engineering proceedings

Proceedings paper

Evaluation of potential carbon dioxide utilization pathways in Uzbekistan †

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† Presented at the 4th International Electronic Conference on Applied Sciences, 27 Oct–10 Nov 2023

Abstract: Reaching net-zero emissions by the mid of this century requires the implementation of massive carbon dioxide (CO_2) emissions reduction strategies along with other greenhouse gases at both global and country scale. Thus, carbon capture, storage, and utilization (CCSU) is one of the promising technologies in combination with renewable energy transition. Currently, CO_2 utilization has been extensively attracted by scientific community worldwide, since it can improve the economic viability of CCSU deployment via creating a market for the recovered CO_2 stream. In this study, a brief assessment and comparison of potential CO_2 utilization pathways in Uzbekistan including CO_2 to chemicals/fuel conversion, CO_2 bio-fixation/mineralization, and direct use of CO_2 such as for enhanced hydrocarbon recovery (EHR) have been conducted considering the CO_2 stationary sources and site-specific conditions of the country. Apart from that, possible challenges and opportunities for large scale CO_2 utilization routes have also been discussed. According to the assessment, there is a great potential for CO_2 direct use as a process boosting agent for EHR in more than 22 major natural gas, crude oil, and coal reservoirs. Moreover, methanol and urea production processes can also make a huge market demand for recovered CO_2 as long as the conventional CO_2 production processes are replaced by sustainable one's.

Keywords: decarbonization, climate change, carbon capture, CO_2 utilization, CO_2 recovery, Uzbekistan.

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

The rising concentration of carbon dioxide (CO_2) in the atmosphere has emerged as a paramount concern for the global community. In order to mitigate the effects of greenhouse gas (GHG) emissions and align with the goals of the Paris Agreement, we should explore all available pathways to approach as close as net-zero emissions by 2050. In this context, Carbon Dioxide Capture and Utilization (CCU) emerges as a promising strategy through not only by reducing the emissions but also transforming CO_2 into valuable resources or reusing it for other applications [1].

The Republic of Uzbekistan (Uzbekistan), located in the Central Asia being one of the two double landlocked country in the world, has been experiencing significant demographic and economic growth in the recent years. In response to those increases, there is a high demand in expanding the industrial sectors in Uzbekistan which is driven by primarily the country's natural resources such as natural gas, coal and crude oil. Meanwhile, Uzbekistan plans to cut its GHG emissions per unit of gross domestic product by 35% by 2030 as a base year of 2010 [2]. Apart from that, Uzbekistan pledged to reach carbon neutrality by 2050 through the different means of decarbonization pathways [3]. In this scenario, there is a strong necessity for the estimation and analysis of CO_2 capture potential of Uzbekistan from large stationary sources and possible CO_2 utilization pathways considering the country's site-specific conditions.

Carbon Capture, Storage, and Utilization (CCSU) is a technology that enables to capture the CO_2 from fossil fuel fired large point sources such as power plants, cement factories, steel and iron industries, crude oil and natural gas refineries, and petrochemical plants. Once the CO_2 is captured by different separation techniques, it is then compressed in high pressure and transported to the storage or utilization site [4]. There are two – direct and indirect – methods for the utilization of captured CO_2. In direct utilization, the captured CO_2 is used as its physical form without undergoing chemical transformation. This can be applied in several industries including enhanced hydrocarbon recovery (EHR), food and carbonated beverages, textiles and greenhouse agriculture. In the indirect use, the captured CO_2 undergoes the chemical or biological processes converting it into multiple valuable products. This can involve broader pathways such as CO_2 to chemicals and chemical feedstock (methanol, urea, organic acids, ethylene and propylene glycol, and etc.), CO_2 to synthetic fuels (methane, dimethyl ether, kerosene, diesel, gasoline, and etc.), CO_2 mineralization (construction aggregates, cement, magmatic rock, and etc.), CO_2 to bio-products (biofuels, bioplastics, bio-additives, and etc.), and carbonation of industrial waste [5].

In recent years, due to the low market value of captured CO_2 which prevents globally application of CCSU, more research and investigations are being focused on CO_2 utilization and its valorization. This paper briefly discusses the potential CO_2 utilization pathways in Uzbekistan and their comparison based on several environmental, economic and technological indications.

