Navigating decarbonisation of steel production: a strategic roadmap for coal producers

Christiaan Frederick Krüger
Haaga-Helia University of Applied Sciences
Degree Programme in Leading Business Transformation
Master of Business Administration
Digital Business Opportunities
Master Thesis
2025

Author
Christiaan Frederick Krüger

Degree
Master of Business Administration

Thesis title
Navigating the decarbonisation of steel production: a strategic roadmap for coal producers

Number of pages and appendix pages
60

The global push for decarbonisation presents coal producers particularly those supplying metallurgical coal to the steel industry with an urgent strategic dilemma. Should they adapt to technological and policy changes, diversify into adjacent markets, or exit coal altogether? While much of the existing literature focuses on decarbonisation from the steel producer’s perspective (IEA, 2020) this thesis re directs the focus and analysis towards the coal supplier. It fills critical literature gaps by offering a supply-side scenario framework and decision-making tools tailored to the unique challenges coal producers face during decarbonisation. The objective of this thesis is to analyse the strategic implications of steel industry decarbonisation for coal producers by assessing impacts on metallurgical coal demand, evaluating strategic responses, and proposing a decision-making framework for long term business continuity and sustainable adaptation to market changes.

The research employs a qualitative-dominant mixed methods approach, combining scenario planning methodologies such as the four archetypes, the shell method, and the 2x2 matrix with comparative case studies of coal suppliers and steel producers. Four coal-centric scenarios are developed based on two key uncertainties: the pace of technological change and the intensity of policy pressure. These are cross-referenced with coal-specific variables such as coal type whether it be thermal or metallurgical, regional market exposure, and policy environment.

The thesis introduces a new strategic decision-making framework that allows coal producers to match their risk exposure and internal readiness and capabilities to one of four strategic pathways, which are: adaptation, diversification, repositioning, or exit. This framework is validated through real-world case studies including BHP, Glencore, Tata Steel, Peabody, and ArcelorMittal, demonstrating how coal suppliers are beginning to adjust their business models during decarbonisation. Strategic alignment between scenario contexts and internal capabilities is shown to be essential for navigating transition risks and maintaining long-term value and continuity.

Key results of this research include: (1) developing the first scenario typology centred on coal producers in the context of steel decarbonisation, (2) distinguishing between thermal and metallurgical coal in strategic planning, and (3) incorporating regional imbalances in policy and market dynamics into coal supply strategy. The thesis offers practical, forward-looking tools for industry decision-makers while also enriching academic literature on industrial transition and climate-aligned resource governance.

Keywords

Coal, Decarbonisation, Steel industry, Scenario planning, Strategic planning, Foresight research

Table of Contents

1 Introduction

1.1 Background and context

The world is increasingly shifting towards decarbonisation which poses a major strategic challenge for coal producers who rely on metallurgical coal sales to the steel industry. The main problem is to determine whether coal producers should peruse and adapt to new technologies, or diversify into new markets, or should they just exit the coal sector altogether. Despite the vast literature on the technological and economic aspects of decarbonisation for steelmakers, the strategic response options for coal suppliers are largely unexplored. This knowledge gap leaves coal producers unprepared to manage the changing dynamics of the industry. To this end, the purpose of this thesis is to equip coal producers with strategic insights, scenario analyses, and practical decision-making frameworks to sustainably manage the challenges posed by steel industry decarbonisation. These practical tools and novel literature will ensure continued availability of affordable energy resources and raw materials for steel that is critical for the steel industry which is an essential driver of infrastructure growth, economic development, and poverty alleviation in transforming developing economies into developed ones. Affordable steel from reliable and cost-effective energy sources is literally the foundation upon which nations build their future - creating the essential infrastructure, driving economic prosperity, and fundamentally improving people's lives.

The steel industry has been a foundational industry for modern infrastructure, construction, and manufacturing, and has greatly contributed to economic growth and development worldwide (Verhoeven et al., 2016). However, it is also among the most energy intensive industries and account for about 7% of the total CO_2 emissions (RMI, 2022). There is a growing global need to change the conventional steel production methods that are dependent on fossil fuels, particularly coal, due to rising international pressures of climate change and the need to reduce greenhouse gas emissions (IEA, 2021).

In response, the steel industry has actively started to invest and shift to new, innovative, lower carbon steelmaking technologies such as hydrogen based direct reduced iron (DRI), carbon capture, utilization, and storage (CCUS) and electric arc furnaces (EAF) which use significantly lower or no coal at all (IEA, 2021). These shifts impact coal producers, especially those focused on metallurgical coal, traditionally used in steel production, in a profound way. Steelmakers are gradually cutting back on their coal consumption, putting coal suppliers in a position of declining demand, market volatility and long-term viability issues (Dudin et al., 2017). Therefore, coal producers must critically reassess their operational strategies, invest in technological innovation, and explore market diversification opportunities such as renewable energy technologies, hydrogen production, critical minerals extraction and AI driven efficiency improvements (Otto et al., 2017; Flores-Granobles & Saeys, 2020).

1.2 Research objective and demarcation

The objective of this thesis is to analyse the strategic implications of steel industry decarbonisation for coal producers by assessing impacts on metallurgical coal demand, evaluating strategic responses, and proposing a decision-making framework for long term business continuity and sustainable adaptation to market changes.

Achieving this will significantly contribute to existing academic literature, offering practical insights and strategic recommendations for stakeholders within the coal and steel production sectors navigating the complexities of the global energy transition.

1.3 Research strategy

This thesis adopts a qualitative-dominant mixed-methods approach, combining scenario planning and comparative case study analyses to explore the strategic implications of steel industry decarbonisation for coal producers. Scenario planning forms the methodological foundation, leveraging established frameworks such as the Four Archetypes, the Shell Scenario Planning Approach, and the 2x2 Matrix Method to develop robust future scenarios specifically tailored from the coal producers' perspective. These scenarios incorporate technological advancements, regulatory shifts, and economic dynamics.

Additionally, comparative case studies of key coal producers and steel manufacturers across different regions will be conducted to empirically assess strategic responses to industry decarbonisation trends. Secondary data sources such as including industry reports, corporate disclosures, policy documents, and academic literature will underpin the scenario development and case study analysis.

Ultimately, a structured decision-making framework will be developed, synthesizing insights from scenario analyses and case studies. This framework aims to provide coal producers with practical tools for assessing and navigating strategic options, including market adaptation, diversification, or phased market exit, thus ensuring their sustainable adaptation to evolving market conditions driven by global decarbonisation efforts.

1.4 Structure of the thesis

This thesis is organised into eight interrelated chapters, each designed to progressively build a comprehensive understanding of the strategic challenges and opportunities facing coal producers amid the global decarbonisation of steel production.

Chapter 1 introduces the background and context of the research, outlines the core objectives, defines the scope, and presents the methodological orientation. Chapter 2 presents a detailed literature review that examines technological innovations in steel production, their implications for coal suppliers, and alternative investment strategies. This chapter also identifies significant gaps in existing research and positions the thesis within the broader academic discourse.

Chapter 3 explains the research methodology, justifying the use of a qualitative-dominant mixed methods approach. It details the scenario planning methods and comparative case study strategies employed to analyse the strategic positioning of coal producers. Chapter 4 applies these methodologies to develop a set of four coal-centric scenarios based on two critical global uncertainties technological pace and policy pressure. Then filters them through coal-specific variables such as coal type, regional market dynamics, and regulatory exposure.

Chapter 5 offers a comparative case study analysis of selected steel producers and coal suppliers, examining how firms in different geographic and regulatory contexts are responding to decarbonisation pressures. These empirical insights serve to validate the scenarios and inform the strategic framework developed in the following chapter.

Chapter 6 introduces a novel decision-making framework designed to guide coal producers in evaluating their strategic options. This framework integrates scenario analysis and case study findings to present four potential strategic pathways: adaptation, diversification, repositioning, and exit. Chapter 7 discusses the broader implications of the research, highlights the original contributions made by the thesis, and reflects on its practical applicability for industry actors and policymakers.

Finally, Chapter 8 concludes the thesis by summarising the key findings, offering strategic recommendations for coal producers and decision-makers, and suggesting areas for further research.

1.5 The use of AI

Artificial intelligence (AI) tools such as ChatGPT was used to help with thesis development through idea organization and language improvement and theoretical framework clarification. All AI-generated content was critically reviewed, edited, and validated by the author to ensure academic integrity and relevance. The abstract contains no AI-generated material. The AI tools operated within Haaga-Helia’s ethical and practical guidelines while maintaining full respect for data privacy and copyright.

2 Literature review

2.1 Introduction and scope

This literature examines technological advancements enabling steel decarbonisation, explores their implications for coal producers, and evaluates alternative investment strategies to ensure long-term business continuity.

2.2 Historical evolution of the steel industry

From the time when the first iron tools were crafted around 1200 - 900 BC to the construction of towering skyscrapers, expansive railways and large industrial machinery, steel has played a fundamental role in shaping human life over the past 3,000 years (Verhoeven et al., 2016). In more recent times, rooted in the fabric of the Industrial Revolution, the invention of steel and mass production catalysed unprecedented economic growth and infrastructural development (Evans & Withey, 2012). However, this remarkable growth has come at a cost. Today, the steel industry is recognized as a significant contributor to carbon emissions, accounting for roughly 5-7% of the total emissions. This highlights the pressing need for strategies to reduce the carbon footprint and address climate change impacts (Wang et al., 2008).

The transformation of steelmaking from blast furnaces during the Industrial Revolution to less carbon-intensive methods showcases an industry marked by its innovation and adaptability. This shift has been greatly influenced by advancements in technology and processes focused on lowering carbon emissions and enhancing efficiency. According to Skoczkowski et al. (2020), substantial technological innovations in response to regulations and market pressures have been witnessed in Europe’s steel industry. These innovations include hydrogen-based steelmaking, direct reduction ironmaking, and carbon capture, utilization, and storage (CCUS) technologies. However, despite these advances, traditional steel manufacturing continues to rely heavily on coal for energy and reduction processes. This reliance highlights the sector's environmental impact and susceptibility to changes in energy trends and regulations. In response, the steel industry is undergoing a transformative phase, propelled by environmental concerns, regulatory actions, and technological breakthroughs (Rechberger et al., 2020).

This literature review delves into three main themes of this transformation: technological transformations in steel production, the resultant impacts on coal producers, and the exploration of alternative investment strategies for coal suppliers. Each theme is crucial for understanding the challenges and opportunities presented by the industry's transition towards sustainability. Chapter 2.3 to 2.5 overview these three themes.

2.3 Technological transformations in steel production

It is essential to understand the current landscape of steel production and its dependence on carbon-intensive processes. The steel industry has historically relied on blast furnace-basic oxygen furnace (BF-BOF) technology, which requires metallurgical coal as a reducing agent. This dependence on coal has made steel one of the highest-emitting industrial sectors. The following section outlines traditional and emerging steel production technologies, laying the foundation for understanding how technological innovations may reshape the role of coal in steel manufacturing.

2.3.1 Blast furnace-basic oxygen furnace (BF-BOF) technology

There are two main steel production methods, the Blast Furnace-Basic Oxygen Furnace (BF-BOF) Route and the Electric Arc Furnace (EAF) Route. The BF-BOF route involves several stages. Ironmaking: Iron ore, coke, and limestone are charged into a blast furnace. The coke acts as both a fuel and a reducing agent, converting iron ore into molten iron. Steelmaking: The molten iron is transferred to a basic oxygen furnace, where pure oxygen is blown through it to oxidize impurities. This process reduces the carbon content and produces molten steel. Refining and Casting: The molten steel is refined to adjust its chemical composition and then cast into slabs, billets, or blooms for further processing. This method's carbon-intensive nature arises from the significant use of coke and the chemical reactions involved in reducing iron ore. Traditionally, the sector heavily relied on the blast furnace oxygen furnace (BF-BOF) method of production. Despite advancements in technology, the BF- BOF approach continues to dominate steel production, representing around 70% of output (IEA, 2023).

2.3.2 Electric arc furnace (EAF) technology

The Electric Arc Furnace (EAF) Route is a more flexible and environmentally friendly steelmaking process that involves: Charging the Furnace: Scrap steel is the primary raw material, which is charged into the electric arc furnace. Melting: Electrical energy is used to generate an arc between electrodes, melting the scrap steel. Refining: The molten steel is refined to achieve the desired chemical composition. Casting: The refined steel is cast into various shapes for further processing. The EAF method's environmental impact depends significantly on the electricity source. Using renewable energy can substantially reduce carbon emissions compared to traditional methods (Flores-Granobles & Saeys, 2020).

Innovations such as hydrogen-based processes, direct reduction ironmaking, carbon capture, utilization, and storage (CCUS) technologies, and artificial intelligence (AI) integration are leading the way in reducing carbon emissions in steel production. These innovations aim to lower the industry's carbon emissions by changing the traditional raw materials and energy sources used in making steel. One notable example is hydrogen-based steel production, which presents a future where steel is manufactured with water vapour as the only emission, this is a considerable contrast to the CO_2-intensive methods of today (Rechberger et al., 2020).

2.3.3 Hydrogen-based steelmaking

Hydrogen steelmaking represents a transformative shift away from carbon-intensive processes with hydrogen used as a reducing agent instead of carbon. The method reduces the steel industry's carbon footprint because the reaction produces water vapour rather than CO2 (Rechberger et al., 2020). Iron placed in a reduction vessel is treated with injected hydrogen gas, leading to the exothermic reaction where hydrogen molecules reduce the iron oxides into metallic iron while producing water. The greatest advantage of hydrogen-based steelmaking is its potential to make ‘green steel’ with virtually no carbon emissions which is consistent with world decarbonisation goals (IEA, 2020). On the other hand, the main challenges are obtaining a steady and affordable supply of green hydrogen which is produced from renewable energy sources, creating the required infrastructure for hydrogen production, storage and transport systems, and modifying current furnace technologies for hydrogen metallurgy which has not been widely adopted yet (IEA, 2021). There are a few leading steel manufacturers who are piloting hydrogen-based steelmaking processes. For example, the HYBRIT project in Sweden looks to bring fossil-free steel to the market by 2026. This shows the potential for wider adoption of this technology (World Steel Association, 2020).

2.3.4 Direct reduced iron (DRI) production

Direct reduction ironmaking is a process of reducing iron ore to metallic iron using a gas-based reducing agent like natural gas as opposed to coke. This method yields direct reduced iron (DRI) or sponge iron that can be melted in an electric arc furnace (EAF) to produce steel (Ramakgala & Danha, 2019). Compared to traditional blast furnace methods carbon emissions are significantly reduced by this approach especially when carbon capture technologies are coupled with it (Wang et al., 2008). The barriers to adoption consist of the need for substantial structural changes, guaranteeing access to natural gas at competitive prices, and the establishment of good CCUS methods to capture the remaining emissions (Fischedick et al., 2014).

