

Developing climate neutrality among supply chain members in metal and mining industry: natural resource-based view perspective

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Abstract

Purpose – This study aims to address three research questions pertaining to climate neutrality within the supply chain of metal and mining industry: (1) How can an organization implement practices related to climate neutrality in the supply chain? (2) How do members of the supply chain adopt different measures and essential processes to assist an organization in responding to climate change-related concerns? (3) How can the SAP-LAP framework assist in analyzing and proposing solutions to attain climate neutrality?

Design/methodology/approach – To address the proposed research questions concerning climate neutrality, this study employs a case study approach utilizing the SAP-LAP (situation, actor, process–learning, action, performance) framework. Within the SAP-LAP framework, adopting a natural resource-based perspective, the study thoroughly examines the intricacies and interactions among existing situations, pertinent actors and processes that impact climate initiatives within a metal and mining company.

Findings – The study's findings suggest that organizations can achieve the objective of climate neutrality by prioritizing resources and capabilities that lead to reduced GHG emissions, lower energy consumption and optimal resource utilization. The study further proposes key elements that significantly influence the pursuit of climate neutrality within enterprises.

Research limitations/implications – This study is one of the earliest contributions to the development of a holistic understanding of climate neutrality in the supply chain of the metal and mining industry.

Practical implications – The study will assist practitioners and policymakers in comprehending the present circumstances, actors and processes involved in enterprises' supply networks in order to attain climate neutrality in supply chains, as well as in taking the right steps to enhance performance.

Originality/value – This study presents a climate neutrality model and provides valuable insights into emission management, contributing to the achievement of the climate neutrality objective.

Keywords Climate neutrality, Metal and mining industry, Supply chain, Sustainable performance, NRBV

Paper type Research paper

1. Introduction

Stringent norms enacted by government and local bodies have made it increasingly imperative for all corporate organizations to become climate neutral (Wolf *et al.*, 2021). Climate neutrality [1] refers to the goal of achieving net zero greenhouse gas (GHG) emissions. It takes into account all GHG emissions that contribute to global warming, including the emission of carbon dioxide, methane, nitrous oxide and fluorinated gases (Place *et al.*, 2022). The manufacturing sector, particularly carbon and energy-intensive manufacturing, can play a pivotal role in meeting the global climate change mitigation targets (Bataille *et al.*, 2018; Martin *et al.*, 2023; Wiese *et al.*, 2022). Awareness and sensitivity toward climate neutrality are



increasing among consumers, investors and the general public, leading to a systematic transformation in all industrial and service sectors (Schütze and Stede, 2021).

The metals and mining (M&M) industry is one of the most critical sectors for the development of the current world order (Cox *et al.*, 2022). Metallic minerals account for approximately 20% of the total raw material consumed worldwide (De Sa and Korinek, 2021). However, this sector is also inevitably associated with significant damage to the environment, which can subsequently accelerate global climate change (Zeng *et al.*, 2021). Significant exploitation of the environment occurs at every step of the M&M industry supply chain, right from excavation (Schoenberger, 2016) to processing (Gorman and Dzombak, 2018; Gupta and Basu, 2019; Raabe *et al.*, 2019) and transportation.

Excavation operations, which lie on the sourcing side of the M&M supply chain, cause GHG emissions, such as CO₂ (Gorman and Dzombak, 2018; Gupta and Basu, 2019; Liu *et al.*, 2021) and methane (Kholod *et al.*, 2020), as well as deforestation, which leads to a reduced carbon sink (Liu *et al.*, 2021). Processes like weathering, neutralization of waste rock and tailings, acid leaching, and metallurgical processing can also lead to GHG emissions, due to the decomposition of carbonate minerals, such as siderite (FeCO₃) and calcite (CaCO₃). Limestone, which is frequently used to prevent acid and metal-rich flow from waste rock, tailings storage facilities, and exposed mine workings, is a significant source of non-CO₂ emissions in the M&M sector (Azadi *et al.*, 2020).

Furthermore, during the processing of mineral ore, there is excessive water consumption and effluent release (Raabe *et al.*, 2019) leading to the contamination of land and water bodies (Bloodworth and Gunn, 2012; Gorman and Dzombak, 2018; Steinberger *et al.*, 2010).

In addition, the material handling and logistics network processes also invariably consume a high amount of energy either in the form of fossil fuels (for road and ship transport) or electricity (for rail transport). Finally, the end-of-life handling of metals requires adequate sorting, processing, and recycling. Poor recycling rates, excessive cost of recovery, and underdeveloped technology for recycling can lead to higher GHG emissions during recycling than during primary production (Yokoi *et al.*, 2022).

The production of metals from processed ore is highly energy-intensive (Bloodworth and Gunn, 2012; Gorman and Dzombak, 2018; Gupta and Basu, 2019; Raabe *et al.*, 2019). This demand and consumption of energy in the M&M industry is increasing exponentially due to the complexity and difficulty of processing mineral deposits of ore, as problems like difficulty in accessing ores and depletion of ore richness are becoming more common (Azadi *et al.*, 2020; De Sa and Korinek, 2021). The overall supply chain in this sector thus has a large carbon footprint and lags in climate neutrality measures (Fischedick *et al.*, 2014; Loftus *et al.*, 2015).

In summary, M&M organizations face sustainability-related challenges across the entire supply chain, right from the point of sourcing of raw minerals, all the way up to the recycling of final products and end-of-life treatment of the mine. Thus, addressing climate neutrality and mitigating the climate crisis is essential for the M&M industry. In this study, we have adopted an organizational case study approach to enable a nuanced examination of the challenges, opportunities and solutions in this regard. Through a detailed investigation, this study assesses the diverse approaches and initiatives undertaken to achieve climate neutrality in the M&M sector by the case firm.

Academic researchers have extensively studied environmental sustainability, climate impact and GHG emissions in the M&M industry over the past few years. Many scholars have also adopted the case study method to investigate various aspects of this area of research (Dewulf *et al.*, 2021; Farmaki *et al.*, 2021; Leal Filho *et al.*, 2021; Mencho, 2022). Further, the unit of analysis in the majority of these case studies has either been a country (Cai *et al.*, 2021; Denoncourt, 2022; Fraser *et al.*, 2022; Kuzior and Grebski, 2022; Matikainen, 2022), a geographical region (Farmaki *et al.*, 2021; Li *et al.*, 2022; Que *et al.*, 2019; Yuan *et al.*, 2022) or a

specific mineral (Dewulf *et al.*, 2021; Kadel *et al.*, 2022). Studies analyzing multiple cases have compared processing plants within the same company (Kadel *et al.*, 2022), multiple projects across organizations (Kshetri, 2022), or multiple companies within the same region (Ng *et al.*, 2022; Serfontein-Jordaan and Dlungwane, 2022).

Despite these wide range of studies and different units of analysis, studies addressing overall climate change and climate neutrality from an organizational perspective are limited (Mishra *et al.*, 2022). With respect to cases from emerging economies, most researchers have covered cases from China (Li *et al.*, 2022; Yuan *et al.*, 2022). Data and cases from India, being a prominent emerging economy and the fifth largest global economy, are lacking in the literature. With the M&M sector accounting for ~2–3% of global GHG emissions [2] and India being among the global top three producers [3] of metals such as crude steel, aluminum, zinc, barite, chromite and limestone, there is a critical need to examine the climate change and climate neutrality initiatives in emerging economies, specifically in the Indian context.

Therefore, to analyze and integrate the diverse climate change and climate neutrality challenges and practices within the context of an M&M organization from an emerging economy, the present study addresses the following research questions:

- RQ1. How can an organization implement practices related to climate neutrality into the supply chain and improve them continuously?
- RQ2. How do members of the supply chain adopt different measures and essential processes to assist an organization in responding to climate change-related concerns?

The situation, actor, process–learning, action and performance (SAP-LAP) model has been used as a framework for analyzing the case organization. The SAP-LAP model offers a structured and comprehensive framework for understanding, evaluating and guiding organizational behaviors, learning processes and performance in complex and dynamic environments. Compared to other frameworks, such as life cycle assessment (LCA) (Farjana *et al.*, 2019), circular economy framework (Kinnunen *et al.*, 2022) or global reporting initiative (GRI), all of which primarily provide an external viewpoint, the SAP-LAP model allows for a deeper analysis of the internal dynamics within the organization. Hence, the study also aims to address the final research question:

- RQ3. How can the SAP-LAP framework assist in analyzing and proposing solutions to attain climate neutrality?

