Mitigating climate change by CO_2 air capture and geological storage: opportunities for Iran

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Abstract

This paper investigates the preliminary strategies and tools for the implementation of CO_2 air capture and geological storage as a potential mitigation option in the future climate policy of Iran. It is a method to capture CO_2 directly from air and store it in geological structures based on large-scale industrial processes to enable the near-permanent sequestration of carbon. The reason for selecting this approach originates from its capability to mitigate CO_2 from all economic sectors with a single technology, while the conventional capture methods are designed only for mitigation of CO_2 from point sources of the power generation and industrial sectors. In order to facilitate the workflow of air capture as efficiently as possible, this study suggests some tools and directions for the selection of potential sectors and the prospective areas for the final site selection of the air capture units.
Keywords: CO_2 mitigation, carbon capture and storage, air capture, Iran.

1 Introduction

As a party to the UNFCCC since 1996 and as a signatory to the Kyoto Protocol since 2005, Iran is committed to fulfill its obligations for reducing Greenhouse-Gases (GHGs) emissions into the atmosphere. Iran is defined as a developing country under the Convention and is not included in Annex I. However among developing countries, Iran's CO_2 emission is considerable and placed the country in the 7th place of the world in 2009 [1]. This amount of emissions is increasing every year with a rather high rate corresponding to 4.7% each year (during 1994 and 2007) due to the increasing energy demands and low energy efficiency [2]. Iran's per-capita CO_2 emission is 6.3 tons per year, which is more than the global average (4.48 tons in 2006) and its growth rate is higher than population growth

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[3]. Mitigation scenarios suggest atmospheric CO_2 stabilization with the use of emerging emission reduction technologies, coupled with significant increases in energy efficiency and renewable energy utilization.

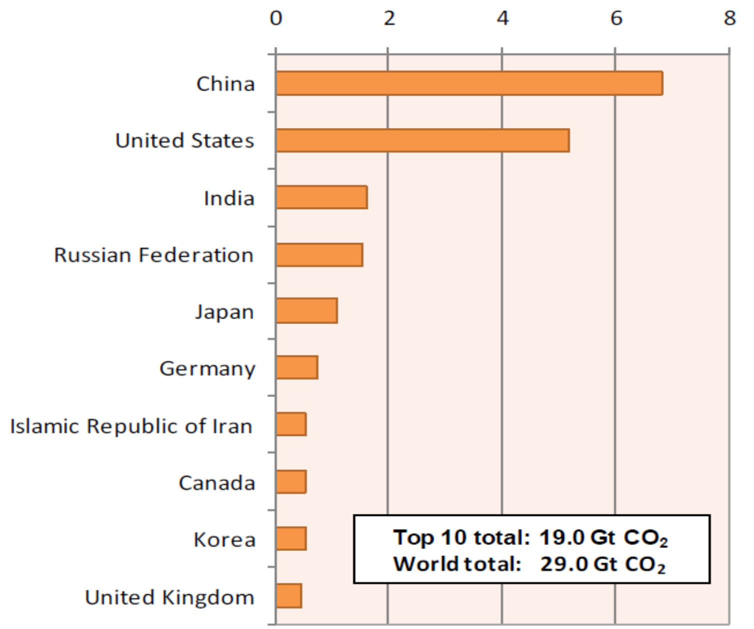

Figure 1: Top 10 CO_2 emitting countries in 2009 [1].

The IPCC Third Assessment Report (TAR) indicates that no single technology option will provide all of the emission reductions needed to achieve stabilization, but a portfolio of mitigation measures will be needed. Recently Carbon Capture and Storage (CCS) technology has been investigated intensively as a potentially valuable option for reducing CO_2 emissions in many countries [4]. According to the International Energy Agency (IEA), CCS is an important part of the lowest-cost greenhouse-gas mitigation portfolio and without it, overall costs to halve emissions by 2050 rise by 70% [5]. CCS covers a broad range of technologies to allow CO_2 emissions to be captured from large point sources and transported to safe geological storage, rather than being emitted to the atmosphere [5]. However CO_2 can also be captured from ambient air, after its emission to the atmosphere, offsetting emissions from distributed sources, or reducing atmospheric concentrations when emissions have already been constrained [6]. This paper is a review of the potentials, approaches and tools which can facilitate the mitigation of CO_2 emission based on emerging air capture technologies.

