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Life cycle assessment of gold production in China

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ABSTRACT

Gold production has significant environmental impacts on ecosystem and human health. China, as the largest gold production country in the world, deserves a special attention. This study assesses the environmental impacts of gold production in China by using life cycle assessment. Key factors contributing to the total environmental burden of gold production were also identified. In addition, uncertainty analysis based on Monte Carlo was conducted to improve the reliability of results obtained in this study. Results show that impact from metal depletion category mainly from gold ore mining was the most contributor to the total environmental impact. Meanwhile, impacts from climate change, terrestrial acidification, human toxicity, particulate matter formation, marine ecotoxicity, and fossil depletion also made contributions. The overall environmental impact was dominated by key factors such as ore mining, energy consumption, and on-site emissions. Policy suggestions (e.g., maximizing resource efficiency, adjusting energy structure, promoting gold recycling, implementing ecological compensation) were proposed to promote the sustainable development of gold production.

1. Introduction

Due to its relative rarity, easy handling and minting, easy smelting and fabrication, resistance to corrosion and other chemical reactions, gold has been widely used for coinage, jewelry and other arts. Now it is one of the most valuable metals and has a significant role in global economy, such as international reserves by most national banks. Studies on the prediction of gold price have been performed (Aye et al., 2015; Wen et al., 2017). As one of the scarce and strategic resources, gold plays a special role on modern industries, with high vulnerability to supply restriction and the low availability of viable substitute (Graedel et al., 2015). But gold production has induced many environment and public health issues worldwide (Jeronimo et al., 2015). For example, gold mining process is directly responsible for ecosystem degradation due to mining-related vegetation removal and soil excavation (Asner and Tupayachi, 2017). Gold extraction and processing are also significant sources of hazardous chemicals such as cyanide and arsenic compounds, leading to serious impact on biodiversity and human health (Akpalu and Normanyo, 2017). Therefore, it is critical to assess the environmental impacts generated from gold production so that appropriate solutions can be found.

Life cycle assessment (LCA) is an effective tool for evaluating a product's environmental burden by quantifying the impacts of all inputs and outputs associated with corresponding production processes (ISO 14040, 2006). LCA has been extensively applied for evaluating the environmental impacts generated from metallurgy industry, such as aluminum (Hong et al., 2012; Zhang et al., 2016), steel (Burchart-Korol, 2013; Chen et al., 2016a), zinc (Van Genderen et al., 2016; Qi et al., 2017), and lead (Davidson et al., 2016; Hong et al., 2017). However, LCA studies on gold production were very few (Norgate and Haque, 2012) and none of them were about China. Moreover, these published studies failed to provide a comprehensive evaluation, leading to incomplete understanding on environmental

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impacts from gold production. For instance, previous studies found that metal depletion made an important contribution to the total environmental impacts generated from lead (Hong et al., 2017) and zinc production (Qi et al., 2017). China has become the world's largest gold producer since 2007 (CGA, 2017), accounting for about 14% of global gold production in 2016 (WGC, 2017a). Consequently, it is necessary to conduct a systematic LCA study so that a holistic picture of environment burden from gold production (such as pollutants from gold production) can be obtained. Also, uncertainty analysis is conducted so that results obtained in this study could be more reliable and provide more valuable policy insights. In addition, a comparison study between gold production and other metal production is conducted to further identify potential improvements for the entire metallurgical industry. The whole paper is organized as below. After this introduction section, Section 2 details research methods and data sources. Then, Section 3 shows research results and Section 4 discusses policy implications. Finally, Section 5 draws research conclusions.

2. Methods and data

2.1. Functional unit and system boundary

Functional unit can provide a quantified reference for related inputs and outputs of an investigated system and therefore is essential for the comparison of LCA results (ISO 14040, 2006). In this study, 1 kg gold production was selected as the functional unit. System boundary is shown in Fig. 1 (using a cradle-to-gate approach), in which the processes of raw materials and energy production, waste disposal, transport, and direct emissions of all stages of gold production were included. All materials and energy consumption, direct emissions, waste disposal, and transport were based on the functional unit.