To address these research questions, this study employs the natural resource-based view (NRBV) approach for analysis (Hart and Dowell, 2011), which has been extensively applied by scholars to investigate climate, sustainability and environmental issues across industries (Andersén *et al.*, 2020; Andersson, 2023; Münch *et al.*, 2022; Nishant *et al.*, 2016). NRBV emphasizes the importance of pollution prevention, product stewardship and sustainable development as key strategies for firms to gain a competitive advantage (Hart, 1995). These strategies are particularly relevant for the M&M industry, which faces significant environmental challenges and regulatory pressure. NRBV can help us understand how natural resources can drive both environmental challenges and competitive opportunities for firms in this sector (Menguc and Ozanne, 2005). By applying NRBV, we can gain valuable insights regarding the implementation of climate neutrality practices and the dynamics within the supply chain (Kim *et al.*, 2020).

The present study contributes to the emerging literature on climate neutrality by addressing several research gaps. First, it provides an in-depth case study of climate neutrality practices and the challenges faced by an M&M sector organization from an emerging economy perspective. The second important contribution of the study is the development of a theoretical framework, using the SAP-LAP connections approach, for

highlighting the factors influencing climate neutrality goals in the M&M industry. Finally, the study develops propositions related to climate neutrality that can be tested in future empirical supply chain research. Therefore, the study facilitates theory-building for a climate neutral supply chain.

The rest of the paper is organized as follows: [Section 2](#) presents the theoretical background, explored using the natural resource-based view (NRBV) for the M&M industry, followed by a review of recent studies in this area. [Section 3](#) describes the research methodology adopted for the study. [Section 4](#) describes the development of the framework for SAP-LAP linkages for a case organization. [Section 5](#) includes the discussion and implications, and finally, [Section 6](#) presents the conclusions and future scope for research.

2. Literature review

2.1 Climate neutrality in the M&M value chain

Climate neutrality in the M&M industry refers to the goal of achieving net zero GHG emissions from the production and use of minerals and metals. Several studies have been conducted on the measurement and estimation of GHG emissions throughout the metal and mining operations and supply chain. These studies have focused on specific metal industries, such as copper ([Liu et al., 2022](#)), aluminum ([Ding et al., 2021](#); [Peng et al., 2019, 2022](#)), iron and steel ([Gan and Griffin, 2018](#); [Hamuyuni et al., 2021](#)), oil ([Nimana et al., 2015](#)), as well as rare elements, such as uranium and lithium ([Manjong et al., 2021](#); [Parker et al., 2016](#)). Some of the studies on GHG emissions in the M&M industry are listed in [Table A1](#) in the appendix.

Many studies have investigated the impact of the M&M industry on the environment from an LCA perspective. Using this approach, the end-to-end supply chain impact in terms of GHG emissions, including raw material procurement, production, consumption, as well as end-of-life treatment has been studied ([Menary et al., 2012](#)). The consumption of energy across the entire supply chain has been reported as the prime contributor toward GHG emissions. The emission is not just restricted to core operations, but also includes emissions from ancillary processes, such as logistics ([Liu et al., 2022](#)). Multiple factors impacting the consumption of energy and GHG emissions have also been discussed widely. The grade of the ore, type of mine (strip vs underground) ([Liu et al., 2022](#); [Nimana et al., 2015](#)), location of the processing plants ([Ding et al., 2021](#)), as well as production technology ([Ding et al., 2021](#); [Ren et al., 2023](#)) are prominent factors impacting GHG emissions across the entire supply chain.

Consumption of energy is reported as the prime contributor towards GHG emissions in the M&M industry. The use of renewable sources of energy has been recommended for significant advancement towards achieving climate neutrality ([Liu et al., 2022](#); [Peng et al., 2019](#)). Studies have reported a quantifiable reduction in GHG emissions per unit of metal produced upon improvement of the energy production technology ([Ding et al., 2021](#)). Recycling the metal through melting, purification and reuse is an important strategy that can reduce GHG emissions. The increasing use of recycled metals has resulted in a reduction in GHG emissions per unit of production ([Dong et al., 2020](#)). Studies have recommended increasing the rate of metal recycling to reduce GHG emissions across the supply chain ([Peng et al., 2019](#)). Due provisions are also required early during the design stage of the products to promote and enable efficient end-of-life treatment ([Ciacci et al., 2020](#); [Dong et al., 2020](#); [Ghisellini et al., 2016](#)). Efforts are required to promote the use of renewable energy sources and harvest the heat produced during metal production ([Gorman and Dzombak, 2018](#); [Pinkman, 2020](#); [Raabe et al., 2019](#)). Many technological advancements to improve operations efficiency are being explored by industries as well as researchers, such as the electrolytic reduction of iron instead of using a coal-based blast furnace, the use of hydrogen as fuel, and CO₂ capture ([Raabe et al., 2019](#)). Research is also being carried out to produce aluminum without any GHG emissions during smelting, as the improved the process will emit oxygen instead of CO₂ ([Pinkman, 2020](#)).

Mining involves moving huge quantities of earth and rock. While some of it is processed and valuable minerals are recovered, the rest of it is discarded (Schoenberger, 2016). These waste products need to be managed effectively (Gorman and Dzombak, 2018; Raabe *et al.*, 2019). Acid and metalliferous drainage (AMD) is generated upon the oxidation of sulfide minerals (mainly pyrite) in waste rocks, with high concentrations of sulphate, iron, and heavy metals. The treatment and disposal of AMD is a major challenge for the mining sector. A comprehensive AMD management plan for the early phases of exploration is necessary to address this problem (Tayebi-Khorami *et al.*, 2019). In addition to moving away from linear to “closing the loop” strategies, a comprehensive strategy that addresses ore body characterization, mine design, ore processing, waste disposal, re-processing, recycling and reuse, as well as site rehabilitation, is required to reduce waste (Edraki *et al.*, 2014). Table A2 in the Appendix outlines factors impacting GHG emissions in the M&M industry.

Recycling may drastically reduce the carbon footprint of metal production as it consumes at least 60% less energy than mining for the majority of regularly used metals (De Sa and Korinek, 2021). Theoretically, metals can be recycled and reused an infinite number of times by melting and converting them back into useful products. Thus, recycling of materials could be a potential panacea to the problems caused by the continuous mining of metals. On one hand, recycled materials account for less than 30% of steel and aluminum production worldwide; on the other hand, for steel and aluminum in the United States and European Union, the amount of scrap generated is at par with the demand for these metals (De Sa and Korinek, 2021; Raabe *et al.*, 2019). This divide can be explained through various challenges related to segregation and the recycling supply chain (Raabe *et al.*, 2019). Thus, urban mining – converting scrap back to metals – can offset some of the energy consumption and emissions from primary extraction as well as subsequent processing (Gorman and Dzombak, 2018; Raabe *et al.*, 2019). However, recycling alone cannot be a viable solution as the demand for many metals far exceeds the available scrap, at least till 2050 (Allwood *et al.*, 2012; Mahfoud and Emadi, 2010), thus necessitating a focused effort on continuing to improve the sustainability of existing M&M processes. The environment tax is another lever being deployed in some countries, such as the United Kingdom, to drive sustainable behavior (Tangtinthai *et al.*, 2019). Carbon pricing instruments, such as emission trading and carbon tax, have been introduced in many countries to incentivize pro-sustainability behavior (Cox *et al.*, 2022). Efforts are being made to decouple economic growth from environmental degradation and consumption of natural resources in the favor of a circular economy (De Sa and Korinek, 2021).

