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GREEN PRODUCTION MANAGEMENT IN THE ALUMINUM INDUSTRY: A SUSTAINABLE APPROACH TOWARDS ENVIRONMENTAL PERFORMANCE

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ABSTRACT

Implementing green production management (GPM) practices has become increasingly vital for ensuring a sustainable future. Integrating green scientific research into the aluminum industry is imperative for achieving economic and environmental benefits. Despite being touted as a "green metal," the aluminum production process presents significant sustainability challenges. Notably, the industry contributes a substantial 3% to global carbon emissions, with the production of one metric ton of primary aluminum releasing 10-20 metric tons of CO_2. Thus, reducing these emissions is critical to promoting environmental sustainability within the industry. This article meticulously examines this pressing issue and analyzes potential strategies to foster a greener aluminum production process. The intrinsic value of this study lies in its capacity to make substantive contributions towards environmentally sustainable practices in this specific industrial domain.

Keywords: green production management; GPM; GSCM; aluminum industry; green economics; energy; sustainability; climate change

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INTRODUCTION

The concept of GPM emerged in the late twentieth century through scientific literature and quickly gained widespread recognition. The imperative of transitioning towards a greener economy has become essential for the planet's future, driven by growing concerns about the global environmental situation from an anthropological perspective. Thus, adopting green principles in supply chain management has gained significant prominence.

This study focuses on GPM within the strategic context of the aluminum industry. Despite aluminum being considered a "green metal" due to its industrial versatility, its production process is the primary focus of research regarding global climate change. Investigating the aluminum industry through the lens of green principles holds global relevance. This research is unique because it explores two critical issues simultaneously: GPM and the aluminum industry. The overarching hypothesis of this study is to identify green imperatives and obligations within this crucial domain. Apart from its general significance, the aim is to discover innovative solutions to specific green business management challenges to thrive within the global economic landscape.

The aluminum industry operates within a global supply chain system. From primary production to the final consumer market, this macroeconomic cycle consumes substantial energy, emits greenhouse gases, and generates various other industrial wastes. What is noteworthy, however, is that a substantial magnitude of carbon dioxide emissions is initiated during the initial stages of aluminum production. Understanding the content and principles of GPM within the global aluminum industry is crucial to identify its main challenges and proposing innovative approaches. According to the International Aluminum Institute, global aluminum production reached 67,841 million tons between October 2021 and November 2022 (IAI, 2022). The global economy has a continuous strategy to increase future production potential further, with renewable energy availability playing a significant role in facilitating aluminum production.

Aluminum production is a strategic economic process, and its management necessitates a high level of responsibility due to the continuous chain of technological processes involved. Supply chain management assumes this responsibility, and the procurement stage represents the initial link in the chain. The primary objective of the procurement stage is to ensure the timely supply of raw materials and equipment to all complex plants. Even minor deficiencies in this process can result in significant complications across the entire operation, so traditional procurement processes must evolve to optimize the aluminum industry using green principles. Consequently, the first strategic step of green business should involve adopting green procurement practices. The primary raw material, bauxite, is used to obtain aluminum oxide, which is necessary for producing liquid aluminum.

The aluminum industry contributes significantly to global economic growth by meeting the diversified needs of industrial sectors and consumers. Rising environmental concerns about traditional aluminum manufacturing methods have inspired the investigation of green manufacturing management (GPM) as a solution. Theoretical research in GPM provides a platform for adopting sustainable techniques in aluminum production, including the three fundamental concepts of cleaner production, life cycle assessment (LCA), and extended producer responsibility (EPR). Cleaner production promotes ecologically friendly technology and processes (Wicaksono, A. D., Agustina, D. & Meidiana, C., 2021), whereas life cycle assessment provides a full assessment of environmental implications (Liu, G., & Müller, D. B. 2012). Extended producer responsibility highlights the obligations of manufacturers across the product life cycle (Gupt, Y & Sahay, S., 2015). Theoretical insights are supplemented by empirical research, which demonstrates real-world implementations of sustainable practices such as energy consumption and CO2 emissions disclosures, energy-efficient devices, and renewable energy integration.

