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Business Model and Feasibility of Carbon Capture and Storage in Depleted Fields and Large Subsurface Geological Sites in Pakistan

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Abstract

Carbon Capture and Storage (CCS) is necessary to overcome the urgent challenge of climate change through capturing and storing carbon dioxide (CO2) emissions from various sources. Significant agreement is the Paris Agreement, adopted in 2016 by the United Nations Framework Convention on Climate Change (UNFCCC). It recognizes the importance of CCS as a potential climate change mitigation solution. Pakistan is also one of the signatory country that have signed Paris Agreement. Prioritizing of the coal-fired power generation policy in Pakistan, inert gasses production from oil and gas fields and emissions form various industries are the major concerns for the atmosphere. Number of different geological sites are assessed for storage of CO2 into a subsurface as fundamental national key policy of Pakistan to participate net-zero carbon mission of the world. Stored C02 on later stages can also be utilized in various industries to achieve financial outcomes.

1. Introduction

Green House Gases (GHG) emissions are the primary cause of rising earth temperature and global warming. Among which carbon dioxide is the most prominent biogenic gas that causes heat to trap in the atmosphere. The global anthropogenic CO2 emission reaching a new high of above 36.8Gt in the year 2022 according to the Report by International Energy Agency 2022 (CO2 Emissions in 2022). Conference of Parties (COP21) led to an unprecedented Paris Agreement, where nearly 200 countries signed a ground breaking contract on climate change, and for the first time, agreed to take action to restrict greenhouse gas emissions, and stop the release of heat trapping gases into the atmosphere by 2050. The remarkable achievement of the Paris Agreement, that comes in effect in 2020, is that all countries will be required to work on climate change. As per the agreement, the world will aim to even out global warming well below 2 degree Celsius above pre-industrial levels, and even less if possible or ideally 1.5 degree Celsius. As a party to the Paris Agreement, Pakistan has set its conditional target to reduce CO2 emissions by 50% of its projected emission by 2030, with 15% from the country's own resources and 35% subject to provision of international grant finance that would require USD 101 billion just for energy transition. To attain this target, Pakistan intends to shift to 60% renewable energy, and 30% electric vehicles by 2030 and completely ban imported coal (Updated Nationally Determined Contributions, 2021) . The main Green House Gases (GHG) emissions in Pakistan comes from the energy sector with 218.9 Mt of CO2 in 2018 as mentioned in Updated Nationally Determined Contributions report, especially fossil fuel based power plants, followed by transport and agricultural sector (Updated Nationally Determined Contributions, 2021) .

In Pakistan Energy Outlook Report (2021-2030) published by Ministry of Planning, Development and Special Initiatives, Pakistan (2022), it is decided to plan by 2030, more than 50% of electricity will be generated by hydro and non-hydro renewable based power plants and only 31% by the fossil fuels which ultimately leads towards clean energy. The Government of Pakistan (GoP) has intended to open, competitive private energy sector providing reliable, least-cost energy supplies to meet the expected growth in the energy demand. Integrated Energy Planning (IEP) is an effective and appropriate tool for realizing the government's vision of developing a sustainable, cost-efficient energy sector that best meets the country's strategic and socio-economic needs and rapidly growing demand for energy.

As a party to the Paris Agreement, Pakistan has set its conditional target to reduce CO2 emissions by 50% of its projected emission by 2030, with 15% from the country's own resources and 35% subject to provision of international financial grant that would require USD 101 billion just for energy transition. (Updated Nationally Determined Contributions, 2021). Due to increasing energy demands globally, fossil fuels are expected to continue their dominance in worldwide energy production. Thus, the reduction of CO2 released into the atmosphere from the emission point sources will help to reduce the effects of climate change.

