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Comparison of life cycle greenhouse gas emissions from unconventional ultra-sour and conventional gas feedstock for power: A case study of the United Arab Emirates

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ABSTRACT

The electricity sector is UAE's leading CO_2 emission source. The country is rich in fossil energy including gas. However, due to demand pressures the country has been forced to develop its unconventional gas resources containing over 20% hydrogen sulfide and 10% carbon dioxide. The sweetening process for this unconventional gas resource is particularly very energy and greenhouse gas emission intensive compared with conventional gas. The present analysis aims to quantify the well-to-grid GHG emissions per kilowatt hour (kWh) of domestic gas-based power delivered in the country. The GHG emissions are estimated making use of mathematical models, simulation software, and engineering principles. The well-to-grid emission lifecycle includes: gas extraction, raw gas gathering and transmission, gas processing, sweet gas product transmission, electricity generation, distribution and transmission, and end-use. Two types of gas resources were examined: ultra-sour and conventional gas. The results show that the well-to-grid GHG emissions of domestic gas-based power ranges from 546 to 630 g CO_2 eq./kWh and 474–545 g CO_2 eq./kWh for ultra-sour and conventional gas, respectively. Thus, placing the country in the low-mid range literature values (416–730 g CO_2 eq./kWh).

1. Introduction

Over the last decade, the rapid economic and demographic growth of the United Arab Emirates (UAE) has pushed the country's electricity grid to its limits (Betancourt-Torcat and Almansoori, 2015). The UAE ranks amongst the top countries with highest per capita electricity consumption in the world (U.S. Energy Information Administration, 2017). The power sector contributes with approximately 50% of the country's CO_2 emissions (The World Bank, 2011). As a result, there are plans underway to increase the electricity mix by adding nuclear and renewable power capacities to the grid (Almansoori and Betancourt-Torcat, 2015).

The majority of the country's natural gas deposits contain a relatively high fraction of sulfur. This type of gas deposits where the concentration of H_2S is higher than CO_2 is recurrent in the Middle East, but rare anywhere else in the world. This local characteristic makes this resource highly corrosive and challenging to process. Technical advances in gas processing and growing domestic demand for natural gas make the country's sulfur rich gas deposits an attractive energy supply alternative. Accordingly, most of the natural gas production growth will come from the country's largely sour (high sulfur content) gas deposits (U.S. Energy Information Administration, 2017). The process is very energy intensive as well as environmentally challenging since significant amounts of GHG emissions are generated (Slagle, 2013).

Various studies have been carried out on the UAE's electricity sector. Betancourt-Torcat and Almansoori (Betancourt-Torcat and Almansoori, 2015; Almansoori and Betancourt-Torcat, 2015) found that in the medium-term gas will remain leading electricity generation while nuclear becomes a very attractive option. The latter option allows reducing CO_2 emissions while increasing energy mix and energy security. Mondal et al. (2014) discuss that CO_2 constraints influence technology choice from conventional plants to more efficient and less CO_2 intensive conventional and non-conventional power technologies (e.g., nuclear and renewables). Sgouridis et al. (2013) indicate that under plausible assumptions for fossil fuel costs (given the existence of significant energy subsidies on the demand side) the benefits of an energy transition outweigh

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its implementation costs. The previous studies focus on techno-economic aspects of the operation, whereas GHG emissions estimates typically include only the power generation stage. Presently, there is a lack of comprehensive analyses on both: UAE's domestic gas production and power supply chain GHG emissions lifecycle from the gas well-to-electricity grid.

There are studies that discuss the GHG emissions lifecycle of gas power generation for certain countries. For the US: Skone (Skone et al., 2012) found that average gas baseload power features 53% lower GHG emissions than average coal baseload power. Heath et al. (2014) found that GHG emissions of electricity generated using gas extracted from the Barnett Shale play (Texas) were very similar to those of conventional gas. Hultman et al. (2011) show that GHG impacts of shale gas power are 11% higher than those of conventional gas, and only 56% that of coal for standard assumptions. For the UK, Stamford and Azapagic (2014) found the central value of GHG emissions for shale gas power to be 462 g CO_2 eq./kWh, with values ranging from 412 to 1102 g CO_2 eq./kWh. The main contributor to the impact (84%) is shale gas combustion in power generation. For China: Raj et al. (2016) found that the GHG emissions of gas combined cycle plants using Canadian shale gas ranges from 567 to 610 g CO_2/kWh (57–62% of the GHG emissions from China's present coal-fired electricity). Also, Chang et al., 2014, 2015 results suggest that a coal-to-shale gas shift while upgrading the present coal-fired power technologies could provide pathways to less GHG intensive power. Most of those recent studies consider shale gas as the power plant's feedstock.