2.3.5 Carbon capture, utilisation and storage (CCUS)

CCUS technology captures CO2 emissions at the source before they can enter the atmosphere. The captured CO2 is either stored in geological formations permanently or used in other industrial applications such as the creation of synthetic fuels or concrete (Global CCS Institute, 2020). The benefit is that CCUS presents a feasible approach to mitigating greenhouse gas emissions from steel production, especially in those processes where direct emission reductions are not always possible (Flores-Granobles & Saeys, 2020). However, deployment of CCUS on a large scale is hindered by high costs, technical and logistical complexities, regulatory and public acceptance issues and the requirement for secure long-term storage solutions (De Ras et al., 2019)

2.3.6 Artificial intelligence integration

AI and machine learning technologies are increasingly being employed to optimise steel production processes. By analysing vast amounts of data, AI algorithms can predict maintenance needs, enhance operational efficiency, reduce energy consumption, and minimise emissions. The benefits are that AI's ability to optimise production processes and predict equipment failures can lead to significant reductions in emissions, operational costs, and unplanned downtime (Pellegrini et al., 2019). On the other hand, the challenge is that Integrating AI into steel production involves overcoming barriers such as substantial investments in digital infrastructure, acquiring and processing relevant data, and developing specialised AI models tailored to the unique needs of the steel industry (John et al., 2022).

2.4 Technological impact on coal producers

Technological shifts in steel production are reshaping coal demand, particularly for metallurgical coal. The rise of low-emission methods like Electric Arc Furnaces (EAF), hydrogen-based steelmaking, and CCUS technologies is reducing reliance on the traditional BF-BOF route. This transition is uneven across regions, with the EU leading in decarbonisation, while countries like India and China maintain BF-BOF dominance due to cost and resource factors (Plakitkina et al., 2021). As a result, coal suppliers must adapt to divergent technological pathways, shifting demand patterns, and evolving policy pressures that affect long-term strategic planning.

2.4.1 Changing demand dynamics for metallurgical coal

These technological changes have important implications for the coal industry, which has historically been integral to steel production as a primary energy and reduction source. The adoption of cleaner steelmaking technologies could reduce coal's role in the steel industry, requiring a re-evaluation of coal suppliers' positions within the steel industry. This review will look into how coal suppliers are navigating these changes, examining the threats to their long-term continuity and the necessity for adaptation in an evolving energy and steel landscape (Dudin et al., 2017). The specific impacts of these technological shifts vary by region, influenced by policy, infrastructure, and economic priorities, as discussed in the next section.

2.4.2 Regional steel production and coal demand variations

As of 2023 global crude steel production reached about 1.88 billion tonnes showing a decline of 0.1% compared to the previous year (S&P Global, 2023). China is by far the largest producer with an output of over 1 billion tonnes, more than half of the world's total. After China, notable steel-producing nations include India (140.2 million tonnes), Japan (87 million tonnes), and the United States (80.7 million tonnes), according to the World Steel Association in 2023. Different regions adopt varying methods for steel production influenced by for example access to raw materials, governmental regulations, and cost of production. The BF-BOF route is predominantly favoured in areas with coal and iron ore like China, India, and Russia. Japan also primarily utilises the BF BOF approach. On the other hand, the Electric Arc Furnace (EAF) method is more common in regions with scrap steel resources and strict environmental laws such as the United States and the European Union. A total of 70% is produced through the EAF route in United States according to the Association for Iron & Steel Technology (2025).The EU produced around 139 million tons of steel in 2023 according to the World Steel Association 2023. A total of 45% was produced via the EAF route and the balace via BF BOF route (Eurofer,2024).

As the worldwide demand, for steel continues to drive industrial growth the traditional Blast Furnace Basic Oxygen Furnace (BF BOF) method remains the mode of production due to its efficiency and cost-effectiveness in regions abundant in raw materials such as coal and iron ore. However, concerns about the impact of greenhouse gas emissions are growing. Despite differences in production methods across regions, there is a need for sustainable practices throughout the steel industry. To address these challenges there is a shift towards embracing the Electric Arc Furnace (EAF) method and other innovative low-carbon technologies in areas with strict environmental regulations and access to scrap steel and renewable energy sources. This transition is intricate and influenced by many factors, regulations, and resource availability—highlighting the industry balance between economic prosperity and environmental responsibility.

The divergence in regional policies reflects the need for coal suppliers to develop market-specific strategies. The different regional policy approaches to steel decarbonisation result in different technological adoption pathways. Some regions invest heavily in hydrogen-based steelmaking and CCUS while others still support incremental efficiency improvements in the BF-BOF process. These policy-driven differences shape the emerging role of decarbonisation technologies in the global steel sector.

India is one of the world’s fastest-growing steel producers and domestic demand is expected to rise significantly in the coming decades. The country has set a target of achieving net-zero emissions by 2070 and in the near term, its policies favour the use of BF-BOF technology because of the availability of coking coal and lack of infrastructure to deploy green hydrogen (India Ministry of Steel, 2023). The National Steel Policy of India encourages an increase in scrap based EAF steelmaking, but at the same time, it recognizes that traditional blast furnaces will remain the dominant technology in the future (Climate Policy Initiative 2023). The government has set up pilot hydrogen steel projects, but large-scale adoption is limited by high costs and energy supply risks (Sambasivam and Sarma, 2024).

To coal suppliers, India is a market for high-grade metallurgical coal and that has been sustained especially as the country seeks to secure long-term coal import agreements from Australia, Russia, and Mozambique (Plakitkina et al., 2021). However, changes in steelmaking policy, such as the possible implementation of carbon taxes or the promotion of green steel production, may affect coking coal demand over the next two decades.

In the European Union, demand for coal, particularly metallurgical coal, has been on a sustained decline, driven by structural changes in the steel industry and reinforced by stringent decarbonisation policies. Several EU-based steel producers have begun phasing out traditional BF-BOF operations in favour of electric arc furnaces and hydrogen-based methods, both of which significantly reduce or eliminate coal usage ((E3G et al. 2025). The EU's tightening of emissions regulations and introduction of instruments such as the Carbon Border Adjustment Mechanism (CBAM) has further accelerated this shift by disincentivising high-carbon steel production (European Commission, 2023). Consequently, coal suppliers that historically relied on European demand now face diminishing market opportunities and must pivot towards regions where decarbonisation is progressing at a slower pace.

The United States has a somewhat ambivalent policy stance with regard to steel decarbonisation. Although federal initiatives, including the Inflation Reduction Act (2022) and infrastructure investments, support green steel production, the country continues to back metallurgical coal mining for export markets (IEA, 2023). The U.S. steel industry has gradually shifted towards EAF-based production over the last few decades, with 70% of the domestic steel production being through this method today, thus reducing its dependence on coal-based processes (Association for Iron & Steel Technology, 2025). But, given the ongoing global push for low-carbon steel, coal suppliers in the United States could face uncertainty about future export market conditions, especially if key buyers like India and China accelerate their transitions away from BF-BOF steelmaking.

Similarly, Australia, the world’s biggest metallurgical coal exporter, also faces policy tensions between maintaining its lucrative coal export industry and fulfilling the global decarbonisation commitments (Gosens et al., 2021). As for domestic steel production, it is minimal, but Australia provides more than 50% of seaborne metallurgical coal, which makes its policy shifts important for world coal markets (Devlin et al., 2023).

2.4.3 Regulatory impacts: policies such as CBAM, EU Fit for 55, U.S. inflation reduction act

Decarbonisation of the steel industry is strongly influenced by government policy, which shapes the pace of technological adoption. In regions with aggressive carbon pricing mechanisms such as the European Union’s Carbon Border Adjustment Mechanism (CBAM) there has been a rapid phase-out of metallurgical coal, forcing steel manufacturers to shift toward electric arc furnaces (EAFs) and green hydrogen-based steelmaking (E3G 2025).

The EU has positioned itself as a global leader in climate policy with instruments like CBAM, which imposes tariffs on carbon-intensive steel imports. This penalises coal-based steel production and incentivises the adoption of low-emission technologies such as hydrogen and EAFs. Additionally, CBAM has disrupted global coal financing by compelling banks and financial institutions to withdraw investments from high-emission sectors, thus accelerating the transition toward green steel (European Commission, 2023; Jamet et al., 2023). The EU's broader “Fit for 55” legislative package further reinforces compliance with climate targets by promoting investment in green hydrogen and carbon capture, utilisation, and storage (CCUS) technologies (European Commission, 2021).

Conversely, countries like China and India have adopted a dual-track strategy—investing in hydrogen steel technologies while continuing to support traditional BF-BOF plants to maintain economic stability and energy security (Plakitkina et al., 2021). The United States, meanwhile, maintains a somewhat ambivalent policy stance. Although federal initiatives such as the Inflation Reduction Act (2022) and infrastructure investments support the growth of green steel production, the country continues to back metallurgical coal mining for export markets (IEA, 2023).

2.5 Alternative investment strategies for coal suppliers

Amid declining demand in traditional markets, coal suppliers are pursuing adaptive strategies such as geographic diversification, technological upgrades, and sectoral pivots. Exporters are targeting regions like India with continued BF-BOF reliance, while also investing in CCUS and AI to enhance operational efficiency (Gosens et al., 2021; Huo et al., 2024). Others are exploring entry into renewable energy and critical minerals, leveraging mining expertise but facing high risks and regulatory hurdles (De Donno, 2024; Barbesgaard & Whitmore, 2024). These shifts reflect the broader challenge of sustaining relevance in a decarbonising industrial economy.

2.5.1 Market diversification and geographic shifts

Market diversification has become a crucial strategic response as global decarbonisation policies continue to erode traditional coal markets, particularly in the European Union and North America. In response, leading exporters such as Australia are increasingly redirecting their focus toward markets where traditional steelmaking processes, especially blast furnace-basic oxygen furnace (BF-BOF), still dominate. Notably, India remains a key destination for metallurgical coal, given its reliance on BF-BOF technology and projected long-term demand growth (Gosens et al., 2021).

Coking coal producers are adapting to these shifting conditions by pursuing long-term contracts in markets where the transition to green steel remains nascent. Simultaneously, they are exploring opportunities to align with the green steel supply chain, which will require supplying coal for transitional hybrid steel processes or pivoting toward entirely new business segments (Devlin & Yang, 2022).

2.5.2 Technological innovation and investments

Technological innovation presents another avenue for coal producers to remain viable amid declining demand. One significant area of focus is the adoption of carbon capture, utilisation, and storage (CCUS) technologies. These allow coal-based industries to mitigate emissions, thereby prolonging the relevance of coal in a decarbonising world.

Artificial intelligence (AI) technologies have also emerged as key enablers of operational efficiency and emissions reductions. AI is currently used in surface mine energy optimisation, fuel-efficient fleet dispatching, and predictive maintenance, which collectively reduce operating costs and environmental impacts. Reinforcement learning-based fleet systems, for example, have been shown to lower greenhouse gas emissions while enhancing mine productivity (Huo et al., 2024; Dyczko, 2024). However, these innovations require significant capital and an evaluation of their long-term cost-benefit performance.

2.5.3 Alternative investment strategies (renewables, critical minerals, AI)

Facing long-term structural decline in coal demand, some producers are exploring strategic pivots into renewable energy and critical minerals. As global demand surges for energy transition materials like lithium, cobalt, nickel, and copper due to the growth of electric vehicles and renewable energy infrastructure, coal producers are well-positioned to leverage their technical and logistical expertise in mining to enter these adjacent sectors (De Donno, 2024).

Diversification strategies under consideration include multi-commodity mining at existing coal sites, lithium extraction via geothermal systems, and the repurposing of old coal assets into renewable or eco-industrial parks (Lebit et al., 2024; Krzemień et al., 2023). For example, some firms aim to develop multi-product operations that extract methane, recover heat from mine water, or support battery material processing (Bondarenko et al., 2023). Nevertheless, the shift is not without challenges. Legal and regulatory hurdles, high upfront capital investment, and lack of sector-specific knowledge remain significant barriers (Barbesgaard & Whitmore, 2024). Previous failures in market entry such as failed transitions into the nickel sector show the complexity of executing such diversification, even when firms possess strong technical capacity.

2.5.4 Challenges and limitations of strategic responses

Despite the promise of technological and market-driven responses, coal suppliers face considerable obstacles. The main of these are financial risks related to stranded assets, fluctuating carbon prices, and inconsistent global decarbonisation timelines. Also, policy volatility such as sudden tax changes, international trade adjustments for example CBAM and ESG-driven financial restrictions can undermine long-term planning.

Technological readiness does not always guarantee implementation success. As seen in numerous failed diversification attempts, companies often underestimate the permitting timelines, skills gaps, and investment needed to shift into renewables or critical minerals. Furthermore, stakeholder resistance including from workforces, investors, or communities reliant on coal can impede transitions. Thus, while strategic responses offer hope for continued relevance, they must be pursued with structured foresight, robust scenario planning, and institutional support.

2.6 Summary of literature gaps and thesis contribution

The current literature about steel sector decarbonisation shows rapid growth but still lacks essential information about coal producers' strategic actions and decision-making systems. The current research primarily examines technological pathways and policy mechanisms for steel producers to decarbonize through hydrogen-based steelmaking and CCUS technologies and regulatory frameworks such as the EU's CBAM and the U.S. Inflation Reduction Act (European Commission, 2023). Research on steel industry decarbonization lacks thorough analysis of coal supplier perspectives because their future depends directly on these transitions.

The first gap that exists in scenario-based assessments is the absence of coal suppliers as the main point of focus of the analysis. The majority of scenario planning exercises examine steelmaker decarbonisation timelines and techno-economic evaluations instead of analyzing coal market dynamics (IEA, 2020). This leaves coal market dynamics not examined. Due to this coal producers lack a structured analytical framework to anticipate regional disruptions, policy uncertainty, or technology adoption trajectories that could shape demand for metallurgical coal.

Second, the current research fails to distinguish properly between thermal and metallurgical coal during transition impact assessments The distinction matters because thermal coal faces rapid replacement by renewables in power generation while metallurgical coal maintains its essential role in industrial processes especially in emerging markets (Plakitkina et al., 2021). Therefore, treating coal as a homogeneous lead to misleading assumptions about market exposure and risk.

Third, although there are more and more case studies of steelmakers' efforts to decarbonize (e.g., HYBRIT, Tata Steel, ArcelorMittal), there is a lack of comparative case studies of coal suppliers. The analyses of how firms such as Glencore, Peabody, and BHP are adapting either by diversifying into renewables, investing in CCUS or exiting coal markets are fragmented and lack a unified strategic typology. To address these gaps, this thesis offers two key contributions:

A scenario-based analysis for coal producers, which maps four decarbonisation futures that incorporate both technological and policy uncertainty across global regions. These scenarios capture the differentiated pace of steel transition between the Global North and South and provide coal producers with a forward-looking lens to evaluate exposure and resilience.

A novel decision-making framework for coal producers, which can be used to support strategic choices in response to steel decarbonisation. The framework integrates case study insights, scenario variables, and strategic positioning to enable coal firms to consider adaptive, diversification, or exit pathways based on their context.

In conclusion, the thesis provides a coal-supplier-centric perspective to the overall decarbonisation debate and attempts to fill the knowledge gap between technological transition theory and coal industry practice.

3 Research methodology

3.1 Introduction and methodological rationale

This chapter details the research methodology that is used to analyse the impact of steel industry decarbonisation on coal producers and their strategic responses to steel decarbonisation. Due to the dynamic nature of global steel production, it is crucial to use foresight research combined with scenario planning and comparative case study analysis to understand the potential future better. As such, this study employs a qualitative dominant mixed methods approach to be able to explore possible industry shifts while ensuring that the findings are based on empirical evidence.