2. Territorial Global Emission of CO2

Despite the fact that burning coal produces more CO2, both oil and gas emit climate-warming CO2. Statistics show that one of the main causes of global warming is coal. Moreover, coal is one of the least expensive energy sources. Compared to hydrocarbons, coal contains a larger proportion of carbon molecules and generates more CO2 after combustion. About 87% of global CO2 is being emitted by burning of the coal. Coal is an important source of energy in the United States, and the Nation's reliance on this fossil fuel for electricity generation is growing. The combustion of coal, however, adds a significant amount of carbon dioxide to the atmosphere per unit of heat energy. There are 106 thermal power plants in India with a total installed capacity of 221,802.59 MW. Of these 106 plants, 53 are coal fired, 24 are gas fired, 11 are oil fired, nine are mixed fuel fired and the remaining two use renewable sources – solar and biomass. Similarly, 33% of CO2 produced by Pakistan is the result of coal burning. Comparison of top 10 global CO2 emitting countries in 2021 are shown in Figure 1 and Pakistan ranks on 28th in number.
Cement production is another important source of CO2 after the after fossil fuel consumption. According to studies and different sources of internet, coal produced around 2.8 billion tonnes of CO2 in 2015, or 8% of the world total—more than any other nation save the US and China. Cement requires the process of the calcination - the process of thermal decomposition of calcium carbonate is known as calcination to produce portland cement clinkers (binder), a well-known industrial process. This process is used to remove CO2 from carbonate rocks; followed by simple chemical decomposition of CaCO3 in the presence of heat

(Nazeer et al., 2018). The process of calcification and further 40% emission of CO2come from burning fossil fuels to heat kilns to the high temperatures needed for this calcination process have produced about 50% of CO2. About 10% of CO2 emission is from the process of mining and transportation of coal to cement industry.

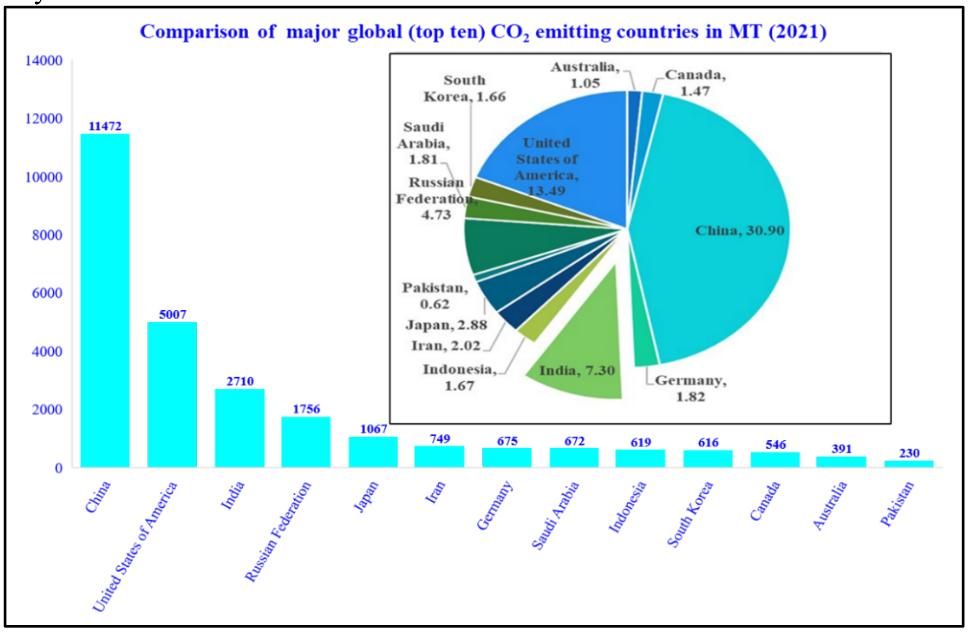

Figure 1 - Comaprison of Top 10 global CO_2 emitting countries in 2021. Pakistan ranks 28th in number **(Global Carbon Project)**

Pakistan is geographically located among the coal producing countries (China, India and Iran). Due to its geographical location, Pakistan is more affected by global warming. As shown in **Figure 2.** (%) of CO_2 in Global CO_2 (MT) emission in neighborhood major Co2 emitter countries are China, India and Iran. Demand of fossil fuels is still need throughout the world. Therefore, minimization of CO2 into the atmosphere from the emission will also be highly helpful to achieve net-zero carbon mission of the world. CCS is one approach that could play an instrumental role in reducing the CO2 emissions in to the atmosphere. This approach can also be applied in Pakistan in number of oil and gas depleted fields and this technique is proven throughout the world. A good seal rock is essential to prevent CO2 escaping to the surface through over burden rocks. **(Chenrai et al., 2022).**

