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Life cycle assessment of potash fertilizer production in China

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ABSTRACT

Fertilizer application leads to energy consumption and greenhouse gas (GHG) emissions. In this study, aiming to quantify the environmental impacts generated from brine-based potassium chloride fertilizer production, a life cycle assessment study was conducted. Additionally, uncertainty analysis based on Monte Carlo was conducted to improve the reliability of results obtained from this study. Results show that potential impacts from global warming category and fossil depletion category contributed the most to the total environmental impacts, with the value of 1.90E+02 kg CO_2 eq (GSD^2 = 1.35) and 2.57E+01 kg oil eq (GSD^2 = 1.39), respectively. Impacts generated from respiratory inorganics and water depletion category also had significant contributions, with additional contributions from the categories of terrestrial acidification, respiratory organics, non-carcinogens, carcinogens, and marine eutrophication. Key factors analysis uncovers that the overall environmental impacts were mainly caused by electricity generation, water consumption, and on-site emissions. Finally, suggestions based on research results and the local reality are proposed. Research findings from this study provide valuable insights to stakeholders so that the overall environmental impacts (specially for GHG emissions) from potash fertilizer production can be mitigated.

1. Introduction

Climate change has become a global concern due to its increasing impacts on the earth's ecosystem (Eleftheriou et al., 2018). Besides the impact on global warming, such as the consequent decrease of snow and ice and the rising of sea level, climate change can also result in substantial economic impact (Revesz et al., 2014). For instance, agricultural sector is one major source of global GHG emissions (Vetter et al., 2017), in which the application of fertilizer induces significant emissions (Wang et al., 2017; Zhen et al., 2017). In order to feed nearly 22% of the world population, China heavily depends on chemical fertilizers to increase grain production (Wang et al., 2018). China has been the world's largest consumer of fertilizer, especially the consumption of potash fertilizer (World Fertilizer, 2017). However, compared with nitrogen fertilizer and phosphatic fertilizer, less attention has been paid on the environmental impacts generated from potash fertilizer. Under such a circumstance, it's critical to investigate the environmental impacts of potash fertilizer so that more accurate GHG emissions generated from the use of potash fertilizer can be evaluated and more appropriate mitigation policies can be prepared.

Life cycle assessment (LCA) is one effective approach for evaluating the environmental impacts of a product by quantifying the impacts of all inputs and outputs associated with the investigated system (ISO, International Organization for Standardization, 14040, 2006). Such a method has been extensively applied for evaluating environmental burdens generated from fertilizer industry. For example, environmental impacts generated from phosphate fertilizer (Silva and Kulay, 2005; Zhang et al., 2017), nitrogen fertilizer (Hong and Li, 2013; Hasler et al., 2015) were evaluated by using LCA. However, few LCA studies focused on potash fertilizer, let alone potassium chloride (KCl) fertilizer. The only available literature is that Nemecek et al. (2007) provided the life cycle inventory (LCI) of potash fertilizer manufactured by solid potash, in which the LCI on KCl fertilizer production were derived from an environmental report for the year 2000 and should be updated due to the rapid technological progress. Increasing attentions are paid on the environmental burden generated from the whole life cycle of agriculture activities, aggravating the necessary of an updated LCI of KCl fertilizer. Also, it's well known that KCl is widely utilized in industry and daily lives. For example, it's the basic material for manufacturing potassium hydroxide, potassium sulphate, ect. Thus, scientific

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evaluation of the environmental impacts of KCl production is the basis of environmental impacts assessment of corresponding down-stream products. To date, a LCA-based study on brine-based KCl fertilizer production has not been conducted worldwide. In the reality, as the world's fourth largest potash fertilizer producer, the majority of potash fertilizer produced in China was manufactured based on potassium-rich brine. Also, China is trying to enhance the capacity of potash fertilizer production. Thus, it's necessary to perform an environmental accounting on brine-based KCl fertilizer production by using the LCA method so that the holistic perspectives on the related impacts can be presented. Key factors leading to these environmental impacts are also identified so that more feasible suggestions for reducing consequent environmental impacts can be provided. Furthermore, uncertainty analysis is performed so that results can be more advisable for decision-makers. The whole paper is organized as below. After this introduction section, Section 2 details research methods and data sources. Section 3 presents research results and Section 4 presents the discussions. Finally, Section 5 draws research conclusions.

