Hybrid Energy Based and CO_2 Sequestration Capable Desert Potential Development

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Abstract

The utilisation prospects of hybrid energy sources such as solar and coal and the processes of solar phototvoltaic generation, coal power generation, oxy-fuel combustion, air separation and CO_2 sequestration environment are analysed for the desert environment. A desert potential development model containing the processes of solar and coal power generation, air separation, oxy-fuel combustion and CO_2 sequestration is developed. The proposed model can be utilised in the deserts of Pakistan such as Thar, Thal, Cholistan and Chaghi Kharan. The positive impact of proposed model on current power generation capability is evaluated. The feasibility of the model is established by taking into account clean energy generation, environmental emissions reductions and sustainable development process.

Key Words: Solar energy, CO_2 sequestration, desert development

Introduction

Energy scarcity, environmental pollution and high fuel prices are all problems in terms of energy production in Pakistan. Due to high population rate, there is continuous increase in power demand. [2, 3] However, due to the gap in supply and demand, a substantial decrease in per capita electricity consumption (350 kWh) is observed.

[4] Pakistan has been facing acute challenges of energy deficit for quite a long time. The country's oil and gas reserves are also depleting at a rapid rate, resulting in an increase in the import of crude oil. [1] Pakistan's total primary energy supply during 2008–09 was 62.88 MTOE (million tonnes of oil equivalent). The nature of primary energy supply sources of Pakistan are highlighted in Fig.

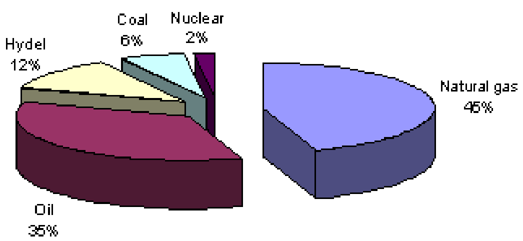

Fig.1: Primary energy supplies in Pakistan in 2009-10 [5]

The figure reveals a large share of oil and gas, followed by hydro and coal fuels. Due to dependence on oil and gas powered carbon economy, the country is facing serious threats of environmental pollution. [6, 7] However, the share of renewable energy sources is negligible. The sensitivity of the situation can be realised from fact that a large share of fossil fuels is used in the power generation industry, as highlighted in Fig. 2:

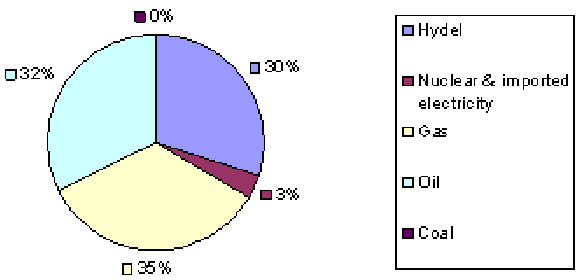

Fig.2: Power generation by energy source in 2008-09 [8]

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[9] Therefore, it is crucial to explore renewable energy generation processes to diminish dependence on imported oil and to increase the use of indigenous sources such as solar energy and coal in major sectors of the economy. Hybrid systems such as solar energy and natural gas are used globally to enhance existing energy capacities. [10, 17] Solar energy and natural gas technologies are proposed for DESERTEC project in MENA (North Africa and Middle East) region.

In light of the potential of solar energy and coal in Pakistan, hybrid-energy-powered and CO_2-sequestration-capable desert potential utilisation model is developedillustrated in Fig.3. The primary inputs of the proposed model are solar energy, air and coal. [23] An important aspect of this energy model is the self-contained nature of power generation processes in a sustainable manner. In this model, CO_2 produced by coal-fired oxy-fuel power generation can be sequestrated.

[8,7] The desert development model can be utilized for the supply of electricity to 25,000 villages/settlements besides deserts, where electricity supplies from a national grid and other sources is not possible or is uneconomical.[3] The proposed model project can be implemented in collaboration with Alternative Energy Development Board (AEDB), Pakistan Council of Renewable Energy Technologies (PCRET), which are actively engaged in the development of renewable and alternative energy development processes.