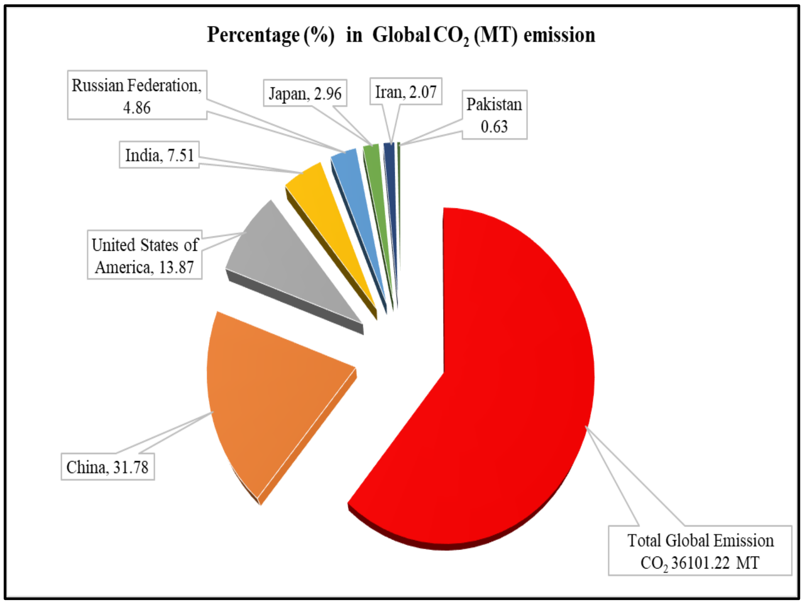

Figure 2 - Percentage (%) of CO_2 in Global CO_2 (MT) emission **(Global Carbon Project)**

3. Theory and/or Methods

This work will focus on the geological feasibility for the storage of CO2 with in different basins of Pakistan. As good reservoir rocks of cretaceous age having a very good porosity and having a very thick layer of sealing rocks are proven in different basins of Pakistan. Some gas fields nearby paleo-highs are emitting 10-65% of CO2 are likely to store CO2 in nearby depleted fields within 50-200 km range to save transportation cost. Last but not least, business model for CCS in Pakistan through integrated geological and geophysical data is presented.

Geological sequestration of CO2 is favorable technique used to store CO2 in depleted fields and this technique is proven in many cases worldwide (IPCC 2007; Kaldi et al. 2009; Metz 2005; Pashin and Dodge 2010).

4. Production of Inert Gases in Indus Basin, Pakistan (Geological Site for Co2 Storage)

The Figures 3a and 3b illustrate the generation of inert gases (CO2, H2S, and N2). The generation of CO2 (>10%) was displayed in **Table 1**. All inert gases and greenhouse gases that are produced might be buried locally or considered for a suitable geological site for CO2 storage. The Indus Basin has been moulded with magnificent mountain ranges, plateform, and foredeep. As a result, there are no issues with geological storage locations in Pakistan.

The diverse tectonic episodes throughout the geological time developed different structural and stratigraphic traps in different basins of Pakistan. The fractured limestones, sandstone reservoir are distributed through Pakistan in Cambrian, Createceous , Eocene, Paleocene , Miocene and considered as potential porous rock to store CO_2 and other inert gasses **(Soulsby, Raza et al., 1989, Ali et al, 1995; Iqbal et al, 2008; Afzal et al, 2009).**

Table:1 *Shows the oil and gas fields emitting CO2 greater than 10%*

S. No	Operated Fields	%age of CO2
1	Field A (Massive Sand)	13.62
2	Field B	21.66
3	Field C	11.50
4	Field D	27.96
5	Field E	10.65
6	Field F	13.68
7	Field G	11.35
8	Field H	10.27
9	Field I	11.05
10	Field J	**62.10**
11	Field K	14.65
12	Field L	10.50
13	Field M	10.74
14	Field N	22.30
15	Field O	**41.32**
16	Field P	**45.01**
17	Field Q	**37.74**