The production process forms the fundamental foundation of the economy. Because the aluminum industry falls under heavy metallurgy, the production process carries particular economic and environmental significance. Aluminum production requires substantial energy consumption and contributes significantly to greenhouse gas emissions. In this regard, the green production phase represents the most comprehensive GPM platform for the aluminum industry. The industry encompasses a complex and lengthy production chain, starting with the mining sector for extracting aluminum ores. Subsequently, aluminum oxide and liquid metal manufacturing processes constitute the backbone of aluminum production, accounting for over 90% of total CO_2 emissions. Technological processes following primary aluminum production exhibit low energy consumption and minimal carbon emissions (Safarov et al., 2023). The primary objective is to continuously reduce greenhouse gas emissions to the greatest extent possible, aiming to achieve 4-5 tons of CO_2 emissions for every ton of aluminum produced. The long-term goal is to attain zero emissions.

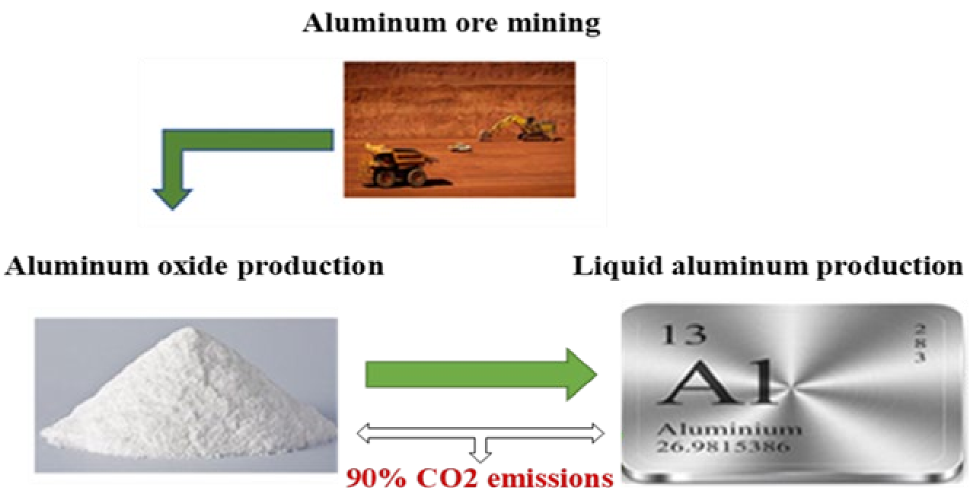

Figure 1. Sectors with the most CO_2 emissions in the aluminum industrial chain
Source: Authors' finding

Implementing energy-efficient technologies and adopting efficient operational processes are crucial to minimizing energy consumption in the aluminum production process. This involves optimizing and improving overall process efficiency through advanced control systems and operational practices. By incorporating these measures, the industry can significantly reduce its energy demands and contribute to sustainable resource management. This focus on energy efficiency aligns with broader objectives of reducing greenhouse gas emissions and promoting environmental sustainability within the aluminum production sector.

From theoretical views to empirical studies, scientific views on the research vectors of green research on aluminum production are freshly examined in this paper. The new contribution of this research work is the definition of the "green production passport" in the example of an existing practical enterprise. The notion of a "green production passport" has evolved in response to the necessity of environmental responsibility. This passport encourages sustainability and responsibility throughout the aluminum product's lifetime. The theoretical foundations of the green production passport are based on GPM concepts. The documentation of energy consumption and emissions data in the passport encourages the adoption of cleaner technologies and practices in aluminum production, lowering the industry's total environmental impact. Empirical studies of aluminum businesses that have implemented the green production passport shed light on the practical advantages of this method. These principles demonstrate increased resource efficiency, reduced greenhouse gas emissions, and improved environmental performance across the whole supply chain.

LITERATURE REVIEW

The subject of green production is relatively new in terms of scientific theoretical exploration. One notable example within the scholarly discourse is Enrique Leff's (1995) work, where the author delved into the economic and environmental principles from an epistemological perspective. Leff's work contributed to the theoretical understanding and conceptual foundations of green production. Tsai et al. (2015) utilized indicators to create an all-encompassing assessment system for green production. The criteria system for green production developed in this study holds significance both in terms of theoretical contributions and its wide-ranging practical applications. The central focus of Zhou et al. (2013) was to concentrate on a holistic approach to enhance the analysis process and facilitate decision-making.

