Resources, Conservation & Recycling 131 (2018) 235–246

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Assessing energy intensity and retrofit opportunities for the aluminum industry: Lessons from Vietnam

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ARTICLE INFO

Keywords:
Aluminum production
Energy intensity
Energy efficiency
Industry
Vietnam

ABSTRACT

- This study provides a novel analysis of energy and technology use in Vietnam's aluminum industry. Vietnam has the world's fourth largest bauxite reserves, and is developing a full aluminum supply chain, from bauxite mining to aluminum smelting. Aluminum production is one of the most energy-intensive industrial processes, yet Vietnam has relatively few domestic energy resources, and no data on energy use in its aluminum industry. This paper quantifies energy intensity in each phase of aluminum production in Vietnam in comparison to global estimates. The paper finds that Vietnam's aluminum production is more energy intensive than the global average, driven by high energy intensity in the alumina production phase. The paper identifies broad barriers to industrial energy efficiency in Vietnam and similar countries, and how these challenges can be incorporated in future research. Potential retrofit technologies are identified for Vietnam's alumina plants, including cost and energy saving potential for each technology. Analysis of net present value, including policy scenario analysis, indicates that some of these retrofit technologies are promising investments in the near term, with simple payback periods of less than ten years for four out of the five technologies identified. The energy footprint of Vietnam's aluminum industry is an important consideration for policymakers in Vietnam, given Vietnam's need for energy resources, and promoting efficient operation of Vietnam's aluminum industry will require additional technology and policy changes. This research demonstrates a mixed-methods approach that can be applied to address the challenges data-constrained planners face in developing energy-intensive industries worldwide.

1. Introduction

Aluminum is one of the most ubiquitous metals in the world, a necessary material for consumer products, infrastructure, technology, and more. Aluminum production is a highly energy-intensive industrial process and causes significant environmental impacts, from greenhouse gas emissions to local water pollution. Many countries track the inputs and outputs of aluminum production due to the industry's large footprint, which enables country-level modeling of historical and forecasted trends of emissions associated with aluminum production (Li et al., 2017; Hao et al., 2016). Databases like the U.S. Environmental Protection Agency's Toxics Release Inventory or the International Aluminium Institute's global life cycle inventory provide historical data on emissions and/or energy use from aluminum-producing facilities. Global life cycle inventories also enable life cycle assessments of the aluminum industry across multiple countries (Paraskevas et al., 2016; Ciacci et al., 2014; Liu et al., 2015; Tan and Khoo, 2005). However, these databases do not have complete coverage of the world's aluminum production supply chain. There is a lack of data for recent and planned facilities, especially in countries without an established infrastructure for reporting and surveys. In addition, there is less data on alumina plants, which supply intermediate material to aluminum smelters and consume a large amount of energy. This research examines aluminum production in Vietnam, where there have been recent efforts to develop an aluminum supply chain, from bauxite mining to alumina production and aluminum smelting. The paper provides a simple mixed-methods approach using primary and secondary data to estimate energy intensity in an area that lacks data for detailed analysis. In addition, given Vietnam's few domestic energy resources, the paper also analyzes technologies for more energy efficient production in Vietnam's aluminum industry. These results demonstrate a way for policymakers in data-constrained environments to assess energy use and identify areas for improvement.

Vietnam's aluminum industry has garnered interest from social scientists, who have focused on the social backlash to the development of Vietnam's aluminum industry around 2009 and 2010 as a unique

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https://doi.org/10.1016/j.resconrec.2017.12.020
Received 28 June 2017; Received in revised form 4 December 2017; Accepted 20 December 2017

case of citizen organizing in Vietnam (Morris-Jung, 2015; Vuving, 2010; Marston, 2012) and of ethnic tension with Chinese developers (Yeophantong, 2015; Fforde, 2012; Lazarus, 2012). There has been scant characterization of the aluminum industry that developed after the protests, or the industry's connection with energy and resource policy in Vietnam. Although much of the early backlash to Vietnam's aluminum industry was environmentally motivated, including anecdotal evidence of pollution and energy-related externalities (Tuoi Tre News, 2014), there are no publicly available environmental impact assessments or any such quantification of actual resource use in the industry. This research estimates energy intensity in Vietnam's aluminum industry and analyzes potential retrofit technologies for a more energy efficient industry. By placing this analysis in the broader context of Vietnam's energy and industrial planning, this study ties the development of Vietnam's aluminum industry to the country's broader energy policy. The case of energy use and aluminum production in Vietnam broadly demonstrates some of the key challenges for energy-intensive industry in emerging economies.

The structure of this paper is as follows: first, the paper provides background information on global aluminum production and processes, and discusses the development of Vietnam's aluminum industry. Next, the methodology is presented. The paper then presents results indicating that Vietnam's aluminum supply chain is more energy intensive than the world average, driven by key steps of the alumina refining process. Challenges to energy efficiency in Vietnam are also identified and discussed. These findings motivate subsequent identification and analysis of retrofit technologies for energy efficiency. Finally, the paper concludes with discussion on environmental impacts, future analysis, and implications for Vietnam's energy and industrial development policy.