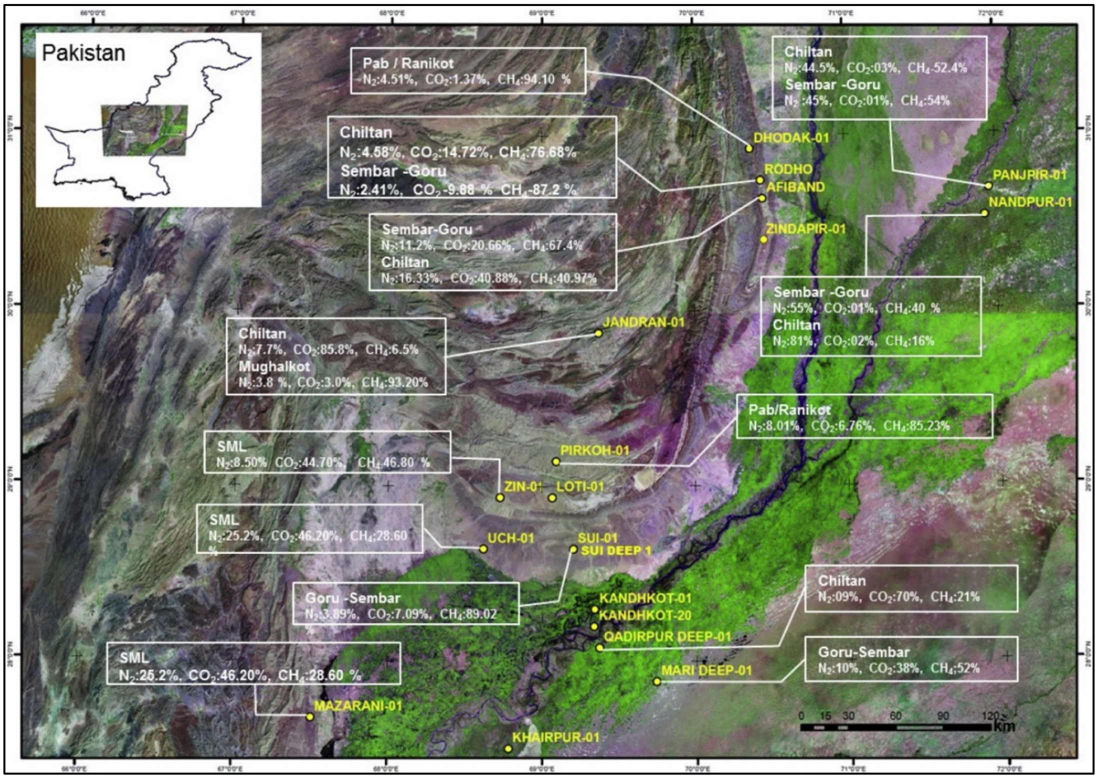

Figure 3a- CO2 and other gas production in the Indus Basin (Nazeer et al., 2018)

