renewable hydrogen energy is a sustainable and secure future energy supply in the era of globalization, and various countries have hydrogen energy technological objectives on their horizon. According to F-AHP, MCDA results, Pakistan has enormous potential for renewable energy sources to generate green hydrogen, which can be necessary for current energy and future energy security. For this purpose, Wind energy sources consider the best choice for hydrogen energy production in Pakistan. Solar and biomass are the second and third available energy sources based on the preference criteria mentioned above. However, geothermal can be considered the least choice for this purpose. These results are verified with the DEA method, where wind energy has been considered the leading source for hydrogen energy production in Pakistan. Again, biomass is the second option for DAE outcomes, while solar is the third position in this lineup. The overall gasoline demand is 14.6billion kilograms in Pakistan, equal to 4.88 billion kg of renewable hydrogen. Similarly, 6.64 billion kg is needed for LDV H2 Demand (kg/Annually). The marginal prices of renewable hydrogen fluctuate from US$0/kg to US$5/kg, with growth of US$0.1 per kg. Thus, there is a need to fix the most efficient RES like the wind for a successful hydrogen energy intervention in Pakistan. Biomass may use hydrogen as the second-best option in this regard. This study's outcome may help select the best options for the future hydrogen economy for available renewable energy sources. This study is based on Pakistan's empirical data, and the experts provided their advice in the local language. Again, the economic situation, resource capacity, and socio-political conditions vary significantly between countries. However, this can be extended to similar studies of other regions or countries. This work may also help conduct specific technological-based techno-economic assessment or find out the best available alternative ways to develop RES base hydrogen energy.

An efficiency score of 1.000 indicates that the origins of renewable energy source at the efficient frontier. In other terms, the concept of cost-benefit analysis is optimal efficiency score of 1.000 or above. For example, optimal efficiency score of wind renewable energy is 1.000, therefore no need to increase the input data and output data in system. While, biomass efficiency score in our paper is 0.975 that need to increases and decreases the inputs and outputs until achieved an efficiency score of 100.The efficiency scores acquired provided the basis for the overall ranking of RES for hydrogen production. Based on current findings that the wind energy is feasible renewable energy source for future hydrogen production in Pakistan.

6. Conclusion and Policy Implications

This study based on 4 criteria (1. market opportunity, 2. economic benefits, 3. environmental impacts, and 4. Social acceptance) choosing the optimum renewable energy sources RES for hydrogen production in Pakistan. In Start, used the Fuzzy-AHP MCDA approach to measure the weight of all criteria. Based on fuzzy-AHP approach results, we found financial benefit criterion obtain weight of 0.30 highest value. The financial benefit criterion got the maximum weight of 0.30. Whereas social acceptance criteria received the lowest weight of 0.21. The environmental impacts get weights of criteria 0.25, and the commercial potential obtain 0.24 weights. In fact, the wind energy and solar energy get criterion equals weights 0.070, under commercial potential criterion.

While the Biomass energy was given the 2nd highest criteria weight of 0.062, and geothermal energy get lowest weighted, which was 0.038. The final results identified that the wind energy has been as optimal and best renewable energy source for green hydrogen production, according to environmental impacts point views.

While, solar energy source was identified to have very low effects on the environment. The Wind energy and solar energy resources get weights of 0.068 and 0.065 respectively. Geothermal energy obtained 0.060, while Biomass with a weight of 0.058 was the least environmentally friendly energy source. Conversely, it was observed that biomass energy has more economic benefits than other RES. Biomass gained weight of 0,084 under the criteria of economic benefit. Solar and wind power each received the same weight of 0.081. Geothermal earned a 0.051 minimum weight. Biomass social acceptance is significantly higher than wind and geothermal but is slightly higher than solar energy. Biomass received 0.065 weight, while under social acceptance, solar energy produced 0.063 weight. Wind with a weight of 0.050 took third place, while geothermal came last, reaching a weight of 0.034.