2. Shortlisting procedure

Given the diverse array of over a hundred CO_2 conversion pathways and numerous CO_2 direct utilization routes available, our approach involves a shortlisted more technologically mature and commercially viable options which will undergo a comprehensive analysis, taking into consideration the specific environmental and resource conditions in Uzbekistan. The shortlisted four pathways including CO_2 to methanol and urea conversion, CO_2 to Enhanced Oil/Gas Recovery, CO_2 use in cement production, and CO_2 to bio-fixation are discussed with their opportunities and challenges with regard to the economic, environmental, and scalability point of view. This assessment is limited to evaluate CO_2 to fuel conversion due to its least carbon retention time among others.

3. Potential CO_2 utilization pathways

As mentioned earlier, the captured CO_2 presents valuable opportunities for utilization within Uzbekistan's industries through two distinct pathways: direct and indirect applications. Direct utilization, which involves the non-conversion of captured CO_2, finds prominent use primarily in enhancing hydrocarbon recovery. This is especially relevant due to the presence of several natural gas and oil reservoirs in the region, as well as its application in the textile fabrication industries.

On the other hand, indirect utilization, which entails the conversion of captured CO_2, plays a vital role in sectors such as chemicals and nonmetallic industries, with a particular focus on applications within the cement industry. The subsequent sub-sections will provide detailed insights into these specific indirect utilization pathways and their significance.

3.1. CO_2 to methanol and urea

All among the CO_2 conversion routes, CO_2 to methanol and urea production are, so far, not only the most mature technologies but also the highest demand in world market with annual consumption of over 110 Mt per year [6].

Methanol is a crucial chemical feedstock for various industries including chemicals and fuels. The main methanol-derived products are formaldehyde, acetic acid, dimethyl ether, and methanol fuel. Methanol to Olefin (MTO) is, as an emerging technology, another promising pathway that enables to obtain various high-value products such as polypropylene, polyethylene, ethylene vinyl acetate, and polyethylene terephthalate. However, from the environmental point of view, the production of hydrogen, the main reactant for CO_2 to make methanol, should be sustainable by water electrolysis or fossil fuel based production with CCSU. The following equation (1) is the base reaction of CO_2 to methanol conversion [7].

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O,\ \Delta H_{298\ K} = -49.4\ kJ/mol \quad (1)$$

Uzbekistan is considered as a leading country in Central Asia by methanol production and its export accounting for 67% of demand [8]. Apart from that, Uzbekistan's Gas Chemical Complex has signed the agreement with Air Products to build a MTO facility by the end of 2025 which will be constructed in the Karakul Free Economic Zone in Uzbekistan's Bukhara region. The total capacity of this facility can reach up to 1.34 million tons annually [9].

Urea production from CO_2 can also be viable option in the case of Uzbekistan as the country's economy is highly dependent on the agriculture. Urea is commonly used in the fertilizer industry due to the least transportation cost and rich nitrogen sources. Moreover, it can be used as a primary source for the production of several essential chemical compounds including a variety of polymers and resins. Since the urea is obtained from the reaction between ammonia and CO_2 (See the reactions (2) and (3) below), the CO_2 uptake potential of urea production is relatively high at 0.733 ton of CO_2 per ton of Urea [7].

$$2NH_3 + CO_2 \leftrightarrow NH_2OCONH_4, \quad (2)$$

$$NH_2OCONH_4 \leftrightarrow NH_2CONH_2 + H_2O. \quad (3)$$

Uzbekistan has already built the facility to produce urea and ammonia under the Navoiyazot Chemical Complex with annual capacity of 660 thousand tons of ammonia and 577 thousand tons of urea [10]. Furthermore, a new ammonia-based fertilizer plant with a total capacity of 1089 Mt of urea and ammonia is under construction in Yangiyer, Sirdaryo Region and expected to be completed by 2025 [11]. Among several conversion methods, one important advantage of urea production using captured CO_2 is the utilization of post-combustion flue gas to obtain CO_2 and nitrogen, the primary components required for ammonia production. As a result, the generation of urea from ammonia reactions with CO_2 taken from combustion exhaust gases would boost the financial viability of a CO_2 capture unit [7]. However, the only concern about boosting the urea production using captured CO_2 is its environmental benefit which is under question due to the release of CO_2 into the atmosphere as the fertilizer is used.

3.2. CO_2 to EHR

Since current low carbon costs fail to motivate investment in CCS, several industry experts believe that EHR projects are the only viable short-term use for significant CO_2 levels. CO_2 injection for enhanced oil recovery (EOR) and Enhanced Gas Recovery (EGR) is growing in the petroleum and natural gas industry as it both utilizes captured CO_2 and boosts oil/gas production, preventing its release into the atmosphere [12]. It is vital in the transition to a more sustainable and low-carbon energy future, particularly in terms of efficiently utilizing existing oil and gas resources while addressing climate change concerns.