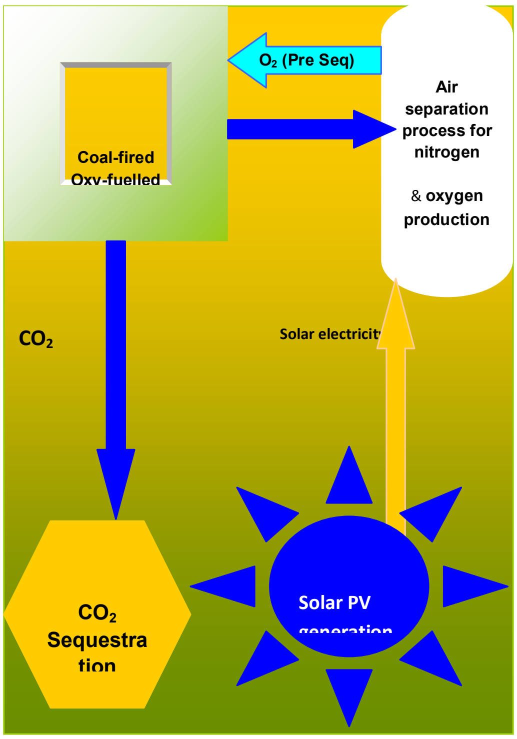

Fig.3: Illustration of the desert potential development model

Methodologies

There are four levels of processes in the desert potential development model. At the first level, power generation is accomplished by solar photovoltaic and coal-fired oxy-fuel combustion process. Coal-fired power plant could provide power supply round-the-clock.

At the second stage, pure oxygen is produced from atmospheric air by the utilisation of air separation process. In the third step, coal-fired power generation takes place. Oxy-fuel combustion process produces 75% less flue gases than air-fuelled combustion. The content of oxygen in the oxy-fuel combustion process is 95%; the resulting emissions are carbon dioxide and water. Carbon dioxide separated by oxy-fuel combustion process can then be sequestrated in the final stage.

Viability of Solar Potential

Pakistan is a solar-rich country, and is blessed with abundant solar radiation due to its ideal location in asunny belt. As such, the country can benefit from solar energy. [13] It has been estimated that over the total geographical area, that is, 796, 095 km2 the available solar energy potential is 5.23 PJ/m2/year. [4, 8, 12, 15] Pakistan receives an average solar radiation of 5–8 kWh/m2/day with an 85% persistence factor on more than 95% of its area. [9] The annual incident solar radiation in the country is in the range of 1900–2200 kWh/m2. [13, 15] The annual mean values of insolation are 19.0 MJ/m2/day over most parts of the country. [7] The mean values of insolation are from 12-13 MJ/m2/day in December/January to 25-26 MJ/m2/ day in June. [16].

[19, 4] Therefore, solar energy could be utilised feasibly for clean power generation process. [13, 23] Furthermore, it is well established that PV is a cost-effective technology as its maintenance costs are small compared with fossil fuel systems. Solar panel modules and electricity generation costs have also decreased with the passage of time. The single and polycrystalline silicon modules manufactured in Pakistan are sold at the prices of $2.90 and $3.25 and amorphous silicon modules at the prices of $2.00-3.00 per watt. [3] A comparative analysis of a 10 MW solar photovoltaic and fossil fuel power plants led to

the findings that though PV systems have high capital costs yet these plants have zero fuel costs, longer life and incur much less maintenance costs than fossil fuel plants of the same capacity.

[21] The Pakistan Council for Renewable Energy Technologies (PCRET) has developed solar cell production capacities to pilot scale, and their planned target for 2011-15 and 2016-2020 are 5 and 20 MW. [37] Akhtar Solar, a subsidiary of Silicon CPV plc, is also engaged in the assembling and manufacturing of solar panels since 2005, and has succeeded in the manufacturing of panels for domestic users. [24] Therefore, the potential utilisation, as stipulated in the model, in the deserts of Pakistan could be used to supplement the existing power generation sources. The electricity produced in these deserts could be transmitted to the nearest national grids to rebalance the gap between demand and supply in Pakistan.

Feasibility of Pulverised Coalfierd Power Generation

Pakistan is a coal-rich country as well. Coal is available in bulk at Thar, desert. Thar Desert coal reserves in Pakistan could be utilised for power generation for a very long time. [25, 36] The total electricity generation potential of the Thar coal is 5000 MW, which could last for 800 years, based on an estimated consumption of 536 million tonnes of coal. Oxy-fuel combustion process could be configured with coal-fired power plant for carbon separation and sequestration. However, the existing share of coal in power generation in Pakistan is very small, as shown in Fig. 4.