Study second phase, we used the data envelopment analysis to measurement the relative efficiency of available each renewable energy analysis after that ranked them based on their calculated scores. In DEA model results showed that the Wind energy obtained highest efficiency score of 1.000, thus, that is achieved best optimal Rank 1 from another RES. It means wind is best renewable energy for Green hydrogen energy production in Pakistan. In next Biomass get the highest score of 0.975 and then Rank 2 in the ranking, as well as solar energy 3 in ranking, which is score 0. 756. Geothermal energy attained a 0.662 efficiency score, which implies that geothermal is the minimum efficient renewable energy source for hydrogen production in Pakistan.

5.1 Policy implication

Renewable hydrogen energy is a sustainable and secure future energy supply, in globalization. Various countries have hydrogen technology path goals to focus on. Pakistan can also exploit its plentiful renewable sources of energy to generate green hydrogen. Hydrogen technology will play an important role in Pakistan's current energy crisis and future energy security. The development of hydrogen from the most efficient renewable energy source is essential if the hydrogen economy is to be a success for Pakistan, with the wind being the most efficient source of renewable energy. Biomass may also be used for the disposal of hydrogen. However, geothermal energy has not yet evolved to be an appropriate alternative for the generation of hydrogen.

The outcome of this study may be helpful in selecting the best choices for politicians to choose for a future hydrogen economy. Nevertheless, this study's results apply only to Pakistan. It is because the experts provided their advice in Pakistani language. Again, the economic situation, resource capacity, and socio-political conditions vary greatly among countries. Nevertheless, the two-stage MCDM framework developed in this study that extend for such kinds of studies in other countries or regions. This work can also be used to conduct a techno-economic assessment of specific technologies or to identify the best alternative solutions centered on RES for the development of hydrogen.

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Consent for Publication:

N/A

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Figures

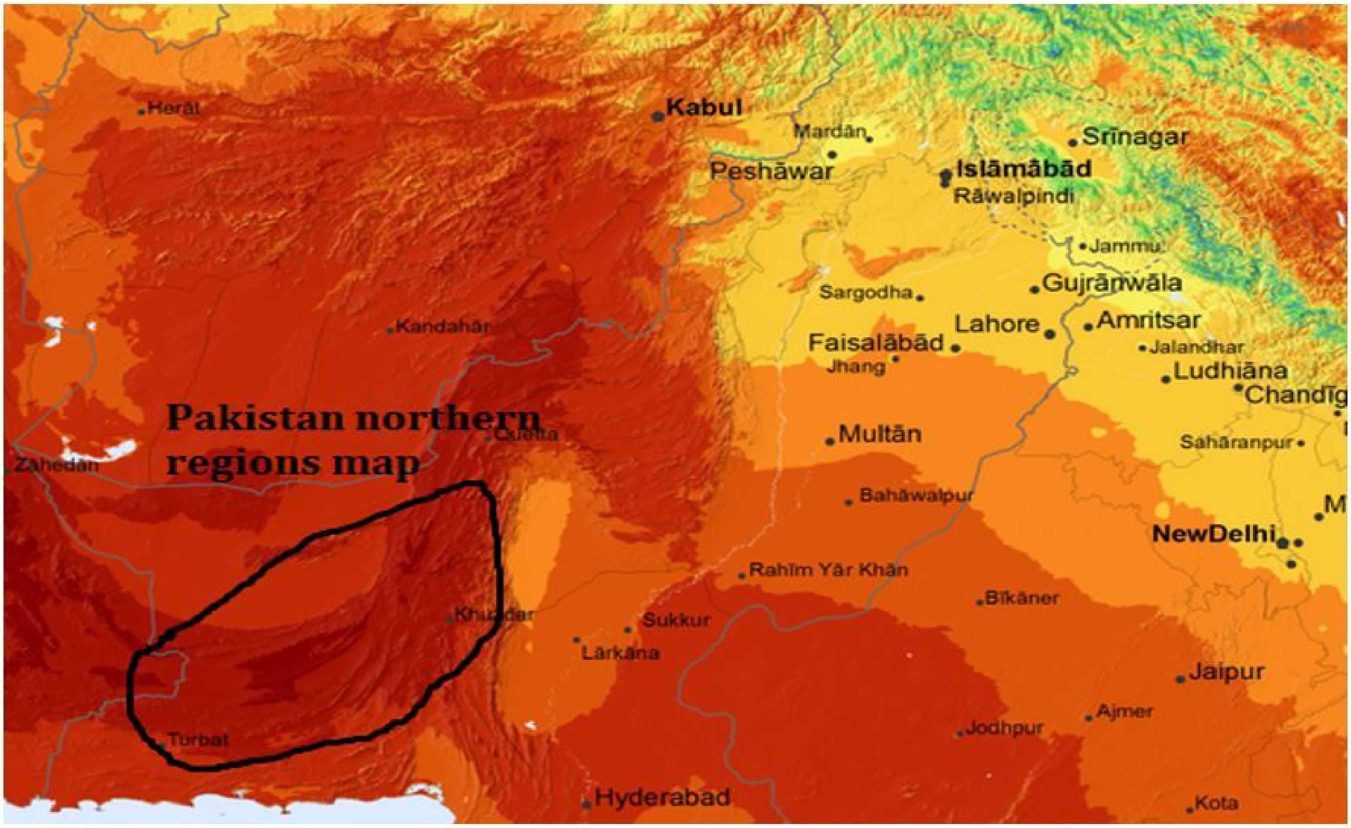

Figure 1

Global horizontal irradiance mapping of Pakistan Northern Region(Reno et al., 2012) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

