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Life cycle assessment of magnetized fly-ash compound fertilizer production: A case study in China

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ABSTRACT

Considering that most previous studies on environmental impacts of magnetized fly-ash compound fertilizer (MFCF) were based on one single stage of field application, this study attempted to assess the environmental impact of MFCF production using life cycle assessment to provide some new information about environmental impacts of MFCF and develop some measures of reducing environmental pollution resulted from the compound fertilizer. In this paper, 1 t of MFCF product was used as the functional unit to evaluate the environmental risk in the stages of transportation, production and field fertilization. The single factor sensitivity analysis was carried out to quantitatively analyze the effects of change of transportation distance and mechanical production efficiency on environmental impacts resulted from MFCF. The most prominent impact category in the life cycle of MFCF was non-renewable resource depletion; its environmental impact index was 1.84×10^{-2} and contribution rate was 39.74%. The second most prominent impact was terrestrial eutrophication; its environmental impact index was 1.43×10^{-2} and contribution rate was 30.75%. The non-renewable resource depletion and terrestrial eutrophication were mainly affected in production and field application stages. Improving coal-fired power generation efficiency, increasing MFCF production efficiency, exploring clean transportation and promoting balanced fertilization were effective ways to reduce the burden on the environment caused by MFCF. The present study can be considered as a useful methodological framework for a deeper understanding of key environmental impacts related to MFCF production.

1. Introduction

Fly ash (FA) is a type of by-product of thermal power generation, and every approximate 4 t of coal burning will produce 1 t FA [1,2]. On Sep.15th, 2010, the international environmental organization Greenpeace released the "2010 China Fly-ash Report", in Beijing. It pointed out that "FA has become the largest single source of pollution of industrial solid wastes in China". With the rapid development of the Chinese power industry, the production of FA was still increasing year by year, reaching 580 million tons in 2013. It has been predicted that the amount of FA produced in China will be 0.6 Gt in 2020, and the accumulated amount of FA is expected to be 3 Gt by 2020 [3]. What a huge amount! If it is not effectively treated, it will give rise to severe environmental pollution problems, including making dust everywhere, leading to air and water pollution, and occupying large areas of land [4]. Therefore, the comprehensive utilization of FA is an effective way to solve its pollution and waste.

The unique composition and properties of FA determine its various uses, such as environmental protection, synthetic materials and utilization in agriculture [5–7]. FA can effectively absorb pigments and impurities dissolved in water and address industrial and residential wastewater due to its porous structure [8]. Concrete production using FA can improve the durability of concrete and reduce the risk of cracking of concrete pavement [9]. Though FA can be used as adsorbent, the technology was quiet complicated, including binder addition and high-temperature calcination, which resulted in a high cost. There were also some weakness in FA concrete, including lower thermal ability and higher sensitivity to water.

FA also has broad prospects in agricultural use [10,11] thanks to the variety of available trace elements for vegetation contained in FA [12], and magnetized fly-ash compound fertilizer (MFCF) is a new avenue of utilization in the field of agriculture. MFCF is a type of compound fertilizer that is evenly mixed with a certain amount of N, P, K and FA and is treated with magnetic field. The magnetism left in fertilizers may effectively improve soil porosity and prevent soil hardening. Without any increase in production costs, MFCF could greatly improve crop yield compared to general compound fertilizer. Some studies have shown that MFCF could improve crop production by

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5~35%, and the use efficiency of N and K were increased by 5% and 2.7%, respectively [13]. The yields of wheat, corn and rice were increased by 7.0~11.5%, 4.5~5.9% and 9.8~10.8%, respectively, after using MFCF in Henan Province of China [14]. MFCF also had a significant effect in increasing production of beet, cotton and citrus. Therefore, MFCF can not only solve the problem of FA pollution but also make huge economic benefits. Another advantage for MFCF utilization in agriculture is cutting down the area of land occupation resulted from FA. Given those advantages, there is no doubt that MFCF will be widely used even though the current application scale is small.

However, the production and use of MFCF would give rise to some environmental impacts, such as global warming, acidification and eutrophication. Most conventional environmental impact assessments were confined to a single production process, while ignoring the environmental impact of transportation, application or other processes [15]. Due to the transfer of pollutants in different production processes or mediums, the assessment results from these conventional methods were inaccurate and could not meet the requirements of environmental protection [16].