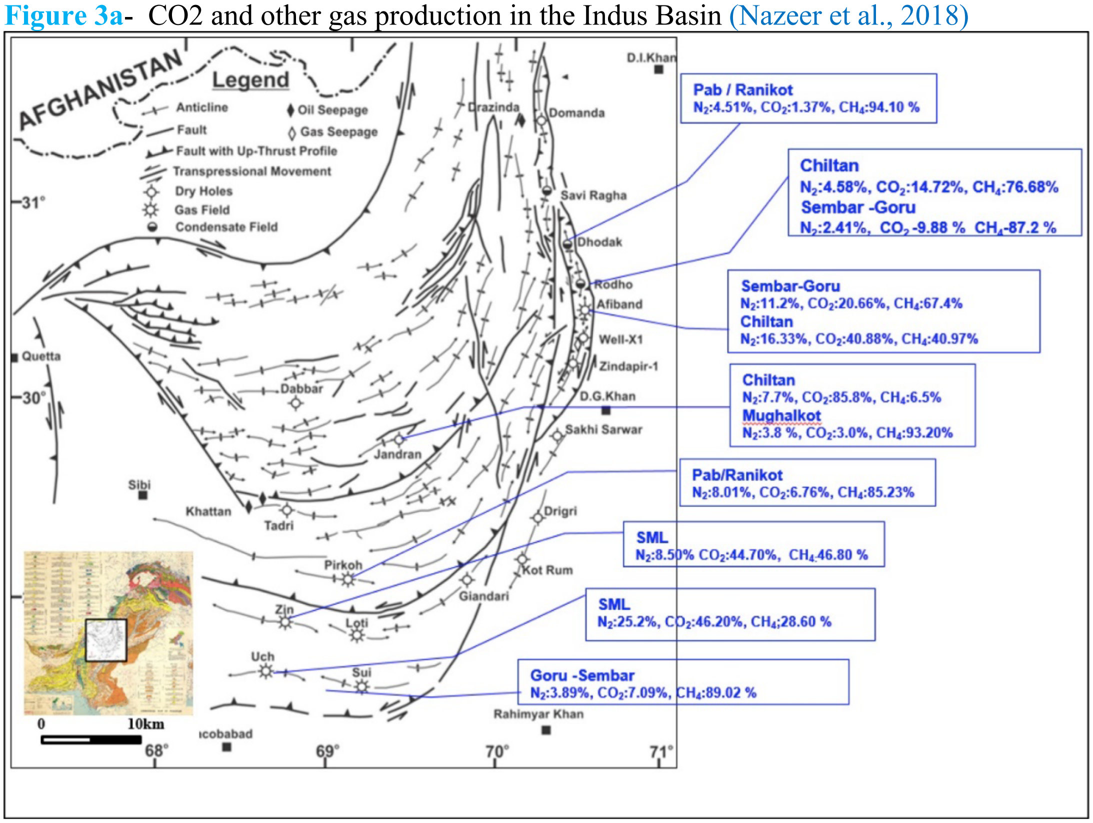

Figure 3b - Variations in gas composition along major faults in the Sulaiman Foldbelt. (Nazeer et al., 2018)

5. Zindapir Anticlinorium, Middle Indus Basin

The Zindapr Anticlinorium is bounded in the east by Sulaiman depression and in the west by Barthi Syncline). The anticlinorium covers an area of approximately 6000 sq.km with Eocene formations exposed in the core of Dhadak, Rodho and Afiband structures whereas Zindapir Anticline has Paleocene rocks in its core. The carbonates of Chiltan Formations (Jurassic), sandstones of Lower Goru (Early Cretaceous) and Pab Formations of Late Cretaceous, Ranikot Sands and Dunghun Limestone of Paleocene age are proven reservoirs in the Zindapir Anticlinorium. Average distribution of inerts gases in study area is given in **Figures 3a and 3b**.

5.1 Geological Model -1

Multiple reservoir are present in the Zindapir Anticlinorium. Hydrocarbon flows from Chiltan (Jurassic), Lower Goru Sands (Late to Early Cretaceous), Pab sandstone (late Cretaceous) and Ranikot sands (Paleocene). Gas condensates flows with inert gases (carbon dioxide and nitrogen) with varying percentage. Inert gases emitting from Dhodhak, Rodho and Afiband fields from different wells may inject to other formations which are not producing hydrocarbons and may be evaluated further to dispose of green house gases. Figure 11 is showing the geological model.

5.2 Geological Model -1

The Zindapir Anticline may be considered as a viable option for the carbon storage and sequestration of inert gases; which are produced from Afiband, Rodho and Dhodak in the North. The inert gases are supposed to captured at the location of their relevant fields and transported to Zindapir through pipeline. Triassic formations may be considered as a viable option for the storage of inert gases with subject to detailed geological and geophysical assessment. Geologiacal Model 2 is illustrated in the **Figure 4 and 5**.