For a preliminary assessment, CO_2 storage to deep underground and oil, coal, and gas reservoirs are the first place where there is sufficient capability for a massive amount of captured CO_2 to be permanently storage and utilization. All major natural gas, coal, and crude oil fields of Uzbekistan are summarized in Figure 1.

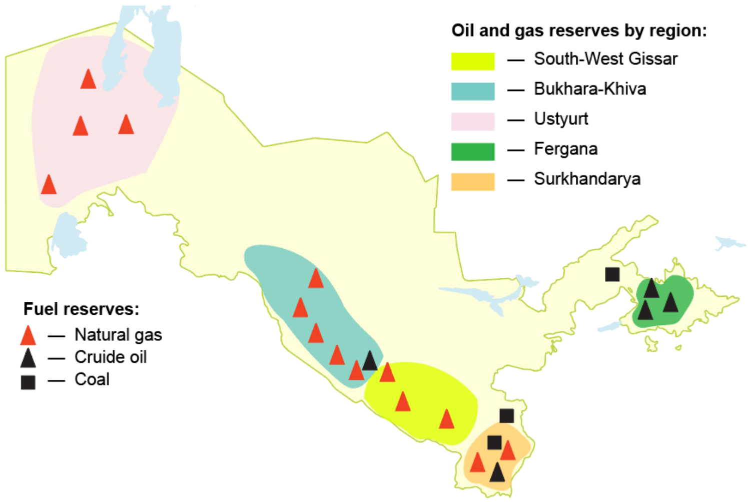

Figure 1. Main large oil and gas reserves in Uzbekistan by region.

According to the Figure 1, Uzbekistan has a great potential for the utilization of captured CO_2 through the EOR, EGR, enhanced coal bed methane (ECBM) pathways. The availability of reservoirs in the neighboring countries also enables the possibility for offshore storage of captured CO_2 avoiding the long distance transportation cost. Since the EOR is considered as the only option so far as fully mature technology to store massive amount of CO_2 allowing a part of investment back, onshore and offshore EOR injection of CO_2 can be the first target in the utilization of CO_2 in Uzbekistan.

3.3. CO_2 mineralization

Carbon mineralization, also known as CO_2 mineralization is a process that includes the transformation of CO_2 from gaseous state to solid by converting it to the mineral forms using chemical and geological materials. In the carbonization process, CO_2 reacts with certain minerals such as magnesium and calcium silicates resulting the formation of stable magnesium carbonates and calcium carbonates [13]. It can then be used as building materials as construction aggregates, concrete curing, and cement production. One of the greatest advantage of this method is to sequester the CO_2 permanently for thousands of millions of years.

In the case of Uzbekistan, with the growing number of population and urbanization, there is a huge demand for the construction materials and aggregates [14]. Calcium and magnesium carbonates, which can be found naturally in rocks and inorganic salts mostly in the regions of Karakalpakstan, Fergana Valley, Tashkent suburbs and Navoi, are the traditional precursors used in the manufacturing of cement. It is worth nothing that captured CO_2, once it has been transformed into calcium or magnesium carbonates, can operate as an alternate input material or precursor for this manufacturing process. However, limited availability of suitable mineral resources, lack of geological assessments, and slow reaction kinetics hinder the application of CO_2 mineralization in the near term.

3.4. CO_2 to bio-fixation

One of the feasible strategies for combatting CO_2 emissions from point sources is the biological pathway. The biological method provides natural CO_2 incorporation into biomass at a relatively low cost in terms of energy. Photoautotrophy and chemolithotrophy are natural mechanisms that have resulted in the consumption of CO_2 biologically. Algae-based CO_2 utilization, among others, can be a promising route that uses photosynthesis to capture CO_2 from flue gas for carbon fixation, particularly in the availability of waste water recources [15]. Microalgae can be cultivated in a closed system (photobioreactor) and an open system (raceway ponds). In terms of algae applications, they are divided mainly into two categories [16]:

- "Bioenergy": Biodiesel, biogas, bioethanol, biojetfuel, etc.
- "Non-energy bio-products": protein, pigments, carbohydrates, biomaterials, animal feed, etc.

Considering the large CO_2 emitting sources in Uzbekistan, particularly natural gas-fired combined cycle power plants, which accounts for more than 85% of the energy sector and low CO_2 concentration in its waste stream, CO_2 microalgae cultivation can be promising pathway as this technology can capture and utilize the CO_2 simultaneously [17]. While the significant space demands of this approach are manageable, certain locations in the country may face challenges related to the availability of water or wastewater [18]. In such cases, there might be a requirement for the installation of closed-loop photobioreactors, which tend to be more costly.