Digitization and other technological advances, such as Industry 4.0, digital twins, etc., are also enabling the M&M industry to drive the sustainability agenda (Gupta and Basu, 2019). From a circularity perspective as well, new-age technologies, such as the Internet of things and blockchain, can contribute significantly. Sensors can be used to describe the metallurgical composition of trash and scrap to enable better classification by type, and blockchain can be used to track items throughout their usage cycle and beyond. Thus, these technologies can help internationalize the closure of material loops (De Sa and Korinek, 2021). In addition, popular technologies like automation, robotics, analytics and big data, 3D printing, artificial intelligence, machine learning and drones are also finding applications in the M&M industry (Barnewold, 2019; Clausen *et al.*, 2022). The terms “Smart Mining” and “Mining 4.0” have been coined to depict the implementation of digital technologies in the mining sector. The current adoption of digital technologies in the M&M sector, even for a developed market like Europe, has been low, even though the potential for digital transformation in this sector is very high (Gao *et al.*, 2019). Implementing digital initiatives can have a widespread impact on firm performance, processes and structures, and it can enable seamless integrations within the entire supply chain. In addition, digital innovations can also drive the sustainability agenda in the supply chain operations of M&M

organizations. Table A3 in Appendix summarizes climate neutrality practices employed in the M&M industry.

While the existing literature provides a comprehensive understanding of the current state of climate neutrality in the M&M industry, there are several areas that warrant further exploration. Firstly, there is a need for more research on the development and implementation of innovative technologies that can further reduce GHG emissions in the industry (Gao *et al.*, 2019). While advancements, such as electrolytic reduction of iron, use of hydrogen as a fuel and CO₂ capture, have been explored, the practicality and scalability of these technologies in real-world settings need to be further investigated (Magro *et al.*, 2019).

Secondly, the role of policy and regulation in promoting climate neutrality in the industry needs more attention (Camilleri, 2020). While some studies have touched upon the impact of environmental taxes and carbon pricing instruments, a more in-depth analysis of the effectiveness of these measures, as well as the exploration of other potential policy interventions, is required. Thirdly, the potential of digital technologies in promoting sustainability in the M&M industry is another research area that needs further exploration. While the concept of “Smart Mining” or “Mining 4.0” has been introduced, the actual impact of these technologies on reducing GHG emissions and promoting climate neutrality is still not well established (Löw *et al.*, 2019). Further, most of the existing literature on sustainability in the M&M sector has been approached from an outside-in perspective, focusing on external factors and influences (Hilson and Murck, 2000). There is a noticeable gap in the literature when it comes to understanding the internal dynamics within the M&M organizations, particularly how they address the issue of climate neutrality. This includes their internal situations, processes and actions that contribute to their environmental impact. This gap becomes even more pronounced in the context of emerging economies. The internal strategies and processes of M&M organizations in such economies, like India, are not well-documented or understood.

2.2 Natural resource-based view

The NRBV has emerged as an extension of the resource-based view (RBV) to specifically address firm strategies and gaining a competitive advantage in relation to the natural environment and sustainability (Hart, 1995). The theory postulates that a firm's competitive advantage essentially relies upon its relationship with the natural environment. Natural resources can provide competitive advantage to firms, and proactive environmental strategies can lead to superior financial performance (Aragón-Correa and Sharma, 2003). As described by NRBV, pollution prevention, product stewardship and sustainable development comprise the framework of three interconnected competences that a company can cultivate. Each of these strategic capabilities is driven by an underlying factor. Pollution control reduces emissions, effluent, and waste. Product stewardship reduces the cost of a product's life cycle, and sustainable development reduces the environmental impact of enterprise growth and development.

The NRBV proposes that businesses can obtain a competitive advantage by emphasizing these qualities and establishing partnerships with the natural environment that are conducive to sustainable growth (Menguc and Ozanne, 2005). In contrast, RBV, with its focus on internal resources and capabilities, may not fully capture the complexities of achieving climate neutrality, which requires firms to engage with external stakeholders, comply with environmental regulations, and innovate in their processes and products (Barney, 2001). Thus, NRBV provides a broader perspective by incorporating natural resources and environmental factors. It highlights how natural resources, which are integral to M&M companies' business, can provide both competitive advantage and addressal of environmental issues (Kim *et al.*, 2020).

NRBV has been extensively used in the literature to study how firms gain competitive advantage through sustainable practices and green innovations. For instance, a study by Cristina De Stefano *et al.* (Cristina De Stefano *et al.*, 2016) used NRBV to examine how firms are driving innovation in automobile sector. Similarly, a study by Cooppola *et al.* (2023) applied NRBV to investigate circular economy capabilities in textile and clothing industry.

NRBV, thus provides a comprehensive and nuanced theoretical lens for studying climate neutrality in the M&M industry. It allows for a deeper understanding of how firms can leverage their natural resources, environmental strategies and innovations to achieve sustainability and competitive advantage, and it is well suited for application in the context of this study.

3. Research methodology

This study employs a case study approach to address the “how” and “why” questions related to climate neutrality. A single-case study, which is exemplary and offers rare research opportunities, can be considered acceptable for theory building (Yin, 1981). The usage of a single-case study helps in the in-depth examination of phenomena that are present in unique real-life settings. This method is widely used as a source of knowledge across multiple areas, as well as for the acquisition and distribution of knowledge (Mariotto *et al.*, 2014; Mishra *et al.*, 2022). Many researchers have also adopted the single-case study research methodology to analyze sustainability in the M&M sector (Leal Filho *et al.*, 2021; Mencho, 2022).

Mariotto *et al.* (2014) presented one of the seminal works on this subject, arguing that the researchers’ ability to understand and describe the context of the case so that the reader can grasp it and generate theory is more significant than the number of cases used in the study. We believe that the strengths of the single-case study approach, including in-depth understanding, rich contextualized data and potential for future research, justify its application in this study. Single-case studies can provide rich, contextual analysis that is often overlooked in broader quantitative research (Yin, 2013). Through the single-case study approach, we were able to gather rich and contextualized data specific to the M&M company under investigation. This included qualitative data, such as interviews and document analysis, which provided detailed insights into the company’s practices, challenges, and achievements related to climate neutrality. Such rich and context-specific data offer a comprehensive understanding of the company’s unique context and can generate valuable knowledge for practitioners and policymakers. A list of some of the studies that argue for the relevance of single-case study is included in Table 1.

In addition, many recently published articles in leading journals are based on single-case studies. For example, studies on topics like transport in supply networks, coping with the postponement boundary problem and modular service delivery systems in a logistics context have been featured in the *International Journal of Logistics Management* (Eriksson *et al.*, 2022; Ponsignon *et al.*, 2021).

From a theoretical perspective, a single-organization case study can be explored to provide insights and build on the body of knowledge in the field (Yin, 1981). This can generate theoretical propositions that serve as a springboard for further research (Eisenhardt, 1989). We believe that the propositions we have developed provide a useful starting point for further research. These can be tested and refined in other contexts, contributing to a more comprehensive understanding of climate neutrality in the M&M supply chain. In future studies, researchers can aim to validate and extend our findings by conducting comparative case studies in different industries and geographical locations. This approach will provide external validity to our research and allow for broader generalizations, as suggested by other researchers (Flyvbjerg, 2001; Stake, 2011).

Figure 1.
SAP-LAP framework

practitioners from the company. Secondary data was collected from publicly available sources, such as websites, as well as electronic and print media.

The profiles of the participants interviewed for primary data collection have been included in Appendix Table A4. An interview protocol that comprised open-ended semi-structured interviews (see Table A5 in Appendix) was developed by reaching out to experts in the field of climate change and environmental science. Once the protocol was developed, it was verified by two experts who had sound knowledge of qualitative case-based research. Videos of pilot interviews were shared with experts, and they were asked to recommend relevant changes that were needed in terms of the wording and sequence of questions and processes used when conducting the interviews. Prior to conducting the interviews, six experts (with expertise in areas ranging from qualitative case-based research to sustainability in M&M) examined the interview questions to ensure content validity and appropriateness of the interview questions (Chenail, 2011; Louise and Alison, 1994). A pilot interview was conducted to ensure that the interview questions are adequate and cover all the aspects of the phenomena, and that the procedures used for conducting interviews do not require any further modifications (Krauss *et al.*, 2009; Turner, 2010). To increase the efficiency of the procedure, questions were streamlined and divided into themes (Åstedt-Kurki and Heikkinen, 1994). Each participant was asked an identical set of questions (see Table A5 in Appendix); however, they were asked to respond to questions pertaining to their area of expertise in greater depth. Interviewees were initially reached via personal and professional connections of the researchers and through snowballing. The respondents were then requested for contact information of additional staff of the firm who could help address the research problem. Out of the total 20 participants who were approached, 13 participants from supply chain, operations, human resource, procurement and logistics were willing to engage in the survey. The interviews were conducted online, through video conferencing, and each session lasted between 60 and 120 min, averaging 90 min.