1.1 What is "CO2 air capture"?

It is physically possible to capture CO_2 directly from air and store it in geological structures [7]. Similar to carbon sequestration in ecosystems, air capture removes CO_2 from the atmosphere, but it is based on large-scale industrial processes to enable the near-permanent sequestration of carbon [8]. Even though the IPCC 2005 report on CCS and its 2007 Fourth Assessment Report mentioned air capture only in passing, the possibility of air capture in response to the build-up of anthropogenic carbon dioxide in the atmosphere receives increasing attention every year [9]. The process uses a chemical sorbent that selectively removes CO_2 from the ambient air and releases it as a concentrated stream for disposal, while the sorbent is regenerated and the CO_2-depleted air is returned to the atmosphere [10]. Although there are no large-scale technologies that achieve air capture at reasonable cost at the moment, some studies suggest that it will be comparatively easy to develop such technologies on the timescales relevant to climate policy [8]. According to Keith [11] there are two factors which make air capture more difficult than exhaust streams: first, the lower concentration of CO_2 in the air which results in higher thermodynamic barriers; and second, the cost of energy and materials for moving large quantities of air through the absorbents. Therefore the techno-economic feasibility of air capture is hotly disputed in the past years. Some studies have concluded that direct air capture has prohibitively high mitigation cost and identified it a poor and risky policy option for mitigating climate change (e.g. [12]). In a recent technical assessment carried out by the American Physical Society (APS), it is stated that based on an analyzed "benchmark system", air capture will cost at least US$ 600 per ton CO_2 avoided and would therefore "play a very limited role in a coherent CO_2 mitigation strategy for many decades" [10]. In contrast, and in response to APS study, [13] noted that the cost estimates of new technologies have often been wrong because these technologies present moving targets and the costs can significantly drop as technology develops. The "benchmark system" used in the APS report is also criticized for being based on concepts that developed in the first days of air capture research, more than 5 years ago; while novel and highly efficient technologies were developed during the last few years [14]. On the other hand, Keith [11] argued that the cost of air capture will not be determined by the current small-scale studies and suggested the "pilot-scale process development" as the only way to make the costs evident. Other studies suggested that air capture could be a useful technology which has implications for climate policy and deserves to be among the policy options in international debates [6, 9, 15].

1.2 Objectives and structure of the paper

It is believed that air capture of CO_2 even in pessimistic view and at high calculated costs, could be considered as a mitigation option to be deployed slowly [10]. The first steps however should be taken by defining priorities for the selecting of CO_2 emitting sectors and consequently the prospective capture locations. In order to accomplish the capture and sequestration workflow as efficiently as possible, regardless of the technology used for the air extraction of

CO_2, strategies could be developed for minimizing the capital and marginal costs associated with the process. In this regard, the following approaches are taken in this study:
1) Selecting the target sectors with higher priority considering their CO_2 emission and economic output.
2) Developing criteria for identifying prospective areas for air capture in order to increase the feasibility and efficiency of the process.

2 Why capture CO_2 from the atmosphere?

Conventional capture technologies are designed for capturing CO_2 from stationary large point sources such as power plants and manufacturing units. However, CO_2 is not emitted only from these sources and the emissions from other source types (e.g. residential and transportation), particularly in developing countries, are considerable [16]. One of the important advantages of air capture, as suggested by [6] and Lackner [17], is its potential capability to mitigate CO_2 from all economic sectors. Figure 2 shows sectoral CO_2 emissions of Iran in 2009, illustrating the significant share of emissions from the transportation and residential sectors.