In scientific literature, the concept of GPM is often examined in the context of green supply chain management (GSCM). GPM refers to adopting sustainable practices and technologies within the manufacturing process to minimize environmental impacts. GSCM has received significant attention in the scientific literature, reflecting its status as a contemporary and pressing issue. The GSCM system comprises four principal stages: green procurement, green production, green transportation, and waste and recycling. The environmental significance of the initial three stages is particularly noteworthy in heavy industries due to their direct and far-reaching implications for global climate change. In the case of the aluminum industry, the final stage holds particular relevance as aluminum is already acknowledged as an environmentally friendly material owing to effective waste management and recycling processes. Notably, the Aluminum Association reports recycling rates for aluminum surpassing 90% in most industrial markets, with recycled aluminum conserving 95% of the energy required for producing new aluminum (The Aluminium Association, 2021). Starting from theoretical foundations, this research endeavors to elucidate the GSCM system specifically within the context of the aluminum industry, with a distinct focus on the first three stages.

Figure 2. The main GSCM stages for the aluminum industry.
Source: Authors' finding

The central tenet of the GSCM system is transforming economic profit into environmental efficiency. A thorough review of the literature reveals that research in GSCM is rapidly advancing, accompanied by proposals for conceptual frameworks for transforming traditional supply chains into environmentally conscious green supply chains (Badhotiya et al., 2017). Key literature sources guiding research in GSCM include comprehensive reviews (Achillas et al., 2019), foundational concepts and design principles (Sarkis & Dou, 2018), optimization models (Paksoy et al., 2019), and strategic approaches (Lyons, 2015). Zhu et al. (2022) thoroughly investigate various aluminum manufacturing systems' environmental consequences and economic benefits, providing valuable insights for policymakers and industries seeking sustainable and efficient approaches.

GPM represents an innovative approach to environmental management adopted by environmentally conscious entrepreneurs across entire supply chains, shifting the focus from individual non-environmental enterprises. Through this holistic perspective, supply chains of diverse enterprises from different countries can be integrated in an environmentally responsible manner (Adel, 2021). As highlighted by Zhu and Sarkis, GSCM encompasses various dimensions, including procurement, logistics, and procurement practices aligned with ecological standards and integrated supply chains that span suppliers, manufacturers, and customers (Zhu & Sarkis, 2004). GSCM has emerged as an environmental innovation incorporating environmental considerations into supply chain management (Seman et al., 2012). In light of the increasing recognition of environmental protection, businesses face mounting pressure to align with the green trend of resource conservation and environmental preservation (Chien & Shih, 2007). In addition to comprehending the fundamental theoretical concepts in the realm of GP, access to up-to-date data from global climate change databases, the aluminum industry, and related topics is imperative for conducting effective research. By remaining attuned to the global agenda, access to the latest statistics on global climate change (United Nations, 2023), green principles (European Commission, 2023), and the international aluminum industry (International Aluminum, 2023) can be ensured.

METHODOLOGY

Identifying the energy sources consumed is a prerequisite for ascertaining the environmental performance of primary aluminum production enterprises. Power plants supplying energy to aluminum plants take precedence among the significant contributors to indirect emissions.

CRU statistics reveal that the average global carbon dioxide emissions from energy supply stand at 8.8 metric tons (t), with the figure varying depending on the specific energy sources employed. An in-depth analysis by Alglave and Dec (2021) elucidates the intricate interplay of factors influencing emission levels across these energy sources. The quantification of emissions and understanding their variability are crucial for comprehensive evaluations, aiding in informed decision-making and adopting sustainable practices within the primary aluminum production industry.

Indirect carbon emissions within the aluminum sector result from generating electricity to fuel the energy-demanding aluminum manufacturing process, affecting the industry's comprehensive carbon footprint. These emissions primarily arise from coal, natural gas, and hydropower sources, with coal being the most significant contributor to carbon emissions, while hydropower presents a more environmentally friendly option contingent upon regional accessibility.

Table1. Indirect carbon dioxide emissions from electricity supply sources are required for 1 ton of primary aluminum production.

Energy sources	CO_2 emissions
Hydro/Nuclear	0-0.3 T
Gas	6 T
Coal	15 T

Source: CRU

The carbon dioxide emission factors linked to various energy sources may exhibit variance due to the specific technologies and the fuel quality employed. Hence, accurate and up-to-date emission factors are crucial when conducting indirect carbon dioxide emissions calculations.

