Journal of CO_2 Utilization 17 (2017) 50–59

Contents lists available at ScienceDirect

Journal of CO_2 Utilization

journal homepage: www.elsevier.com/locate/jcou

Region prioritization for the development of carbon capture and utilization technologies

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ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 31 August 2016
Accepted 6 October 2016
Available online 24 November 2016

Keywords:
Carbon utilization
CO_2 emissions
Industries
Waste
Value chains
CO_2 reuse

ABSTRACT

In recent years several strategies have been developed and adopted to reduce the levels of the Greenhouse Gas Emissions released to the atmosphere. The adoption of Carbon Capture and Utilization (CCU) technologies may contribute towards carbon sequestration as well as to the creation of high value products. This study presents a methodology to assess the potential of CO_2 utilization across Europe, and to identify the European regions with the greater potential to deploy nine selected carbon dioxide utilization technologies. The results show that Germany, UK and France at the first level followed by Spain, Italy and Poland are the countries where the larger quantities of available CO_2 could be found but also where the majority of the potential receiving processes are located, and therefore with the greatest potential for CO_2 utilization. The study has also revealed several specific regions where reuse schemes based on CO_2 could be developed both in Central Europe (Dusseldorf and Cologne – Germany, Antwerp Province and East Flanders – Belgium and S'ląskie – Poland) and in Scandinavia (Etelä-Suomi and Helsinki-Uusimaa – Finland). Finally, among all the selected technologies, concrete curing and horticulture production are the technologies with the higher potential for CO_2 utilization in Europe.

1. Introduction

In 2011 the European Council announced that one of the environmental targets set in the Roadmap for 2050 is to reduce the levels of the Greenhouse Gas Emissions (GHG) at least by 80–95% below the values from 1990 by 2050 [12]. In the last couple of decades the European Union authorities together with all the EU member countries have made efforts to reduce emissions, with the following main pillars of their strategy towards a low carbon economy and society: (a) promotion of renewable energy sources, (b) implementation of energy saving measures and (c) development of carbon capture and storage (CCS) projects. All the efforts were also supported by the adoption of several regulations such as the EU Emissions Trading System (EU-ETS) EC [11].

This is the main reason why CCS has been rapidly developing worldwide during the last decade from pilot and demonstration plants to full scale projects, with geological and ocean storage being the main options for CO_2 storage. Indicative projects include the Sleipner CO_2 Storage Project (0.9 Mtpa) and the Snøhvit CO_2 Storage Project (0.7 Mtpa), in Norway, which already operate from 1996 and 2007 respectively, and the Don Valley Power Project and the Teesside Collective Project in the UK (both expected to operate during the next decade) [3,27].

By contrast, carbon capture and utilization (CCU), which includes the utilization of previously captured CO_2 as working fluid or as feedstock in industrial applications, has begun to get the same level of attention only during the last few years [40]. New CO_2-based value chains can be developed using CCU technologies and can play an important role in the future either through the development of sustainable energy carriers, as well as through the production of different types of carbon derived products [2]. In order to enable the development of such value chains, it is critical to gather detailed information both about the available CO_2 sources (e.g. purity, mass flow) and for the alternative CCU technologies (e.g. technology readiness level, cost, quality requirements). Then, it is necessary to identify the regions in which both sources and industries where CCU technologies could be installed co-exist in order to activate subsequently all the relevant stakeholders. Parallel to that, emphasis should also be given to the

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http://dx.doi.org/10.1016/j.jcou.2016.10.002
2212-9820/

development of improved capture and purification technologies and more efficient transformation processes. Additionally, CO_2 used as raw material will be coupled with other sources and materials providing an opportunity to develop industrial symbiosis. For example, in Iceland a factory (Carbon Recycling International) produces methanol at a large scale, using CO_2 containing flue gas from a geothermal power plant as well as electricity geothermal [7].

The "enCO_2re" (Enabling CO_2 reuse) project, a flagship project financed by the European Institute of Innovation and Technology – Climate Knowledge Innovation Community, focuses on all the aspects of a successful CCU scheme; from mapping all potential CO_2 sources and sinks to developing new and improved carbon neutral products and educating its industrial partners, entrepreneurs, decision makers and researchers about recent developments and relevant issues.