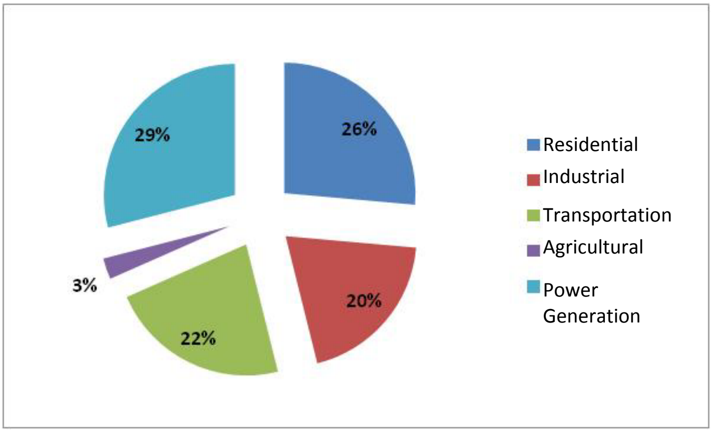

Figure 2: Sectoral CO_2 emission of Iran in 2009.

Compared to point source capture, air capture has the advantages of capturing emissions from diffuse sources such as automobiles, airplanes, agriculture, and home heating [6]. In order to include that portion of CO_2 which is emitted from distributed and small sources, direct capture from air is necessary [18]. Moreover, this method may allow for the capture of emissions from all economic sectors with a single technology: “it removes emissions from any part of the economy with equal ease or difficulty, so its cost provides an absolute cap on the cost of mitigation” [7]. Therefore by applying air capture, any emitted CO_2 can be compensated and it is not necessary to develop different capture process for different kinds of emitters [17]. This may result in stronger economies of scale and smaller adjustment costs due to its independence from existing energy infrastructure [7]. On the other hand a considerable amount of anthropogenic carbon dioxide have already emitted to the atmosphere and direct capture of CO_2 has the potential to be one of the few methods for the systematically management of already dispersed emissions [19].

3 Potential sectors for air capture

Despite the fact that CO_2 can be captured from air regardless of the emitting source or sector, identifying the sectors with higher emission intensity is essential for a cost-effective capture by giving priority to the prospective areas associated to high emitting sectors. It is clear that each sector is assigned to some geographical coordinates and exploring the nationwide geographical distribution of sectors is the first step for a successful air capture project. The selection of sectors should be carried out by considering their economic outputs because in Iran, with a growing economy, economic growth is strongly associated with CO_2 emission levels [2]. In order to assess the economic sectors, we classified them in 5 main groups consisting of residential & services, industrial, transportation, agriculture, and power generation. The economic data, corresponding to each sector, is retrieved from Central Bank of Iran (CBI) database. The residential and services sector includes all residential buildings, trade, hotels, restaurants, storage and communications, financial intermediary activities, real estate and professional services, public services as well as social, personal and domestic services. Industrial sector includes all industrial activities from manufacturing, mining and petroleum to the construction and water production. Due to the important role of transportation in Iran's CO_2 emission, it is excluded from residential and services to be investigated in a separate group. The agricultural sector includes agriculture and its related activities and services: crops, livestock and poultry farming as well as fishery and forestry. And power generation sector includes electricity production from fossil and renewable energy sources. As a preliminary assessment, the Pearson product-moment correlation coefficient (PMCC) between CO_2 emissions and economic output (contribution to GDP) related to each sector during 1994 and 2007 is calculated. The PMCC for residential and services, transportation and power generation are 0.99, 0.98, and 0.99, respectively, indicating strong correlations for these sectors. The PMCC for industrial sector also shows positive value (0.89) but not as strong as the above sectors (Figure 3). Correlation coefficient for the agricultural sector is negative and fairly week (−0.46). Therefore agricultural areas can be neglected in the site selection for CO_2 air capture.