Knowing the net anode consumption is necessary to determine the atmospheric release of carbon dioxide resulting from the electrolysis process in the production of liquid aluminum. With the aid of the specific production technology, the quantity of CO_2 emissions per metric ton of aluminum can be derived using a prescribed formula:

$$12\,(C) + 16\,(O) * 2 = 44\,(CO_2)$$

The provided equation is a representation of the balanced chemical equation describing the combustion reaction between carbon (C) and oxygen (O2) to form carbon dioxide (CO_2). Specifically, it illustrates the reaction's stoichiometry, indicating the molar quantities of the reactants and products involved. According to the equation, 12 moles of carbon (C) react with 32 moles of oxygen (O2) to yield 44 moles of carbon dioxide (CO_2). In the balanced equation, this indicates a 1:2 ratio between carbon and oxygen and a 12:44 ratio between carbon and carbon dioxide. The subsequent calculation pertaining to the given formula is as follows:

$$44\,(CO_2) / 12\,(C) = 3.66$$

This computation establishes the molar ratio between carbon dioxide (CO_2) and carbon (C) consumed during combustion. By dividing the quantity of 44 moles of CO_2 by 12 moles of C, a ratio of 3.66 is obtained. This ratio signifies that for each mole of carbon combusted, 3.66 moles of CO_2 are generated. Subsequently, the quantity of CO_2 direct emissions can be ascertained by multiplying the ratio mentioned above by the variable (A), which represents the amount of anode utilized in the combustion process:

$$CO_2 = A * 3.66$$

The final parameter of significance in the ecological assessment is the electricity consumption (E) associated with the manufacturing of one metric ton of aluminum:

$$E = E_d / P$$

In this equation, E represents the electricity consumption required for the production of one metric ton of aluminum. The variables, E_d signifies the total energy consumed over a day and P refers to the daily quantity of aluminum produced. By evaluating this ratio, the energy efficiency of aluminum production can be gauged, offering insights into the electrical energy demand per unit of output. The main methodological approach for determining anode consumption within the aluminum industry involves assessing anode consumption, electricity consumption, and the volume of direct and indirect emissions, which constitute the primary indicators utilized in formulating a green passport.

RESEARCH FINDINGS

The electrolysis process produces primary aluminum, and the need to conduct green scientific research is most applicable to the electrolysis plant because it consumes the most electricity. The eco-economic importance of the electrolysis process can be demonstrated using two main factors:

1. The price of aluminum is mainly determined here.
2. The focal point for general environmental assessment is observed here.

Azerbaijan generated a total of 27,855.7 million kWh of electricity in 2021, as reported by the Ministry of Energy (2022). The electricity consumption in the country during the same period was 23,435.6 million kWh. In the context of aluminum production, the predominant electricity source is renewable energy, particularly from hydroelectric power stations located in the industrial region. According to data from the State Statistics Committee of the Republic of Azerbaijan (2022), hydroelectric power plants produced 1277.3 million kWh of electrical energy in 2021. The Central Dispatch Department is responsible for organizing the operational management of the energy system. Its primary role as the system operator is to ensure a stable and reliable electricity supply in the country while adhering to technical regulations and other relevant norms, including quality standards for electricity (Azerenergy, 2021). Thermal power plants hold the largest share in global electricity generation, with the combined output of other types of power plants being approximately three times lower than that of thermal power plants. In Azerbaijan, thermal power plants contribute to around 90% of the energy production. The significant reliance on thermal power plants for electricity generation in Azerbaijan can be attributed to easier fuel provision and supply, the utilization of higher-power turbines, and the simultaneous provision of heat energy (Kalbaliyev et al., 2011). In terms of green energy production, Azerbaijan demonstrates satisfactory performance compared to the global average. The majority of greenhouse gas emissions originate from coal-fired thermal power plants, but Azerbaijan does not employ solid fuels for energy supply; all thermal power plants in Azerbaijan utilize liquid fuel. The largest electricity supplier in the country is the Azerbaijan Thermal Power Plant located in Mingachevir, boasting a capacity of 2400 MW. Hydroelectric power plants play a vital role in the power generation landscape, with Mingachevir HPP (430 MW), Shamkir HPP (380 MW), and Yenikand HPP (150 MW) situated in close proximity to the Ganja Aluminum Complex which is main manufacturing facility of Azeraluminium LLC.