4. Discussion

In this section, we compare five different CO_2 utilization methods in terms of their environmental benefits, scalability, maturity, and economic feasibility for the context of Uzbekistan, without specific metrics. Taking into account the various aspects and criteria for each unique situation and technology presents challenges in achieving a precise comparison. Therefore, the discussion aims to offer a broader understanding of the feasibility of each approach. Figure 2 represents the comparison of CO_2 utilization pathways in Uzbekistan's condition based on four different parameters.

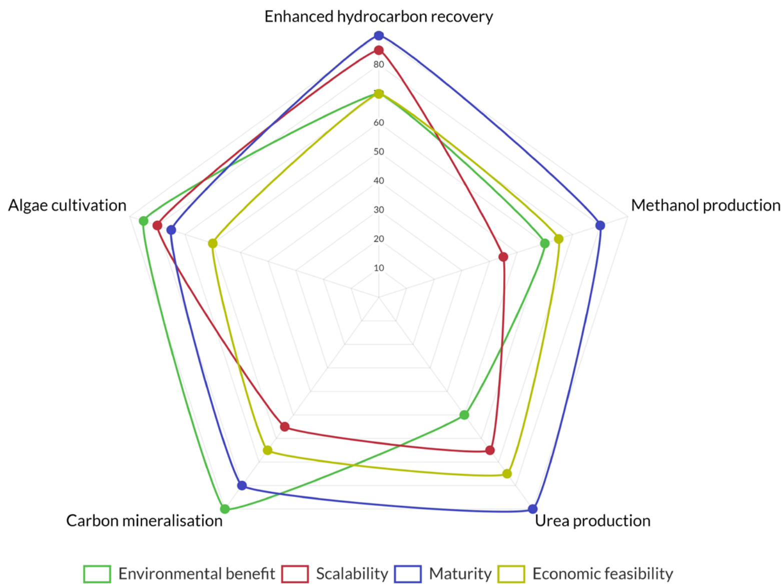

Figure 2. The general comparison of potential CO_2 utilization pathways in Uzbekistan based on four different parameters.

From the environmental point of view, CO_2 to algae cultivation and carbon mineralization pathways are seen as the most promising but those technologies have not reached the full maturity yet [19]. High energy intensity of the mineral carbonation process and the high cost of photobioreactors along with the controlling challenges prevents those utilization routes from massive deployment. In terms of the urea and methanol production from captured CO_2, they can be economically viable covering a part of the capture costs since the methanol to olefin and fertilizer markets are facing a rapid improvement in the country. However, there is a strong necessity to solve the problems associated with the logistics to export overseas and the making the process more sustainable. As for the CO_2 injection as a process booster into the oil and gas reservoirs, in the near term, it can be the most promising route regarding the conditions of Uzbekistan as long as the natural gas and oil prices in the world market stay stable. Nevertheless, the main concern for the implementation of EOR and EGR in the country is the evaluation of the environmental benefit as the process leads to the increase in the production of fossil fuels and the availability of open data sources about the current state and technical characteristics of the reservoirs.

5. Conclusion

In this paper, possible CO_2 utilization pathways in Uzbekistan are discussed with a general comparison based on available resources, scalability, environmental and economic viability. We have explored about the potential opportunities and challenges that can lay ahead by examining different approaches and technology within the context of Uzbekistan. For the current and near term, CO_2 to enhanced hydrocarbon recovery can be the feasible option until finding more sustainable and large scale CO_2 conversion pathways. Algae cultivation may also be viable as long as the capital cost of the reactors are reduced or the availability of wastewater is maintained. However, there is a huge demand for further investigation of possible pathways taking into account the existing resources and limitations.

Author Contributions: Conceptualization, A.N. and A.K.; methodology, M.V., M.F. and A.K.; software, A.K. and Z.T.; writing—original draft preparation, A.K. and Z.T.; writing—review and editing, A.K.; visualization, A.K. and Z.T.; supervision, M.V., A.N. and M.F.; A.K. and Z.T. contributed equally to this paper. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Slovak Research and Development Agency under contract nos. APVV-18-0134 and APVV-19-0170.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The first author acknowledges the national scholarship program of the Slovak Republic for making an opportunity to carry out this study in Slovakia under the international collaboration.

Conflicts of Interest: The authors declare no conflict of interest.

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