In general, the literature on GHG emissions lifecycle for ultra-sour gas resources and UAE's electricity sector is scarce. Additionally, due to the high concentration of acid gases (particularly H_2S) in the country's gas reserves, and the highly energy-intensive processes employed to sweeten the ultra-sour gas, conducting a lifecycle assessment of the UAE's electricity sector is needed and is novel. To the authors' knowledge only one previous lifecycle assessment of the UAE's electricity sector is available in the literature (Treyer and Bauer, 2016). Nonetheless, that study assumed that the vast majority of power plants in the country are conventional natural gas single cycle units; when in reality they are combined cycle units.

On the other hand, for the present study process models are developed in ProMax® v3.2 (simulation software) according to the specific characteristics of the UAE's gas reserves, processing methods, and transmission infrastructures. Additionally, a mathematical model developed especially for the UAE's electricity sector in the General Algebraic Modeling System (GAMS®) is used to illustrate the operation of the country's power system (Betancourt-Torcat and Almansoori, 2015; Almansoori and Betancourt-Torcat, 2015). The aim of the present study is to fill the existing gaps by conducting a comprehensive well-to-grid GHG lifecycle assessment on the entire UAE's domestic gas power supply chain through process modeling. This is required to understand the environmental impacts of the cradle-to-grave UAE's electricity sector.

Comparisons between domestic ultra-sour and conventional gas electricity generation in the UAE are discussed. Additionally, the UAE's electricity sector is benchmarked against other countries and technologies. The results presented in this study can help to understand the environmental impacts associated to the generation of electricity in the country using domestic ultra-sour and conventional gas resources, which can help decision-makers to draw strategies and policy making. The remainder of this paper is organized as follows: Section 2 shows the well-to-grid GHG emission lifecycle stages for the UAE electricity sector. Section 3 explains the analysis methodology approach. Section 4 presents the results and discussions of the GHG emissions lifecycle for the UAE's electricity sector for ultra-sour and conventional natural gas feedstocks; as well as comparisons with electricity generation in other countries. Concluding remarks are presented at the end of this work.

2. Methods

In this work, the lifecycle assessment method has been used to estimate and compare the GHG footprints of rarely ultra-sour natural gas versus conventional gas. The general framework, principles, and requirements for conducting and reporting the lifecycle assessment were taken from the International Organization for Standardization (ISO) methodology described in ISO 14040/44 (International Organization for Standardization (ISO), 2006a; International Organization for Standardization (ISO), 2006b). The present study takes into account the GHG emissions proceeding from carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and sulfur hexafluoride (SF_6). The GHG emissions were expressed in terms of carbon dioxide equivalent (CO_2 eq.) using the 100 year global warming potential (GWP) factors reported by the Intergovernmental Panel on Climate Change (IPCC) (see Table A1) (Intergovernmental Panel on Climate Change (IPCC), 2007). The proposed methodology is not case specific and can be applied to any geographical area.

2.1. Study scope

The present study aims to estimate and compare the GHG emissions lifecycle of generating electricity using unconventional (i.e., ultra-sour) and conventional natural gas resources (Alkatheri et al.,). The considered well-to-grid (WTG) lifecycle starts with natural gas extraction at the reservoirs and ends at grid's electricity transmission to customers. The GHG emissions are benchmarked against electricity generation from other sources and different countries. The lifecycle starts when the natural gas is collected using well pad gathering systems, and transferred via pipeline to processing facilities located near the fields. The gas is sweetened to meet final gas product pipeline specifications at a maximum of 4 ppm of H_2S and 1% mole of CO_2. The gas product is transmitted through a pipeline system to different power stations located in a region/country to generate electricity (Abu Dhabi Gas Development Company Ltd, 2016). Finally, electricity is dispatched to consumers through the grid. According to the characteristics of the region's electricity sector, specific shares of simple and combined cycle natural gas plants as well as steam turbines can be assumed to meet the region's electricity demand.

2.2. System boundaries and broad description

The analyzed WTG GHG emissions lifecycle can be divided in two segments: upstream and downstream. The upstream includes all activities before fuel is combusted at the power plants. Such activities comprise: natural gas extraction, raw natural gas gathering and transmission, gas processing, and sweet gas product transmission to the power plants' gates. On the other hand, the downstream includes electricity generation, transmission and distribution, and end-use. Fig. 1 shows the system boundaries, main unit operations, and main factors defining the well-to-grid GHG emissions of the system. In this study, the GHG emissions associated to gas extraction are estimated based on typical average emission values reported in the literature (Skone et al., 2012). Similarly, fugitive and venting emissions for upstream processes are calculated adapting GHG emission factors (according to process type and transportation pipeline length) from guidelines for natural gas transmission and storage (Interstate Natural Gas Association of America (INGAA), 2005). Table A2 shows details on the fugitive and venting emissions factors (Interstate Natural Gas