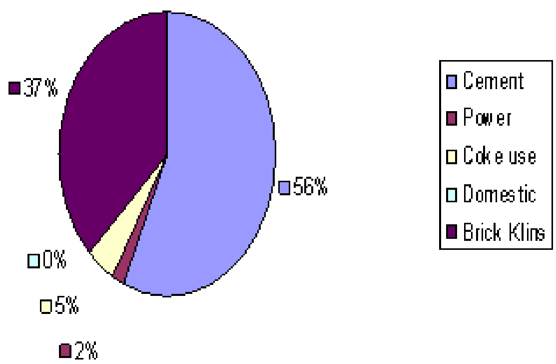

Fig.4:Share of coal fuel in major industries (2007-08) [8]

[36] It is important to note that coal is also an inexpensive fuel. Pakistan can produce electricity from coal at a low price. [38] In a study carried out by PB Power, it is found that electricity can be generated from coal–fired power plant at the cost of $250 to 320/MWh. Therefore, use of coal in power generation could bring down electricity generation costs. The amounts of electric power that could be generated from each tonne of the coal, based on 2 kWh electric power/kg coal, are estimated, in Fig. 5.

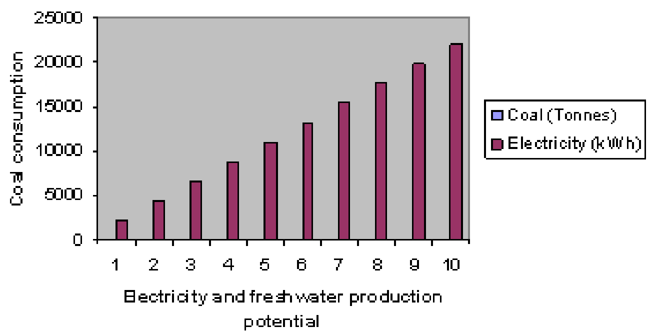

Fig.5: Estimated amounts of coal-fuelled electric power

Oxyfuel Combustion

Since, coal-fired power plants contain flue gases and CO_2 as a dilute gas, which makes the sequestration process difficult and costly, therefore oxy-fuel combustion process is integrated with coal-fired power generation in the proposed model. [35] In this process, the mass concentration of flue gases in oxy-fuel combustion process are increased to 48 (molecular weight of CO_2) in comparison to 28 (molecular weight of N_2) (28). [35] However, the amount of electricity generated by a power plant using anoxy-fuel combustion is less than conventional coal powered plants, because it drives oxidiser and compressor that result an average 9% reduction in plant efficiency.

Air Sepration Process

Oxygen can be attained from atmospheric air by hybrid membrane and cryogenic distillation system. [33] In this process O2/N_2 polymeric membrane, under induced pressure difference, could be utilised to separate oxygen from air, which is then processed in a cryogenic stage to get it further pure. Coal-fired power plant and air separation unit can be integrated to attain the objectives of power generation and carbon sequestration. [34] Both plants require pure oxygen mixed with recycled flue gases to maintain adiabatic flame temperature.

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The energy mass balance for air separation process can be estimated on the basis of the composition of oxygen in atmospheric air. In the air separation process, electricity consumption in oxidiser is a main cost item for generation of oxygen. Since for every one mole of carbon, two moles of oxygen are required to produce carbon dioxide (combustion equation), therefore for every one tonne of coal, two tonnes of oxygen would be required, which would produce two moles of carbon dioxide. [34] Therefore, for each tonne of oxygen production 448 kWh energy would be required.

Potential Desert Sites in Pakistan

Since large land spaces are required for the installation of solar panels for phototvoltaic power generation, therefore low opportunity cost deserts' land spaces are proposed as suitable sites.[28] Approximately, 70 million hectares of Pakistan have arid or semi-arid climate and out of 41 Mha of arid areas, 11 Mha falls under the category of main deserts. 15] The basic amenities, like electricity is scant in these deserts. These deserts are rich in high radiation solar energy and coal reserves. [10,11] The intense solar radiation received by the deserts of Pakistan, together with lignite coal reserves at Thar desert means that there is low opportunity cost for utilization.

