Comparison of carbon balance measuring tools in an enhanced oil recovery project based on the carbon dioxide from the ammonia production process streams

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A B S T R A C T
A number of studies addressing the environmental impact of deploying carbon capture utilization and storage are focused on sources of CO2 in the power sector. However, there is a lack of environmental studies on the use of CO2 from process stream within the oil and gas industries. The carbon balance of an enhanced oil recovery project for the specific case of using CO2 process stream of ammonia production from emission factors and regional databases in the Mexican oil and gas sector was assessed. Two independent tools to assess life cycle assessment according to guidelines ISO 14040/14044 were utilized: (i) use of Umberto software to quantify the environmental impact with ReCiPe model midpoint; and, (ii) The American Petroleum Institute method through the use of emissions factor for each source and emission gas of the activity/facility in a spread sheet. The results of the tools were compared and the dissimilarities analysed. The emissions profiles from all direct and indirect activities associated with the enhanced oil recovery system were compared with a “cradle-to-grave” model. The functional unit is one barrel of crude oil extracted and consumed. Global warming as the environmental indicator of both tools was used. Additionally, the energy balance of the project was estimated. The global warming impact of the enhanced oil recovery system was 0.51 tCO2e/barrel (bbl) using the American Petroleum Institute tool, whilst the emissions using Umberto software were 0.54 tCO2e/bbl. Also, for each MJ of energy produced a value of 72 tCO2e/MJ oil and of 66 tCO2e/MJ oil, were obtained. This study demonstrates that both tools delivered an accurate estimation of the greenhouse gas emissions in the enhanced oil recovery system for the oil and gas industries. However, American Petroleum Institute has the advantage that the calculations can be performed manually in a spread sheet using emissions factor adjusted to the facilities and Country. Regarding the results of both tools, this work shows that American Petroleum Institute results have proven to be an efficient tool for practitioners and researchers that intend to analyse the greenhouse gas emission of carbon capture utilization and storage systems to estimate, with accuracy, the global warming impact.

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1. Introduction

The number of studies addressing the environmental impact of deploying carbon capture and utilization (CCU) and/or carbon capture and storage (CCS) is rather limited and focuses on sources of CO2 from the power sector (Corsten et al., 2013). Moreover, CCS
from industrial applications has so far received little attention, despite International Energy Agency–United Nations Industrial Development Organization, IEA-UNIDO (2011) highlighting that CO2 emissions should be reduced up to 4.0 gigatonnes (Gt) annually by 2050. The CCS studies suggest that the global warming (GW) resulting from power plants needs to be reduced (Leung et al., 2014).

Many studies marginally discuss different aspects (Cuellar-Franca and Azapagic, 2015) when assessing the environmental performance of power plants with CCS and CCU, despite the difficulty in directly comparing the relative importance of upstream (e.g. coal mining, coal transport, monoethanolamine production), as mentioned by Corsten et al. (2013), and downstream emissions (e.g. CO2 capture). This emphasises the need for optimal designs in all the value chains. Nevertheless, as the available recent literature aiming to address the life cycle assessment (LCA) of CCS focuses on different technologies, as well as system boundaries; database sources, transparency in the data reported and specific assumptions are not clearly evident in the studies. This makes it even more difficult to draw robust conclusions on the potential environmental impact of CCS and CCU. Marx et al. (2011) gave a synthesis report about LCA-CCS evaluations, in which some shortcomings in the studies’ underlying assumptions and methodologies were found. Petrikopoulou and Tsatsaronis (2014) established that the principal aim of CCS technology is how their environmental impact can be reduced and energy efficiency maximized. Consequently, a valuable way to assess the LCA of enhanced oil recovery operations is to review the carbon emissions profile for the whole operation, and compare this with projects of CO2 storage profile.

This subject is important since frequently the LCA practitioner will not find one obvious choice among a number of different databases or calculation methods, and the question, therefore naturally arises: “Does my choice of method or database have any influence on the conclusions?” Based on simulation results and process configuration of the CCS system, the LCA method has been applied to evaluate the environmental impact of the system taking into account the complete life cycle from raw material to CO2 injection or refinery product combustion from commercial software (Von der Assen et al., 2014). In addition, the life cycle inventory (LCI) calculations could involve either the whole system boundary or not, and include different raw materials (coal and natural gas) or only main stages of the LCA, i.e. a gross inventory, without going into the details of each stage from extraction of raw material to use. Therefore, system boundary or expanded system boundaries and their stages are neither clearly specified nor detailed, generating different results of net emission per barrel of oil in the enhanced oil recovery (EOR) system (Cuellar-Franca and Azapagic, 2015). Specific to the oil and gas industries, there is a lack of direct measurements, or offshore/onshore monitoring of emission gases is rare, and so for most sources only the activity data, such as fuel consumption or the rate of a process activity are available. When direct measurement systems are not in place, the calculation of emissions can be made from an activity factor (Stewart and Hazeldine, 2014).

