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Life cycle environmental impacts of cornstalk briquette fuel in China

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HIGHLIGHTS

- First detailed LCA on cornstalk biomass briquette fuel (BBF) in China.
- Provides up-to-date LCI for cornstalk BBF based on full-scale operational data.
- Results show cornstalk BBF is more environmentally friendly than coal.
- Cornstalk BBF is also favourable when compared with other biomass solid fuels.

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ABSTRACT

The use of agricultural residues to produce biomass briquette fuel (BBF) can reduce waste of resources and consumption of fossil fuels. We report the first detailed environmental impact assessment of cornstalk-based BBF in China using a cradle-to-grave life cycle assessment (LCA). The LCA study was conducted based on a typical large-scale cornstalk BBF demonstration project in China with an integrated and automated production system. The key life cycle stages such as cornstalk growth, cornstalk transportation, BBF production, transportation and utilisation were investigated. Our results suggest that cornstalk BBF in China is much more environmentally friendly than coal and is favourable when compared with other types of solid fuels produced from different biomass feedstock. For example, the climate change and fossil depletion impacts of cornstalk BBF in China (11 g CO_2 eq./MJ and 2 g oil eq./MJ, respectively) are an order of magnitude lower than those of coal (146 g CO_2 eq./MJ and 26 g oil eq./MJ, respectively). The results of this study can assist policy makers in evaluating the potential benefits of the large scale use of BBF made from agricultural residues.

1. Introduction

In recent years, there has been increasing interest at the global level in the use of biomass as a renewable feedstock due to the growing awareness of climate change and the need to produce energy with less dependence on fossil fuels in order to increase the security of fuel supplies, maintain stability against potential price shocks and reduce imports, as well as to reduce the environmental impacts of fossil fuel use [1]. Biomass not only offers a potentially "clean" energy source, but is also the only type of renewable carbon resource that can be relatively easily collected, stored, and transported, and is the form of renewable energy most similar to fossil fuel energy sources, such as coal. Biomass is also the only renewable energy resource that can be directly converted into solid, liquid and gas forms [2], all of which play important roles in meeting energy demand. In China, traditional biomass energy (e.g., burned in rural areas as energy for household cooking) is currently the major form of bioenergy use. It has been estimated in a renewable energy map of China that modern biomass energy (including biomass power, liquid fuel, district heating, etc.) will account for about 25% of China's renewable energy use by the year 2030 [3].

Agricultural and forestry residues form the major sources of biomass resources. However, these sources have various limitations, such as their scattered distribution, low energy density, and inconvenient storage and transportation compared to fossil fuels, which significantly limits their large-scale application [4]. To enable the large-scale utilisation of agricultural and forestry residues, it is necessary to first convert them into a high density,

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high energy content and low moisture solid fuel, e.g., biomass briquette fuel (BBF) [5]. The process of creating BBF involves compressing unshaped raw material into higher-density briquette fuel by drying, chopping, and compressing into briquettes (or pellets) [6], thereby reducing transportation and storage costs, improving the utilisation efficiency, and generally expanding the scope of its application [7]. BBF can be used not only in power generation [8,9], district heat [10] and domestic boilers heating [11,12], but also in cooling devices [13], combined heating and power (CHP) systems [14,15], Fischer–Tropsch (FT) diesel production [16] and gasification and combustion equipment [17,18]. It is estimated that the use of BBF will reach 50 million tonnes in China by the year 2020 [19], and BBF plays an increasingly important role in modern biomass energy.

The increasing numbers of studies relating to BBF technology and its applications and life cycle assessments (LCAs) have provided information on the social, economic and environmental performance of BBF [5,20–28]. A life cycle approach involves a cradle-to-grave assessment, where the product is evaluated from its initial production stage involving recovery of raw materials, through to its end use. It is rapidly becoming a commonly-used approach for environmental management [29] and an important decision-making tool for promoting alternative fuels because it systematically analyses the energy balances, environmental impacts, and cost benefits, which can in turn guide the implementation of fuel policies [30–32].