The final assessment is carried out based on the emission intensity of the sectors which is the quantity of emissions in relation to the economic output of the sectors. The national CO_2 emission intensity measures the quantity of CO_2 emission in relation to the economic output of a country and is independent of the absolute quantity of CO_2 emitted. The emission intensity of sectors are

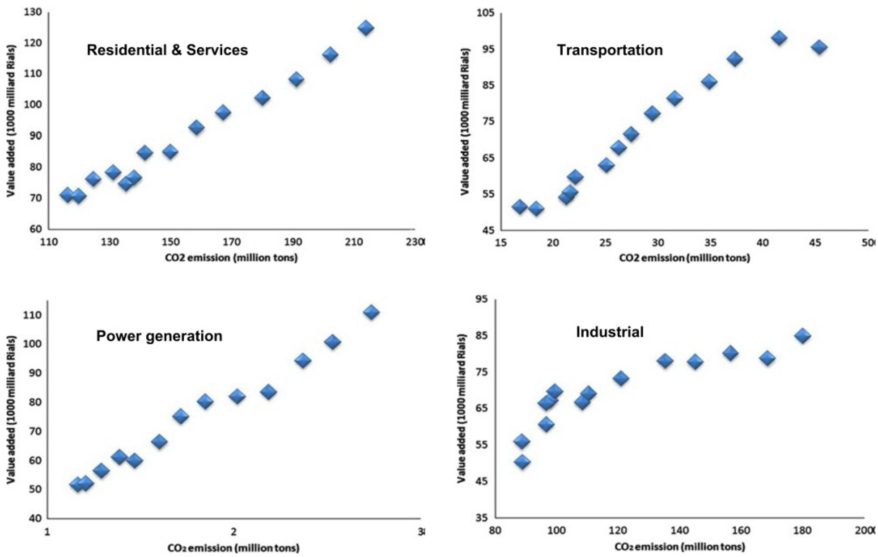

Figure 3: Correlation between CO_2 emission and economic output of sectors in Iran [2].

studied by considering the following equation which simply shows the relation between the CO_2 emission intensity (Ie), energy usage (W) and economic output (GDP):

$$I_e = \frac{\sum_s^n C_s \times W_s}{GDP} \tag{1}$$

where the index s refers to energy sectors, considering that there are n energy sectors [2].

From an emission intensity point of view, energy sectors are divided into 3 groups: high-intensive, mean-intensive and low-intensive. Power generation is the highest intensive sector and is the only one which could be placed in the first category. Since the intensity in this sector is considerably higher than in the other sectors, we illustrated it in a different graph (Figure 6). The transportation sector is categorized as a mean-intensive sector and the other sectors are placed in the low-intensive group (Figure 4).

4 Selecting prospective capture areas

Prospective areas can be defined in regards to various capture scenarios and plans. However some general criteria for selection of potential regions can be considered. It is clear that the selected areas are only meeting the general criteria and more detailed surveys should be carried out for the site selections of capture projects. Particularly the suggested prospective areas should be considered as the

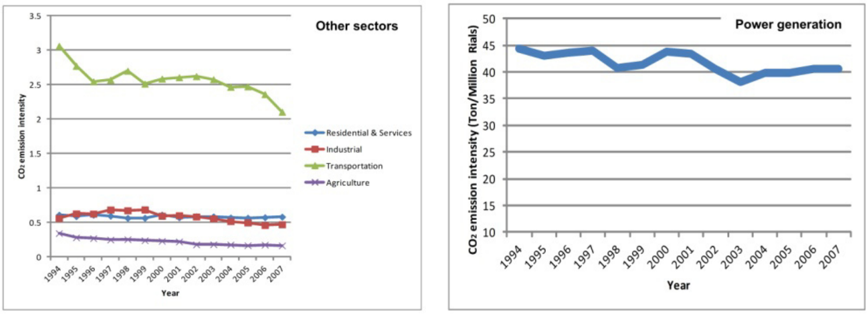

Figure 4: CO_2 emission intensity of sectors in Iran [2].

candidates for undergoing CO_2 atmospheric dispersion and concentration modeling, which will be explained in more detail with a case study in the next section. Two main criteria which should be considered in the preliminary selection of prospective areas are as follows.