A potential assessment of power generation and energy equivalent at the desert of Thar, Cholistan, Thal and Chaghi Kharan. The climatic data the cities near to these deserts is obtained, which is processed in RetScreen International software (RetScreen, 2011) to get the amount of electric power generation and the associated costs. The break up of the amounts of electric power to be exported, the energy equivalent and capital costs are provided in Table 1.

Table 1. Estimated (solar PV) power, energy equivalent and plant costs

Percentage solar (PV) utilisation	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	Total
Cholistan											
Solar (PV) electricity exported to the grid/ day (GWh)	193.5	387	580.5	774	967.5	1161	1355	1548	1742	1935	10642.5
Energy equivalent (P J)	0.69	1.39	2.08	2.78	3.48	4.17	4.87	5.57	6.27	6.96	38.26
Capital Cost in Million ($)	223	446	669	892	1115	1338	1561	1784	2007	2230	12265
Thar											
Solar (PV) electricity exported to the grid/ day (GWh)	162.7	325.7	488.7	651.7	814.7	977.7	1141	1304	1467	1630	8962
Energy equivalent (P J)	1.58	1.17	1.75	2.34	2.93	3.51	4.1	4.69	4.28	5.86	32.21
Capital Cost in Million ($)	188.7	377.4	566.1	754.8	943.5	1132	1321	1510	1698	1887	10378.5
Thal											
Solar (PV) electricity exported to the grid/ day (GWh)	170.1	340.3	510.5	680.7	850.9	1021	1191	1362	1532	1702	9360
Energy equivalent (P J)	0.61	1.22	1.83	2.45	3.06	3.67	4.28	4.9	5.51	6.12	33.65
Capital Cost in Million ($)	197.3	394.7	592	789.4	986.7	1184	1381	1579	1776	1973	10853.7
Chaghi Kharan											
Solar (PV) electricity exported to the grid/ day (GWh)	133.1	266.3	399.5	532.7	665.9	799.1	932.3	1066	1199	1332	7325
Energy equivalent (P J)	0.47	0.95	1.43	1.91	2.39	2.87	3.35	3.83	4.31	4.79	26.3
Capital Cost in Million ($)	154.4	308.9	463.3	617.8	772.2	926.6	1081	1236	1390	1544	8494.2

Carbon Sequestration

Carbon dioxide emissions released from the coal-fired power plant can be sequestrated by either deep ocean storage or underground geological sequestration. [31, 32] Since underground carbon sequestration is at early stage of development, therefore, it is less feasible than underground geological sequestration. [31] Moreover, good and limited geological sequestration storage potential exists in most of the areas of Pakistan, which is highlighted in a survey map of British Geological Society, 2007. In this method, carbon dioxide could be stored in deep underground layers such as natural gas and oil fields. [32] By this method, carbon dioxide could be stored securely similar to natural gas storage in geological formations. The problems of CO_2 leakages and salinity, can, however, be looked after properly. [32] Carbon separation and carbon dioxide sequestration process would also provide means to stabilise carbon dioxide concentration in the desert environment in the long run.

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Conclusion

The ongoing potential analysis of deserts reveals that the proposed methodologies can sustainably resolve the problems of electric power shortage, environmental emissions and high power costs in Pakistan. The proposed desert potential development model may change the fate of the power industry. The ongoing process can also promote commercialization,industrialisation activities in the deserts andthe creation of employment opportunities. It would bring ultimately deep social, environmental and economical changes.

Nevertheless, considerable challenges exist in the realization of this objective, such as resources immobilization, lack of initiatives, lack of awareness, and lack of institutional infrastructure, for which concerted efforts are required from concerned quarters, so that short, medium and long term projects can be launched in the deserts.

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Acronyms

AEDB: Alternative Energy Development Board
Fig: Figure
kWh: Kilo watt hours
MENA: Middle East North Africa
MJ; Mega Joules
MTOE: Million Tonnes of Oil Equivalent
MW: Mega watts (106)
PICRET: Pakistan Council of Renewable Energy Technologies
PV: Photovoltaic
PW: Peta watts (1012)
CO_2 :Carbon di Oxide
O_2 : Oxygen

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