Among the LCAs in recent years for BBF [21–28], Adams et al. [21] studied the potential environmental impacts associated with integrating torrefaction into bioenergy systems to produce torrefied wood pellets, and compared their results with conventional wood pellet production. Tabata et al. [22] discussed the effectiveness of a system using woody biomass that would result in increased net energy production through wood pellet production, along with the energy recovery processes related to household energy demand, and evaluated the direct environmental load of the system, including the wood pellet production and utilisation processes. Laschi et al. [23] evaluated both the environmental impacts related to high-quality pellet production and the critical steps throughout the production process using a cradle-to-gate LCA approach in Tuscany, Italy. They also examined forest activities to evaluate the environmental impacts of wood extraction at the global level. Tsalidis et al. [24] evaluated the environmental benefits in terms of global warming, acidification and the photochemical oxidation potentials of biomass direct co-firing with coal using a 20% energy input basis relative to coal-fired power generation in the Netherlands, in which solid biofuel was produced from Dutch or Canadian forestry biomass via pelletisation, torrefaction or torrefaction and pelletisation. Benetto et al. [25] analysed the production chain of grape marc pellets and, using an LCA based on primary data from field experiments, evaluated the overall environmental performance of using grape marc pellets for heat production, and performed a comparison with fossil fuel and other renewable energy resources. Rousset et al. [26] conducted an environmental impact assessment for wood charcoal briquettes produced from eucalyptus wood in Brazil, with a specific focus on the impacts relative to the Global Warming Potential (GWP). Pa et al. [27] investigated the replacement of natural gas by wood waste for district heating and wood pellet gasification systems with and without emission controls using a streamlined LCA. Fantozzi et al. [28] presented an LCA study on household heat from short rotation coppice wood pellet combustion, and analysed thermal energy generation from wood pellet combustion obtained from dedicated energy crops (poplar) compared to the natural gas chain used in a domestic boiler.

Despite the various studies to date including the aforementioned LCA studies of BBF from forestry residues, to the best of our knowledge, there have been very few detailed LCA studies of BBF from agricultural residues, such as cornstalk. As one of the world's major agricultural economies, China produces 600–800 million tonnes of crop straw every year [33]. Cornstalk is one of the major types of crop straw, accounting for one third of total production and amounting to 250 million tonnes per year [34]. However, there have been few studies of the environmental impacts of cornstalk briquette fuel in China. Hu et al. [5] conducted a preliminary LCA on cornstalk briquette fuel in China based on a typical fully-operating plant and covered only emissions of greenhouse gases (GHG) and criteria air pollutants. To the best of our knowledge, there is no detailed and comprehensive LCA study of cornstalk briquette fuel in China in the international scientific literature. To fill this gap we therefore performed an LCA of briquette fuel produced from a large-scale cornstalk briquette fuel demonstration project that incorporates a fully integrated and automated production system. A comprehensive assessment of the life cycle environmental impacts was performed, covering key life cycle stages including cornstalk growth, cornstalk transportation, briquette fuel production, transportation and utilisation. The results from our study can provide evidence for policy makers in evaluating the potential environmental benefits of large-scale production of BBF and enhancing the efficiency in the use of biomass resources in China. Section 2 presents a description of the cornstalk briquette fuel demonstration project, and the LCA system boundaries and methodology for the study. Section 3 describes the life cycle inventory (LCI) analysis of the key life cycle stages of the BBF. Section 4 presents the results of the environmental impacts from the LCA, and finally Section 5 summarises the conclusions from the study.

2. Method

2.1. Project description

With the growing concern related to energy security and various forms of environmental pollution, technological innovations in energy-related equipment have begun to focus on improving efficiency, reducing consumption, and protecting the environment. Drying, chopping, briquetting, and cooling machines are the major components in large-scale BBF operations. By integrating the machines involved in these processes, biomass material can be converted into high-efficiency BBF [6]. A fully operational 5220 t/a (5000 t for sale outside the plant, and 220 t for consumption within the plant) cornstalk BBF plant with an integrated and automated production system located in Ruzhou City, Henan Province, China, was used as a case study. The plant covers an area of 20,000 m^2, comprising a 4500 m^2 area of built-up land, a 15,000 m^2 raw material site and a 500 m^2 workshop. The system combines: (1) the cornstalk storage stage; (2) the first chopping stage; (3) the stages of second chopping, drying, briquetting, cooling and screening, and briquette fuel packing; and (4) the briquette fuel storage stage (see Fig. 1).

2.2. LCA methodology

The life cycle environmental impacts were evaluated according to the ISO 14040 [35] and ISO 14044 [36] standards following an attributional LCA approach [37] and using process-based LCI technique and the SimaPro 8.2 software [38]. The system boundary for the present analysis was field-to-energy (FTE), comprising 4 key stages (see Fig. 2): cornstalk growth (ST1), cornstalk collection and briquette fuel transportation (ST2), briquette fuel production (ST3) (including biomass storage, the first and second chopping, and drying, briquetting, cooling and screening, briquette fuel packing and storage), and BBF utilisation in heating equipment (ST4).