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Integration of coal mining and metallurgy sectors: Transforming partnership models for sustainable development

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Abstract

The article examines the characteristics of traditional partnerships and those created to achieve sustainable development goals.

Although perceived as a positive contribution to solving sustainable development problems, numerous studies demonstrate the ineffectiveness of such partnerships. This presents researchers and practitioners with the critical challenge of understanding how to improve partnership effectiveness.

An empirical analysis of partnerships in the coal mining and metallurgical sector was carried out. Five types of relationship clusters were identified: partnerships focused on economic benefits; partnerships focused on scientific and technical cooperation; partnerships focused on joint value creation; partnerships focused on new opportunities; and partnerships focused on relationships. It was concluded that in the coal mining and metallurgy sectors, partnerships for economic benefits and partnerships for scientific and technical cooperation predominate. In this context, it is necessary to develop a mechanism aimed at improving common technologies and economic indicators in order to ensure the effectiveness of the partnerships created to pursue sustainable development goals.

The article aims to develop and analyse new models of interaction between the coal mining and metallurgy sectors, with a view to improving environmental and economic sustainability.

Keywords: sustainable development, metallurgical industry, coal mining industry, interfirm relationships, partnership models, partnership management strategy.

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整合煤炭和金属部门：转变伙伴关系模式促进可持续发展

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简介

文章讨论了传统伙伴关系和为实现可持续发展目标而建立的伙伴关系的特点。
尽管伙伴关系被视为对解决可持续发展问题的积极贡献，但有许多研究证明这种伙伴关系并不有效。这对研究人员和从业人员了解如何提高伙伴关系的有效性提出了重要挑
战。
对煤矿和冶金行业的公司伙伴关系进行了实证分析。确定了五类关系集群：追求经济效益的伙伴关系；以科技合作为目的的伙伴关系；以共同创造价值为目的的伙伴关系；以新机遇为重点的伙伴关系；以关系为重点的伙伴关系。结论是，煤矿和冶金部门主要是追求经济效益的伙伴关系和以科技合作为目的的伙伴关系。在这方面，为了使为实现可持续发展目标而建立的伙伴关系发挥效力，有必要建立一个旨在提高联合技术效力和改善经济效益的机制。
文章旨在开发和分析煤炭开采和冶金行业之间互动的新模式，以改善环境和经济的可持续性。
关键词: 可持续发展、冶金工业、煤矿工业、企业间关系、伙伴关系模式、伙伴关系管理战略。

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Introduction

The successful implementation of the Sustainable Development Goals (SDGs) can only be achieved through the formation of partnerships between businesses, public organisations and the public sector [Prescott, Stibbe, 2015; Clarke, MacDonald, 2019; MacDonald et al., 2019]. Only through partnerships will it be possible to achieve a ‘safe space for human action’ [Rockstrom et al., 2009], as new forms of collaboration will allow more effective solutions to be developed to achieve sustainable development goals [Biermann et al., 2009; Keohane, Victor, 2011; Zelli, 2011]. Research in the field of partnership formation argues that such partnerships are characterised by a polycentric governance architecture [Cole, 2015] and are multilateral.

Despite the emergence of many multi-stakeholder partnerships, academic research finds little evidence of their positive impact on achieving the Sustainable Development Goals. This poses an important challenge for researchers and practitioners to understand and improve the effectiveness of partnerships, especially as their popularity grows.

The focus of this study is on the effectiveness of partnerships to reduce the carbon footprint in the metals industry. Existing works mainly focus on individual aspects, such as the use of hydrogen or coal processing, without addressing the comprehensive approach to the transformation of partnership models and their impact on sustainable development.

Life cycle assessment and emission modelling methods were used to analyse environmental aspects, which made it possible to identify the most promising technologies in terms of sustainable development.

1. Theoretical review of the literature

1.1. Characteristics of traditional partnerships and partnerships for the achievement of sustainable development goals

Historically, partnerships emerged as business partnerships for mutual economic benefit. Approaches to forming partnerships have been determined by their effectiveness, the achievement of intended results, the activity of the participants in the interaction, the emphasis on long-term cooperation and the multidimensional nature of the relationships within the framework of value creation.