Total	Thermal (gas, oil)	Hydroelectricity	Internal Thermal Plants of the Enterprise	Wind	Solar	Waste
27,887	24,308	1,277	1,961	91,4	55,2	193,2

Figure 3. Azerbaijan's electricity production in 2021 (million kWh)

Source: Azerbaijan's State Statistics Committee

Aluminum production, in conjunction with iron, consumes roughly 6% of the world's electricity supply. Approximately 85% of the total electricity required for aluminum production is consumed during the electrolysis process alone (Gupta, 2017). Until recently, the production of one metric ton of aluminum necessitated around 17,000 kWh of electricity (Claisse, 2016), though global estimates suggest an average of 15,000 kWh. Alcoa, a prominent industry player renowned for its efficient technologies, asserts that one metric ton of aluminum consumes 13,000 kWh of electricity (Pyrogenesis, 2022).

The energy itself was generated here, with an international average of 10 tons of CO_2 gas per ton of aluminum., necessitating the analysis of energy sources to determine the amount of carbon dioxide emitted on a pure energy basis for 1 ton of liquid aluminum. According to the statistics shared by the US Energy Information Administration, 696 million tons of CO_2 emissions occurred during the production of 1,579 million MWh of electricity at the gas-fired TPP (EIA, 2022). This equates to approximately 0.44 tons of CO_2 emissions per 1 MWh of energy.

	Electricity production (million kWh)	CO2 emissions (million tons)
Coal	897,885	919
Natural Gas	1,579,361	696
Petroleum	19,176	21

Figure 4. US Electricity Production and CO_2 Emissions (2021).
Source: US Energy Information Administration.

The bulk of CO_2 emissions linked to manufacturing one metric ton of liquid aluminum predominantly arise from sources other than the electrolysis process.

	Electricity (Indirect)	Perfluorocarbon	Process (Direct)	Ancillary Materials	Thermal Energy	Transport
Refining	0.4	-	-	0.4	1.6	0.2
Anode Production	-	-	0.1	0.7	0.1	-
Electrolysis	10.3	0.8	1.5	0.1	-	0.2
Primary Aluminum	10.7	0.8	1.6	1.2	1.7	0.4

Figure 5. In 2021, the amount of CO_2 emitted per ton of aluminum by the main stages of the production chain (in tons).
Source: International Aluminum Institute.

Prominent research institutions affiliated with the aluminum industry have made noteworthy environmental statements. Energy-related CO_2 emissions from the global aluminum industry amounted to 663 million tons in 2019, with the top 11 countries responsible for 86% of the world's aluminum production (Hasanbeigi et al., 2022). The most recent report from the International Energy Agency (IEA) indicates that the aluminum industry is projected to contribute 3% of global direct industrial CO_2 emissions in 2021 (Hodgson & Vass, 2022). The International Aluminum Institute reports that the production of one metric ton of aluminum entails approximately 16 metric tons of CO_2 emissions throughout the entire process (International Aluminum Institute, 2022). The predominant factor influencing these figures is the choice of energy source. The selection of energy sources stands as a pressing concern in the contemporary aluminum industry and the push for a green economy. For instance, if coal is used as the energy source (E), CO_2 emissions can be generated from 15 to 20 metric tons per metric ton of aluminum. In the case of oil, the emissions also range from 10 to 15 metric tons, while for liquefied gas, they are 6 to 10 metric tons. However, if water and alternative sources are extensively employed, the emissions can be reduced to 2 metric tons or even lower. Opting for green energy sources can result in zero CO_2 emissions throughout the production process. The following formula expresses this principle:

$$E\,(coal) - 1T\,(Al) = 15\text{-}20T\,(CO_2)$$

$$E\,(oil) - 1T\,(Al) = 10\text{-}15T\,(CO_2)$$

$$E\,(natural\ gas) - 1T\,(Al) = 6\text{-}10T\,(CO_2)$$

$$E\,(renewable) - 1T\,(Al) = 0\text{-}2T\,(CO_2)$$

Typically, manufacturing one metric ton of aluminum involves utilizing approximately two metric tons of alumina. Additionally, producing one metric ton of aluminum requires 0.4-0.5 metric tons of carbon anode blocks. According to the International Aluminum Institute, the electrolysis process involved in aluminum production releases 13 metric tons of CO_2 emissions. Among these emissions, 10.3 metric tons are attributed to electricity generation from fuel employed in production. The direct emissions directly from the electrolysis process account for more than 1.5 metric tons of CO_2 (Figure 5).