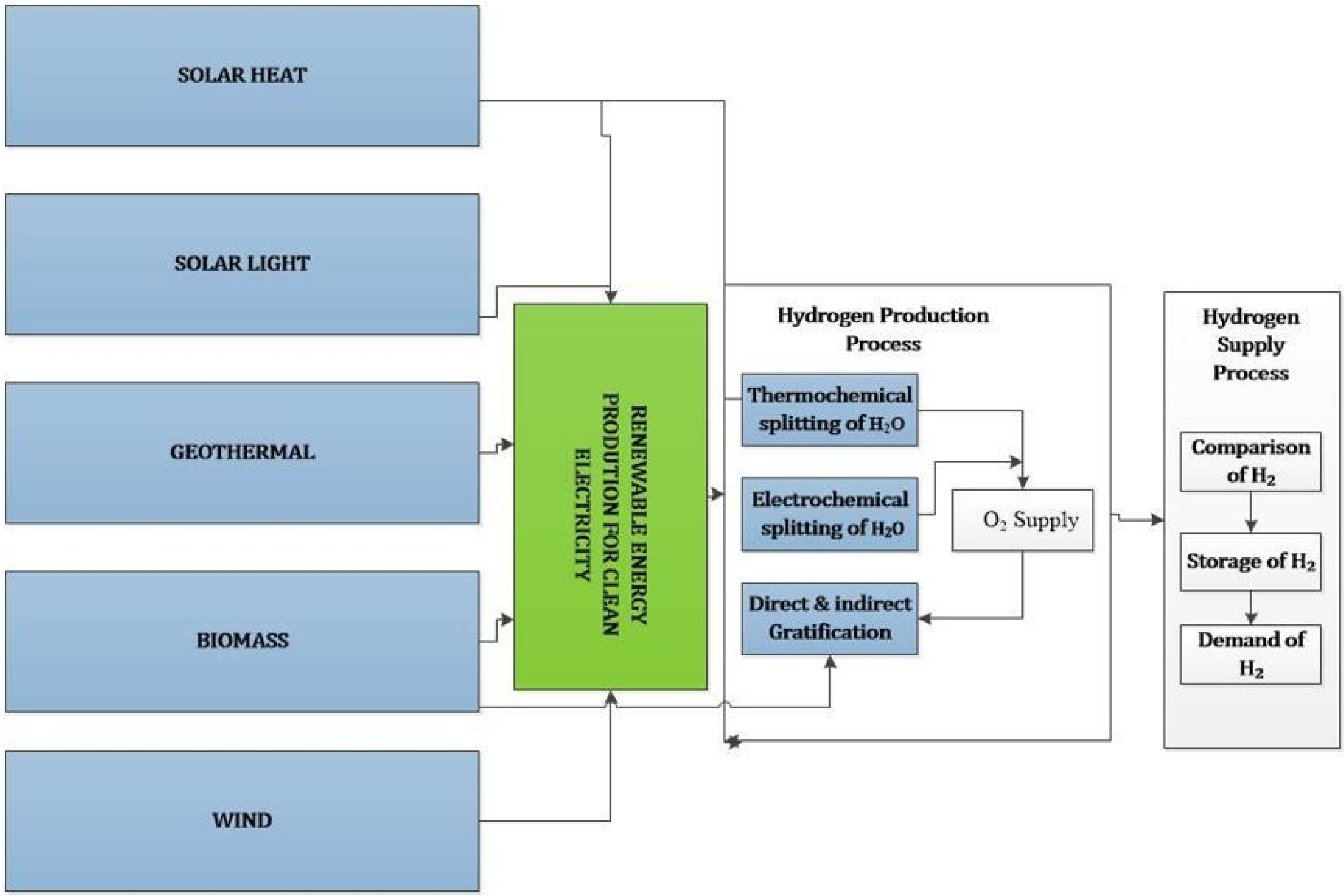

Figure 2

RES-based hydrogen production and supply

Figure 3

Pakistan wind resource assessment map(Simões and Estanqueiro, 2016) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