A win-win approach and emphasis on long-term cooperation means that when mutually beneficial relationships are established and developed, the partners add value to each other and the gain of one party becomes the gain of the other (win-win). If there is no mutual benefit in the relationship, then the gain of one party is the loss of the other.

The activity of the participants in the relationship is realised through trust in each other and the quality of the relationship, which is reflected in the frequency of interaction between the parties.

The multidimensionality of relationships is determined by a variety of factors and levels of relationship management: at the level of the organisation as a whole, at the level of the organisation's divisions, at the individual level of individual employees. At the same time, the factors of interaction include factors of the external environment of relationships and the atmosphere of interaction (Fig. 1).

The external environment of interaction reflects the level of competition between partners, their interdependence, trust, commitment to relationships and interaction with stakeholders.

The atmosphere of interaction[1] is both the result of the development of the relationship and a factor in further cooperation. It is determined by the balance of power of the partners in the relationship, mutual understanding, the level of cooperation between the partners, including the exchange of knowledge, cooperation in the field of R&D, the implementation of standards, etc.

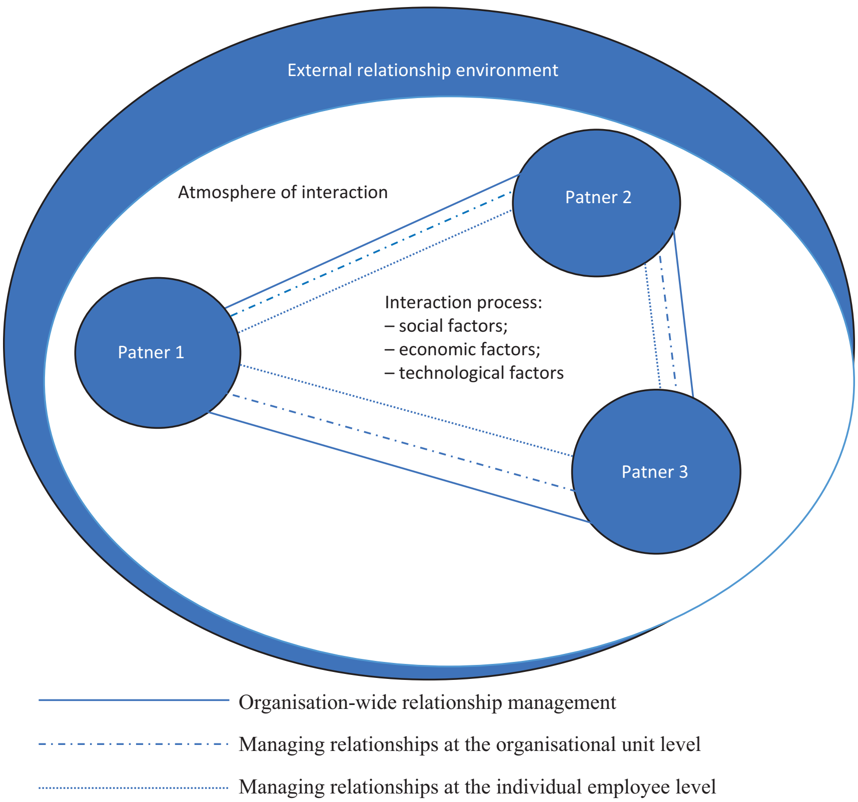
Mutual understanding is defined as the willingness of partners to understand each other's situation and to help each other achieve common goals. An important condition for mutual understanding is the willingness to share knowledge and information in order to reduce the risks of interaction.

In addition, existing studies highlight two other characteristics of relationships - trust and commitment to the relationship. Trust is formed on the basis of shared values and interpersonal communication, and commitment to the relationship is expressed as the willingness of partners to invest in the development of the relationship, thereby reducing the risk of opportunistic behaviour on the part of the partner.

Factors of inter-firm interaction are important: technological, social and economic.