Secondary data for the study was collected from a review of the firm's website, published documents and reports. In addition, interviews with the firm executives in print and electronic media were also transcribed to gather insights regarding sustainability initiatives at the firm, to triangulate and confirm the findings.

To facilitate triangulation, secondary data were added to the primary data, and any ambiguous datapoints were addressed. Data analysis procedures included the convergence of evidence from multiple sources, validation of emerging themes from different sources, and comparison with existing literature (Voss *et al.*, 2002). A pictorial representation of themes emerging from both primary and secondary sources has been included in Appendix Figure A1.

3.1.3 Error and bias prevention. During the different steps of this study, such as data gathering, analysis, and reporting, we avoided information bias by obtaining data from multiple different sources, like interviews, the firm website, and reports from the firm as well as press interviews and conference presentations by the firm leadership. Observer bias was prevented by using a standardized interview protocol. Selection bias was controlled by selecting a range of respondents from the case firm. Further, initial findings were shared with participants to validate them and avoid any ambiguity or missing information.

Common method bias was minimized or controlled during the design of study procedures (Podsakoff *et al.*, 2003). During the data collection procedure, all the technical terms were clearly defined and conveyed to the participants to allow them to share their responses honestly without thinking about socially desirable answers. It was emphasized that there are no right or wrong answers, and respondents should share their opinion without worrying about their impact.

3.1.4 Data analysis and validity assessment. Responses were carefully analyzed to understand the key phenomena. The analysis helped us understand the practices adopted by

the firm to promote climate neutrality and the challenges faced in its successful implementation. Interviews were transcribed and tabulated for data analysis. Pattern-matching was performed and merging themes were identified from transcripts. Preliminary analysis reports were analyzed by each author separately. Any ambiguity in interpretation and reporting were clarified in subsequent discussion with key participants.

The case study protocol and case database were developed to ensure reliability (Yin, 1981). Each author performed the classification on their own, ensuring inter-rater reliability, and any disagreement was resolved by a researcher who was not a part of the study. Content validity was ensured by careful preparation of the questionnaire and by avoiding any ambiguous terms or technical jargon. Construct validity was maintained by using multiple data sources, including primary sources, such as discussions with key informants, as well as secondary data sources, such as formal and informal reports, information provided on the official firm website, social media posts and newspaper reports. Internal validity was also maintained by pattern-matching and correlating the findings with available literature. Considering that this is a single case study, it was difficult to establish external validity. As is the nature of empirical studies, generalization of results to other populations cannot be ensured, and further research efforts with different populations and methods are needed.

4. Case analysis

4.1 Problem description

The current study focuses on an illustrative case of ABC Ltd, operating in the M&M industry. The M&M industry is one of the major consumers of resources in the world, providing building blocks like iron, steel, and aluminum for traditional sectors, as well as, lithium, cadmium, cerium, dysprosium, terbium, etc. for supporting the electronic and digitally connected world. It is also one of the major contributors to GHG emissions. However, this industry is increasingly witnessing external pressure from local authorities and regulators, as well as customers and investors, to achieve climate neutrality. There is also an increasing amount of activism aimed at the operations of these firms from multiple non-governmental entities. How an organization engaged in the M&M sector addresses the challenges posed by this paradoxical situation frames the context of this study. Thus, an in-depth analysis of the ABC Ltd supply chain and steps needed to work towards climate neutrality can offer important insights to help address the climate crisis.

4.2 Background of the case firm

ABC Ltd. Is one of the largest natural resource companies in India, with a large market share in aluminum, copper, zinc, lead, silver, iron ore, oil and gas and commercial energy. It operates across the value chain of natural resources sectors, covering exploration, asset development, extraction, processing and value addition. ABC Ltd. is the largest natural resource company in India, with 87,500 employees and an annual revenue of US\$19bn. In India, the firm has a market share of 80% in zinc, 45% in aluminum production and 25% in crude oil production. It is among the top three producers of zinc and aluminum worldwide. The firm is listed in India and in the United States (on NYSE) and has a market capitalization of US\$12.56bn. The firm has overseas operations and assets in South Africa, Namibia, Ireland and Australia as well.

Climate change and global warming are key focus areas for the firm. It has started working on different areas of climate change, including analysis of GHGs and energy performance; business-wise transition risk assessments; and work on scope 1, scope 2 and scope 3 emissions; as well as their disclosure. To address climate-related risks, it is focused on four fundamental elements: governance, strategy, risk management, and metrics and targets. The case firm is committed to identifying and comprehending climate trends and

implementing proactive initiatives to reduce GHG emissions and improve resource efficiency.

4.3 SAP-LAP analysis of ABC Ltd

4.3.1 Situation. ABC Ltd. operates in a capital-intensive industry that requires large investments for exploration, setting up mining and processing facilities, and setting up large ancillary services, such as power plants and even townships for operations. The capital-intensive nature of business demands that ABC Ltd. seek capital and investments from the market. Investors across the globe are placing utmost importance on impact investment, which seeks to generate financial returns, while simultaneously creating a positive social and environmental impact. Therefore, every investment decision is evaluated through a sustainability lens. Further, measures adopted by many countries and regulators regarding the consumption of goods and services are another driver of climate neutrality. For example, the EU has proposed levying a tax on imported goods based on the GHGs emitted during their production. ABC Ltd. exports more than 50% of its aluminum produced and this taxation has a direct impact on the firm's access to these markets, resulting in a high level of focus and attention to climate risk-management activities. When questioned about the awareness regarding climate neutrality practices, a procurement manager from ABC Ltd. responded,

While our firm has committed to achieving net zero emissions by 2050 and has taken several steps towards that goal, we are also focusing on reducing other harmful gases besides carbon dioxide, such as methane and nitrous oxide.

The case company's annual reduction in GHG emissions is 4%. The case firm is implementing several initiatives to improve this statistic, including the replacement of fossil-fueled heavy vehicles with advanced lithium-ion forklifts, which saved nearly 690 metric tons of CO₂ and in addition, also allowed for longer working cycles and increasing productivity. With respect to climate change-related initiatives, an associate manager from the sustainability division stated,

As part of our sustainable minimization programme, our company has put in place a number of steps to cut down on energy use and greenhouse gas emissions (GHG). For example, we have worked on a number of projects to save energy and have made our operations more energy efficient by using a number of new methods.

The M&M ecosystem in India, the case firm's primary country of operation, is still in the early stages of achieving climate neutrality. Though the case firm has made declarations and commitments to become carbon neutral by 2070, and has taken multiple steps in this direction, some prominent challenges persist. Sustainability across the entire supply chain network is the prime cause of concern. There is a need for all the firms across the network, and the entire industry, to adopt strategies to mitigate climate risk throughout their entire supply chain. While the case firm has the motivation and incentive to drive climate neutrality at the firm level, adopting practices at the supply chain level is difficult due to interdependency among several members, specifically small and medium enterprise (SME) firms. Similarly, business facing stiff cost competition are not keen to invest in sustainability unless incentivized.

4.3.2 Actors. Actors represent decision makers who are involved in strategic decisions related to climate change strategy and implementation of climate risk management. Firm ABC Ltd. encourages active participation from all levels of management, suppliers, and customers in continuous improvement. Within the organization, the leadership and top management are the internal actors, and many actors outside the organization influence these internal actors. ABC Ltd. has entered several internal cross-functional collaborations

comprising key executives to focus solely on environmental, social and governance (ESG) initiatives.

In the words of a senior manager from the environment division,

In our climate risk strategy, we *are* using a number of practices that are good for the environment. Senior and middle-level executives are involved in our internal forums, the ESG management committee, and a number of communities of practice.