The most commonly practiced CCS approach, in terms of CO2 sequestered, is CO2-enhanced oil recovery (CO2-EOR). The CO2 injection from natural sources for EOR has been applied commercially since the early 1970s in the United States for oil recovery, typically in no longer productive mature fields. However, today EOR operations are carried out with the aim of maximizing oil output with the minimum CO2 injection (International Energy Agency, IEA, 2015). According to Leach et al. (2011), approximately 30–40% of the CO2 injected during a single injection usually remains trapped in the reservoir. This value is similar to that reported in the first CO2-EOR case study in Mexico performed at the Artesa reservoir in the Chiapas and Tabasco states, where 40% of CO2 injected was stored (Leon-Garcia et al., 2015).

As with any secondary recovery methods, additional energy is consumed in the CO2 capture, resulting in a higher environmental impact per MWh than without CO2 capture (Petrikopoulou and Tsatsaronis, 2014). The production of additional oil will be CO2-EOR that, when combusted will generate additional CO2 emissions (Jaramillo et al., 2009). Along with this, there is a discussion as to whether these technologies can provide products that sequester the CO2 for a long or short period (Electric Power Research Institute, EPRI, 2013), how much CO2 is really sequestered by each technology, and if CCS should be considered as a mitigation technology (Armstrong and Styring, 2015). Thus, climate change mitigation and long-term CO2 storage goals are not principal drivers for EOR projects (IEA, 2015). EOR also sequesters CO2 in the process with potential climate benefits. An important portion of the injected CO2 remains in place, a technology that has been proved in USA (Dai et al., 2014a) and Canada with the world’s first commercial scale post-combustion coal fired carbon capture and storage in the Saskatchewan Project (Stephene, 2014). All studies show a substantial reduction of greenhouse gas (GHG) emissions from power production, in the order of 40–97% (Corsten et al., 2013). According to Cuellar-Franca and Azapagic (2015), the reduction in the global warming potential (GWP) is sensitive to CO2 capture and allocation methods as well as the assumptions for heat recovery from the system.

IEA-UNIDO (2011) published a Technology Roadmap CCS in industrial applications providing an outlook of industrial CCS up to 2050, where high-purity CO2 sources like ethylene oxide and ammonia production were included in this roadmap.

The 2014 global status of CSS projects states that four projects are in operation from CO2 fertilizer plants: three for EOR and one as geological storage, with a contribution of 4.5–5.1 MtCO2/year (Global CCS Institute, 2015). These values represent a marginal fraction of the total anthropogenic emission (32,000 Mt CO2/y) by this sector (Armstrong and Styring, 2015). In 2014, the start up operation of the commercial North Burbank Unit (NBU), in Kansas-Oklahoma USA, CCU and the CCS (EOR) from a fertilizer-urea plant (National Energy Technology Laboratory, NTEL, 2015) were included.

The United Stated Environmental Protection Agency (USEPA) lists 22 ammonia manufacturers in the United States. Eighteen of these are capturing CO2 as a by-product and selling it as an industrial product to the market (USEPA, 2015). NTEL (2013) published a report on alternative sources of CO2, documenting a cradle-to-gate footprint per unit of CO2 produced from ammonia production. This study has not found cradle-to-grave life cycle results published on EOR production from CO2 by ammonia plants. There are not many references in the literature describing the use of LCA-CCS studies in petrochemical processes or the oil refinery (Nagashima et al., 2011).

Consequently, this work was motivated by the need within the oil and gas sectors, to analyse and compare the results of other methodological models, to identify environmental “hot spots” in the LCI calculations of the CCUS-LCA studies. This study might therefore suggest potential improvement actions to enable a reduction in the environmental impact of the upstream and downstream processes of the oil and gas industries, as well as to assist LCA practitioners to compare the results when they use the CCUS system using regional or local databases.

1.1. Overview of CCUS in Mexico

The Mexican Government recently published the CCUS Technology Roadmap recognizing the need for CCS to aid in reaching the CO2 reduction goal in view of the fast growth in electricity demand
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