4.1 Association with high emitting sectors

Economic sectors are associated with, or at least are more concentrated in, specific spatial locations. Having spatial associations to the sectors with higher capture priority is among the criteria for selecting prospective capture regions. In this regard, the higher priority should be given to the power generation and transportation sectors because of the strong correlation coefficient between CO_2 emission and economic output as well as the higher emission intensity in these sectors. The residential and services sectors should also be selected among candidate sectors for two reasons. First, like the above sectors it showed strong emission-economy correlation coefficient and second, even though it is categorized among low-intensive sectors, it shares major spatial locations with the transportation sector and in the selection of prospective areas we can consider major cities as important CO_2 emission source related to both residential and services, and transportation sectors. This originates from the fact that a growing share of CO_2 emissions is associated with road transport in and around cities [20]. Figure 5 shows the contribution of road transportation in the total CO_2 emission from transportation sector of Iran.

4.2 Distance to potential storage sinks

Regardless of the capturing technology, transportation of CO_2 from capture sites to the storage sites is one of the important components of any CCS project. Although the high capture costs and the security concerns related to long-term geological storage are among the most important issues, identifying and structuring transportation alternatives is also critical for CCS implementation [21]. The cost of CO_2 transportation rises proportionally with distance between the capture sites and possible storages [22]. It is possible to minimize transportation costs by giving priority to the prospective capture spots which are

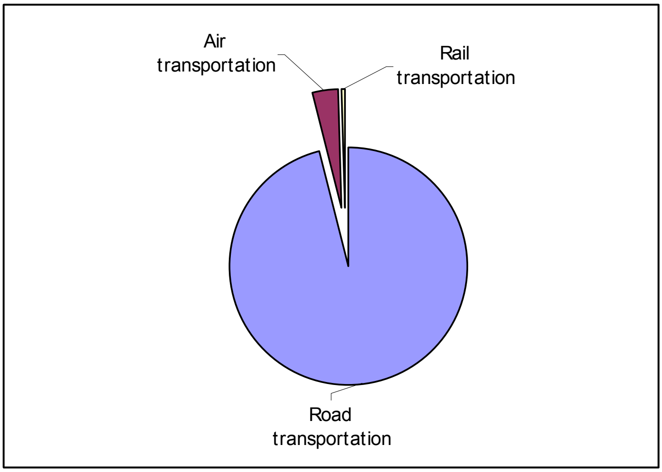

Figure 5: The share of Iran's CO_2 emission by transportation type during 1997 and 2006.

as close as possible to the potential storage sites. In considering the possible storage sites, there is a growing interest in Iranian oil industry to utilize CO_2 for co-optimization of Enhanced Oil Recovery (EOR) and sequestration. Enhanced oil recovery using carbon dioxide (CO_2-EOR) is a method that can increase oil production beyond what are typically achievable using conventional recovery methods while facilitating the storage of CO_2 in the oil reservoir [23]. This method even seems a favorable option, but has limitations for large scale CO_2 mitigation from all economic sectors as is intended for CO_2 air capture. Beside its limited capacity, there are other constraints associated with this method; the Iranian oil fields are mostly cracked carbonated type and are not suitable for gas injection, and on the other hand the majority of emission sources are widespread in the country and very distant from major oil fields [24]. Another possibility is injecting CO_2 in deep saline formations that are believed to have the largest capacity and are much more widespread than other options [25]. Zagros sedimentary basin in the south and southwest of Iran, Kopet-dagh sedimentary basin in the northeast, the Central Iranian basin and Southern Caspian basin are the potential sinks for geological storage in the future [24, 26].

5 Conclusion

This study does not deal with the chemical process of CO_2 air extraction. Instead, we focus on strategies that could be employed to make assessments and develop approaches and tools to facilitate the workflow of air capture as efficiently as possible. Since air capture is an emerging technology and there are uncertainties about its possible role on near-future mitigation actions, further studies are needed to bridge the gap between the development of chemical processes in laboratories and the planning for the feasible large-scale capture and storage practices. While CO_2 air capture has some encouraging potential advantages for climate change mitigation, its implementation should be done along with other mitigation options including large-scale utilization of renewable energy, increasing energy efficiency and developing green energy technologies. Moreover, conventional capture methods could simultaneously be considered for a portion of large emitters. No matter the scale of CO_2 capture that technology will enable, the efforts for shifting to low carbon energy systems should be continued.

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