Social factors are expressed in the level of satisfaction with relationships, the level of conflict between group members, and the compatibility of the main goals of interaction [Gummesson, 1999]. Economic factors reflect the level of costs incurred by participants in maintaining relationships, as well as the positive impact of relationships on the performance of partners. Technological relationship factors are related to the compatibility and complementarity of technologies used by relationship partners and to joint innovation.

Fig. 1. Characteristics of traditional partnerships



Source: compiled by the authors.

[1] The term 'interaction atmosphere' was introduced by researchers in the IMP group.

Table 1
Comparative characteristics of traditional partnerships and those created to achieve sustainable development goals

Relationship component	Traditional partnerships	Partnerships created to achieve the Sustainable Development Goals
Purpose of the interaction	Achieving high economic results, increasing competitiveness	Achieving sustainable development goals
Participants in the partnership	Commercial companies	Commercial companies
Factors of interaction	State companies	Government companies
Atmosphere of the interaction	Economic, technological, social	Public organisations
Activity of interaction participants	Trust and commitment to relationships	Regulators

Source: compiled by the authors.

Thus, studying the process of relationship development allows us to take into account the diversity of factors and aspects of joint activities and is the basis of the strategy for managing the development of relationships.

1.2. Partnerships to achieve the Sustainable Development Goals

Partnerships to achieve sustainable development goals were first described in [Murphy, Bendell, 1997] and subsequently studied in detail in [Biermann et al., 2009; Rockstrom et al., 2009; Pattberg, Widerberg, 2016] and others.

For example, research [Eweje, 2007] argues that partnerships created to achieve sustainable development goals are characterised by more intense interactions, but are more focused on formal reporting within the existing institutional structure. As a result, there is an increasing gap between expectations and results achieved, which calls into question the effectiveness of such partnerships [Pattberg, Widerberg, 2016].

The ineffectiveness of creating such partnerships is also noted in [Glasbergen, 2007, p. 14]: partnerships mainly deal with limited governance of SDG issues, and thus the partnership paradigm is a fragmented way of achieving sustainable development.

In addition, a number of authors criticise the concept of sustainable development itself [Redclift, 2005], noting that sustainable development is a compromise between development and sustainability: between those who prioritise economic development and those who seek to improve social and environmental conditions [Kates et al., 2005]. The works [Hahn et al., 2014; Prescott, Stibbe, 2015] show that most of these partnerships have only indirect economic benefits, which reduces the interest of the participants in the partnership.

The nature of the quality of relationships in such partnerships has also been criticised. For example, the authors [Bendell et al., 2010] argue that the paradigm of such partnerships is moving away from a methodology towards an ideology of ‘partnershipism’, defined as ‘the orthodox view that partnerships, when well managed, always lead to net positive outcomes for participants, communities and society as a whole’ [Bendell et al., 2010, p. 352]. This view suggests that partnerships are a matter of operational objectives and reflects unrealistic expectations of partnerships.

For example, partners may receive or perceive only indirect benefits from coalition building, at least in the short term. Moreover, partnerships may even threaten their own interests, as power relations change when the issue is resolved [Zammit, 2003; Utting, Zammit, 2009].

A comparative analysis of traditional and sustainable development partnerships is presented in Table 1.

Studies by various authors suggest measures to

Table 2
Value analysis of relationships between companies in the coal mining and metallurgy sectors

Components of value	For coal mining companies	For companies in the metallurgical sector
Strategic component	Coking coal sales	Providing a key component for smelting iron and steel
Economic component	Reducing the cost of transporting and storing raw materials Optimising logistics Improving financial performance	Efficient allocation of resources Reducing production costs Improving financial indicators
Social component	Creating a system of shared values through collaborative innovation Improving environmental performance Reducing carbon emissions	

Source: compiled by the authors.

improve the effectiveness of such partnerships. For example, the Marine Stewardship Council standard suggests defining common goals, principles, roles, responsibilities and outcomes for achieving goals, as well as providing partnership participants with worksheets for achieving interaction goals [Foley, 2013].