Scenario planning is the foundation of this research. This provides a structured approach to looking at various possible futures under uncertain conditions. This method does not rely on single outcome predictions but instead considers several factors including technological advancements, regulatory changes and economic fluctuations that are likely to determine the position of coal in steel production (Wack 1985). In addition, a comparative case study analysis is performed to see how various coal producers and steelmakers are dealing with the industry challenges. Finally, a structured decision-making framework is developed to assist coal producers in evaluating their strategic options concerning the steel industry's future decarbonisation and adaptation, diversification or phased market exit.

3.2 Research design

This research follows a qualitative-dominant mixed-methods approach, combining scenario planning and comparative case study analysis to explore how coal producers are responding to the decarbonisation of the steel industry. This allows for a deep understanding and exploration of the steel industry trends while also ensuring empirical case study analysis to validate. Quantitative methods can provide quantifiable evidence such as coal demand forecasts and carbon pricing trends, but qualitative research is crucial for examining the strategic responses of coal producers in a changing market environment.

According to Creswell and Clark (2017), mixed-methods research is especially useful when studying complex socio-economic transitions, as it enables exploratory foresight research and real-world validation. Because the steel industry is experiencing profound regulatory and technological changes, a flexible and iterative research process is needed to reveal emerging trends. The study employs an inductive research approach that generates a structured decision-making framework for coal producers obtaining insights from industry reports, academic literature, and stakeholder perspectives.

From a theoretical point of view, this research is consistent with critical realism, an ontological position that takes objective industry trends as given while also acknowledging that their meaning and effects are socially constructed (Bhaskar, 2008). This enables a fair assessment of both the macro-level industry changes and the firm-level strategic responses.

3.3 Scenario planning methodology

Scenario planning is particularly well-suited for examining long-term strategic uncertainty, where the interplay between policy, technology, and market evolution can result in divergent futures. In the context of this research, scenario planning is used to explore how regulatory interventions such as CBAM and IRA, technological disruptions such as hydrogen steel and CCUS, and shifts in demand for metallurgical coal may shape the strategic landscape for coal producers. As argued by Schoemaker (1995), scenario planning is useful when key variables are uncertain, outcomes are path-dependent, and traditional forecasting techniques fall short due to high volatility or structural shifts. This makes it ideal for assessing transition risks in carbon-intensive sectors such as steel and coal.

To construct and validate plausible future scenarios, this study applies three widely recognized scenario planning methodologies:

The Four Archetypes Method: Dator (2009) developed this method which classifies the possible futures into continued growth, collapse, discipline, and transformation. These four archetypes provide a structured approach to assessing long-term industry trajectories.

The Shell Scenario Planning Approach: This method was first introduced by Royal Dutch/Shell and is based on an inductive and iterative process of identifying uncertainties, engaging industry experts, and developing narrative-based scenarios (Wack, 1985). This method can be applied effectively in industries that are experiencing technological and regulatory changes such as coal supply chains (Ramirez & Wilkinson, 2014).

The 2x2 Matrix Method: The scenarios are organized using this approach based on two primary uncertainties: For example, technological adoption rate and regulatory stringency, which define four different possible futures. This framework allows coal producers to map their strategic positioning based on policy and technology developments (Chermack, 2011; Wright et al., 2013).

3.4 Comparative case study strategy

Comparative case study analysis complements scenario planning by anchoring these future pathways in current empirical reality. The inclusion of cases across steelmakers and coal suppliers allows the research to examine how firms in different regulatory, technological, and geographic environments are responding to the pressures of decarbonisation. The cross-case comparison supports the identification of patterns, divergences, and best practices, thus providing an empirical foundation for validating the scenario narratives and for informing the design of a practical decision-making framework. This combined methodological approach strengthens both the depth and applicability of the research findings (Yin, 2018).

3.5 Data collection methods

The empirical data of the research consists of secondary data. Secondary data sources are industry reports, company disclosures, policy documents and academic literature. Useful information on steel industry decarbonisation trends is available from industry reports from organisations such as the International Energy Agency (IEA), World Steel Association (WSA) and Carbon Trust (IEA, 2020). Detailed information on investment decisions, emissions reduction strategies and supply chain shifts are available from the corporate reports of major coal suppliers and steel producers (BHP, 2022; ArcelorMittal, 2020). The EU Carbon Border Adjustment Mechanism (CBAM), the U.S. Inflation Reduction Act and India’s National Steel Policy are policy documents that help provide the regulatory context in which coal suppliers’ risks and opportunities are being assessed (European Commission, 2023). Further, academic literature on scenario planning, strategic adaptation and industrial decarbonisation informs the theoretical framework of this study (Schwartz, 1996; Ramirez & Wilkinson, 2016).

3.6 Data analysis techniques

The methodology involves a structured process of identifying key uncertainties, developing future scenarios using established scenario planning tools, and analysing case studies to validate the assumptions made. This thesis employs multiple research methods to offer practical recommendations for coal producers facing the challenges of steel industry decarbonisation.

The novelty is to extend IEA scenarios through a coal supply side lens. This recontextualises decarbonisation pathways in terms of exposure to regulatory and investor risks, business model vulnerabilities, and regional policy divergence. To construct and validate plausible future scenarios, this study applies three widely recognized scenario planning methodologies. They are the four archetypes method, the shell scenario planning approach and the 2x2 matrix method.

A comparative case study approach is used to evaluate how different coal suppliers and steel manufacturers are responding to decarbonisation. Case study selection is based on geographic differences, coal type differentiation between metallurgical and thermal coal, and strategic response type namely adaptation, diversification, or market exit. The comparative cases focus on firms’ responses in different institutional environments to allow for cross-case learning and regional strategy evaluation. This helps build the scenario narratives and validate strategic realism.

3.7 Development of decision-making framework

To provide practical guidance for coal producers, a structured decision-making framework is developed. This framework classifies coal producers based on their market exposure, regulatory risks, and alignment with future scenarios. This framework integrates the best from both the case study analysis and the scenario planning exercise to offer strategic, context specific tools that coal firms can utilize to decarbonisation.

By incorporating foresight research, scenario planning methodologies, and comparative case studies, this study develops a structured analytical framework for coal producers navigating steel industry decarbonisation. The next chapter applies these methodologies to construct four distinct future scenarios, forming the foundation for strategic recommendations.

4 Scenario planning analysis and coal centric scenario development

4.1 Introduction to scenario planning

Scenario planning is a strategic foresight tool used to explore possible future developments in uncertain conditions and complexity (Wack, 1985). The method has been widely adopted in industries undergoing significant transformation, including the energy and steel sectors (Schwartz, 1996). Scenario planning allows stakeholders to develop pragmatic strategies that anticipate multiple potential futures rather than the present or probable futures (Ramirez & Wilkinson, 2016).

Scenario planning has been a core concept in the management of industrial transitions for situations that are characterized by long-term structural uncertainties from regulatory changes, technological forces, and market uncertainty. The tool was first proposed by Herman Kahn and later formalized by Wack (1985) and van Notten et al. (2003) to help decision makers prepare for possible scenarios instead of relying on best–guess forecasts. The approach has been widely applied in energy transitions, climate policy planning, and industrial transformation processes to figure out the risks and opportunities of decarbonisation. The IEA has employed scenario analysis to model different energy sector results, such as coal phase out, wind and solar power expansion, and hydrogen usage in the decarbonisation of heavy industries (IEA, 2020).

Steel industry decarbonisation efforts make coal producers’ future uncertain. Thus, by using scenario planning methodologies, coal producers can, identify alternative investment strategies, such as diversification into critical minerals or carbon capture technologies (Bontoux et al., 2020) and develop adaptive business models, including hybrid models that support green hydrogen while maintaining high-quality metallurgical coal production where necessary (Sweeney, 2017). Engage in Policy scenario modelling, to understand the impact of various regulatory interventions on coal demand (Ramirez & Wilkinson, 2016). And lastly prepare for supply chain reconfigurations, for identifying shifts in global trade patterns as decarbonisation accelerates (Cairns & Wright, 2018).

Through the application of scenario planning, the uncertainties of the steel decarbonisation transition can be systematically addressed, and strategic responses can be formulated for coal producers. These foresight tools will be vital in guiding coal industry investment decisions and ensuring long-term resilience in a low-carbon economy.

4.2 The role of Scenario development in steel decarbonisation

Scenario development serves as an essential tool when studying future paths of steel production by simulating potential pathways, which enables, assessing challenges and defining necessary milestones for the shift to sustainable steel production. (P. Mulvihill & Victoria Kramkowski, 2010;

Saartje Sondeijker et al., 2006) This section explores key decarbonisation scenarios, their expected outcomes, and the necessary research for improving the industry's transition plan. Through scenario planning, stakeholders can better understand how the steel industry might evolve under various technological, economic, and regulatory conditions. (P. Mulvihill & Victoria Kramkowski, 2010; Saartje Sondeijker et al., 2006) By applying this method, stakeholders get to understand the effects of different approaches on emission reductions, economic viability, and market adoption of decarbonisation solutions. Analysing multiple scenarios provides stakeholders with better preparation for uncertainties and therefore they can develop specific measures to promote industry progress toward reduced carbon emissions.

4.3 Major scenario planning methods

Various scenario planning methodologies have been developed to facilitate strategic foresight exercises. The three dominant approaches include the Four Archetypes Method, the Shell Method, and the 2x2 Matrix Method. Each of these methods provides a different approach through which to structure scenario narratives and evaluate potential industry transitions.

4.3.1 The four archetypes method

The Four Archetypes Method: Dator (2009) developed this method which classifies the possible futures into continued growth, collapse, discipline, and transformation. These four archetypes provide a structured approach to assessing long-term industry trajectories (Bengston et al., 2016). In the continued growth scenario, the future assumes that progress and technological innovation drive economic and industrial expansion. Growth remains the central driver of policy and industry decision-making. In contrast, the collapse archetype visions a breakdown of current systems because of resource depletion environmental degradation, financial instability, or political failure. In the discipline archetype, the future is structured from centralized control and strong governance enforces sustainability, order, and efficiency. It could be driven by policy and strict industrial regulation. Finally, the transformation archetype is where there is a fundamental change to the economic, social, or technological landscape. It is often linked to technological revolutions which bring about a drastic change in production, consumption, and organization of human society. In the case of industrial transitions, new energy systems and AI-driven automation.

In context to the steel industry decarbonisation, the continued growth scenario could see gradual decarbonisation from gradual efficiency improvements and slow technology adoption, allowing coal producers to adapt gradually. The collapse scenario could see economic decline in coal-dependent regions due to failed transitions or uncompetitive markets. With discipline, strict carbon regulations speed up decarbonisation through policy and regulation. The Transformation scenario foresees hydrogen steelmaking and CCUS fully replacing coal, from technological breakthroughs and policy shifts. Applying the Four Archetypes Method helps coal producers anticipate these futures and determine whether to adapt, diversify, or exit the market.

4.3.2 The shell method

The Shell Method, developed by Royal Dutch/Shell, is an iterative, inductive, scenario planning process (Wack, 1985). It entails recognizing driving forces, distinguishing predetermined elements critical uncertainties, and developing scenario stories based on group discussions with experts. This approach is relevant for coal suppliers because it provides flexibility in understanding how technological, regulatory, and economic factors interact over time (Ramirez & Wilkinson, 2014). The main uncertainties such as hydrogen adoption rates, carbon pricing policies, and global trade dynamics can be tested through Shell's iterative methodology. Fregnani (2023) observes that the Shell scenario method is more time-consuming than frameworks like the 2x2 matrix or four generic archetypes. The Shell approach requires extensive stakeholder engagement and iterative analysis, making it better suited for organisations with substantial foresight capacity. In contrast, archetype and 2x2 methods offer faster, more accessible scenario development, especially useful in time-constrained or resource-limited contexts.

4.3.3 The 2x2 matrix Method

The 2x2 matrix method: The scenarios are organized using this approach based on two primary uncertainties: For example, in relation to the steel industry decarbonisation technological adoption rate and regulatory stringency could be used which would define four different possible futures. This framework allows coal producers to map their strategic positioning based on policy and technology developments in the steel industry (Chermack, 2011; Wright et al., 2013).

Table 1. - 2x2 matrix - tech adoption and regulation stringency

	Low regulation	**High regulation**
Slow tech adoption	Business-as-usual, continued reliance on coal	Policy-driven transition with forced compliance
Fast tech adoption	Market-driven transition favouring renewables	Full-scale transformation led by government and industry

4.4 Developed scenarios for steel decarbonisation and implications for coal producers.

The IEA'a study looks at four decarbonisation scenarios: Business-as-Usual scenario, Technology Breakthrough scenario, Policy-Driven Transition scenario and Hybrid Adaptation scenario. These scenarios were selected based on IEA's Sustainable Development Models, WSA's Low-Carbon Transition Framework, and industrial climate strategies (IEA, 2020). The next section explores how these scenarios impact coal suppliers, shaping future demand for metallurgical coal and alternative business strategies.

4.4.1 Business-as-usual (BAU) scenario: the persistence of BF-BOF

In this scenario, steelmakers still depend on blast furnace–basic oxygen furnace (BF-BOF) technologies with only marginal enhancements in productivity and carbon footprint. Energy optimizations that lower emissions do not lead to a fundamental departure from metallurgical coal (IEA, 2020).

For coal suppliers, this scenario maintains demand for metallurgical coal, especially in areas where policy support for green steel is limited. Nevertheless, long-term risks rise as global regulatory pressures make coal-based steel uncompetitive in the international market (Plakitkina et al., 2021). The EU’s Carbon Border Adjustment Mechanism (CBAM) could levy tariffs on carbon-intensive steel imports, which would compromise the market presence of traditional steel producers (Jamet et al., 2023).

4.4.2 Technology break throughs scenario: hydrogen and CCUS revolution

This scenario envisages a complete transformation of steelmaking with green hydrogen and carbon capture technologies displacing metallurgical coal (IEA, 2020). BF-BOF is gradually replaced, and hydrogen-based direct reduced iron (DRI) becomes the predominant steelmaking method.

From the coal suppliers' point of view, this scenario describes a severe, protracted decline in metallurgical coal demand, especially in developed markets where governments subsidize hydrogen steelmaking (IEA, 2020). Those companies which depend on exporting coal to steelmakers must find new sources of revenue, for example, by providing carbon materials for the chemical industries or by exploring the extraction of critical minerals like lithium and nickel (BHP, 2022)

4.4.3 Policy driven transition scenario: government mandates shape the market

The primary driver of steel decarbonisation in both regions is carbon pricing, emissions regulations, and green subsidies, not technological disruption (IEA, 2021; European Commission, 2023; E3G, 2025) Tax incentives for EAF steelmaking, mandatory CCUS adoption, and carbon taxes on BF-BOF operations are enforced by governments.

This scenario presents an accelerated demand decline for coal suppliers as carbon intensive steel incurs financial penalties. Aggressive carbon pricing by the EU, Japan, and South Korea increases the costs for coal-based steelmakers (Clark, 2015). In response, coal companies may invest in CCUS or develop alternative revenue streams, such as carbon-based industrial products (Green & Vallée, 2022)

4.4.4 Hybrid adaptation scenario: regional disparities in decarbonisation

In this multi-speed transition, steelmakers implement decarbonisation technologies at different rates depending on local policies, economic constraints, and energy access (Ellen MacArthur Foundation, 2019). Some regions exit BF-BOF first, while others stick to metallurgical coal because of cost competition (Jermain et al., 2024).