At the supply chain level, ABC Ltd. has partnered with various technology providers to deploy technology to reduce waste and GHGs emissions. The firm has access to R&D through partnerships with top academic institutions. ABC Ltd. Is also collaborating with other industries outside the M&M sector to find uses for some of the waste that is generated as a by-product of its operations. When asked about collaborations and partnership-related initiatives for climate-friendly operations, a manager from the strategic sourcing and procurement division responded,

We began collaborating with industry, and they began lifting waste from us and replacing some of the minerals that they were obtaining to make their products.

Besides corporate firms and academic institutions, local communities around ABC Ltd. are also important actors in climate change management. The firm must consider the ecological and environmental impact that it has on these communities. ABC Ltd. has taken multiple steps to mitigate the impact on the communities in the vicinity of its operations; however, effectively managing these actors remains a challenge for the firm. Being in the business of natural resource extraction through mining, local communities are often at loggerheads with the firm. This is evident from multiple litigations that the firm has faced from the local community representatives.

The organization is also collaborating with other organizations within its domain in various forums, such as the Confederation of Indian Industries (CII) and Federation of Indian Chamber of Commerce and Industry (FICCI), to voluntarily adopt global standards on emission and environmental control. All these stakeholders exercise direct as well as indirect influence on the operations of ABC Ltd.

4.3.3 Processes. The greatest challenges faced by the M&M sector in driving climate neutrality include high energy consumption and GHG emissions. GHG emissions in the M&M industry are a result of direct operations of machinery, required for processes like smelting and electrolysis, and the functioning of power plants, boilers, furnaces, etc. In addition, some of the metal processing methods, such as use of blast furnaces, are dependent on chemical processes that consume carbon and emit GHGs. Beyond the factory processes, the upstream supply chain process of mining minerals is also energy-intensive, involving high fossil fuel consumption for operating machinery and transporting the mined ore. For the year 2021, the total GHG emissions for scope 1 and scope 2 were over 60mn metric tons for ABC Ltd. The aluminum business, being the largest in the organization, is responsible for more than 50% of these emissions for ABC Ltd. The processes in this sector give rise to additional environmental hazards in the form of by-products or waste products of mineral processing, such as fly ash, tailings, slag, jarosite, etc. Driving climate neutrality with processes which, by their sheer nature, generate a large quantity of emissions and are environmentally damaging in all respects, is a challenge that ABC Ltd. has to overcome.

4.3.4 Learning. Careful examination of the situation, actors and processes leads us to various lessons learned in order to work towards climate neutrality across the entire supply chain. The firm is confronted with a conundrum: it must achieve cost competitiveness while employing various tools and techniques to reduce climate risk. The firm needs to drive sustainability, not at the cost of losing profits, but as a lever for competitive advantage. The firm believes that in spite of being a part of the M&M sector, it can achieve the objective of

Climate
neutrality
among supply
chain members

zero harm, zero discharge and zero waste, while minimizing other forms of emissions, like methane and nitrous oxide. It can achieve this by collaborating with all the stakeholders and deploying technology, including digitalization. Highlighting the significance of digitalization in the firm's operations, one of the participants said,

Digitalizing and automating operations can make operations run more efficiently and save energy in most of our operations.

Another challenge that ABC Ltd. is facing is an underdeveloped supply chain ecosystem. For example, one way to reduce GHG emissions is to purchase green electricity, but this is difficult to implement due to the lack of a large vendor base. In the words of one of the deputy managers in the logistics division,

Changes at the industry level are needed to deal with climate neutrality. Our supply chains are not developed enough yet to take any actions related to climate change. There also needs to be supportive government policy and rules. To reach any goal related to climate change, there must be changes to the ecosystem as a whole.

The landed cost of renewable electricity for ABC Ltd. is higher due to the high investment required; thus, any investment in this field requires long-term contractual commitment, not only from the case firm, but also from the government and other industries.

Similarly, an ecosystem of partner vendors, who can use the wastes from ABC Ltd.'s manufacturing processes, is lacking. For example, fly ash and bottom ash are useful in the manufacture of cement and bricks, but the availability of recipients and the transport of these products remains a challenge. Government and regulatory bodies can play a significant role in addressing this issue. Appropriate supportive policies can guide firms to work towards climate neutrality. In the words of an assistant general manager in the sustainability division,

Government policies can help create an ecosystem and give message to firms what they need to do.

While the changing macro environment has its challenges, it also provides opportunities for the firm to tap into the global energy transition by capturing the growth in renewable materials and low-carbon metals. ABC Ltd. has identified such opportunities and devised a detailed strategy to realize them, as summarized in [Table 2](#).

4.3.5 Actions. Actions signifies how learnings can be implemented in terms of changes that a firm can incorporate into its supply chain. ABC Ltd. is already taking the initiative to work on climate change actions. The firm has been publicly committed to working towards climate change by reducing GHGs emissions. ABC Ltd. is also upgrading and innovating its offered products to produce metals with a significantly smaller carbon footprint.

One of the project managers said,

We are trying to come up with new products, like low-carbon product lines, to meet the needs of new markets.

In this context, the firm has come up with a new green metal product, with lower intensity of GHG emissions, made using aluminum dross, a by-product of the aluminum smelting process.

ABC Ltd. is continuously improving its existing operations to enhance efficiency, reduce its carbon footprint, and minimize other GHG emissions. For example, the firm has upgraded their turbines by replating the turbine blades in the zinc operations, lowering GHG emissions per unit of energy produced while also boosting output by 15%. Similarly, the firm has worked towards improvements in boiler efficiency, reduction in the use of carbon-intensive furnace oil, and upgradation of smelter technologies, among other efforts.

The company's waste management system is designed to handle waste effectively and responsibly. It begins by reducing waste both quantitatively and qualitatively (by reducing

Table 2.
Strategies to address
climate change

Opportunities	Business unit	Strategy to realize opportunity
Green aluminum	Aluminum	Introduction of a new form of aluminum to serve Europe's sustainability-minded clientele Lowering the possibility of CBAM-related fines
Green copper	Copper	Planning to introduce green copper in near future Greater scrap utilization in production
Electric vehicles	All business	Decrease the use of diesel Reduce hazardous pollutants (fugitive emissions) from vehicles, hence reducing underground mines' air circulation needs
Renewable power	Aluminum, zinc, steel, copper	Decreased operational coal consumption Decreased water consumption aiding 2030 Net Water Positive (NWP) organization objective Lower ash production results in less expensive ash usage

Source(s): Created by authors

its toxicity), followed by recovery and recycling, which reduces the amount of waste that must be disposed of in a landfill or incinerated. The hazardous trash is sent to authorized handlers or recyclers. The waste stream is recycled by storing large amounts of low-toxic waste in tailings dams, ash dykes, or other safe landfill structures, before being used as raw materials by other companies.

Consistent with the tenet of NRBV, the firm is also investing its resources and capabilities toward minimizing GHG emissions, optimizing resources and improving energy efficiency. ABC Ltd. is working to increase natural gas generation, as natural gas has a 30% lower carbon footprint than oil. The company has signed a memorandum of understanding (MoU) regarding the use of natural gas in its alumina calciners, which will cut the GHG intensity of alumina operations by 20%. The firm has also decided to invest heavily in energy transition and improve its climate change performance.

The firm has also taken the initiative to significantly decarbonize its transportation and logistics operations. When asked about some recent examples of the firm's initiatives towards climate change action, a manager from the engineering division said,

... Our company is committed to making sure that all of our light-motor-vehicle fleet will be carbon-free by 2030 and that 75% of our mining fleet will run without fossil fuels by 2035.

The entire fleet of turbines in the zinc operations has been modernized, resulting in lower GHGs emissions per unit of energy produced and higher machine output. In terms of water conservation, the firm has partnered with the civic authorities to treat municipal sewage water and use it in their operations.

To develop an ecosystem focused on sustainability, ABC Ltd. is incubating start-ups addressing climate change through a program aimed towards the identification of solutions related to the industry's numerous climate change challenges. Consequently, the firm was able to improve aluminum recovery and reduce CO₂ emissions by more than 260,000 metric tons annually through several initiatives, for example, by collaborating with a start-up in the refining sector.