In the early 1990s, the life cycle environmental assessment (LCA) method emerged [17,18]. It was known as the most potential evaluation method in the 21st century [19–21]. LCA has been used to study agricultural fertilizer systems, including evaluating the greenhouse gas emissions of ammonium nitrate, diammonium phosphate, compound fertilizer, urea and bicarbonate with different nitrogen contents, and it provided a reference for the evaluation of nitrogen footprint identification [22]. LCA was also used to study the technology of balanced fertilization, and it has provided the basis for establishing the inventory of farmland greenhouse gas emissions and proposed measures for agricultural greenhouse gas emission reduction [23]. LCA is an effective tool for evaluating and solving environmental problems because it includes a complete life cycle from cradle to grave of one product [24–28]. However, so far, the research using LCA to evaluate the environmental effect of MFCF was limited. Thus, purposes of this study were to (i) assess the potential environmental impact caused in the life cycle of MFCF production: transportation of raw materials, production of fertilizer and application of fertilizer and (ii) select the measures to reduce the environmental pollution caused by magnetized fertilizer.

2. Materials and methods

2.1. Life cycle assessment

LCA is defined by the International Standardization Organization (ISO) as the compilation and evaluation for a product or a process. It is an analytical method that includes the whole life cycle process for MFCF [24]. LCA is a novel tool for environmental protection and environmental management; it cannot only effectively evaluate the environmental impacts of the production process but also take into account the pre-investment and post-use phase [29]. Through LCA, the new measures for improving product design can be found, and it also provides new ideas to reduce environmental pollution.

According to the basic framework of international standard ISO 14040, LCA were divided into 4 parts: system boundaries (ISOl4040), inventory analysis (ISOl4041), environmental impact assessment (ISOl4042) and interpretation of results (ISOl4043) [30].

2.2. Functional unit

The functional unit and system boundaries play important roles in LCA, and the end results of a LCA are dependent on the system boundaries and the functional unit (FU). The most commonly used functional unit was based on mass [31–33]. In this paper, the FU was defined as a “product of 1 t of MFCF”. The inputs and outputs of material flow and energy flow, as well as the potential risks of environmental pollution throughout the 1 t MFCF life cycle were analyzed in this study.

2.3. System boundaries

The MFCF system throughout its life cycle included three stages: material transportation, production process and fertilization. The transportation stage involved the transportation of raw materials and MFCF. The production process included three steps: firstly, calculating the weight ratio of raw materials (N, P, K) for 1 FU MFCF production and then mixing them; secondly, making the mixture into small and roundish grains using a spheroid granulator and then drying them; lastly, magnetizing these roundish grains and making them naturally dried. After the above steps the MFCF was packaged and transported to the field. During the stage of field application, it was assumed that the same agricultural activities were applied to MFCF and conventional fertilizer, so the environmental impacts resulted from infrastructure, ploughing, irrigation, pesticide use, weed mowing and harvesting were excluded from the boundaries of this study. In summary, the potential environmental impacts in the MFCF system throughout its life cycle were as follows:

Transportation: use of diesel;.

Production: use of energy and coal;.

Field: volatilization and leaching loss of fertilizers, inputs of heavy metal.

The system boundaries of 1 FU MFCF product are shown in Fig. 1.

2.4. Inventory

Life Cycle Inventory (LCI) is an important part of the life cycle assessment; the end result depends on the precision and integrity of LCI. In this study, the data used to calculate environmental impacts of MFCF were taken from other research results [22,34–38]. Table 1 shows the inventory considered in the study, according to the FU described in Section 2.2.

2.4.1. Basic data calculation

According to the system boundaries of LCA, the calculation of basic data included three stages: transportation, production and fertilization.

2.4.1.1. Transportation. Raw material and finished product were transported to factory and field using a diesel lorry. In this stage, diesel was consumed in large amounts and which resulted in air pollution, such as CO_2, CO and SO_2. These gases could make great harm to human health [39,40]. Dust was also observed when materials were transported. Because the amount of dust could not be found, it wasn't listed in the inventory.

The traffic vehicle in this research was the lorry and its fuel was diesel. The diesel lorry could load up to 5 t of goods. To optimize the calculation and application of the methodologies, some assumptions were made. It was assumed that the distances of transportation were 10 km for FA and 15 km for N, P, and K. The transportation distance of MFCF was 30 km from factory to field. Power plant and fertilizer plant were usually built in suburbs with less traffic flow, so traffic congestion was ignored in this study.

2.4.1.2. Production. The production machineries could consume large amounts of electricity. Thermal power was dominant in China. Many types of harmful gases were discharged to air when coal was burned. Those gases could result in a number of serious environmental problems.

Many types of machinery were used when MFCF was produced according to production experiences from the Huanan Magnetized

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