For coal suppliers, this scenario extends the period of metallurgical coal demand degradation, which allows them to slowly shift their business models. Steelmakers can incorporate green hydrogen into their BF-BOF operations and continue to demand some coal while decarbonizing their operations (World Steel Association, 2020).

There is a significant gap in the literature that has not been applied to assess how coal producers should respond to the evolving steel decarbonisation landscape using scenario planning and future research in detail, highlighting not only what options are available but when coal producers should act. Although, there are many decarbonisation scenarios for the steel industry, very few studies have been done on how these scenarios directly affect the business model of coal producers, particularly while considering such nuances as the type of coal, market trends, and geographical region. The strategies that metallurgical coal suppliers from resource-dependent economies may need may be quite different from the strategies of those operating in highly regulated markets. Moreover, the literature focuses on steelmakers' technological transitions, not the strategic adjustments coal producers must make to survive changing demand. This thesis tries to contribute to this gap by incorporating coal-specific market variables into the scenario planning process to create a structured framework through which coal producers can steer through the uncertainties of steel's green transition.

4.5 Developing coal-centric scenarios: a novel framework

The section introduces new scenarios for coal producers which address an important knowledge gap in current research. The framework differs from the International Energy Agency (IEA) scenario planning efforts because it focuses on coal supplier perspectives instead of steelmaker decarbonization. The framework provides a novel contribution to strategic foresight for coal producers by integrating coal type, either thermal or metallurgical applications, geographic market differentiation and policy exposure to carbon regulations.

4.5.1 Methodological basis and scenario logic

This framework follows a structure of three steps, a foundational 2x2 matrix structure based on uncertainties, an interaction of these uncertainties with three coal variables and finally a scenario outcome.

The first step and foundation structure is a 2x2 matrix based on two global uncertainties (Ramirez & Wilkinson, 2016). The matrix structure is built around two essential uncertainties which define the global steel industry's decarbonisation pathway: The first is pace of technological change – whether steelmakers adopt breakthrough technologies such as green hydrogen, CCUS, or AI-optimised production rapidly or slowly. The second is intensity of policy pressure – whether governments enforce aggressive climate policies like carbon pricing, border adjustments, or direct subsidies for low-carbon steel, or maintain a more passive regulatory stance.

The second step is where these above uncertainties are filtered through and interact with three coal specific modifiers/variables that are highly important for coal producers, which are coal type, geographic market, and policy exposure.

Coal type**:** The production of blast furnace steelmaking (BF-BOF) depends on metallurgical coal whereas thermal coal functions mainly as a power generation fuel. The two types of coal have distinct timelines for decarbonisation and substitution risks.

Geographic market: The process of steel decarbonization develops at different speeds across various regions. The EU and OECD markets advance rapidly because of public pressure and policy mandates yet countries like India, China and most of Southeast Asia maintain their focus on cost-competitiveness and energy security.

Policy exposure: The level of exposure of coal suppliers to carbon pricing, trade restrictions and environmental regulations varies according to the location of their end-markets.

The last step scenario outcome formation: The interaction of the 2x2 uncertainties with these coal variables produces four differentiated scenario outcomes. This happens by filtering each global scenario through the coal-specific lenses of product type, market geography, and policy exposure. For example, a high-tech/high-policy world severely challenges metallurgical coal producers exposed to EU markets, while thermal coal suppliers focused on India may remain resilient under slower policy transitions. This filtering tool converts abstract global forces into concrete, region- and product-specific strategic futures for coal suppliers. These reflect strategic realities for different types of coal producers based on their regional orientation, customer base, and product mix.

4.5.2 Scenario matrix overview

The four scenarios provide a differentiated view of the coal market. This matrix does not assume a uniform decline in coal usage, capturing the uneven, multi-speed nature of the transition. It also highlights potential business models under each scenario—whether maintaining core operations, adapting to new regulations, or pivoting to adjacent sectors like industrial carbon products or critical minerals.

Table 2 consolidates and operationalizes the four decarbonisation scenarios developed in Section 4.4. It structures them into a 2x2 matrix based on global uncertainties in technological adoption and policy pressure. Each scenario quadrant is then further enriched by coal-specific dimensions such as coal type, metallurgical vs thermal, geographic market orientation, EU vs Asia, and level of policy exposure. This structured filtering approach enables a closer analysis of how global decarbonisation trends could impact different categories of coal suppliers. For example, the “Technology Breakthrough” scenario aligns with the “Tech breakthrough” cell in the table, where metallurgical coal demand collapses and policy-exposed firms face market exit risk, especially in carbon-regulated regions like the EU. Under the “Business-as-Usual” scenario, both met and thermal coal maintain stable demand, as reflected in the corresponding cell indicating “strong stability” in markets like India and China. Thus, the table not only captures the complexity of the global energy transition but also contextualizes each scenario’s implications in a differentiated and actionable manner. It serves as the analytical bridge between foresight methodology and the strategic decision-making framework developed in Chapter 6.

Table 2. Interaction Between Global Uncertainties and Coal-Specific Dimensions

S	**Tech**	**Pol**	**Met Coal**	**Thermal Coal**	**Policy-Exposed Firms**	**Policy-Sheltered Firms**	**Geographic Market**
A	Low	Low	Stable demand, moderate risk	Sustained demand	Low reputational risk	Strong stability	Both EU and Asia maintain status quo
B	Low	High	Financial risk without tech exit	Rising cost pressure	High CBAM/tax burden	Resilient if domestic	EU tightens, India/China remain reliant
C	High	Mod	Demand collapse via H2 steel	Gradual erosion	Market exit risk	Redirect to Asia	EU decarbonises rapidly, Asia lags
D	Mix	Mix	Mixed export viability	Slower decline	Dual-market strategy	Gradual adaptation	Dual-speed world: West leads, East adapts

Column 1
S - Scenario
A - Business-as-usual
B - Policy-driven
C - Tech breakthrough
D - Hybrid adaptation

Column 2
Mix - Mixed

Column 3
Pol - Policy
Mod - Moderate
Mix - Mixed

4.5.3 Scenario integration and strategic implications

The coal-based scenarios presented in this chapter follow the IEA steel sector decarbonisation models in their naming conventions and structural design yet, their purpose and perspective are fundamentally different. The IEA scenarios present steel producers demand-side perspective which focuses on industry emissions paths and technology adoption within the steel sector. In contrast, this thesis reframes the narrative from the standpoint of coal producers, applying the same external drivers such as policy and technology but integrating them with coal-specific variables, such as:

Firstly, the distinction between thermal and metallurgical coal, which face different decarbonisation pathways and substitution risks. Secondly, the regional divergence in steel decarbonisation timelines (e.g., EU vs. India/China), which reshapes trade flows and strategic export destinations. And thirdly, the degree of regulatory exposure through instruments like the EU's Carbon Border Adjustment Mechanism (CBAM), which increases financial risks for coal-linked steel exporters.

The reframing process converts general energy transition models into operational strategic instruments for coal producers. The framework presents multiple strategic realities which coal suppliers need to prepare for simultaneously across different regions instead of showing a single global trajectory.

From a strategic perspective this framework enables coal producers to assess their future market position which guides their investment decisions and operational and market strategy development. The scenarios present multiple possible outcomes instead of a single prediction yet they establish a systematic method to forecast disruptions and select appropriate responses. The scenario logic generates four main strategic options as listed:

1. Adapt**:** Gradually align operations with low-carbon steel trajectories in regulated markets by improving ESG practices or participating in green value chains for example Scenario 4.
2. Diversify**:** Invest in adjacent sectors such as carbon-based industrial products, CCUS, or critical minerals like lithium and nickel for example Scenario 2 and
3. Reposition**:** Focus on markets where steel decarbonisation is slower, maintaining coal exports in regions with low regulatory pressure for example Scenario 1 and 4.

4. Exit: Prepare for long-term withdrawal from metallurgical coal markets where hydrogen steelmaking is rapidly emerging for example Scenario 3.

The framework combines demand-side transition logic with supply-side coal dynamics to help coal producers manage volatility while identifying opportunity zones and developing future-oriented business models in a global economy with carbon constraints.

4.5.4 Conclusion

The chapter presents a new coal-focused scenario framework that addresses a critical gap in decarbonisation research by shifting strategic foresight to coal producer perspectives. The framework developed through a 2x2 matrix built on the pace of technological change the intensity of policy pressure to identify four possible futures for coal suppliers during steel industry decarbonisation.

While structurally aligned with International Energy Agency (IEA) and World Steel Association (WSA) scenarios, this framework contributes uniquely to the literature by offering three critical advancements**.** The first is that it centres the coal supplier’s perspective, which is often marginalised in dominant steel-sector decarbonisation studies. These studies typically adopt a demand-side view, focusing on emissions trajectories, green steel targets, or production technologies. This framework provides coal producers with a supply-side perspective that examines their risk exposure and market survival and strategic response to industry changes.

The second it that it differentiates between coal types, recognising that metallurgical and thermal coal are exposed to decarbonisation at different speeds and intensities. Metallurgical coal is exposed to immediate substitution risks in hydrogen steelmaking pathways, while thermal coal’s fate is more heavily dependent on regional energy transitions. By capturing these nuances, the framework allows producers to assess risk and opportunity with greater accuracy.

The third is that it incorporates regional asymmetries, acknowledging that steel decarbonisation is proceeding unevenly across the globe. The EU, Japan and Korea are accelerating transitions due to policy pressure and carbon pricing, while India, China and much of Southeast Asia continue to prioritise energy security and cost-efficiency. This enables producers to segment their strategy geographically and avoid one-size-fits-all assumptions.

Together, these elements make this framework a realistic, actionable, and forward-looking tool for coal suppliers operating in a carbon-constrained global economy. The four scenarios present different strategic realities which coal producers need to prepare for instead of forecasting a single outcome. The different scenarios provide a context for decision-making around operational, investment and market selection. The four broad strategic response pathways receive further development in Chapter 6.

Through this scenario framework coal producers not only anticipate disruption, but also shape their response to it. The framework enables coal producers to navigate uncertainty better while seizing residual opportunities and actively position themselves in the changing industrial environment. Most importantly, the strategic framework established in this chapter serves as the basis for the decision-making model which will be introduced in the following chapter.

5 Comparative case study analysis

5.1 Steel producers transitioning to green technologies

The shift towards low-carbon steel production is already underway, with the large steel producers already investing in hydrogen based direct reduction (DRI), carbon capture and utilization (CCUS) and renewable energy powered electric arc furnaces (EAF). These technologies represent different approaches within the broader framework of industrial decarbonisation, showcasing the feasibility, challenges, and policy drivers influencing the shift away from traditional blast furnace-basic oxygen furnace (BF-BOF) steelmaking. The following case studies illustrate how major steel producers are adopting real world solutions to meet climate goals and regulatory pressures by altering their production methods. This chapter analyses how key players in the steel and coal industries are responding to decarbonisation by examining selected case studies. These cases reflect varying technological approaches, geographic settings, and regulatory contexts. The insights derived from these real-world transitions provide empirical grounding for the strategic decision-making framework in the next chapter.

5.1.1 HYBRIT – Sweden’s fossil-free steel initiative

HYBRIT (Hydrogen Breakthrough Ironmaking Technology) is an initiative launched by SSAB, LKAB and Vattenfall to develop the first ever fossil free steel production process. SSAB, LKAB and Vattenfall have identified green hydrogen as a replacement for metallurgical coal in the traditional BF-BOF steelmaking process. The project aims to use green hydrogen as a reducing agent in the direct reduction of iron ore, while not using any metallurgical coal at all and thus replacing natural gas as well in the process, powered entirely by renewable electricity to eliminate carbon emissions at every stage of the steel production chain (HYBRIT, 2022).

Using hydrogen based direct reduction, HYBRIT aims to decrease Sweden’s industrial carbon footprint by 10%, a significant achievement as steel production is estimated to emit 7% of the total CO_2 emissions globally (RMI 2022). The project has also got a significant financial backing from the Swedish Energy Agency and the European Union which shows how important policy incentives are in boosting industrial decarbonisation (IEA, 2021). But HYBRIT shows that zero emission steelmaking is possible, and thus feasible to adopt globally, even though it has higher initial capital costs.

5.1.2 ArcelorMittal – scaling carbon capture and hydrogen-based steelmaking in Europe

Among the world's biggest steel producers, ArcelorMittal is pursuing a two-track approach that involves reducing its carbon emissions by 30 % by 2030 and reaching net-zero emissions by 2050 The company is investing in both hydrogen-based direct reduction and carbon capture, utilization, and storage (CCUS) within its Smart Carbon Strategy. ArcelorMittal has started pilot projects using green hydrogen for iron ore reduction in Germany, with plans to increase production capacity by 2025. In Germany and Spain, the company has also incorporated CCUS technologies into its current BF-BOF operations, which shows that carbon mitigation can be integrated with, rather than replace, conventional steelmaking that depends on coal. (ArcelorMittal, 2020). Ghent in Belgium hosts one of Europe's leading industrial decarbonisation initiatives, where ArcelorMittal is implementing flagship carbon capture and utilization projects, including Steelanol, which transforms carbon-rich steelmaking gases into bioethanol as part of the EU's Innovation Fund support (Arcelor Mittal, 2022). ArcelorMittal's approach reflects the importance of transition strategies that consider technological readiness, infrastructure constraints, and cost feasibility. CCUS is an interim solution to help reduce carbon emissions while other technologies are being scaled up to achieve hydrogen-based steelmaking in the long term.

5.1.3 Tata Steel – India's gradual transition to low-carbon steel

India's biggest steel producer Tata Steel is following a hybrid approach to decarbonisation as moving from BF-BOF to hydrogen steelmaking is not without its issues in a country where coal still reigns supreme (Tata Steel, 2023). The company has made investments into pilot hydrogen-based steelmaking facilities as well as the development of CCUS projects in order to decarbonize its current operations.

As for India, the cost restraints, policy risks and missing energy infrastructure are the factors that make the full-scale hydrogen adoption extremely challenging (Sambasivam and Sarma, 2024). Nevertheless, Tata Steel has announced its ambition to decrease its emissions intensity by 20% by the year 2030, by: Increasing the share of scrap-based EAF steelmaking, in order to match the existing BF-BOF production; Collaborating with the Indian government on hydrogen infrastructure development; and Implementing CCUS at existing steel plants, so that at least 5 million tonnes of CO_2 can be captured every year by 2035.

Tata Steel's strategy is a clear example of how different energy policy, infrastructure and economic conditions across regions affect the decarbonisation pace. India's transition is expected to be gradual due to short term focus on country wide economic focus and would require an aggressive policy- driven approach to increase the pace of decarbonisation, while European steelmakers are already in the process of phasing out coal-based production.

5.2 Implications for coal suppliers

The company examples above show the different technological pathways through which steelmakers are striving to reduce their carbon footprint. A key takeaway for coal suppliers is that metallurgical coal demand is already declining in some areas due to the promotion of hydrogen based direct reduction and CCUS technologies (IEA, 2021). However, the rate of change is entirely different. For instance, in Europe, the phasing out of coal-based steel production is being facilitated by the EU's Carbon Border Adjustment Mechanism (CBAM) and the strict climate policies which have forced steelmakers to shift to green hydrogen and electric arc furnaces. On the other hand, India is adopting a more incremental approach because coal-based steelmaking still prevails due to competitive advantages and inadequate infrastructure. Although, steps towards decarbonisation are being taken, coal demand is still very high in the near future.