Pakistan has many subsurface storage containers with many suitable CO2 storage sites. Moreover, depleted fields in upper and lower Indus basin can also be utilized for underground geological containers to hold and store CO2. CO2 can be stored in basalts rock where mineralization of injected CO2 can take place at faster rate. Basalt rocks are present in Punjab platform where the depth is varied between 1000 to to 1500 m. One of the most important storage site for CO2 sequestration is deep saline aquifer where dissolution of CO2 into the brine phase occurs slowly but steadily (as a function of temperature and salinity) and is found to be in the range of 13-17% after 17 years of injection for the Sleipner case (Philip Ringrose et al. 2018). When CO2 is added to siliciclastic rocks, such as sandstones, as soon as the formation water is saturated with CO2, the injected CO2 will simply remain as a separate phase. Over centuries or longer, feldspar group minerals may react with CO2 that has dissolved into the reservoir brine to form carbonates and clays. Other depleted fields like Sari Hundi in Southern Indus Basin, Baho Gas field in Central Indus Basin and Dakhni Oil field in Upper Indus Basin. These fields may act as best storage sites for CO2. Main content of the CO2 is stored and preserved in the Geologic formation whereas, the rest of CO2 can be used in Enhance Oil Recovery (EOR), Enhance Coal Bed Methane Recovery (ECBM), cement and fertilizer industry, production of urea and for many other industries in Pakistan.