1.1. State of the art

Due to the earlier development of CCS, there already exist several attempts to map on a global level the sites where CCS currenly takes place as well as sites with increased potential for investment. The Scottish Carbon Capture & Storage (SCCS) interactive world map of carbon capture and storage projects provides information about large-scale operating and planned projects with annual capacity greater than 0.5 Mt per annum (Mtpa) and also includes smaller scale but significant pilot projects from capture and storage to full-chain CCS [38]. Similar maps have been also created by the MIT Carbon Capture and Sequestration Technologies Program [27] and the IEA Greenhouse Gas R&D Programme [21]. Going one step further than simple mapping, the U.S. Department of Energy (DOE) Carbon Storage Atlas provides an estimate of the CCS potential across the United States and other portions of North America, by combining the available CO_2 stationary sources and the alternative storage points [44], whereas Szulczewski et al. [42] have performed a US-wide assessment of CO_2 storage capacity by using both analytical models and regional geological models and have estimated a total storage capacity of over 100 Gt in the continental US. Moreover, the Capacity Map developed by SETIS assesses the public and corporate R&D investment in Carbon Capture and Storage in the EU (among other low-carbon energy technologies), thus highlighting candidate countries for the development of such projects and providing a benchmark for future investments [6].

Similar studies, focusing on the CCU potential, are in their beginning. Pérez-Fortes et al. [32] analysed two different CCU options, methanol synthesis and accelerated aqueous carbonation of waste (fly ash), and assessed the role of CCU on the future European energy and industrial sectors, through a techno economic analysis. Process flow modelling was used to estimate all the relevant technical and economic values, assuming that the CO_2 source is a conventional power plant. Wei et al. [46] examined the potential of developing CCU projects in China, using technology readiness level (TRL) and geographic distribution as their two main criteria, and identified specific regions that are potential candidates to develop CCU technologies at different timeframes. A similar analysis was performed by Reiter and Lindorfer [36], who have evaluated the potential of using several alternative CO_2 sources within the power-to-gas industry in Austria, with the results revealing that the available CO_2 is enough to satisfy all the power-to-gas processes in the country. The ideal source has been identified as CO_2 from biogas upgrading facilities or bioethanol plants, based on capture cost, specific energy requirement and CO_2 penalty. A team led by Element Energy, and comprising Carbon Counts, PSE, Imperial College and the University of Sheffield, has carried out a study of industrial CO2 capture for storage or utilization and developed three alternative scenarios for the deployment of CCU technologies in the UK by 2025. The four technologies that were selected to be included in these scenarios are methanol production, mineral carbonation, polymer production and direct industrial use of CO_2. The annual CO_2 utilization ranged from 0.5 to 0.7 Mtpa for the moderate scenario to 9 Mtpa for the very high utilization scenario [14]. However, all these focus either on a few CO_2 end-receiving processes or on a specific country. von der Assen et al. [48] have mapped the available CO_2 sources greater than 0.1 Mtpa on a European level and have identified the favourable locations for CO_2 utilization with the lowest environmental impacts of CO_2 supply, the so-called CO_2 oases, by using environmental-merit-order curves.

The present paper will attempt to assess the potential of CO_2 utilization across Europe, and to identify the European regions with the greater potential to deploy nine selected carbon dioxide utilization technologies. The selection of these technologies is primarily based on their TRL and is validated by the industrial stakeholders involved in the project. The current production level of the goods that could potentially use CO_2 as raw material and the availability of by-products that could be combined with CO_2 in order to create new opportunities are retrieved from publicly available databases for the baseline year 2013. The countries with the higher potential are identified and a more detailed analysis at a regional level is carried out in order to pinpoint the regions that could be considered as candidates for the development of CO_2-based industrial clusters and thus for further study. Furthermore, a preliminary rough estimation of the amount of CO_2 than can be used by each technology is also performed. Section 2 briefly presents the methodology that will be followed for the estimation of CO_2 availability and potential for utilization, while Section 3 illustrates the results of the application of this approach in Europe. Section 4 summarizes the findings, highlights the most prominent regions for the development of CCU schemes but also enumerates several suggestions to improve the approach towards a more accurate estimation.

2. Methodology

A top-down methodological approach has been developed in order to identify the key European regions with potential for developing CCU partnerships (Fig. 1). The selection of a top-down approach is also driven by the possibility of using common available statistical data that allows the determination of maximum values of different flows [23].

The approach is divided in two blocks. In the first block, the current potential for CO_2 utilization at regional level in Europe is quantified and characterized. The calculated values represent what can be defined as the potential demand for CCU. The second block characterizes and quantifies CO_2 emitted by industrial stationary sources at a regional level and can be regarded as the potential availability of CO_2 as a feedstock or supplementary resource. The outputs of both blocks are estimated on a regional level and are juxtaposed in order to prioritize regions with potential to develop CCU business models. At this point the analysis is exclusively based on quantities and distances, whilst purities should be dealt with separately at a later stage, in opportunity development for the identified key areas. A detailed description of the top-down methodology is presented in the following sections.

2.1. Assessing the potential for CO_2 utilization

CO_2 is currently used as an input in several industrial processes with the various technologies and products being in different stages of development. For the purposes of this analysis, a list of CO_2-receiving processes has been compiled based on an extensive