In order to effectively manage climate focused initiatives, ABC Ltd. has also established a multi-layered climate governance organizational structure that oversees the firm's sustainability issues and seeks to integrate measures related to mitigate climate change into overall business practices. Together, these governance mechanisms ensure that the operations follow the highest moral principles, all applicable laws, and best practices in energy and carbon management to reduce overall climate impact. In addition, during the

interview with the human resource manager, a number of initiatives pertaining to human resource practices were discussed. When asked about the initiatives, the human resource manager responded:

We have changed the way our incentives work in a number of ways. For example, executive pay could be tied to how well the company does with sustainability. Also, an employee's eligibility for an ESOP (Employee Stock Option Plan) will depend on how well they do on sustainability parameters. In the same way, climate KPIs (Key Performance Indicators) will be used to measure the performance of people in positions like energy manager, environment manager, or sustainability manager, as well as those on the executive team of the company.

ABC Ltd. has incorporated the "shadow price" as part of the capital expenditures approval process in the future, with the intention of redirecting investments towards clean technology, lower-carbon solutions and renewable energy projects across its operations and supply chain. This will aid the firm in mitigating climate risks and exploring options to decrease its carbon footprint, GHG emissions and associated transitional expenses. In order to optimize decision-making, the carbon price will be utilized to monetize GHG emissions incorporated in business strategies.

Overall, ABC Ltd. has taken multiple actions to improve its climate performance. The firm is actively taking steps to reduce the energy consumption across its supply chain by driving innovation towards new product development, production, as well as logistics. However, being one of the largest natural resource companies, ABC Ltd. can also influence the climate performance in the upstream and downstream supply chain. In this study, we found little evidence of ABC Ltd. trying to improve GHG emissions in its vendor base (except in the case of green electricity procurement). By promoting climate positive actions in its vendor organization, the M&M firm can have a far greater cascading effect to promote climate neutrality. Thus, although ABC Ltd.'s initiatives reverberate vigorously within its own operations, their transformative impact does not transcend upstream and downstream vendors or partners across the supply chain. Ensuring the climate neutrality behaviors and pro sustainability initiatives beyond its own area of control has been a challenge for ABC Ltd.

4.3.6 Performance. The performance of ABC Ltd. is measured based on the benefits realized after implementing climate change practices. The SAP analysis facilitates the understanding of the requirements of the climate change strategy, and based on the actions suggested, the performance is analyzed for ABC Ltd. The potential changes in performance have been estimated after our interaction with the management of ABC Ltd. Despite high growth, ABC Ltd. has prevented an increase in CO₂ emissions and has been able to maintain a constant amount of CO₂ emission over the last 2 years. It has also managed to recycle 100% of the high volume, low toxicity waste, which is typically stored in tailing dams, landfills, etc. The fly ash recycling rate was more than 100% in the last fiscal year, which included the consumption of legacy waste. ABC Ltd. was able to recycle 31% of the total wastewater consumed in its operations for non-drinking purposes, such as agriculture, landscape, etc. In the same year, the firm significantly increased the share of renewable energy in its energy mix. It produced its first climate change report a year ago, with board oversight and conformity with the Task Force on Climate-related Financial Disclosures framework. The inaugural study analyzed climate-related threats and opportunities and outlined the organization's operational resilience under several climate-related scenarios. ABC Ltd. has also started reporting its scope 3 emissions after inventorying emissions in this category for its business units. The company signed an MoU to use electric mining trucks in its mining operations, and it was the biggest user of green power in the fiscal year 2021.

Consequently, ABC Ltd. has made significant progress in reducing its emission and achieving climate neutrality. Since 2012, ABC Ltd. reduced the GHG emission intensity (tons of CO₂ emitted per ton of metal produced) by 21%, resulting in the prevention of 14 million

tons in CO₂ emission. On an absolute basis, the firm has managed to produce 8.5% more metal, while retaining the same amount of GHG emissions. Data on key performance metrics and targets of ABC Ltd. has been summarized in [Tables 3 and 4](#).

[Figure 2](#) depicts a systematic analysis of climate neutrality practices in the M&M industry supply chains, as well as the various resources, assets, and capabilities required to achieve climate neutrality therein.

While the organization has demonstrated significant reduction in GHG emissions on the road to climate neutrality, there have also been a few setbacks. Specifically, with regard to managing a symbiotic relationship with the local communities, the firm has a lot of ground to cover. In 2018, one of the large copper manufacturing facilities was shut down after protests by the local community for allegedly causing environmental degradation and release of harmful wastes, along with non-adherence to regulatory norms. A similar problem in Africa led to litigation by the local community on grounds of water contamination by the firm in 2011.

5. Discussion

The present study assesses the current situation of climate neutrality practices in the M&M industries, which can help the actors develop a relationship between the firm and its natural environment and further build mechanisms for effective implementation of climate neutrality practices. The findings of the study firmly uphold the fundamental claim made by NRBV that focusing a firm's resources and capabilities on environmental initiatives can help businesses achieve a competitive advantage, while simultaneously achieving climate neutrality by minimizing GHG emissions, lowering energy consumption and making best use of available resources.

Overall, the firm faces multiple and unique challenges that need to be addressed. On the external front, regulatory environment, local policies and investor activism are the driving forces for climate neutrality practices. However, within the supply chain, lack of a well-

Metric	FY 20	FY 21	FY 22
GHG emission (MTCO ₂ e)	59.34	60.24	62.83
GHG emission intensity (MTCO ₂ e per INR million revenue)	71.37	61.95	47.94
Energy consumption (million GJ)	526	524	564
Renewal energy used (as a % of total energy consumed)	0.1%	0.4%	2.6%
Water recycled %	28.9	30.7	30.6

Source(s): Created by authors, based on ABC Ltd.'s published reports

Table 3.
Key climate neutrality
metric performance for
ABC Ltd

Area	Metric	Target
Climate change	Absolute GHGs emissions	25% reduction by 2025
	GHGs emissions intensity	20% reduction from 2021 baseline
	Renewable energy (RTC equivalent)	500 MW
	Energy savings	10 million GJ
Water conservation	Water recycling	10% increase from 2021
Waste management	Fly ash utilization	Sustain at 100%
	HVLT utilization	100%
	Tailings dam audit findings closure	–