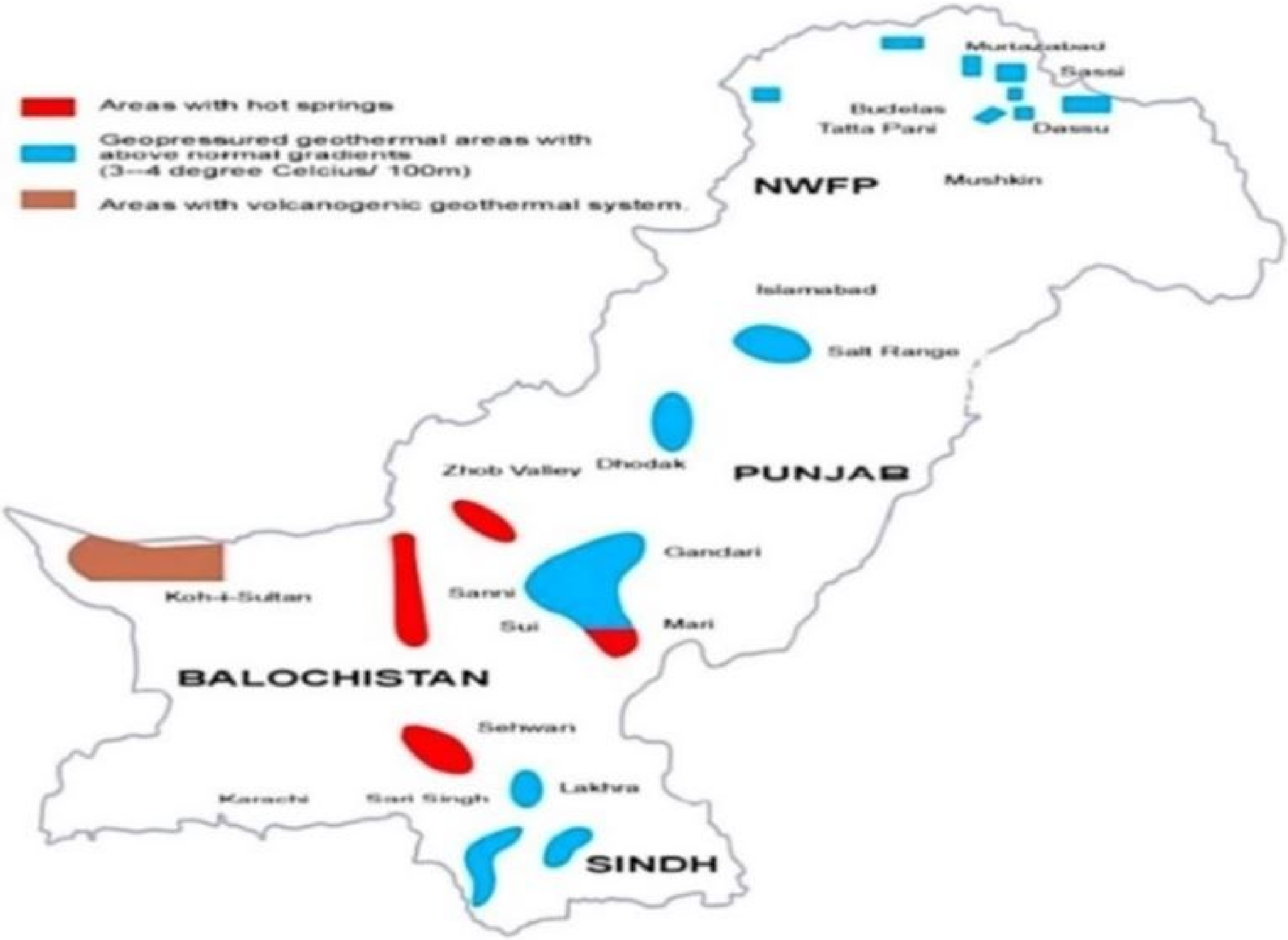

Figure 4

Map of hydro-geothermal resources in Pakistan(Yousefi et al., 2010) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