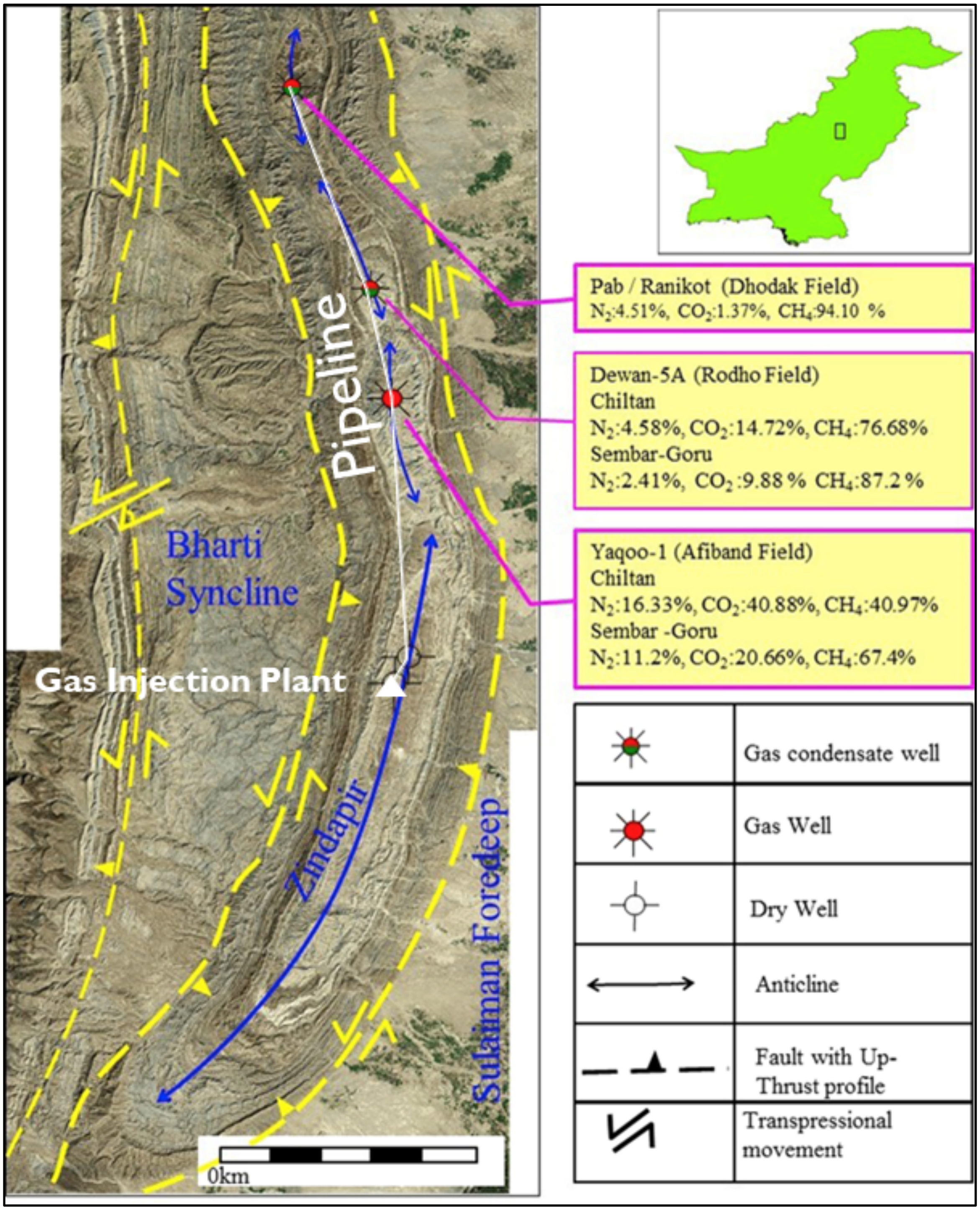

Figure 4 - Proposed injection plant at Zindapir Anticline as viable option inert gases produced from Afiband, Rodho and Dhodak from south to north. **(Nazeer Ph.D. Thesis , 2019)**

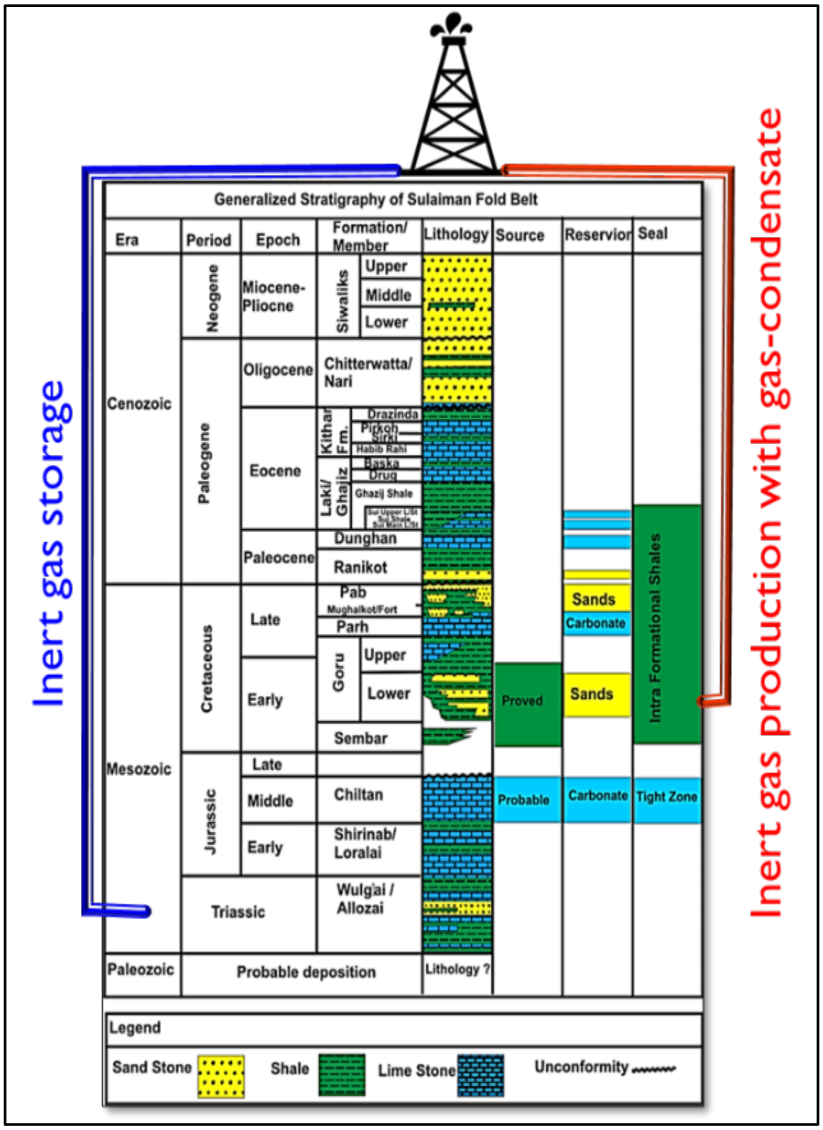

Figure 5 Inert Gasses collected at gas field and injected to another reservoir. Multiple reservoirs are present in the study area. Traissic reservoir may be evauated for the inert gasses storage. (Nazeer Ph.D Thesis , 2019, Nazeer, et al., 2018)