Source(s): Created by authors, based on ABC Ltd.'s published reports

Table 4.
Performance metric
and targets for
ABC Ltd

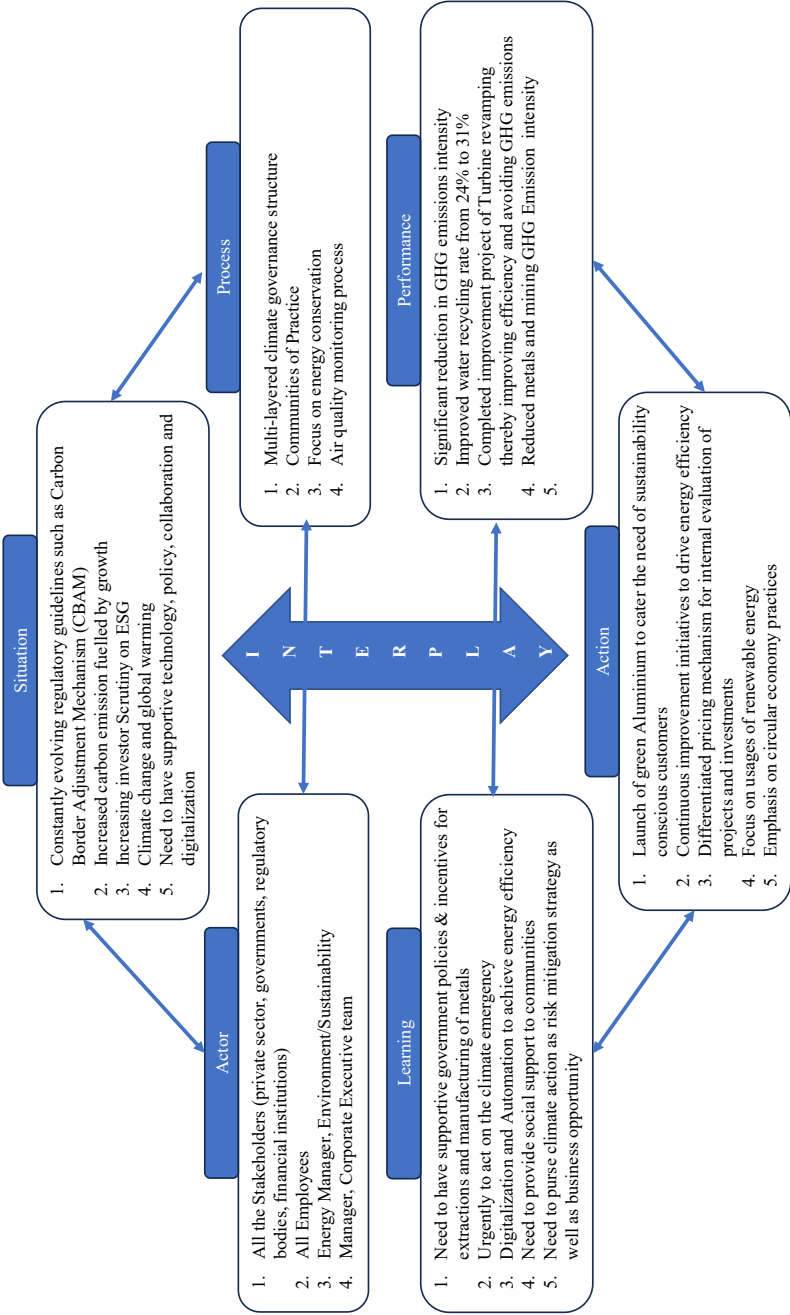


Figure 2.
A theoretical
framework for climate
neutrality in the M&M
industry supply chain
based on SAP-LAP
linkages

Source(s): Created by authors

developed climate-friendly network of firms that can, for example, consume waste produced by ABC Ltd. or provide green electricity, is lacking. Being in the business of exploitation of natural resources, M&M firms have to also face the consequences of being negatively perceived by local communities. Hence, the organizations need to not only act to reduce their GHG emissions but also ensure that their actions are perceived positively by the communities in the vicinity of their operations. The firms, while addressing all these external challenges, have to remain competitive and deliver value to their shareholders and keep the employees satisfied. Driving financial and operational efficiency in the supply chain within external constraints is a challenge that is unique and specific to M&M firms.

Product stewardship as a capability, as described in NRBV, refers to taking ownership of the entire value chain of the product system. Ensuring the adoption of a climate risk strategy in upstream and downstream processes ensures that the overall impact of a firm's activities on the environment is minimized across the sourcing (of raw materials), manufacturing, and usage stages. Policies like the EU carbon tax, ESG-focused investment initiatives, customer awareness and preference for sustainably produced products, etc. provide multiple avenues for M&M firms to grow and prosper. However, these efforts primarily target the consumption phase of the M&M lifecycle. Conversely, in the production phase, M&M companies, particularly in emerging economies, have to confront the hurdle of an underdeveloped environment-friendly ecosystem. Major challenges include the lack of ample renewable energy sources, a network of industries capable of handling M&M waste, and collaborative initiatives with local government bodies for aspects like urban mining and wastewater treatment. With most of the extraction and primary processing happening in developing economies, mere regulations controlling the processing and production in the M&M sector are insufficient. This sector needs active governmental intervention to drive climate neutrality, specifically in emerging economies.

In order to benefit from the consumption-related regulations, ABC Ltd. is also investing in R&D and developing “green” metals – essentially, metals with a far lower carbon footprint compared to those produced through traditional manufacturing methods. Such new “low carbon” products will enable growth and profitability for M&M firms in the coming years. In one of the published reports, the chairman remarked,

ABC wants to capture the opportunities being created due to climate change related policies being crafted globally which provides incentives and preferences for sectors like Renewable energy, Green hydrogen, Green metals etc.

In our interaction with the case firm employees as well, the EU regulatory changes on Carbon Border Adjustment Mechanism (CBAM) came up frequently. Similarly, investor activism has played a role in ABC Ltd.'s access to capital about 10 years ago when a couple of international institutional investors had sold off their holdings in ABC Ltd., citing environmental concerns. At the production stage, ABC Ltd. is consistently reducing its GHG emissions. It is the largest buyer of renewable energy and makes efforts to save energy in its operations. However, ABC Ltd. faces challenges in adequate renewable energy availability and has to set up its own power plants. The firm has collaborated with multiple SME industries to use the fly ash generated from metal processing for construction purpose. Such initiatives can be driven by M&M firms at a local level. However, there is a need for a comprehensive plan to drive climate neutrality during the processing and production stage in M&M.

Hence, we argue that while regulatory efforts during the *consumption stage* are crucial in driving sustainable product design, a more comprehensive approach is essential for fostering a conducive environment in the *production phase* of the M&M sector. This is particularly pertinent in the context of emerging economies, where the challenges are unique and necessitate active government support beyond regulatory and control measures.

Proposition 1a. Consumption side regulations, public policy, and investor activism can drive sustainable product development in M&M firms

Proposition 1b. Government intervention in nurturing a supportive ecosystem for sustainable production in the M&M sector can enhance climate performance in emerging economies

To achieve climate neutrality, the firm must take a number of steps in its supply chain to reduce its own emissions, use renewable energy, and invest in the reduction or removal of emissions. Focusing on energy conservation in the core processes operations can help address the GHG emissions challenge. The case firm has employed a continuous improvement drive to constantly identify opportunities to conserve energy and improve the efficiency of its processes. The firm is also promoting overall maximization in renewal energy usage to further lower the scope 2 emissions.

ABC Ltd. has taken significant steps to drive climate neutrality within its supply chain through a series of strategic initiatives. Continuous improvement efforts and targeted investments, such as re-plating of turbine blades, improving boiler efficiency, reducing the use of carbon-intensive furnace oil, upgrading smelter technologies, and driving the “waste to wealth” initiative to recycle/reuse mineral processing waste have helped ABC Ltd. not only reduce GHG emissions but also improve operational efficiency. In addition, ABC Ltd. has prioritized the adoption of renewable energy sources throughout its supply chain operations. The company has introduced electric vehicles in its fleet to reduce carbon emissions associated with transportation. ABC Ltd. recognizes the environmental advantages of natural gas compared to oil and has actively pursued the increase of natural gas generation. The company has also signed an MoU to explore the use of natural gas in its alumina calciners.

ABC Ltd. has leveraged collaboration with external partners to drive further innovation and emission reduction in the M&M sector. Collaborating with a start-up in the refining industry, the company successfully improved aluminum recovery and significantly reduced CO₂ emissions. Similarly, for water conservation, the firm has partnered with civic authorities to treat municipal sewage water, enabling its reuse in the firm’s operations.

Achieving climate neutrality is a difficult task that requires implementation of measures to reduce emissions, use of renewable energy, investment in emission reduction or removal, and strong collaboration within the entire supply chain, leading to the following proposition:

Proposition 2. Innovation and continuous improvement in the supply chain, along with collaboration among supply chain partners, can help organizations in achieving climate neutrality in the M&M industry

In the context of our study’s findings, a profound resonance with the NRBV theory emerges. This theory expounds upon three fundamental strategic capabilities, each with distinct environmental driving forces and resource bases: pollution prevention, product stewardship and sustainable development. These capabilities are intricately connected with different sources of competitive advantage.

Pollution prevention, as advocated by NRBV, pertains to avoiding waste and emissions from the outset, yielding cost efficiencies by reducing inputs, streamlining processes, and lowering compliance and liability expenses. As firms seek to reduce their environmental footprint, they inherently drive down costs, improve operational efficiency, and enhance their overall resource utilization. Our research discovered that, by driving lower emissions and reducing the GHG footprint, ABC Ltd. was able to improve operational efficiency, resulting in overall lower cost of operations. As evidenced in our arguments leading to [proposition 2](#), the firm’s collaborative efforts across the supply chain, initiatives such as “waste to wealth,” and continuous improvement initiatives are a source of competitive advantage for ABC Ltd.