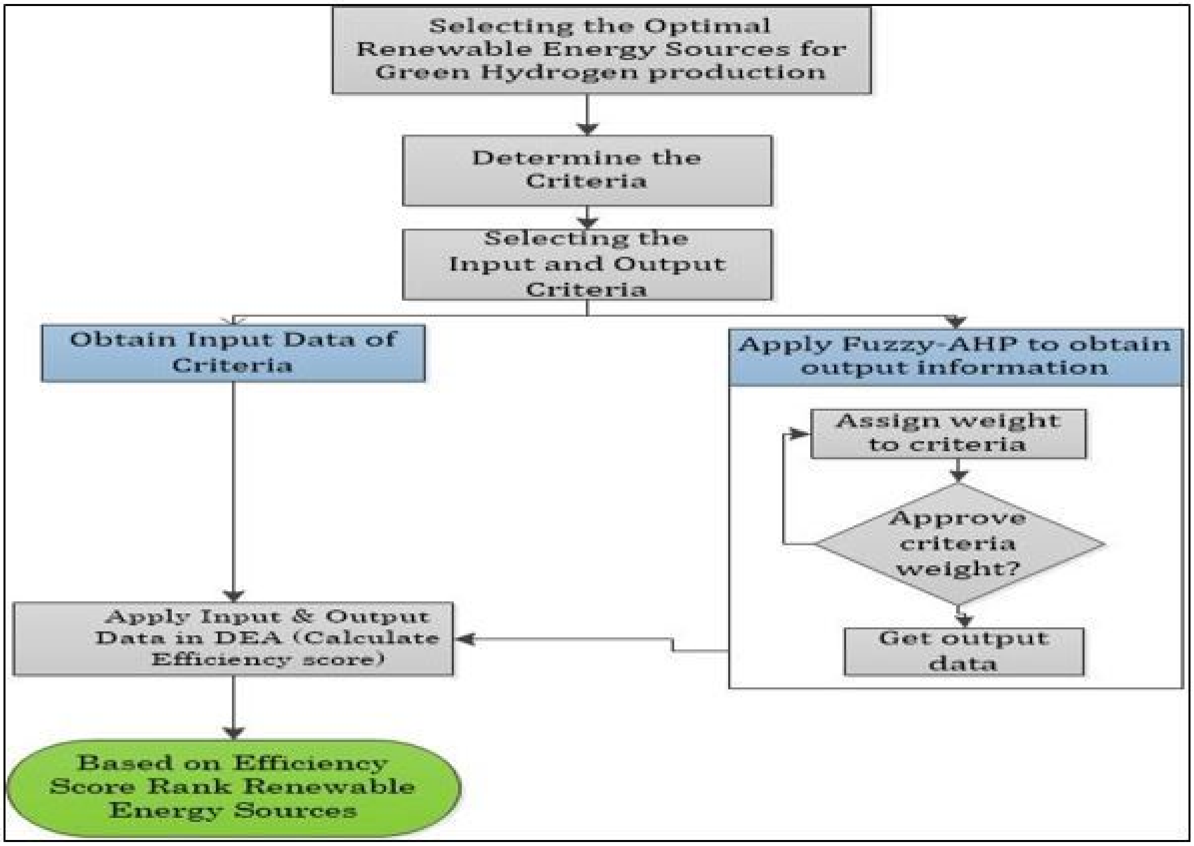

Figure 5

A Research Framework Diagram

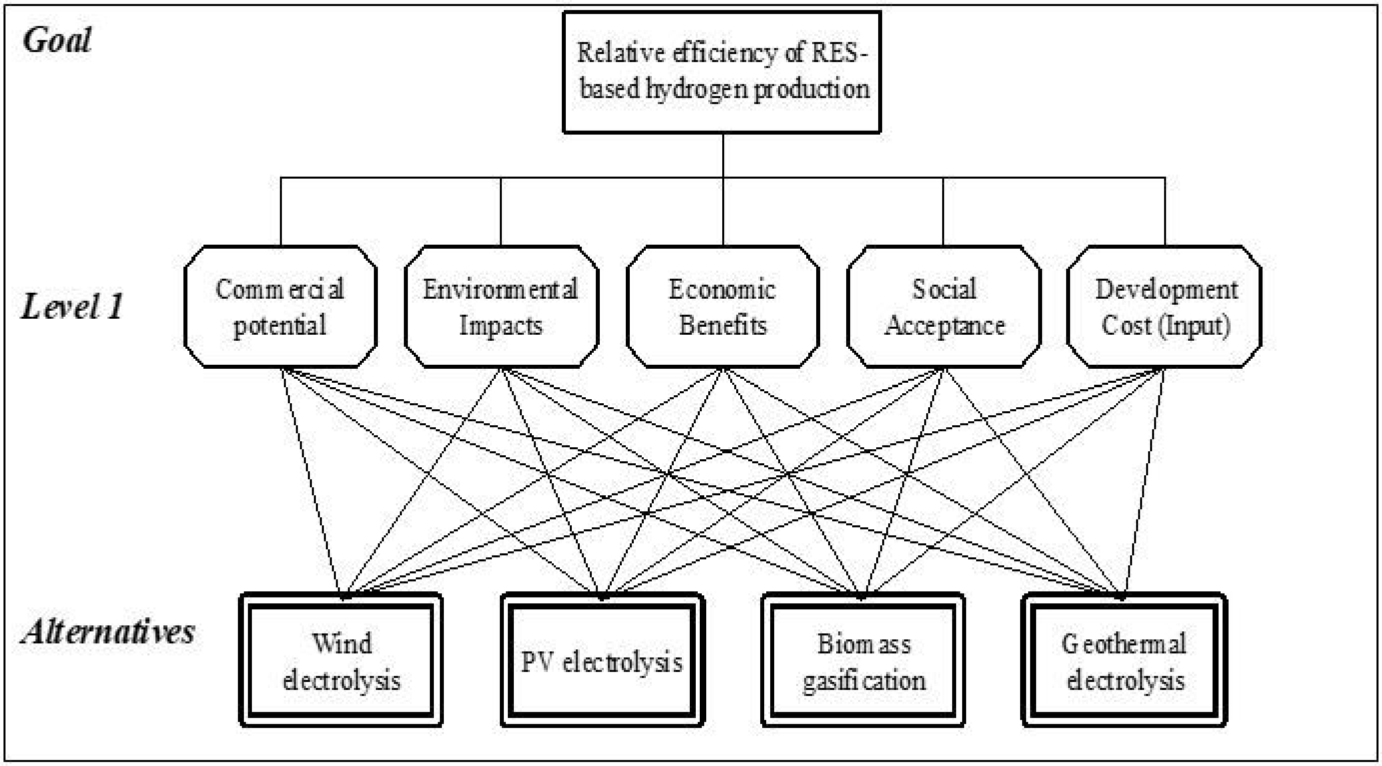

Figure 6

Output oriented CCR model