6. Discussion (Key Points)

Different geological sites were assessed for placement of CO2 into a subsurface formation as fundamental national key policy of Pakistan to mitigate the GHG (Green House Gas). Government must adopt firm policies to take private stakeholders in confidence that policies will not change frequently and that CCS is essential to reduce carbon emissions. A proposed business plan is given at the end in order to make CCS a new profitable sector as it needs significant investment to develop infrastructure while taking into account different technologies. Stored carbon can be utilized to boost up number of industries like refrigerants, fire suppressions, chemicals, plastics, building materials, mineralization, food products and enhance fuel recovery (EOR, ECBM). **Figure 5** for the wide array of potential carbon utilization options is illustrated in Figure 2 by The National Energy Technology Laboratory, U.S.A. that elaborates utility and usage of storage of Carbon in different economic sectors in Pakistan. Pakistan is also one of the signatory country in the list of countries that have signed Paris Agreement on net zero carbon, apart from being part of net-zero carbon large economic benefits can also be achieved through storage of carbon. Some of the key points are as under:

a) CO2 is naturally occurring gas in the subsurface of the erath.
b) Stratigraphic and structural traps or a combination of such traps can be used for the process of the physically trapping during carbon sequentration .
c) Traditional structural traps have anticline folds or sealed fault blocks.
d) Porous, fractured rerservior rocks are best candidates for carbon storage.
e) Potential geological sites include coal seams with depleted hydrocarbon pools, coal seams and organic shales, depleted reservoirs, dry wells and abandoned wells.
f) The formation water in a geological reservoir have different densities from CO2, when CO2 gas is injected, it puts pressure on the water phase, or salt water, causing the free CO2 to rise. Presence of cap rock and structurally controlled trapping prevents CO2 to leaks.
g) CO2 -EOR is recommended technique for the depleting oil fields.
h) The CO2 storage by structural mechanism is primarily based on the sealing potential of the caprock, posing a significant challenge to select the appropriate location (Song and Zhang, 2013).

Adapted from National Energy Technology Laboratory (www.doe.netl.gov)

Figure 5: Utility and usage of storage of Carbon in different economic sectors

7. Conclusions

Following conclusions can be drawn as:

I. Climate change data clearly shows the importance of carbon capture and storage in today's need to act collectively to mitigate the effects of global warming.Coal is major source of CO2 emision.

II. Every one has to play its roles to mitigate green house effect.

III. China, India and Iran jointly shares 40% of Total Global Terrotrial emission of CO2 in the world.

IV. Pakistan is geographically located among the coal producing countries (China, India and Iran).

V. Due to its geographical location, Pakistan is more affected by global warming.

VI. Depleted oil and gas field and abandoned well can be used Carbon Sequestration.

VII. Stored Co2 can also be utilized in different industries on later stages.

8. Recommendations

a. Pakistan has to align fossil fuel production and consumption with the Paris goals and guarantees choices to develop appropriate technology for the benefit of everyone.

b. Authors strongly recommend Government of Pakistan, Sindh Coal Authority, National and International Donor Agencies and E&P companies to carry out Pilot project to exploit CBM resources in Lower Indus Basin, Sindh. CBM is safer than burning of coal.Proper legislation is required to trained and educate the public about the global warming and it impact over the globe.

c. Pakistan has to strongly develop the strategy with coordination of its neighbouring countries (China , India and Iran) to mitigate green house gasses as joint effort

d. Automobile industry should be encouraged to tranfer of technology to align the nation according to Paris Agreement.

e. Training of geoscientist , engineer and other professionals should be encouged at national level to develop carbon capture and storage technology.

f. Real time monitoring CO2 and Green House gasses should be monitored at surface facilities at real time according to the international standards.

g. Flaring of gases in the oil and gas field could be bypassed with appropriate technology.

h. Appropriate training is required by E & P companies to implement Paris Agreement (2015) and Talona Dialogue (2018) to mitigate green house effect as joint effort.

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