The Ganja Aluminum Complex has an annual production capacity ranging from approximately 50,000 to 55,000 metric tons, reaching up to 105,000 metric tons (Azeraluminium, 2023). Notably, the complex relies on electricity sourced from hydroelectric power for its production operations, meaning that the complex has accurately quantified indirect CO_2 emissions in aluminum production, determining them to be at a level of 0 metric tons. The combined capacity of hydropower plants in the Republic of Azerbaijan is approximately 1,200 megawatts (MW). Within the economic zone of Ganja, where the complex is situated, the three largest hydropower plants have a total energy potential of 960 MW. The Ganja Aluminum Complex is indexed to these energy resources, with its consumption accounting for 90 MW. These factors indicate that aluminum production in Azerbaijan is conducted using a renewable and environmentally friendly energy source.

The primary factor contributing to CO_2 emissions during the aluminum production process is the use of anode blocks. Conducting a technological assessment for precise mathematical calculations is imperative for determining how much CO_2 they produce. At the Ganja Aluminium Complex, producing one metric ton of aluminum requires consuming 0.408 metric tons of anode blocks. Consumption of 1 ton of anodes creates 3.66 tons of CO_2:

$$12\,(C) + 16\,(O) * 2 = 44\,(CO_2)$$

$$44\,(CO_2)\,/\,12\,(C) = 3.66\ T$$

$$CO_2 = 0.408 * 3.66 = 1.49\ T$$

As a result, during the production of one metric ton of aluminum at the Ganja Aluminum Complex, approximately 1.49 metric tons of CO_2 are emitted into the atmosphere.

The electrolysis process is responsible for the highest electricity consumption within the aluminum industry as a whole. At the Ganja Aluminum Complex, this process's average daily electricity consumption amounts to 2,000,000 kW/h. In the year 2022, the complex achieved an annual primary aluminum production of around 53,000 tons. Based on the provided data, it is indeed possible to calculate the energy consumption required for the production of 1 ton of aluminum:

$$E = E_d\,/\,P$$

$$E_d = 2\ 000\ 000\ (kW/h)$$

$$P = P\,(annual)\,/\,365 = 53\ 000\ T\,/\,365 = 145\ T$$

$$E = 2\ 000\ 000\ (kW/h)\,/\,145\ T = 13\ 800\ (kW/h)$$

Table 2. Ganja Aluminum Complex, daily electricity consumption for electrolysis (first 10 days of January 2023).

Electrolysis		%	Current intensity	Voltage
Alternating current AC	Direct current DC			
kW/h	kW/h		kA	V
1918400	1827920.667	95.28	228.833	332.833
1991000	1951362.000	98.01	238.000	341.625
2011350	1985117.000	98.70	241.000	343.208
2011350	1985014.750	98.69	240.958	343.250

Table 2. Continued

2000900	1973589.333	98.64	240.917	341.333
2014650	1988250.000	98.69	241.000	343.750
2022900	1996235.500	98.68	240.917	345.250
2016300	1989833.917	98.69	240.958	344.083
2009700	1984635.000	98.75	241.000	343.125
2011900	1984189.667	98.62	240.917	343.167

Source: Authors' finding

The Green Production Passport for primary aluminum production offers a comprehensive summary of sustainable and eco-conscious practices utilized throughout production. It outlines the fundamental elements and strategies implemented to mitigate the environmental consequences and foster sustainability in primary aluminum production. Based on the data collected, generating a Green Production Passport for primary aluminum production is feasible.

Green Production Passport of Ganja Aluminum Complex

Per ton of primary aluminum production

Anode consumption – 0.408 T
CO_2 emissions (indirect) – 0 T
CO_2 emissions (direct) – 1.49 T
Electricity consumption – 13 800 kWh

Figure 6. Green production evaluation in the example of a manufacturing enterprise
Source: Authors' finding

In aluminum production, threshold values for carbon dioxide emissions are typically expressed as metric tons of CO_2 per metric ton of aluminum, with variability influenced by factors including the production process, energy source, and process efficiency. The present investigation has revealed that the Ganja Aluminum Complex emits roughly 1.49 metric tons of direct CO_2 per metric ton of aluminum manufactured, a figure marginally below the Aluminum Association's CO_2 emission performance standard for primary aluminum production utilizing smelter-grade alumina.

