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Life cycle impact assessment of ammonia production in Algeria: A comparison with previous studies

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ABSTRACT

In this paper, a Life Cycle Analysis (LCA) from "cradle to gate" of one anhydrous ton of ammonia with a purity of 99% was achieved. Particularly, the energy and environmental performance of the product (ammonia) were evaluated. The eco-profile of the product and the share of each stage of the Life Cycle on the whole environmental impacts have been evaluated. The flows of material and energy for each phase of the life cycle were counted and the associated environmental problems were identified. Evaluation of the impact was achieved using GEMIS 4.7 software. The primary data collection was executed at the production installations located in Algeria (Annaba locality). The analysis was conducted according to the LCA standards ISO 14040 series. The results show that Cumulative Energy Requirement (CER) is of 51.945×10^3 MJ/t of ammonia, which is higher than the global average. Global Warming Potential (GWP) is of 1.44 t CO_2 eq/t of ammonia; this value is lower than the world average. Tropospheric ozone precursor and Acidification are also studied in this article, their values are: 549.3×10^{-6} t NMVOC eq and 259.3×10^{-6} t SO_2 eq respectively.

Introduction

Nowadays, ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to fertilizers, which are very accommodating to increase the crop yields (Gilbert and Thornley, 2010). Ammonia is also a building-block for the synthesis of many chemical products (nitric acid, ammonium chloride…) and it is used in many commercial cleaning products (either as its salts, solutions or anhydrous). There are several manufacturers around the world who produce 157 million tons of ammonia per year (IFA, 2012), which Algeria provides 0.4% (Benouaret, 2011).

Worldwide the ammonia production is mainly synthesized by the Haber-Bosch process (Kool et al., 2012). Natural gas is the main raw material for ammonia production, accounting for almost 80% of the global ammonia production (IEA, 2007). However, this is an energetically demanding process and mainly provokes the generation of greenhouse gases (GHGs). Actually, ammonia industry production is responsible for about 0.93% of the global emissions of GHG (Gilbert and Thornley, 2010). Approximately 1.5 tons of CO_2 is emitted to the atmosphere during the production of 1 ton of ammonia (Anderson et al., 2008). Greenhouse gas emissions from fertilizers production are set to increase before stabilizing due to the increasing demand to secure sustainable food supplies for a growing global population (Gilbert et al., 2014). The increase in greenhouse gases (GHGs) in the atmosphere is one of the major environmental problems affecting the world's population in this century (De Morais et al., 2013).

Nowadays, the fertilizer production sector (ammonia production) has been treated by several authors (Davis and Haglund, 1999; DOE, 2000; Kongshaug, 1998; Patyk, 1996). Based on the outcomes of these studies, Wood and Cowie (2004) concluded that the production of 1 ton of ammonia requires an average energy consumption of 25×10^3 to 35×10^3 MJ. In 2007, Williams and Al-Ansari (2007) determined a global average energy consumption of 36.9×10^3 MJ/t. Haas and van Dijk (2010) estimated an average energy use for ammonia production in Europe of about 34.7 GJ/t. These studies have been devoted to the GHG emissions evaluation and primary resource requirement. In addition, the input inventories used in these studies are based on bibliographic data or simple estimates (Wood and Cowie, 2004).

Life Cycle Assessment evaluates the environmental impacts generated by a production process or service. The main advantage of LCA is its ability to take into account all inputs and emissions related to a product in a particular function throughout its life cycle "from cradle to grave". It is commonly used to conduct a complete evaluation of the emissions (standardized method for the system of international standard series ISO).

This study presents a LCA of anhydrous liquid ammonia produced in Algeria (Annaba fertilizer production complex). It is based on an inventory with primary data, and aims to evaluate the environmental impacts associated with the life cycle of the product in comparison with previous studies. Several Impact categories that were considered in this study are: resources use, Global Warming Potential, acidification potential and Tropospheric ozone precursor potential.

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As previously mentioned, all studies have been devoted to the assessment of GHG emissions, and due to the absence of the results of Acidification and Tropospheric Ozone impacts in the bibliography, the comparison of our results will be summarized in the comparison of GHG emissions and energy requirement. This will allow us to assess the extent of the environmental impact of the Algerian ammonia production process, and ascertain its position in terms of the environment compared to other factories worldwide.

Methodology

For this study, a LCA has been developed and implemented starting from ISO 14040 standard. ISO 14040:2006 specifies the principles and framework for conducting life cycle assessment. ISO 14044:2006 establishes requirements and provides guidelines for conducting a LCA. The latter consists of four phases: the definition of the goals and scope of the study, life cycle inventory, evaluation of the impact of the life cycle and life cycle interpretation (Finnveden et al., 2009; ISO, 2006a, 2006b).