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

		Amount	Unit
Raw materials and energy consumption	Gold ore	261.93	t
	Steel	344.09	kg
	Xanthate	74.19	kg
	Gold concentrate	7.07	t
	Sulfur concentrate	801.78	kg
	Limestone	1.66	t
	Sodium cyanide	198.95	kg
	Water	226.48	m^3
	Sodium metabisulfite	118.02	kg
	Copper sulfate	94.42	kg
	Ferric sulfate	492.95	kg
	Electricity	3.01×10^4	kWh
	Coal	1.04	t
	Gasoline	33.58	kg
	Diesel	161.66	kg
Waste treatment	Hazardous waste incineration	9.51	kg
	Municipal solid waste landfill	38.03	kg
	Wastewater treatment	10.04	t
Air emissions	SO_2	74.52	kg
	Arsenic	0.29	g
	Particulates (diameter < 0.10 μm)	526.07	g
	Carbon dioxide	1.47	t

2.2. Life cycle inventory

Life cycle inventory (LCI) of gold production are shown in Table 1. All the energy and materials consumption, direct emissions, waste disposal, and transport were based on one functional unit within the system boundary.

2.3. Data sources

The LCI of gold production shown in Table 1 are collected based

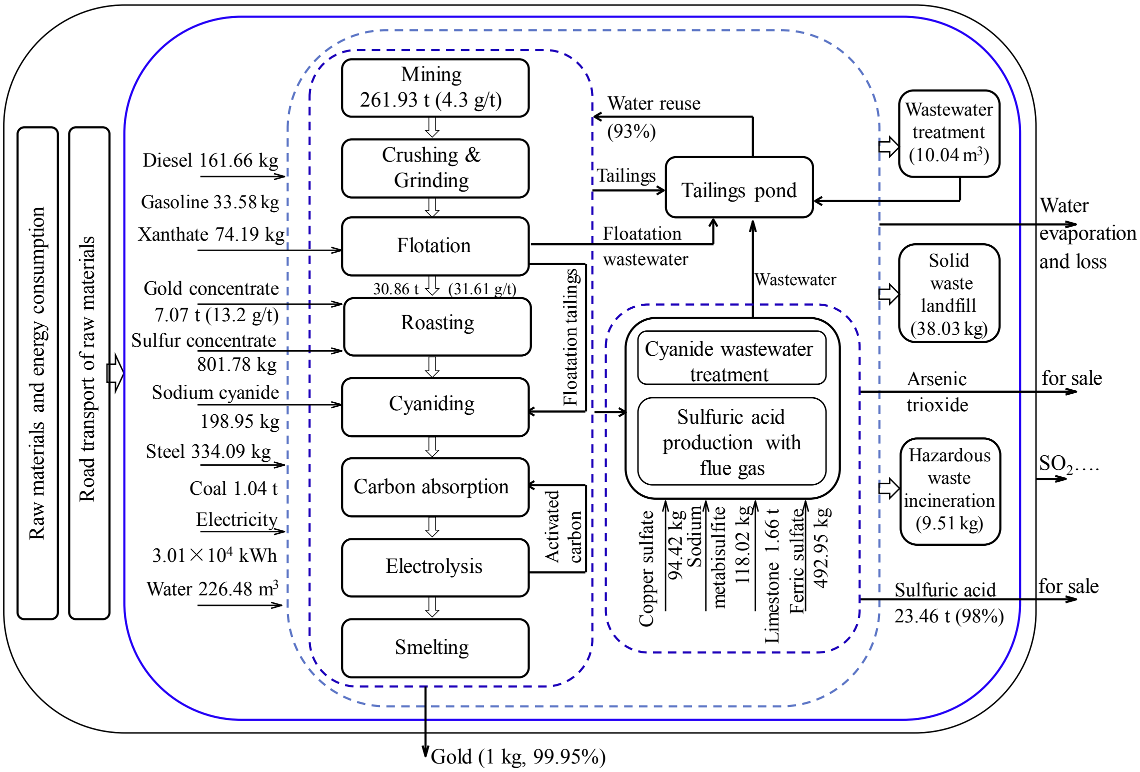

Fig. 1. System boundary.