2. Methods and data

2.1. Functional unit and system boundary

Functional unit provides a quantified reference for related inputs and outputs of an investigated system (ISO, International Organization for Standardization, 14040, 2006). In this study, 1 ton K_2O production (1.67 KCl fertilizer with a K_2O content of 60.03%) is selected as the functional unit. System boundary (see Fig. 1) was set via a cradle-to-gate approach, in which the processes of raw materials and energy production, on-site emissions, transport of raw materials, and waste disposal associated with KCl fertilizer production are included. In addition, allocation method of the cut-off approach is applied for the open-loop recycling considered in this study. According to Nicholson et al. (2009), the environmental burden directly caused by a product are assigned to that product when cut-off method is adopted. Thus, the environmental impacts generated from KCl production process are allocated to KCl fertilizer product (with a K_2O content of 60.03%) in this study.

Table 1
Life cycle inventory (Values were presented per functional unit).

		Amount	Unit	GSD^2
Raw materials and energy consumption	Land occupation	7.91E−01	m^2	1.58
	Brine (KCl ≥1%)	1.17E+02	m^3	1.24
	$CH_3(CH_2)_{10}CH_2NO$	7.40E+02	g	1.24
	Water	7.70	m^3	1.24
	Electricity	1.11E+02	kWh	1.24
	Natural gas	2.20E+01	m^3	1.24
	Gasoline	8.88E+01	mL	1.24
	Diesel	6.07E+02	mL	1.24
Waste treatment	Solid waste landfill	1.22E+02	g	1.24
	Wastewater treatment	3.17E+01	L	1.24
	Mother liquor (high content of $MgCl_2$)	100% reuse		1.24
	Bittern	100% reuse		1.24
	Tailing	100% reuse		1.24
Air emissions	NO_X	1.58	g	1.61
	PM_{10}	3.70E+01	g	2.07
	CO_2	4.88E+01	kg	1.26

GSD^2: squared geometric standard deviation.

2.2. Life cycle inventory

Table 1 lists the LCI results of KCl fertilizer production. All materials and energy consumption (e.g., water, electricity, natural gas, diesel, gasoline, and flotation agent), on-site emissions (i.e., CO_2, particulates, and nitrogen oxides) during manufacturing process, transport of raw materials, and waste disposal associated with the investigated product are based on the functional unit. Based on the actual operation data of selected plant, mother liquor, bittern, and tailing generated during manufacturing process were 100% reused. Data quality information of

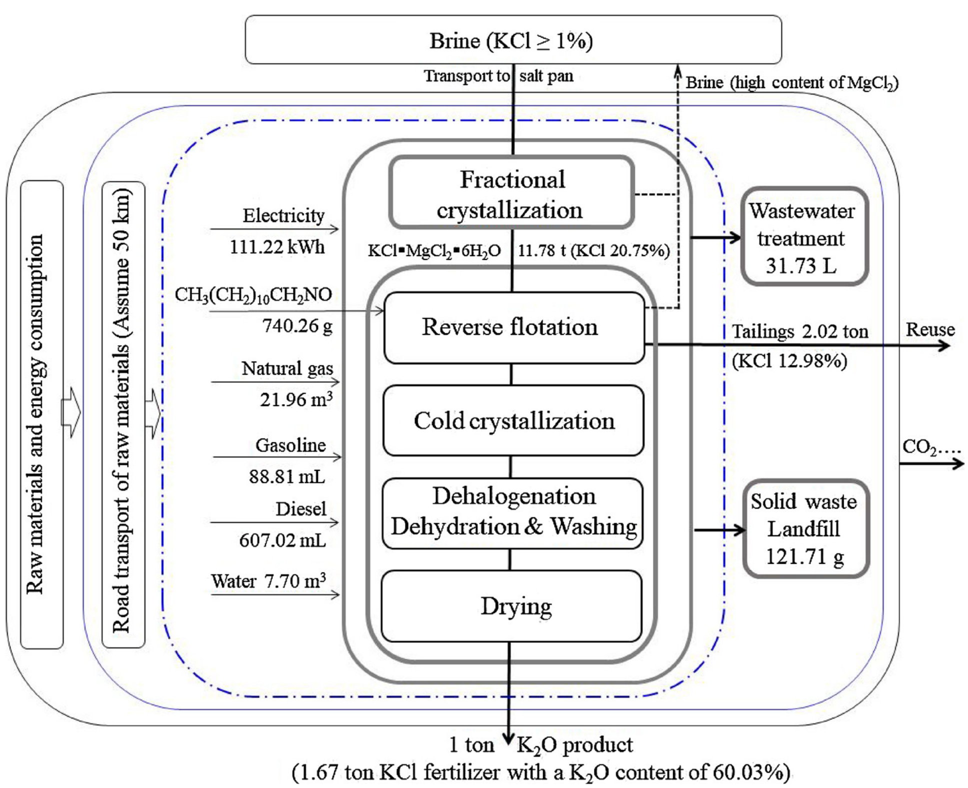

Fig. 1. System boundary.