Hybrid approaches are also visible in global markets, with companies including ArcelorMittal and Tata Steel using hydrogen steelmaking along with CCUS to enable a step-by-step transition. This dual strategy allows steelmakers to maintain some coal usage while decreasing emissions.

These regional differences indicate that coal suppliers must develop their strategies to fit certain markets instead of adopting a one-size-fits-all approach. For coal suppliers these variations in decarbonisation pathways have significant implications for the long-term business strategy. The long-term decline in metallurgical coal demand in developed markets like the European Union, Japan, and South Korea indicate that suppliers should consider diversifying their portfolios. In emerging markets, including India and Southeast Asia, steelmakers are still reliant on BF-BOF, and hence demand for high-grade metallurgical coal remains relatively stable. Nevertheless, as regulatory pressures rise, even these markets will gradually transition toward sustainable technologies. There are opportunities for coal suppliers in meeting the need for high grade metallurgical coal in areas where hydrogen infrastructure has not yet been developed. Furthermore, investment in alternative revenue streams from critical minerals for battery storage or carbon capture solutions could prove to be a more sustainable long-term strategy. It is therefore crucial to understand these variations for coal suppliers who are trying to adapt to the changing steel market trends.

The next section examines the shifting role of coal suppliers in a decarbonizing world in more detail and the strategies they are implementing to remain competitive.

5.3 Examples of coal suppliers adapting to decarbonisation

As the steel industry accelerates its transition towards low carbon production technologies, coal suppliers have had to come up with new business strategies to remain competitive. The decline in the demand for thermal and metallurgical coal due to regulatory pressures, carbon pricing mechanisms, and the growing interest in green hydrogen and electric arc furnaces (EAF) has forced coal companies to diversify their revenue sources and operating models. Several of the major coal suppliers have acted quickly to these shifts, and several examples of successful adaptation to sustainable business models in a decarbonizing economy have been demonstrated (Jermain et al., 2024).

5.3.1 USA's Xcoal's strategic shift to metallurgical coal - USA HQ

Xcoal Energy & Resources - a coal supplier from the USA - has emphasised metallurgical coal on the understanding that while thermal coal demand is declining, high quality coking coal used in steelmaking is still in demand in certain markets. Xcoal has thus maintained strategic relevance by focusing on the supply of high-quality metallurgical coal to the steel industry, especially in India and China where BF-BOF steelmaking continues to dominate. This strategy shows that coal producers can sustain their businesses by focusing on markets where coal demand is still on the rise, while the world moves towards decarbonisation.

5.3.2 Peabody's USA investment in CCUS for emissions mitigation

CCUS technologies which Peabody Energy, one of the world's largest coal mining companies has greatly invested in to mitigate emissions from coal-based steelmaking. CCUS technologies are increasingly being explored by coal producers as a means of reducing emissions from industrial operations, particularly in steelmaking (Global CCS Institute, 2020). Peabody has identified carbon sequestration projects to give coal-based industrial applications a lifeline, so steelmakers can meet ever stricter emissions targets, while continuing to use BF-BOF production. This approach is also a mitigation-based strategy where coal suppliers are investing in emissions reduction technologies instead of moving away from coal. Nevertheless, CCUS is currently dependent on government subsidies, carbon credit markets and improvements in storage infrastructure for it to be viable in the long run (IEA, 2020).

5.3.3 Australia's BHP's diversification into critical minerals

BHP a global mining giant has adopted a diversification strategy of moving away from coal mining and diversifying its portfolio into important minerals used in battery technologies like lithium and nickel (BHP, 2022). This strategy matches the increasing international demand for electric vehicle (EV) batteries, energy storage systems and renewable energy components, allowing BHP to continue to be a major player in the industrial supply chain without coal. BHP has been able to position itself as a long-term supplier to the emerging clean energy markets by leveraging its mining and commodity trading expertise. Here is how a coal dependent firm can successfully pivot to a new industry – the BHP way.

5.3.4 The Swiss HQ Glencore's hybrid approach: coal and renewable energy

Another major mining and commodity trading firm, Glencore, has also taken a hybrid approach of continuing coal production in certain markets while growing into renewable energy projects (Glencore, 2023). Glencore knows that there are still some developing countries that need coal for their industrialization, so it still supplies metallurgical coal to areas where decarbonisation is not very rapid (Glencore, 2023). However, the company has also invested in large-scale renewable energy projects such as solar and wind power installations at former coal mining sites (Glencore, 2023). Glencore also has interest in copper assets in Africa to support demand for energy transition metals (Glencore, 2024). This dual approach enables Glencore to strike a good balance between short-term profits and long-term sustainability and therefore to ensure that the direction of the company's business is in line with the energy transition worldwide while at the same time meeting the needs of markets that still need coal.

These cases depict the numerous adaptation strategies that coal suppliers can adopt in the face of change in the steel industry market. Some companies, for example, Xcoal, have concentrated on market repositioning towards metallurgical coal, while others, for example, Peabody Energy, have aimed at technological decarbonisation of existing operations. Furthermore, some firms, including BHP and Glencore, have chosen diversification, and have redirected their business toward renewable energy and critical minerals (Glencore, 2023; Glencore, 2024).

5.4 Conclusion

The global steel industry is undergoing a profound transformation driven by carbon emission reduction and the target to transition towards sustainable production methods. This shift presents both challenges and opportunities for coal suppliers, who must strategically adapt to remain viable in this evolving industrial landscape. The literature highlights those technological innovations, policy shifts, and market dynamics are reshaping the role of coal in steel production and energy generation.

Decarbonisation in Steel Production has brought about the development of new technologies such as hydrogen-based steelmaking, Direct Reduced Iron (DRI), Carbon Capture, Utilization and Storage (CCUS) and growth of Electric Arc Furnaces (EAF) (Rechberger et al., 2020; World Steel Association, 2020). These innovations are decreasing the reliance on coking coal in developed economies, with Europe and North America taking the lead in moving to lower carbon steelmaking methods (Devlin et al., 2023). However, coal is still widely used in steel production in Asia, especially in India and China, where blast furnaces are still commonly used (Coheit & Valacchi, 2022; Indian Ministry of Steel, 2020).

These shifts have called for strategic adaptations for coal producers. Market diversification has become essential as traditional markets for coking and thermal coal shrink due to environmental regulations and shifting investment priorities. Major Western banks’ coal financing decline by over 40% from 2019-2023 has also forced coal companies to find other funding sources, particularly from Asian financial institutions (Green & Vallée, 2022; Jamet et al., 2023). In response, coal suppliers must either reinforce trade ties with regions where traditional steelmaking remains prevalent or diversify into alternative energy markets (Devlin & Yang, 2022).

Another strategic opportunity for coal producers is investment in critical minerals. With growing demand for lithium, nickel, and cobalt from the growing electric vehicle (EV) production and renewable energy storage, coal mining expertise and infrastructure can be re-purposed to these high growth sectors (Lebit et al. 2024). However, financial constraints, regulatory hurdles and high capital costs are major challenges to this transition (Barbesgaard & Whitmore, 2024).

Renewable energy integration and AI adoption are also key pathways for sustainability. The repurposing of coal mines into eco-industrial parks and geothermal energy hubs can create new revenue streams while reducing carbon footprints (Krzemień et al., 2023; Gerbelová et al., 2020). AI-driven mining optimizations have demonstrated increased efficiency, with fleet automation reducing greenhouse gas (GHG) emissions by up to 30% (Huo et al., 2024). These technological innovations enhance cost efficiency and enable coal suppliers to remain competitive amid changing market conditions.

CCUS technologies offer a potential bridge for coal producers seeking to align with global decarbonisation goals. While CCUS can provide economic benefits through enhanced oil recovery (EOR), carbon trading, and methane extraction, its large-scale adoption remains constrained by high implementation costs and reliance on government incentives (Xiang et al., 2023; Zhai et al., 2022). Expanding policies such as the U.S. Section 45Q tax credit could improve CCUS's financial viability, making it a more attractive option for coal producers seeking to mitigate emissions (Fan et al., 2022).

Ultimately, the future of coal suppliers depends on their ability to proactively engage with emerging industrial trends, diversify revenue streams, and embrace technological innovations. As global decarbonisation efforts accelerate, coal producers must adopt flexible, forward-looking business models to ensure long-term viability in a changing energy and industrial landscape. By leveraging existing expertise, investing in new technologies, and adapting to evolving policy and market conditions, coal suppliers can navigate the challenges of the energy transition while maintaining economic relevance in a low-carbon future.

6 A Strategic decision-making framework for coal producers

6.1 Introduction and purpose of framework

The global push to decarbonize steel production creates a strategic decision point for coal producers. The industrial sector faces transformation because of regulatory demands and investor requirements and new technologies including green hydrogen and CCUS systems which affect coal operations especially in steel production. The steel industry's transition has received extensive attention, but less focus has been directed at how coal producers should respond, adapt, or reposition themselves in the face of this disruption.

This chapter aims to fill this gap by presenting a scenario-based strategic decision-making framework that is particularly relevant for coal producers. The framework is intended to assist firms in determining their current position in the energy transition, evaluating external risks and opportunities, and assessing potential strategic options in response to changing decarbonisation pathways.

The current chapter extends the coal-based scenarios in Chapter 4 which reframed global steel decarbonisation futures through the lens of the coal supplier. The research uses findings from Chapter 5 which shows major producers already navigating technological changes and ESG pressures and regional market differences.

The purpose of the framework has three parallels. The first is to translate uncertainty into structure: The framework enables firms to understand and categorize the strategic environments they may face across different regions and customer segments by using scenario logic. The second is to guide strategy selection: The framework presents a series of actionable pathways. They are adaptation, diversification, repositioning, and exit. Each of these pathways are linked to specific external scenarios and internal risk profiles. The third is to enable practical decision-making: The framework provides a practical tool that firms can use to plan their transitions by integrating financial, policy, and technological considerations into a step-by-step process.

The framework enables coal producers to transition from observing risks passively to actively making decisions based on specific scenarios. The framework enables companies to survive the low-carbon transition while positioning themselves strategically for success. The following section explains the framework structure and presents strategic choices for coal producers and demonstrates practical implementation through industry case studies and external validation.

6.2 Framework structure and criteria

The framework established in this chapter enables strategic decision-making through transition uncertainty by using specific analytical criteria. The framework consists of two interconnected components which include strategic positioning dimensions for measuring external decarbonisation forces and assessment metrics for evaluating internal response capabilities through:

1. adaptation
2. diversification
3. repositioning or
4. exit

The diagnostic process uses these components to help producers determine their position in the energy transition and identify strategic options that remain feasible given external and internal limitations.

6.2.1 Strategic positioning dimensions

The first component of the framework is concerned with profiling external operating conditions of coal producers. The diagnostic starts with three core dimensions which directly build on the scenario typology presented in Chapter 4: market exposure, regional decarbonisation dynamics, and coal type and product focus.

Market exposure describes the geographic areas where coal sales occur and serves as a primary factor that determines short-term policy and demand risks. Producers who export coal mainly to India Southeast Asia and China operate in regions where steel decarbonization progresses at a slower pace because of industrialization needs and weak regulatory enforcement. The European Union along with South Korea and other OECD countries expose their producers to stronger policy-driven demand changes because of instruments like the Carbon Border Adjustment Mechanism (CBAM) and increasing ESG pressures from governments and customers. The geographical differences between regions form the basis of the coal-centric scenario framework which guides producers to select their strategic direction.

Regional decarbonisation dynamics reflect how quickly a given steel-producing region is transitioning away from coal-intensive processes. For example, Sweden and Germany have started using hydrogen-based direct reduced iron (DRI) and electric arc furnace (EAF) technologies because their governments support these initiatives through policy mandates and public investment. The Indian market depends on BF-BOF methods because its infrastructure is limited, and energy availability and costs remain a priority. The varying regional differences in coal distribution and risk profiles exist even when global coal demand stays constant.

The third dimension is coal type and product focus. This captures whether the firm is primarily producing thermal or metallurgical coal. Thermal coal, which is used for power generation, faces substitution risk due to the global expansion of renewable energy. The decline of thermal coal is particularly evident in Europe. Metallurgical coal even though it is more resilient in term of substitution it is also increasingly threatened in advanced economies by the emergence of hydrogen-based steelmaking. As discussed in Chapter 2 and illustrated through BHP's and Anglo American's portfolio shifts in Chapter 5, these differences in substitution timelines and investor sentiment are crucial for determining the right strategic. view.

The three dimensions enable producers to determine their initial position in the energy transition. The resulting profile functions as the basis for matching the firm to one of the four coal-centric scenarios and for evaluating which strategic pathway may be most appropriate:

1. Business-as-Usual,
2. Policy-Driven Transition,
3. Technology Breakthrough, or
4. Hybrid Adaptation

6.2.2 Assessment metrics

After establishing external positioning, the framework moves to an internal capability assessment layer. The framework includes three essential metrics which function as filters which convert scenario fit into practical strategic feasibility. The three essential metrics are:

1. financial indicators
2. regulatory risk profile and
3. technological adaptability.

The first metric is financial indicators which assesses a firm's capital structure and investment flexibility. High EBITDA margins, low leverage, and strong cash reserves typically shows that a producer is capable of absorbing transition costs. This is either through diversification into new commodities, investment in emissions mitigation technologies, or exit planning. By contrast, firms with constrained balance sheets may be limited to slow adaptation or phased divestment. As Chapter 5 showed through the case of BHP, financial strength is often a precondition for a proactive transition.

The regulatory risk profile shows how much a producer is exposed to decarbonisation-related policies and compliance such as carbon pricing and environmental compliance mandates or trade-based emissions penalties. The metric holds particular importance for exporters who sell to high-regulation jurisdictions because indirect policy exposure through CBAM's embedded emissions accounting creates substantial costs for non-EU producers. Companies that face high exposure to these instruments will likely experience medium-term demand loss which makes diversification or exit more critical.

The third metric, technological adaptability, measures the extent to which a producer is able to respond to the changing steelmaking technologies. This includes participation in CCUS or hydrogen pilot projects, active collaboration with green steel manufacturers, or alignment of logistics with low-emission supply chain standards. Producers who can serve decarbonising customers are more likely to remain competitive during the transition.

These metrics enable coal producers to transition from qualitative scenario fit to quantified strategic analysis which helps them determine both the most suitable strategy for future conditions and its operational and financial feasibility in the present.

6.2.3 Framework flow and integration

The overall structure of the framework can be summarised as a three-stage process, combining external scenario fit with internal strategic capacity:

Table 3. - Framework structure

Framework Stage	Core Elements	Purpose
Strategic Positioning	Market geography, decarbonisation pace, coal type	Establish exposure to decarbonisation risks
Internal Assessment	Financial indicators, policy exposure, tech readiness	Determine the firm’s capacity to adapt or transform
Strategic Pathway Selection	Align with Adapt, Diversify, Reposition, or Exit	Choose a realistic and scenario-aligned response to the transition landscape

The flow enables organizations to establish strategic directions which combine evidence-based risk assessment with organizational preparedness. The following section provides extensive details about these strategic pathways together with their connection to particular scenarios and practical steps for coal producers to implement them.