Assessing the impacts of life cycle

Global Emission Model for Integrated Systems (GEMIS) 4.7 is a life cycle analysis database program developed as a tool for the comparative assessment of environmental effects of energy by *Öko-Institut* and *Gesamthochschule Kassel* (GhK). Firstly, it contains an impact assessment method and a database of materials, processes, transport means and energy, allowing modeling of the product. The database includes a list of products, processes and scenarios. Integrated database was established based on *Eidgenössische Technische Hochschule Zürich* (ETH) and *Bundesamt für Umwelt*, *Wald und Landschaft* (BUWAL) Swiss references and German *Gesellschaft für Technische Zusammenarbeit* (GTZ). In a LCA study, the analysis step of environmental impacts concerning the studied system is divided into two stages. The classification step determines the flows derived from the Life Cycle Inventory (LCI) that contributes to environmental effects, while the characterization step weighs the same flow within each of effect classes (GEMIS 4.7, 2011). In this study, two categories of environmental impacts indicators are distinguished: (i) Resource Indicators characterizing the real consumption of resources (raw materials and energy) that create the product throughout its life cycle, and (ii) Impacts Indicators characterizing the actual pollution and/or potential generated by the product throughout its life cycle (GEMIS 4.7, 2011).

Impact indicators

- Resources Use (GEMIS 4.7, 2011): The Cumulative Energy Requirement (CER) is a measure of the total amount of primary energy resources necessary to delivering a product or service (Energy consumption is expressed by Low Heating Value LHV[1]). CER is composed of both the energy used in the production process as raw material (process gas), and that used as fuel (gas fuel), and it can be divided between the portion of renewable and non-renewable primary energy. The Cumulative Materials Requirement (CMR) is a measure of the total amount of raw materials needed to deliver a product or service. In GEMIS, the CMR is an important complement to the CER.
- The Global Warming Potential (GWP), in equivalent of carbon dioxide, is the contribution to atmospheric absorption of infrared radiation by anthropogenic derived gases such as CH_4, CO_2 and N_2O, which contribute to an increase in global temperature. Usually, GWP data refer to a time horizon of 100 years (GEMIS 4.7, 2011; Hauschild and Potting, 2005; Sporyshev and Kattsov, 2006).
- The acidification potential (AP), in equivalent of sulfur dioxide acidification, refers to the problem of "acid rain" which reduces the productivity of natural ecosystems (forests) or artificial (crops). The human infrastructures (buildings, vehicles…) are also weakened by this phenomenon (Guinée et al., 2002; Harrison, 2001).
- Tropospheric ozone precursor potential (TPOPP), in equivalent of Non-Methane Volatile Organic Compounds (NMVOC), is the equivalent based on the rate of ozone formation from the precursors, measured by the equivalent of precursors, measured as ozone precursor equivalents. The TOPP represents the potential formation of near-ground (Tropospheric) O_3 which can cause the "Summer Smog" phenomenon (GEMIS 4.7, 2011; Osman and Ries, 2007 from EEA, 2001).

Each impact category or subcategory possesses its own method of characterization. This denomination designates the relationship between the category indicator, characterization model and characterization factors (Guinée et al., 2002; Pennington et al., 2004). The factors taken in this study are presented in Table 1.

LCA of ammonia

Context of the study

The studied system operates at two different industrial sites, separated by nearly 800 km (extraction and processing of natural gas in the first and the production of ammonia in the second), which requires a gas transfer by pipeline. The study was conducted beginning from the natural gas extraction to the storage of final product (from cradle-to-gate) through the transport of gas and the different stages of the production of ammonia.

Fertial-annaba complex

The Fertial-annaba complex (originally called ASMIDAL) was commissioned in 1972 to meet the needs of the domestic market for fertilizers. Its primary mission is the development, production and marketing of nitrogenous and phosphoric fertilizers and chemicals such as ammonia and nitric acid.

As a result of the partnership signed on August 2005 with the Villar-Mir Group, the company invested 200 million dollars in the restoration of equipment (FERTIAL-News, 2012). This gave "Fertial-Annaba" a good place on the national market, since it guarantees the economic independence of the country in this strategic sector.

Natural gas field of Hassi R'Mel

The exploitation area of natural gas (Hassi R'Mel) is located in the south of Algeria, 525 km southern Algiers in Laghouat town, 70 km west of Beriane, 120 km northwest of Ghardaia and 120 km southeast of Laghouat. The complex field of Hassi R'Mel was discovered in the sixties and highlighted a gas wet to a depth of 2132 m. It is the largest gas processing installation in Algeria.

System boundaries

Primary modeling can be done in the form of a tree process providing an overview of the studied system and the different steps making up the life cycle. Fig. 1 illustrates the various unit processes. To take into account the materials and energy that enter the system, two system boundaries have been defined for this analysis. The background system boundary (frame with a solid line) presents materials, energy consumption and associated emissions of all processes. The second border (frame with a broken line) is the foreground system boundary. This second boundary presents the processes for which primary data were collected directly from production plants. The transport phase separates the operations carried out in the two production sites.

[1] The usable energy content of fuel is typically calculated using the lower heating value (LHV) of that fuel, i.e. the heat obtained by fuel combustion (oxidation). LHV of natural gas is: 33.0812 MJ/Nm^3, Coal: 26 MJ/kg and oil: 41 MJ/kg (ADEME, 2007; GEMIS 4.7, 2011).