2. Background

2.1. Global aluminum production and energy use

Aluminum production is one of the most energy-intensive industrial processes. In addition, although about half of global aluminum production uses electricity from hydropower sources, the continued use of coal as the primary fuel for electricity generation for aluminum production in many countries means that aluminum production is still a significant source of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions. According to the International Energy Agency (IEA), the aluminum industry accounts for about 1% of global CO_2 emissions (IEA, 2012).

Annual world aluminum demand is expected to increase two- to three-fold by 2050. The bulk of growth in consumption of aluminum will take place in China, India, and other developing countries, where consumption is expected to nearly quadruple by 2025 (Menzie et al., 2010). To meet this increased demand, production is projected to grow from approximately 41 million tons (Mt) of primary aluminum in 2010 to 89–122 Mt in 2050 (IEA, 2012). This significant increase in aluminum consumption and production will drive a corresponding increase in the industry's absolute energy use and CO_2 emissions, unless energy efficiency in the supply chain improves.

Bauxite, the ore for aluminum, is highly abundant. Bauxite is mined and processed into alumina (Bayer process), before being transported to an aluminum smelter, which converts alumina into aluminum (Hall-Heroult process). These steps comprise primary aluminum production, whereas secondary aluminum production refers to production of aluminum from recycled sources. As a rule of thumb, it takes roughly two tons of dried bauxite to produce one ton of alumina, and two tons of alumina to produce one ton of aluminum metal.

China and Australia are the world's top bauxite and alumina producers (after Indonesia banned bauxite exports in 2015), while China is also the world's top aluminum producer (Fig. 1) (USGS, 2015a,b). Globally, aluminum smelters tend to be located in areas where electricity is inexpensive and abundant. In addition to low-cost energy, the ability to mobilize large amounts of capital and infrastructure also determines the placement of aluminum smelters. Aluminum smelters require many of the hallmarks of development – large amounts of capital, a reliable electricity supply, and advanced technologies – whereas bauxite and alumina production are relatively less capital- and electricity-intensive. In the next section, this paper introduces Vietnam's aluminum industry within the context of these global patterns.

2.2. Vietnam's aluminum industry

Vietnam has the world's fourth largest bauxite reserves (USGS, 2015b), a remarkable alignment of geology and national borders. The Central Highlands have the most concentrated bauxite deposits in Vietnam, with the most favorable type of bauxite (gibbsite) for conversion to alumina (see Appendix A). Despite its ample bauxite reserves, Vietnam is not a significant producer of bauxite, alumina, or aluminum. Yet other countries with major bauxite reserves are also top bauxite, alumina, and aluminum producers (Fig. 2).

The Vietnamese government previously considered producing bauxite and alumina in order to spur economic development. Preliminary exploration of Central Highlands bauxite first occurred with support from the Soviet Union in the 1980s, and then multinational aluminum companies after the collapse of the Soviet Union (Morris-Jung, 2015). In 2007, Nguyễn Tấn Dũng, Vietnam's Prime Minister at the time, approved the 2007–2015 Master Plan on Exploration, Exploitation, Processing, Refining, and Use of Bauxite Ores. The Master Plan laid out a goal of Vietnam producing 13–18 Mt/year of alumina by 2025, which would put it on par with countries like Jamaica and Guinea (Tran, 2011). The state-owned Vietnam Coal and Mining Corporation (VINACOMIN) was named as the primary implementer of this plan.

VINACOMIN ultimately selected CHALIECO, a subsidiary of the Aluminum Corporation of China (CHALCO), to finance and construct two alumina plants in the Central Highlands. A major public backlash, combined with financial obstacles, quickly eliminated hopes of a larger aluminum industry in Vietnam. The bauxite mines became highly politicized, as environmental scientists expressed concerns and General Võ Nguyên Giáp, a popular war hero, linked the bauxite mines with Chinese imperialism and national security threats (Morris-Jung, 2015). As of 2016, Vietnam had just one operating alumina plant, the Tan Rai plant in Lam Dong province with a planned capacity of 650,000 t of alumina per year. Another alumina plant (the Nhan Co plant in Dak Nong province) and an aluminum smelter are planned to open soon (Table 1).

Currently, Vietnam is dependent on imports of aluminum to meet demand, and demand is rising as the standard of living also increases. A full supply chain within the country could reduce import dependency. The government faces a policy choice to be made in the next few years: to leave the aluminum industry to wither without government subsidies; to continue supporting a small industry that supplements imports; or to expand it to meet domestic demand and high-level development goals.

A major factor in this decision is the performance of the current plants. The energy intensity of aluminum production is thus an important metric of a production unit's technological and economic success, given that energy inputs make up the bulk of operating costs. Aluminum is sometimes referred to as "packaged electricity" due to the sheer amount of energy and electricity required to produce it. In addition, the use of coal as the primary energy input in Vietnam's aluminum industry played a part in inciting health and environment-motivated backlash from Vietnamese scientists and NGOs, mentioned above. Thus, the efficiency of energy use is a critical aspect of industry performance both generally and in Vietnam.

Using energy intensity as a metric of economic and technological success, this paper quantifies energy use in Vietnam's aluminum