6.3 Strategic pathways for coal producers

The scenario-based framework established in this chapter enables coal producers to develop proactive and coherent responses to steel sector decarbonisation uncertainties. The positioning dimensions and assessment metrics from Section 6.2 enable firms to identify one of three main strategic pathways which include adaptation, diversification, reposition or exit. Different business units within a producer can combine multiple pathways while producers can shift between pathways during different periods of time. Strategic alignment becomes the key factor because it requires selecting a response that corresponds to both external decarbonisation pressures and internal organisational capacity.

The pathways match conditions found in the four coal-centric scenarios presented in Chapter 4. The adaptation pathway works best in markets that depend on coal yet face tightening ESG standards. Diversification emerges as most successful strategy for when policy and investor pressure make continued coal reliance unattainable. Exit is the most appropriate response when production no longer provides benefits because demand has collapsed, and reputational risk becomes too great. The following sections provide detailed explanations of each pathway through industry case illustrations and scenario logic.

6.3.1 Adaptation pathway: enhancing competitiveness in remaining coal markets

The Adaptation Pathway applies to firms that continue to operate in markets where coal retains short to medium-term demand resilience where non-market pressures such as environmental reporting obligations or financing conditions are intensifying. This strategy aligns most strongly with Scenario 1: business-as-usual and Scenario 4: hybrid adaptation where traditional coal use continues with growing scrutiny.

The steelmaking industry in India and Southeast Asia and parts of Africa maintains its use of BF-BOF technologies and coal remains their most economical feedstock. The markets still use BF-BOF technologies but customer expectations regarding emissions and traceability and environmental impact are changing. National governments now implement climate targets while international buyers and financiers enforce stricter ESG compliance standards.

Coal producers operating in this environment need to implement strategic upgrades which enhance operational efficiency and environmental performance and stakeholder alignment without giving up coal production. The typical initiatives include investing in advanced mining technologies to reduce water and energy consumption, improving product quality and publishing transparent sustainability reports aligned with global frameworks such as the Task Force on Climate-related Financial Disclosures (TCFD).

The adaptation strategy is illustrated through Peabody Energy's example in Chapter 5. Peabody Energy has maintained its coal focus through digital optimization tool investments and carbon capture support and ESG disclosure improvements to keep investors and regulators satisfied. The adaptation strategy demonstrates its core principle through these actions which show coal producers can stay in specific markets by enhancing operational integrity and showing awareness of transition.

6.3.2 Diversification pathway: investment in alternative revenue streams

Companies that anticipate long term erosion in coal demand due to structural policy changes and technological advancement use diversification as a proactive strategy. The pathway matches Scenario 2: Policy-Driven Transition and Scenario 3: Technology Breakthrough which both indicate major market contraction.

The approach of adaptation works to maintain coal sector competitiveness, but diversification requires moving capital and assets and capabilities toward industries which align with global decarbonisation trends. The production of critical minerals including lithium and nickel and graphite represents one possible diversification path because these materials are vital for battery storage and renewable energy technologies. The manufacturing of carbon-based industrial materials including electrode paste and activated carbon represents another possible diversification path. The third diversification path involves investing in carbon capture, utilisation, and storage (CCUS) infrastructure. Legacy coal infrastructure including land and grids and railways can be converted for renewable energy generation which provides a low-cost entry into new business models.

BHP’s strategic repositioning in Chapter 5 demonstrates this pathway effectively. BHP has removed thermal coal from its portfolio and has redirected capital to commodities that are central to the energy transition. BHP has made substantial investments in nickel and copper to position itself to benefit from the electrification of transportation and clean energy growth while minimizing long-term exposure to coal-related risk.

The implementation of diversification requires both significant capital investment and substantial capability development. The process needs more than operational agility because it requires governance transformation and technical retraining and strong partnerships. The firm needs to obtain financing that matches the transition and demonstrate a trustworthy and clear diversification story to stakeholders for success.

The pathway should be considered by firms when they are exposed to permanent climate regulation and investor pressure and possess sufficient balance sheet strength to support investments in future-oriented sectors. The goal extends beyond survival but to build a sustainable platform for long-term growth that goes beyond coal operations.

6.3.3 Reposition pathway

Repositioning refers to the strategic redirection of a coal producer's commercial focus toward markets where the pace of decarbonisation is slower, or policy constraints are less stringent. Unlike adaptation, which involves operational or technological alignment with low-carbon expectations, repositioning retains the existing product base (e.g., high-grade metallurgical coal) but shifts the geographic or segmental targeting.

This strategy is particularly relevant in the context of Scenarios 1 and 4, where regional differences in decarbonisation create asymmetries in coal demand. For example, while EU and Korean markets impose strict carbon regulations, regions such as India, Southeast Asia, and parts of China continue to rely on BF-BOF steelmaking, sustaining demand for metallurgical coal.

Coal producers choosing the reposition strategy may pivot exports to jurisdictions with lenient carbon policy, realign logistics and port infrastructure toward high-volume Asian clients or delay or minimise capital reallocation while continuing to monetise existing reserves.

Repositioning is a mid-term strategy that leverages spatial asymmetries in transition timing. While it does not entail technological transformation, it requires proactive risk monitoring and commercial agility. It allows firms to maximise short- to medium-term returns while maintaining optionality for future diversification or exit.

6.3.4 Exit pathway: strategic exit and asset repositioning

The Exit Pathway is followed when market, policy and financial indicators together indicate that coal production is no longer viable. In this context and important to note that exit is not an emergency retreat. It is rather a strategic decision to preserve capital, reduce reputational risk, and redeploy resources toward new growth opportunities. This pathway is most aligned with Scenario 2 and Scenario 3, where the economic and regulatory conditions for coal are deteriorating rapidly.

Large publicly listed firms have shown growing interest in exit strategies because institutional investors have intensified their focus on climate risk issues. Companies achieve these exits through asset sales and spin-offs and managed demergers which enable them to separate coal-related liabilities from their ESG credentials. The case of Anglo American demonstrates this logic in Chapter 5. Thungela Resources became an independent company after Anglo American demerged its South African thermal coal operations in 2021. The strategic move enabled Anglo

American to concentrate on copper and platinum while maintaining its climate-friendly position. The company implemented stakeholder consultation and just transition planning to reduce community and worker disruption during this process.

The exit strategies include phasing out operations while maintaining profitability during the transition and reinvesting proceeds into renewable energy or green logistics and supporting workforce retraining. The International Labour Organization (ILO) and various national recovery schemes support exit through government-supported transition plans in jurisdictions with strong regulatory frameworks. The exit pathway becomes essential when coal revenue decreases while policy exposure becomes unsustainable, and investors limit financial support. Strategic exit provides access to new capital while reducing long-term liability when defending coal assets becomes unproductive under these conditions.

6.3.5 Summary of scenario-pathway alignment

The following table demonstrates how each strategic pathway connects to its best scenario environment and strategic objective:

Table 4. - Strategic pathway to scenario environment and strategic objective

Pathway	**Best-fit scenarios**	**Strategic goal**
Adaptation	1 & 4	Remain competitive in moderately exposed markets through ESG alignment and upgrades
Diversification	2 & 3	Shift revenue base toward emerging green sectors such as minerals, CCUS, or carbon products
Reposition	1 & 4	Sustain profitability by focusing on markets with slower decarbonisation trajectories
Exit	2 & 3	Minimise losses, preserve value, and reinvest in new low-carbon opportunities

The chapter has now explained the logic, rationale, and real-world evidence for each of the strategic responses available to coal producers. The following section will operationalise the framework through practical application guidance, including a step-by-step process and a scenario-based decision tree.

6.4 Practical application of the framework

While the strategic pathways introduced in Section 6.3 offer conceptual clarity for coal producers navigating decarbonisation, the practical effectiveness of the framework lies in its structured application. This section converts the scenario-pathway logic into an operational framework which coal producers can apply to evaluate their position and determine their scenario environment and develop realistic action plans. The process is designed to be modular, scalable, and adaptable to firms of different sizes, geographies, and financial profiles.

The framework’s application unfolds through five sequential steps. Each builds upon the dimensions introduced in Section 6.2 and links directly to the scenario logic developed in Chapter 4. Together, these steps allow firms to move from diagnostic awareness to actionable transition strategy.

6.4.1 Strategic Matching: Diagnostic-to-Decision Framework

The following section explains how coal producers can move from strategic diagnostics to a best-fit strategic pathway using the scenario framework established in Chapter 4. The process combines both market foresight and internal capability assessment through five structured steps. The producer reduces the range of viable responses step by step until they reach a strategic fit that matches both scenario conditions and internal readiness.

Step 1: profile the coal producer. The firm begins by profiling its operations to determine exposure to transition risk. This includes identifying the type of coal produced (thermal, metallurgical, or both), export markets, decarbonisation pathways of end customers, and exposure to direct or indirect carbon regulation. For example, metallurgical coal producers must assess whether their customers are transitioning to hydrogen-based steelmaking. Thermal coal producers must evaluate emissions policy, renewable energy displacement, and carbon pricing dynamics in key markets.

Step 2: identify the external scenario. Based on the operational and market profile, the firm aligns itself with one of the four coal-centric scenarios developed in Chapter 4: Scenario 1 business-as-usual, Scenario 2 policy-driven transition, scenario 3 technology breakthrough or scenario 4 hybrid adaptation. Exporting primarily to EU or OECD markets indicates high regulatory risk and aligns with Scenarios 2 or 3. In contrast, exposure to India, Southeast Asia, or Africa suggests more favourable short- to medium-term demand and aligns with Scenarios 1 or 4. This step anchors the firm's strategic environment within a structured future narrative, enabling proactive strategy formation rather than reactive responses.

Step 3: evaluate internal readiness. The firm assesses its internal capacity to execute strategic change. This includes financial indicators such as cash flow and debt ratios). It includes its technological adaptability such as readiness for CCUS or hydrogen integration, and its regulatory resilience such as the ability to comply with CBAM or carbon tax pass-through. These metrics serve as a filter that is highlighting which pathways are not only theoretically suitable but also practically implementable. Firms with strong financial and ESG performance may pursue diversification or exit. Those with moderate readiness may lean toward adaptation, while firms with limited flexibility may need to consider repositioning to slower-transitioning markets or pursuing a phased exit.

Step 4: match to strategic pathway. Based on external scenario alignment and internal capacity, the firm selects one of the four strategic pathways presented in Section 6.3: adaptation, diversification, repositioning, or exit. The objective is not to reach a perfect decision, but to align the chosen strategy with both external pressures and internal realities.

Step 5: design an action plan. The final step involves translating the chosen pathway into a time-bound action plan. This includes investment or divestment timelines, capital and resourcing needs, stakeholder engagement, and financing instruments. By linking foresight with execution, this approach helps ensure strategic clarity and transition readiness.

6.4.2 Illustrative application examples

The following examples show how different coal producers would choose their strategic responses according to market conditions and internal capabilities to demonstrate the practical use of the scenario framework.

Example 1: Diversification under Scenario 3 (Technology Breakthrough). Consider a metallurgical coal producer that mainly exports to European steelmakers. These customers are actively piloting hydrogen-based steel production and are under sustained pressure from ESG-conscious investors for decarbonisation. The coal producer has moderate capital reserves but limited technological integration with emerging green steel supply chains. Under these conditions, the producer would likely align with Scenario 3: Technology Breakthrough, where rapid tech change and policy intensity converge. The framework recommends a diversification strategy for the company because of its limited internal readiness for high-tech adaptation, which involves gradually phasing out legacy coal operations and reinvesting in transition-aligned sectors such as critical minerals, carbon-based industrial materials, or clean energy infrastructure.

Example 2: Adaptation under Scenario 1 (Business-as-Usual). By contrast, a thermal or metallurgical coal producer selling into India or Southeast Asia where BF-BOF remains dominant and policy constraints are modest may be operating within Scenario 1: business-as-usual. If the firm has a strong balance sheet and strong supply chain integration, the recommended strategy would be adaptation. This could involve targeted upgrades to product quality, enhanced ESG disclosure, and logistics optimisation to strengthen competitiveness in markets with delayed decarbonisation.

Example 3: Repositioning under Scenario 4 (Hybrid Adaptation). A diversified producer with global operations may find itself exposed to both fast-transitioning and slow-transitioning markets. For example, a firm supplying both the EU and Southeast Asia could align with Scenario 4: hybrid adaptation. If internal capabilities are uneven across regions, the framework would recommend a repositioning strategy which scales down exposure in high-risk jurisdictions while redirecting volumes toward markets with stable demand and low regulatory pressure.

6.4.3 Summary table: scenario-to-strategy alignment

To assist firms in visually mapping their scenario fit to strategic options, the following table summarises the framework's logic:

Table 5. - Scenario fit to strategic options

Coal-centric scenario	**Transition drivers**	**Recommended strategic pathway**	**Typical market context**
1: Business-as-Usual	Low policy pressure, slow tech change	Adaptation / Repositioning	India, Southeast Asia, Africa
2: Policy-Driven	High policy pressure, slow technology shift	Diversification / Exit	EU, South Korea, Japan
3: Technology Breakthrough	Rapid tech change, moderate to high policy pressure	Exit / Diversification	Sweden, Germany, hydrogen pioneers
4: Hybrid Adaptation	Mixed pace of change, regional fragmentation	Adaptation / Diversification / Repositioning	Global firms with multi-market exposure

This table, when combined with the diagnostic flow in the prior section, offers producers a comprehensive roadmap for determining the most realistic and resilient response to coal transition dynamics.

6.4.4 Six cross-cutting strategic insights

Building on the structured application of the framework, this section distils six cross-cutting insights that shape the feasibility, urgency, and effectiveness of each strategic pathway. These insights emerged from aligning scenario dynamics with firm-level readiness across a range of contexts. These insights are listed below:

1. The first is that geographic agility matters. Firms operating in slower-transitioning regions such as India, Southeast Asia enjoy a wider window for adaptation and repositioning compared to firms exposed to rapid decarbonisation markets like the EU.
2. Second is that policy is catalytic. Policy instruments such as CBAM or net-zero mandates rapidly reshape market access and demand profiles. They serve as accelerators or constraints depending on a firm's exposure.
3. Third is that "no-regret" investments offer resilience regardless. Enhancing ESG reporting, upgrading product quality, and logistics optimisation are universally and mostly beneficial and can be deployed across scenarios with minimal downside.
4. Fourth is that strategic exit is legitimate. In high-risk or declining markets, managed withdrawal is a valid and sometimes optimal pathway. This is especially the case when together with reinvestment in transition-aligned sectors.
5. Fifth is that Transition finance determines viability. Access to capital and green financing channels increasingly influences whether a firm can implement diversification or technology-intensive responses.
6. Sixth and last is that the scenario-context fit is dynamic. Firms must periodically reassess their scenario alignment and strategic posture, particularly when customer behaviour, policy signals, or internal capabilities shift.

These insights provide a strategic compass for coal producers, bridging abstract future scenarios with concrete strategic choices.

6.5 Validation of framework through example cases

To ensure the strategic decision-making framework developed in this chapter is not only theoretically coherent but also grounded in the real-world. This section validates its logic through the company example analysed in Chapter 5. Peabody Energy, BHP, Anglo American, and Glencore represent a cross-section of producers operating in different regulatory environments that are exposed to varying decarbonisation scenarios and deploy distinct strategic responses.

What emerges from these cases is compelling. The strategic pathways of adaptation, diversification, reposition, and exit outlined in Section 6.3 are already being applied by leading firms. These companies are navigating the same coal-centric scenarios developed in Chapter 4 and responding in ways that is similar with the scenario-to-strategy logic detailed in Sections 6.2 and 6.4. This not only validates the relevance of the framework but also confirms its practical adaptability to varying market contexts, capital conditions, and stakeholder pressures.