DISCUSSION

The investigation into green production management within the aluminum industry necessitates a meticulous examination of the smooth integration of environmentally friendly measures throughout the entirety of the aluminum supply chain, with a particular emphasis on adopting sustainable technologies. Attaining a comprehensive grasp of other potential environmental benefits and challenges associated with the widespread adoption of green practices in the realm of production management is of utmost significance. The scholarly work authored by Hasanov & Safarli (2023) introduces a novel eco-design model and presents innovative green strategies that are specifically customized to address the distinct challenges encountered in their research domain effectively. Furthermore, many cutting-edge projects have been introduced to facilitate the comprehensive greening of the aluminum industry. Notably, one such initiative is Inert Anode Technology. Hasanov (2023a) investigated that the prospective adoption of this technology could prevent 120,000 tons of CO2 emissions in the future, accompanied by a notable environmental cost advantage amounting to $5,865,000 for the Ganja Aluminum Complex.

The subsequent gap pertains to establishing sustainable material-sourcing practices in the aluminum industry. The conventional process of primary aluminum production heavily depends on alumina and carbon anodes, which have been associated with substantial environmental impacts. Consequently, further research is needed to investigate ecologically viable sources of raw materials as alternatives. Luthin, Backes, and Traverso (2021) demonstrate a methodology for discerning environmental trade-offs and proficiently conveying the outcomes to facilitate sustainable decision-making within the aluminum industry.

The final and pivotal issue to address involves the enhancement of energy efficiency within the aluminum industry. The electrolysis process used in aluminum production is acknowledged for its substantial energy consumption. Thus, there is a pressing need for comprehensive research efforts to identify feasible renewable energy alternatives, investigate innovative technologies, implement effective practices to optimize energy efficiency, curtail greenhouse gas emissions, and advance the overall sustainability of the production processes. Hasanov (2023b) conducts a comprehensive review of the green energy sector in Azerbaijan, which holds potential relevance for the aluminum industry's future prospects in the country. This research offers valuable insights and opportunities for developing the aluminum industry within the context of Azerbaijan's green energy landscape. Tian et al. (2022) developed an all-encompassing model aimed at analyzing energy conservation and mitigating CO_2 emissions within the aluminum industry in China. In their scientific work, Yu et al. (2021) thoroughly examine the challenges and opportunities involved in the transformation towards a low-carbon industry. The authors provide valuable insights into the possible benefits and consequences that may arise from implementing sustainable practices in this domain.

CONCLUSION

In the contemporary era, the survival of any economic organization or business heavily relies on adhering to green standards. The importance of these principles is constantly increasing as society progresses. Like many others, the aluminum industry is confronted with the pressing issues of greenhouse gas emissions and energy consumption that have become the focus of the global scientific community. In the global business environment, both the US and European markets have implemented restrictions on purchasing products from companies that fail to meet green standards. This holds significant consequences for the aluminum industry, as plants that rely on coal and oil as energy sources face considerable challenges in meeting these standards. The aluminum industry must collaborate with green energy sources to combat global climate change.

This study provides a comprehensive understanding of GPM within the unique context of the aluminum industry and systematically explains the green principles from the initial stages of input to the ultimate output directions. The key findings of this research emphasize the transformation of traditional production management into GPM, opening up new avenues in the strategic eco-environmental field. The fundamental purpose is to present an innovative approach and encourage scholars to further expand on the explanations provided in this study for future research endeavors. This research encompasses practical studies of a real-world production enterprise, and its primary objective is to establish a "green production passport" specifically tailored to the strategic aluminum industry.

This article aims to develop a customized "green production passport" for the aluminum industry, specifically for the Ganja Aluminum Complex. The study's primary objective affirms the practicality of instituting such a passport, given that the complex's emissions amount to approximately 1.49 metric tons of direct CO_2 per metric ton of aluminum produced and refrain from relying on coal-oil-based indirect energy sources. As a subject of study, the Ganja Aluminum Complex's CO_2 overall emissions from aluminum production are notably lower compared to similar facilities worldwide, highlighting the company's unwavering dedication to environmental responsibility.

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