Further, the product stewardship capability encapsulates the holistic view of a firm's product systems throughout their life cycle. Companies that embark on product stewardship consider the environmental implications of sourcing, manufacturing, distribution, usage, and disposal, fostering a strategic pre-emption by securing access to green resources and creating advantageous standards. In our study, we discovered that ABC Ltd. has started the journey towards "green metals" by investing in research and development and reducing the emissions from metal production. As described in [propositions 1a](#) and [1b](#), regulations, public policy and investor activism can foster the creation of sustainable product lifecycle in the M&M sector. This parallels the essence of product stewardship, which encourages firms to proactively design and develop products that minimize environmental impact across their entire lifecycle, aligning with regulatory and consumer preferences.

Finally, sustainable development is the most encompassing capability, as it not only aligns with environmental concerns but also encompasses economic and social dimensions and the impact of a firm's operations. This strategic capability acknowledges the interdependencies between economic growth, environmental protection, and social well-being. In our study, we discovered that ABC Ltd. has some ground to cover with respect to this capability. There are instances where ABC Ltd. developed a strained relationship with the communities that the firm operated in, resulting in protests and conflicts. These challenges reflect the intricate social dynamics often witnessed in regions rich in natural resources. Despite ABC Ltd.'s robust corporate social responsibility (CSR) initiatives, these instances highlight the need for a more concerted effort to uplift and empower marginalized communities residing around its mining and processing sites. This aligns seamlessly with the essence of the sustainable development capability, which places equal emphasis on economic prosperity and social welfare. The journey of ABC Ltd. towards achieving climate neutrality cannot be separated from its interactions with the local communities. Sustainable development demands a comprehensive approach, where the company also actively contributes to the growth and well-being of the regions it influences.

Our findings from this case study are well-aligned with the existing literature on sustainability. Researchers have previously found that low emission products have a positive impact on firm competitiveness ([Ar, 2012](#)). Studies have also shown improved emission performance when appropriate regulatory measures are enacted ([Ouyang et al., 2020](#); [Zailani et al., 2012](#)). The positive influence of environmental governance on sustainability outcomes has also been reported ([Walls et al., 2012](#)). Similarly, innovation as well as transparency and communication have also been linked with better environmental outcomes ([Băndoi et al., 2021](#); [Kuzma et al., 2020](#)).

6. Implications

This paper contributes to the emerging academic literature that analyzes climate neutrality comprehensively, taking into account all relevant contextual variables. Thus, the current study contributes to the development of a holistic understanding of climate neutrality in the supply chain of the M&M industry. The study explores current issues that organizations face in achieving climate neutrality, the roles of various stakeholders in this pursuit, and suggests necessary actions and measures, ultimately evaluating performance outcomes. Through the propositions outlined in the text, the study emphasizes the need for a holistic approach to climate neutrality in the M&M industry. By integrating sustainability throughout the product life cycle, fostering a culture of sustainability, adopting innovative emission reduction approaches, and promoting collaboration, organizations can take concrete steps towards achieving climate neutrality and contribute to a more sustainable future. This not only assists organizations in addressing current challenges in achieving climate neutrality and implementing corrective measures, but also guides them towards growth and

competitive advantage. The findings of the study are based on experts' opinions. Therefore, the study can serve as a foundation for future research that employs evidence-based data to validate the results obtained through the SAP-LAP method. This study also contributes to the body of knowledge on NRBV theory and its application in the context of climate neutrality in M&M sector. The study has highlighted the need for strategic management of natural resources and its link to competitive advantages in achieving climate neutrality goals. Our analysis demonstrated how effective natural resource management practices, such as the utilization of renewable energy sources, adoption of cleaner production technologies and resource conservation strategies, can contribute towards sustainable competitive advantages. Overall, this study advances the theoretical implications of the NRBV theory by illustrating its relevance and applicability in understanding the strategic implications and competitive advantages associated with resource-based approaches to climate neutrality within the M&M sector.

The study further offers several important managerial implications for practitioners in the M&M industry. We can derive meaningful recommendations from the synthesis of this case study. First, in embracing regulatory drivers and investor activism, M&M firms can harness external forces to drive sustainable product development. As regulations evolve and investors demand ethical practices, firms can leverage these drivers to innovate products with a reduced environmental footprint. By adhering to the NRBV principle of pollution prevention, M&M entities can not only comply to, but also thrive within, regulatory frameworks. Additionally, M&M firms, specifically in emerging economies, need to reimagine governmental influence. Fostering a supportive ecosystem for sustainable production, M&M entities can transcend regulatory compliance and actively nurture an environment conducive to green practices.

Second, cultivating a culture of sustainability emerges as the cornerstone of effective climate neutrality in the M&M sector. When M&M firms embed sustainable practices across all organizational levels, they create a synergy that drives climate-conscious decisions and fosters responsible behavior.

Third, driving innovation and continuous improvement within the supply chain, encapsulates the essence of sustainable development. By collaborating with supply chain partners, M&M firms can leverage collective expertise to optimize energy consumption, reduce emissions and enhance operational efficiency. This strategy aligns with sustainable development's emphasis on balancing environmental concerns with economic and social dimensions. Furthermore, acknowledging the impact of M&M operations on marginalized communities and fostering their well-being encapsulates the essence of sustainable development.

7. Conclusion, limitations and future scope

This in-depth case study examined the end-to-end operations of an M&M firm. This sector is of immense significance, given its role in supplying critical raw materials for the digital economy. Based on the insights from literature, key sustainability challenges in the M&M sector and their proposed solution have been investigated in detail. This study has identified the key situations, actors, processes, learnings, actions and performance aspects of sustainability from a firm's perspective using the SAP-LAP framework and theoretical underpinning of NRBV theory. Having outlined the identified best practices, such as investment in renewable energy sources, initiatives for continuous improvement, and strategies for waste management, this study can serve as a practical guide for firms aiming to reduce their carbon footprint. The study also offers a detailed analysis of investor and regulatory actions and their impact on the climate neutrality practices, thus providing valuable insights for governments and regulatory authorities.

Furthermore, the study contributes to the development of a theoretical framework for understanding factors influencing climate neutrality goals in the M&M industry. By utilizing

the SAP-LAP connections approach, this study examined climate neutrality from an internal viewpoint. This perspective complements the external view often employed in supply chain research and offers a more comprehensive understanding of climate-neutral supply chains. By applying the NRBV theory to climate neutrality, this study expands the application of NRBV to industries beyond those dealing with traditional resources. It demonstrates how NRBV can be leveraged to address complex environmental challenges and manage natural resources for sustainable outcomes in an M&M setup. The development of propositions related to climate neutrality based on the study's findings paves the way for future empirical research. These propositions can serve as a foundation for further investigation of the effectiveness of specific strategies adopted by the case firm. The learnings and insights from this study can be applied in similar contexts or serve as a basis for future comparative studies. The study encourages scholars to explore these propositions through rigorous empirical research, contributing to the advancement of knowledge in the field of sustainable supply chain management.

The study also has several limitations that can be addressed through future research endeavors with respect to the connection between supply chain sustainability and climate neutrality. First, the findings emanate from a single-case study, which serves as a starting point for enhancing external validity and generalizability. Future research employing a comparative case study or a multi-case approach can broaden the scope of findings, making them applicable to various M&M industry segments or other sectors focusing on climate neutrality. Second, while this study presents a robust theoretical framework supported by empirical evidence, it is crucial to consider alternative explanations for observed outcomes. External factors such as industry dynamics, technological advancements, or market forces may have influenced results, warranting additional explanatory research. Third, the NRBV theory, while emphasizing strategic resource management, may not fully encompass the dynamic capabilities needed for firms to adapt and innovate in response to evolving environmental and regulatory challenges. Integrating NRBV with dynamic capabilities and other pertinent management theories in future research could provide a more comprehensive perspective.

Notes

1. <https://unfccc.int/blog/a-beginner-s-guide-to-climate-neutrality>
2. Creating the zero-carbon mine | McKinsey (<https://www.mckinsey.com/industries/metals-and-mining/our-insights/creating-the-zero-carbon-mine>)
3. Industry Insights: Metal Industry – Omnifin (<https://omnifin.in/metalandminingindustry/>)

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Appendix

The supplementary material for this article can be found online.

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