Peabody Energy is a clear example of the adaptation pathway. They operate largely in the United States and the Asia-Pacific, and their strategic environment aligns with what Chapter 4 identified as Scenario 1 (business-as-usual) and Scenario 4 (hybrid adaptation). While demand for coal remains relatively stable in many of Peabody's key markets, the company is increasingly exposed to ESG pressure, investor scrutiny, and policy tightening. This is particularly evident in their thermal coal operations. In response, Peabody has made incremental investments in operational efficiency, digital mine optimisation, and environmental reporting transparency. These measures are the same as the type of adaptive strategies outlined in Section 6.3.1 and show an effort to extend competitiveness in legacy markets without immediately and completely changing its business model. Importantly, Peabody's approach shows that adaptation is not a passive defence but a conscious, efficiency-driven response to shifting external expectations.

In contrast, BHP is a great example of the diversification pathway, as described in section 6.3.2. As discussed in Chapter 5, BHP has proactively divested from thermal coal, exited several coal-intensive joint ventures, and reallocated capital into critical minerals such as copper, nickel, and potash. The commodities essential to the global clean energy transition. This strategic position is best understood through the lens of Scenario 2 (policy-driven transition) and Scenario 3 (technology breakthrough). Both impose medium- to long-term demand degradation and reduction on metallurgical and thermal coal. BHP's repositioning strategy reflects not only a financial de-risking of its portfolio but also a deliberate alignment with investor sentiment and long-term market trends. BHP has essentially implemented the diversification logic described in Section 6.2.2 that combined financial capability, policy foresight, and technological adaptability to execute a transformation strategy.

The Exit Pathway described in Section 6.3.3 receives its most evident demonstration through Anglo American. The company detailed its complete thermal coal exit through the demerger of South African coal assets into Thungela Resources during 2021. The company made this decision because of rising investor demands and reputational risks and European climate regulations which matched Scenario 2 conditions. Strategic exit serves as a powerful reallocation strategy which demonstrates its strength rather than indicating weakness according to Anglo's case. Anglo released resources to concentrate on platinum group metals and copper development after removing assets that lost value in ESG and capital markets. The strategic exit approach represents a valid and frequently value-enhancing response to coal's diminishing market acceptance in specific regions according to Section 6.4.

The fourth scenario Hybrid Adaptation's complexity is demonstrated in Glencore case as a company which faces different decarbonization paths in its various operating regions. Glencore maintains its major coal asset base in South African and Australian operations but has dedicated funds to energy transition minerals and carbon trading initiatives. The company implements a managed decline strategy that allows it to extract value from profitable coal operations in markets with slow transition rates while it increases its exposure to future-oriented commodities. The hybrid strategy which combines adaptation with repositioning and diversification matches the practical application process described in Section 6.4. Glencore demonstrates that the strategic pathways in this framework function as adaptable options which companies can use together based on their geographic reach and asset maturity and stakeholder connections. Glencore follows a reposition strategy by maintaining metallurgical coal exports to India and other slow-moving markets while building up its renewable energy and transition metal investments. The company demonstrates adaptable geographic operations through its hybrid strategy which stops short of complete asset divestment.

Together, these cases support the fundamental premise of the framework by showing how coal producers face distinct market conditions which lead them to adopt strategic approaches that match the decision framework presented in this thesis. The diagnostic dimensions of coal type, geographic exposure and policy intensity identified in Section 6.2 appear as consistent differentiators between the strategic choices of these companies. These example cases clearly validate the diagnostic dimensions introduced in Section 6.2

Table 6. - Validation of framework through example cases

Company	**Scenario alignment**	**Strategic pathway**	**Notable feature**
Peabody Energy	Scenario 1 / 4	Adaptation	Efficiency upgrades, ESG alignment
BHP	Scenario 2 / 3	Diversification	Shift to critical minerals and decarbonisation tech
Anglo American	Scenario 2	Exit	Strategic divestment to preserve capital and ESG
Glencore	Scenario 4	Adaptation Diversification Repositioning	Managed decline narrative and portfolio balancing

In conclusion, the case study validation confirms that the framework developed in Chapter 6 works well in practical situations. The pathways of adaptation, diversification, reposition, and exit are not only theoretically sound but also have been actively pursued by leading firms under conditions remarkably like those described in the coal-centric scenarios. As such, the framework serves not only as a theoretical contribution to transition strategy literature but also as a usable, scenario-aligned planning tool for coal producers navigating the complexities of the green industrial transition.

7 Discussion

The chapter interprets the results of the thesis in the context of coal transition dynamics and strategic foresight. It synthesizes the scenario analysis, framework development, and case validation into key insights that inform both academic discourse and practical decision-making for coal producers and policy makers. The chapter is divided into four sections: integration of findings, original contributions, reflections on real-world application, and directions for future research.

7.1 Aligning scenario analysis with strategic responses

The core of this thesis depends on the creation of a coal-based scenario framework (Chapter 4) which was intentionally distinguished from typical steel sector decarbonisation scenarios developed by institutions such as the IEA or the World Steel Association. The previous models tend to focus on the demand side by concentrating on steelmakers and macroeconomic projections. This thesis shifts the analysis to coal producers because they represent strategically important yet frequently overlooked actors in the green transition.

The four scenarios—Business-as-Usual, Policy-Driven Transition, Technology Breakthrough, and Hybrid Adaptation—were each shown to produce unique demand trajectories and regulatory environments for coal. These were not abstract constructs but empirically anchored in regional decarbonisation asymmetries and technological readiness (see Section 4.4). This scenario typology then served as the backbone for a strategic decision-making framework that maps producer characteristics—coal type, market geography, policy exposure—to appropriate pathways of adaptation, diversification, or exit (Chapter 6).

The connection between scenarios and strategic responses was proven through real firm case examples presented in Chapter 5 which include Peabody, BHP, Anglo American and Glencore. The cases showed that major producers are currently dealing with different decarbonisation environments through strategies which align with the pathways identified in this thesis. The combination of theoretical foundations with framework development and practical applications strengthens the research findings while making them applicable to current industrial decarbonisation discussions.

7.2 Implications for global coal markets

The scenario-strategy logic developed in this thesis implies that global coal markets are fragmenting not just by geography but by function. Metallurgical and thermal coal are diverging in terms of both risk exposure and timeline for substitution. Producers exposed to high-regulation markets, especially those linked to European steel supply chains, face steep transition costs and are more likely to pursue exit or diversification. On the other hand, firms operating in transition-delayed economies may continue coal production, albeit under tightening ESG expectations and diminishing capital availability.

The market fragmentation presents an obstacle to the general assumption that global coal demand is decreasing uniformly. Instead, the findings suggest a multitrack transition, where firms must develop region-specific, product-specific, and time-sensitive strategies to remain competitive or exit gracefully. These findings have commercial implications and regulatory and financial consequences for policymakers, insurers and investors who need to assess transition risk exposure in the coal value chain.

7.3 Coal producer-centric scenario analysis original contribution to the field

One of the thesis's central contributions is the development of a scenario framework explicitly tailored to coal producers. The framework addresses a major deficiency in transition planning literature because supplier perspectives have traditionally received minimal attention. The framework addresses a blind spot in existing foresight tools through its inclusion of coal-specific variables which include coal type differentiation and regional policy divergence.

The contribution extends beyond theoretical foundations. The framework presented in Chapter 6 enables practical strategy development through a systematic method to connect scenario environments with viable strategic responses. The framework provides a flexible tool which coal producers along with investors and transition finance institutions and policymakers can use for market or company risk assessments.

7.4 Novel decision-making framework development original contribution to the field

The second major contribution is the development of a practical, modular decision-making framework for coal firms. This framework is based on scenario foresight and has been validated through industry case studies, and it enables firms to move from qualitative scenario assessment to structured, actionable strategy design.

Where much of the existing literature focuses on macroeconomic modelling or emissions pathways, this framework bridges the gap between risk diagnosis and strategic implementation. It incorporates both external exposure and internal readiness metrics, allowing coal producers to choose strategies that are not only theoretically sound but also operationally feasible. This positions the framework as a useful decision-support tool for industry actors navigating transition complexity under real-world constraints.

7.5 Industry relevance and practical insights

The strategic decision-making framework established in this thesis exists for practical application rather than theoretical examination. The framework gains its power from its direct connection to real-world operations. The framework works well with both internal strategy development of coal companies and external ESG assessments for investors. The framework uses data that coal producers already track such as market exposure and emissions profiles which enables straightforward implementation without significant methodological challenges. The framework's five-step application process described in Chapter 6.4 provides a structured decision-making approach for situations with high uncertainty and disruption levels. The framework's modular design enables its application by both multinational corporations operating globally and regional businesses of any size.

Importantly, the framework also provides clarity in ambiguity. As shown in the case of Glencore and others, coal producers are increasingly faced with hybrid conditions: some markets demand ESG upgrades, others remain coal-reliant, and investor sentiment is shifting unevenly. The framework allows firms to segment exposure and implement mixed strategies, aligning with contemporary portfolio realities.

7.6 Recommendations for coal producers and policy makers

Coal producers should start by mapping their portfolio through scenario-strategy logic. Companies need to measure their exposure to CBAM-type risks while working with customers to understand their future technology choices and developing transition pathways for both revenue preservation and capital reallocation.

The framework provides policymakers with understanding of coal firm business logic. The framework can assist policymakers to develop specific incentives and financing instruments and transition mechanisms which match firm-level strategy formation. It can also assist regulators to determine where voluntary exit is possible versus where additional transition support may be required.

7.7 Limitations and future research directions

The results of this thesis as with scenario-based research depend on current market and policy trajectories. The fundamental principles of the scenarios might break down if major changes occur in geopolitical energy policies or breakthrough technologies or global trade regulations. The validation process mainly concentrated on large firms which have capital access although the framework shows potential for broad application. Further research is needed to test the framework's relevance for junior miners, state-owned entities, and firms in markets with less regulatory transparency.

Future research should investigate how financial risk modelling through climate Value-at-Risk integrates with the framework while developing coal operation adaptation metrics and studying how investor coalitions and green finance standards affect strategic pathway selection.

7.8 Recommendations and conclusions

The main goal of this thesis was to explore how coal producers especially those supplying the steel sector can strategically respond to the pressures of industrial decarbonisation. Most scenario-based analyses adopt a steelmaker-centric or demand-focused lens, this study proposed a supply-side reframing. Specifically, it introduced a coal-centric scenario framework and developed a corresponding decision-making model that enables coal firms to anticipate change, assess exposure, and implement scenario-aligned strategies.

The four future scenarios presented in Chapter 4 include Business-as-Usual, Policy-Driven Transition, Technology Breakthrough and Hybrid Adaptation which result from different levels of policy intensity and technological disruption. The scenarios were based on existing foresight literature but specifically adapted to match the current situation of coal producers. The plausibility of these scenarios was confirmed through case study analysis which showed that Peabody, BHP, Anglo American and Glencore are using strategies that match the scenario logic.

Chapter 6 then introduced a strategic framework which coal firms could use to align their market exposure with internal capacity through four core pathways: adaptation, diversification, reposition or exit. The framework was further operationalised through step-by-step application tools and a scenario-to-strategy decision tree which helped producers transform theoretical understanding into practical action planning.

The thesis showed that coal transition exists in multiple forms. It is regionally fragmented, product-specific, and temporally staggered. Strategic responses need to be adaptable and differentiated because of this. The key finding shows that producers can implement structured scenario-based strategies to manage risk and reputation while seizing opportunities in a global energy system undergoing transition.

7.9 Strategic implications for coal producers

The research findings of this thesis provide essential guidance to coal producers regarding their business strategy in response to growing decarbonization challenges. The research presents a challenge to the traditional binary approach which has governed coal industry discussions about business continuation versus shutdown. The thesis introduces multiple transition pathways which enable businesses to transition through staged regional approaches with operational feasibility.

The Adaptation Pathway presents a practical short-term solution for producers operating in emerging markets that include Southeast Asia, India, and Africa. The firms can stay commercially viable through product quality improvements and emission intensity reduction and ESG standard alignment while global capital becomes more selective. In contrast, firms operating in highly regulated jurisdictions or facing accelerated technological substitution will find more value in Diversification or Exit. The more capital-intensive pathways enable producers to prevent asset stranding while rebuilding their reputation and establishing long-term sustainability in transition-aligned sectors including battery minerals and carbon-based industrial products and renewables.

The framework enables firms to implement mixed strategies across their portfolios by adapting in one region and repositioning exports to markets with slower transition trajectories and diversifying into transition metals or exiting coal when risks exceed returns. The framework presents a realistic approach to transition risk because it mirrors how risks develop in practice and provides coal producers with a strategic framework for future planning.

7.10 Recommendations for coal producers

The coal industry should implement scenario-based planning through the framework established in this thesis to evaluate their exposure and develop resilience. Companies should establish ESG reporting systems because capital access and offtake agreements now require transparent disclosure of their emissions and governance and supply chain practices. Companies should maintain direct contact with their steel-producing customers to understand how their demand patterns change because of policy changes and innovation and investor pressure. Firms operating even in markets with persistent coal demand should develop long-term repositioning strategies while limiting investments in assets that will become stranded.

7.11 Recommendations for policymakers and financial institutions

Transition Finance should be supported through public and blended finance mechanisms that assist coal firms in responsible diversification or exit processes when private capital is insufficient. Governments should align social transition programs with corporate pathways—targeting support to workers and communities based on anticipated firm decisions. The scenario-pathway logic can assist regulators in identifying firms or sectors most at risk and tailoring policy instruments accordingly.

7.12 Final reflections and closing remarks

The research has sought to reposition coal producers as active agents who can direct their own transition instead of viewing them as helpless victims of decarbonization. The research introduces a coal-focused scenario framework and decision-making model to address a fundamental gap in decarbonisation literature while providing useful insights for companies operating in an unstable industrial sector.

The research confirms that transition does not occur at a uniform rate and does not follow a straight line. The future of coal will be shaped by multiple possible outcomes because different companies will either exit the market with planning or adjust to low-carbon standards or shift to markets that transition slowly or transform their operations through diversification. The ability to handle this complexity depends on structured foresight and cross-scenario planning and the willingness to act before markets or mandates force change.

As the global economy accelerates toward low-carbon industrialisation, the strategic choices made by coal producers today will shape not only their own trajectories but also the pace and equity of the energy transition. This thesis offers a roadmap to help make those choices deliberate, data-driven, and aligned with both market and social imperatives.

Sources

Association for Iron & Steel Technology (AIST), 2025. *Roadmap for Iron and Steel Manufacturing*. [online] Available at: https://www.aist.org/getmedia/46298d18-16aa-4e81-850e-0ff764b068a3/25-feb-ist-p8.pdf.

ArcelorMittal. (2020). Climate Action in Europe. [online] Luxembourg: ArcelorMittal. Available at: https://corporate.arcelormittal.com/sustainability/climate-action-in-europe.

ArcelorMittal. (2022). *ArcelorMittal inaugurates flagship carbon capture and utilisation project at its steel plant in Ghent, Belgium*. [online] Available at: https://corporate.arcelormittal.com/media/press-releases/arcelormittal-inaugurates-flagship-carbon-capture-and-utilisation-project-at-its-steel-plant-in-ghent-belgium.

BHP**.** (2022). *BHP Annual Report 2022*. [online] Melbourne: BHP Group Limited. Available at: https://www.bhp.com/investors/financial-results/2022-annual-report.

Barbesgaard, M. & Whitmore, A., 2024. Blood on the Floor: The Nickel Commodity Frontier and Inter-Capitalist Competition Under Green Extractivism. *Journal of Political Ecology*. [online] Available at: https://journal.culanth.org.

Bhaskar, R., 2013. *A Realist Theory of Science*. London: Routledge.

Bengston, D.N., Dator, J., Dockry, M.J. & Yee, A., 2016. Alternative futures for forest-based nanomaterials: an application of the Manoa School's alternative futures method. *World Future Review*, 8(4), pp.197–221.

Bondarenko, V., Salieiev, I., Kovalevska, I., Chervatiuk, V., Malashkevych, D., Shyshov, M. & Chernyak, V., 2023. A new concept for complex mining of mineral raw material resources from DTEK coal mines based on sustainable development and ESG strategy. *Mining of Mineral Deposits*. [online] Available at: https://mining.org.ua.

Bontoux, L., Sweeney, J.A., Rosa, A.B., Bauer, A., Bengtsson, D., Bock, A.K., et al., 2020. A game for all seasons: Lessons and learnings from the JRC's scenario exploration system. *World Futures Review*, 12(1), pp.81–103.

Cairns, G. & Wright, G., 2017. *Scenario Thinking: Preparing Your Organization for the Future in an Unpredictable World*. Cham: Springer.

Chermack, T.J., 2011. *Scenario Planning in Organizations: How to Create, Use, and Assess Scenarios*. San Francisco: Berrett-Koehler Publishers.

Clark, P., 2015. Coal in Decline: The Regulatory Shifts Reshaping Global Markets. *Financial Times*. [online] Available at: https://www.ft.com.

Climate Policy Initiative, 2023. *Taking Stock of Steel: India's Domestic Production Outlook and Global Investments in Green Steel Production*. [online] Available at: https://www.climatepolicyinitiative.org/taking-stock-of-steel-indias-domestic-production-outlook-and-global-investments-in-green-steel-production/.

Creswell, J.W. & Clark, V.L.P., 2017. *Designing and Conducting Mixed Methods Research*. 3rd ed. Thousand Oaks, CA: Sage Publications.

De Donno, M.G., 2024. Metals for the Energy Transition: Exploring Opportunities Amidst Supply-Demand Imbalance. *Energy Transition Conference*. [online] Available at: https://energytransitionconf.org.

De Ras, K., Van de Vijver, R., Galvita, V.V., Marin, G.B. & Van Geem, K.M., 2019. Carbon capture and utilization in the steel industry: challenges and opportunities for chemical engineering. *Current Opinion in Chemical Engineering*, 26, pp.81–87.

Devlin, A. & Yang, A., 2022. Regional supply chains for decarbonising steel: energy efficiency and green premium mitigation. *Energy Conversion and Management*, 254, 115268.

Devlin, A., Kossen, J., Goldie-Jones, H. & Yang, A., 2023. Global green hydrogen-based steel opportunities surrounding high-quality renewable energy and iron ore deposits. *Nature Communications*. [online] Available at: https://www.nature.com.

Dudin, M.N., Reshetov, K.Y., Mysachenko, V.I., Mironova, N.N. & Divnenko, O.V., 2017. Green Technology and Renewable Energy in the System of the Steel Industry in Europe. *International Journal of Energy Economics and Policy*, 7(2), pp.310–315.

Dyczko, A., 2024. AI-driven coal quality prediction: Enhancing accuracy in forecasting key parameters. *Journal of Mining and Energy Technology*, 45(2), pp.112–126.

E3G, 2025. *The State of the European Steel Transition*. [online] Available at: https://www.e3g.org/wp-content/uploads/The-State-of-the-European-Steel-Transition-Report.pdf.

Ellen MacArthur Foundation, 2019. *Completing the Picture: How the Circular Economy Tackles* Climate Change. [online] Available at: https://ellenmacarthurfoundation.org.

European Commission. (2021). *'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality*. Brussels: European Union. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550.

European Commission. (2023). Guidance document on CBAM implementation for installation operators outside the EU. [online] Brussels: European Union. Available at: https://taxation-customs.ec.europa.eu/system/files/2023-12/Guidance%20document%20on%20CBAM%20implementation%20for%20installation%20operators%20outside%20the%20EU.pdf.

European Steel Association (EUROFER), 2024. *European Steel in Figures 2024*. [online] Available at: https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2024/European-Steel-In-Figures-2024-v2.pdf.

Evans, C. & Withey, A., 2012. An enlightenment in steel? Innovation in the steel trades of eighteenth-century Britain. *Technology and Culture*, 53(3), pp.533–560.

Fan, J.L., Li, Z., Li, K. & Zhang, X., 2022. Modelling plant-level abatement costs and effects of incentive policies for coal-fired power generation retrofitted with CCUS. *Energy Policy*, 169, 113114.

Fischedick, M., Roy, J., Abdel-Aziz, A., Acquaye, A., Allwood, J.M., Ceron, J.-P., et al., 2014. Industry. In: Edenhofer, O., et al., eds. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, pp.739–810.

Flores-Granobles, M. & Saeys, M., 2020. Minimizing CO_2 emissions with renewable energy: A comparative study of emerging technologies in the steel industry. *Energy & Environmental Science*, 13(7), pp.1923–1932.

Gerbelová, H., Spisto, A. & Giaccaria, S., 2020. Regional energy transition: An analytical approach applied to the Slovakian coal region. *Energies*, 13(13), 3462.

Glencore. (2023). *Sustainability Report 2023*. [online] London: Glencore International. Available at: https://www.glencore.com/.rest/api/v1/documents/static/be5b0554-2c1d-415d-8072-be6a30d91d79/GLEN-2023-Sustainability-Report.pdf.

Glencore. (2024). *Climate Action Transition Plan 2024–2026*. [online] London: Glencore International. Available at: https://www.glencore.com/.rest/api/v1/documents/static/1dcd075b-bd27-4930-84c1-9f00aba0e129/GLEN-2024-2026-Climate-Action-Transition-Plan.pdf.

Global CCS Institute. (2020). *Global Status of CCS Report: 2020*. [online] Melbourne: Global CCS Institute. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf.

Gosens, J., et al., 2021. Australia's Metallurgical Coal Market Outlook: Exports and Decarbonisation. *Energy Studies Review*, 28(2), pp.45–62.

Green, F. & Vallée, J., 2022. The impact of carbon pricing on coal investments: Evidence from global financial markets. *Energy Policy*, 163, 112899.

HYBRIT, 2022. *Fossil-Free Steel: The HYBRIT Project*. [online] Available at: https://www.hybritdevelopment.se.

Huo, Y., Zhang, X., Li, M. & Wang, L., 2024. Reinforcement learning for fleet dispatching in mining operations: Productivity improvement and emissions reduction. *International Journal of Mining Science and Technology*, 39(1), pp.88–102.

International Energy Agency (IEA), 2020. *Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking*. Paris: IEA.

International Energy Agency (IEA), 2021. *Net-Zero by 2050: A Roadmap for the Global Energy Sector*. Paris: IEA.

International Energy Agency (IEA), 2023. *World Energy Outlook 2023*. [online] Available at: https://www.iea.org/reports/world-energy-outlook-2023.

Intergovernmental Panel on Climate Change (IPCC). (2018). *Global Warming of 1.5°C: An IPCC Special Report*. Geneva: IPCC. Available at: https://www.ipcc.ch/sr15.

Ministry of Steel, Government of India. (2021). *Annual Report 2020–21*. New Delhi: Government of India. Available at: https://steel.gov.in/sites/default/files/2025-04/Annual%20Report-Ministry%20of%20Steel%202020-21%20%281%29.pdf.

Indian Ministry of Steel, 2023. *India's National Steel Policy: 2023 Review*. New Delhi: Government of India.

Jamet, J., Laurent, E. & Yanguas, P., 2023. The carbon border adjustment mechanism: Implications for global trade and industrial policy. *Journal of Environmental Economics*, 45(2), pp.78–94.

Jermain, A., Lewis, T. & Patel, M., 2024. The role of coal suppliers in a decarbonizing world: Transition strategies and investment shifts. *Journal of Energy Economics*, 49(2), pp.76–92.

John, N., Wesseling, J.H., Worrell, E. & Hekkert, M., 2022. How key-enabling technologies' regimes influence sociotechnical transitions: The impact of artificial intelligence on decarbonization in the steel industry. *Journal of Cleaner Production*, 370, 133624.

Krzemień, A., Frejowski, A., Valverde, G.F., Fernández, P.R. & García-Cortés, S., 2023. Repurposing end-of-life coal mines with business models based on renewable energy and circular economy technologies. *Energies*, 16(4), 1782.

Lebit, H., Brunner, B., Kharitonova, N. & Deemer, E., 2024. Direct Lithium Extraction from Geothermal Brines: The New Oil. *Offshore Technology Conference*. [online] Available at: https://www.otcnet.org.

Meha, D., Pfeifer, A., Sahiti, N., Schneider, D.R. & Duić, N., 2021. Sustainable transition pathways with high penetration of variable renewable energy in coal-based energy systems. *Applied Energy*, 295, 117040.

Mulvihill, P.R. & Kramkowski, V., 2010. Scenario analysis and sustainability transitions: Lessons from the electricity sector. *Sustainable Development*, 18(6), pp.377–389.

Mulvihill, P.R. & Kramkowski, V., 2010. Extending the Influence of Scenario Development in Sustainability Planning and Strategy. *Sustainability*, 2(1), pp.1–18.

Otto, A., Robinius, M., Grube, T., Schiebahn, S., Praktiknjo, A. & Stolten, D., 2017. Power-to-steel: Reducing CO_2 through the integration of renewable energy and hydrogen into the German steel industry. *Energies*, 10(4), 451.

Peabody Energy, 2020. *Sustainability Report 2020*. St. Louis, MO: Peabody Energy.

Pellegrini, L., Sandri, M., Villagrossi, E., Challapalli, S., Cestari, L., Polo, A. & Ometto, M., 2019. Successful use case applications of artificial intelligence in the steel industry. *Iron & Steel Technology (AIST)*. [online] Available at: https://www.aist.org.

Plakitkina, L.S. & Makarov, A., 2021. Strategic policy and investment frameworks for decarbonizing coal-intensive industries. *Russian Journal of Industrial Economics*, 24(1), pp.12–29.

Plakitkina, L.S., Plakitkin, Y.A. & D'yachenko, K.I., 2021. Decarbonisation of economy as a factor of influence on the development of coal industry of the world and Russia. *Ferrous Metallurgy. Bulletin of Scientific, Technical and Economic Information*, 77(8), pp.902–912.

Plakitkina, L. et al., 2021. Steel Industry and Coal Demand in Emerging Markets. *Journal of Industrial Economics*, 34(1), pp.89–112.

Ramakgala, C. & Danha, G., 2019. A review of ironmaking by direct reduction processes: Quality requirements and sustainability. *Procedia Manufacturing*, 35, pp.242–245.

Ramirez, R. & Wilkinson, A., 2014. Rethinking the 2×2 scenario method: Grid or frames? *Technological Forecasting and Social Change*, 86, pp.254–264.

Rechberger, K., Spanlang, A., Sasiain Conde, A., Wolfmeir, H. & Harris, C., 2020. Green hydrogen-based direct reduction for low-carbon steelmaking. *Steel Research International*, 91(11), 2000110.

RMI, 2022. *Steel GHG Emissions Reporting Guidance*. [online] Available at: https://rmi.org/wp-content/uploads/2022/09/steel_emissions_reporting_guidance.pdf.

Sambasivam, B. and Sarma, R.N., 2024. India's National Green Hydrogen Mission: an analysis of the strategies, policies for net-zero emissions and sustainability. Environmental Research: Energy, 1(4), p.045015.

Schoemaker, P.J.H., 1995. Scenario planning: A tool for strategic thinking. *Sloan Management Review*, 36(2), pp.25–40. [online] Available at: https://sloanreview.mit.edu/article/scenario-planning-a-tool-for-strategic-thinking/.

Schwartz, P., 1997. *The Art of the Long View: Planning for the Future in an Uncertain World*. New York: John Wiley & Sons.

S&P Global, 2024. Global crude steel production remains flat in 2023. [online] Available at: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/012524-global-crude-steel-production-remains-flat-in-2023.

Skoczkowski, T., Verdolini, E., Bielecki, S., Kochański, M., Korczak, K. & Węglarz, A., 2020. Technology innovation system analysis of decarbonisation options in the EU steel industry. *Energy*, 212, 118688.

Sondeijker, S., Geurts, J., Rotmans, J. & Tukker, A., 2006. Imagining sustainability: the added value of transition scenarios in transition management. *Foresight*, 8(5), pp.15–30.

Sweeney, J.A., 2017. Game On: Foresight at Play with the United Nations. *Journal of Futures Studies*, 22(2). [online] Available at: https://jfsdigital.org.

Tata Steel, 2023. *Hydrogen-Based Steelmaking and India's Decarbonisation Pathway*. Jamshedpur: Tata Steel.

Verhoeven, J.D., Pendray, A.H. & Dauksch, W.E., 2016. Did the First Iron Blacksmiths Learn to Carburize Iron? Part II: Experiments Showing That it is Very Likely That They Did. *JOM*, 68(8), pp.2256–2260.

Wack, P., 1985. Scenarios: Uncharted waters ahead. *Harvard Business Review*, 63(5), pp.73–89.

Wang, C., Larsson, M., Ryman, C., Grip, C.E., Wikström, J.O., Johnsson, A. & Engdahl, J., 2008. A model on CO_2 emission reduction in integrated steelmaking by optimization methods. *International Journal of Energy Research*, 32(12), pp.1092–1106.

World Steel Association, 2020. *Steel's Contribution to a Low Carbon Future and Climate Resilient Societies*. [online] Available at: https://www.acero.org.ar/wp-content/uploads/2020/02/Position_paper_climate_2020_vfinal.pdf.

World Steel Association, 2023. *World Steel in Figures 2023*. [online] Available at: https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2023.pdf.

Wright, G., Cairns, G. & Bradfield, R., 2013. Scenario methodology: New developments in theory and practice: Introduction to the Special Issue. *Technological Forecasting and Social Change*, 80(4), pp.561–565.

Xcoal Energy & Resources, 2021. *About Us*. [online] Available at: https://www.xcoal.com.

Xiang, X., Li, K., Li, X. & Hou, Y., 2023. Investment feasibilities of CCUS technology retrofitting China's coal chemical enterprises with different CO_2 geological sequestration and utilization approaches. *International Journal of Greenhouse Gas Control*, 119, 103851.

Yin, R.K., 2018. *Case Study Research and Applications: Design and Methods*. 6th ed. Thousand Oaks, CA: Sage Publications.

Zhai, H., Dindi, A., Coddington, K. & Garofalo, J., 2022. On the policy-driven potential for decarbonizing a fossil-rich power sector via carbon capture and sequestration. *Social Science Research Network*. [online] Available at: https://ssrn.com.

Van Notten, P.W.F., Rotmans, J., van Asselt, M.B.A. & Rothman, D.S., 2003. An updated scenario typology. *Futures*, 35(5), pp.423–443.