Works [Turcotte, Pasquero, 2001; Clarke, Fuller, 2010] indicate that since participants can only receive indirect economic results from the interaction, it is necessary to form a mechanism for the exchange of knowledge, innovations that contribute to the achievement of sustainable development goals and assistance in solving the problems of participants [Koschmann et al., 2012]. Researchers [Albani, Henderson, 2014] believe that participants in such partnerships should adapt their vision of the concept of efficiency to achieve sustainable development goals. In [Elkjaer, Simpson, 2011] the creation of an effective mechanism for managing such partnerships is proposed.

Partnerships formed to achieve the SDGs therefore need to be transformed, both to increase their effectiveness and to improve the quality of relationships. However, the SDGs themselves and the context of the sector may be important to the effectiveness of forming partnerships for the SDGs.

Next, we will consider forming partnerships between companies in the coal mining and metallurgical sectors to reduce their carbon footprint.

2. Models for integrating the coal mining and metallurgical sectors

Partnerships between coal mining and metallurgical companies play an important role in the development of the industry, ensuring a reliable supply of raw materials and increasing production efficiency.

D. Wilson and S. Jantariya's model describes three components of relationships in partnerships:

– strategic component - optimal allocation of resources, development of key competencies, achievement of strategic goals;
– economic component - increasing competitiveness, reducing costs, improving the quality of goods and services, ensuring access to resources, markets, technologies;
– social component - creating trust and commitment to relationships, creating a system of shared values [Wilson, Jantrania, 1994].

Coal mining enterprises supply metallurgical enterprises with coking coal, which is a key component in the process of smelting iron and steel. An analysis of the value of the relationship between enterprises in the coal mining and metallurgical sectors is presented in Table 2.

At the same time, it is necessary to develop strategic models of interaction between market participants in order to ensure stability of supply and adaptation to economic and environmental changes [Islamov, 2010].

Partnership models are a range of different forms of collaboration between companies aimed at improving operational efficiency, optimising production processes and ensuring long-term sustainability. The interaction of companies within the framework of such models helps to reduce costs, implement innovative solutions and reduce the negative impact on the environment. In today's environment, the development of partnerships is particularly important as it allows companies to adapt to dynamic changes in the market environment and increased competition.

The development of the mining and metallurgical industry has historically been accompanied by the formation of various forms of inter-company cooperation aimed at increasing production efficiency and rationalising the use of resources. As early as the beginning of the 20th century, companies recognised the need for cooperation, which led to the creation of the first strategic alliances. These associations allowed participants to share infrastructure, improve technological processes and reduce operating costs. In the second half of the 20th century, globalisation processes and increased competitive pressures became important factors contributing to the expansion of such forms of cooperation. As a result, companies began to actively diversify their assets and develop new markets, using partnership strategies as a tool to strengthen their position.

The classification of partnership models is based on a number of key criteria, including the level of integration, the strategic objectives of the cooperation and the nature of the interaction between the participants. The following main models can be distinguished:

- Vertical integration involves the unification of successive stages of the production process within a single corporate structure, from the extraction of raw materials to the release of the final product. This form of interaction helps to reduce costs by 15-20% through the comprehensive optimisation of technological operations and logistical processes [Porter, 1985]. However, this format requires significant financial investment and complex management, making it more suitable for large companies with sustainable resource capabilities.
- Horizontal integration involves the merger of companies operating at the same stage of the production chain, which allows the expansion of sales markets and the strengthening of competitive positions. This approach helps to reduce the level of competition and increase the market power of the merged enterprises, but is associated with the risk of violating antitrust laws [Teece, 1986].
- Cluster cooperation involves the formation of network structures of firms that share technological resources and production capacities. For example, cluster interaction models implemented in China in 2021 led to a significant reduction in carbon dioxide emissions and increased environmental sustainability of the industry [Zhang et al., 2021].
- Strategic alliances are agreements between companies aimed at achieving common goals, such as developing innovative products or exploring new markets. These alliances can be temporary or long-term and allow companies to minimise operational risks by taking advantage of complementary resources [Dyer, Singh, 1998].

At present, strategic alliances have taken on more complex and diverse forms due to differences in the objectives of interaction, the degree of technological integration and the degree of interdependence of the parties. One of the most common areas of cooperation are alliances focused on joint research and development (R&D) aimed at developing innovative methods of coal mining and improving metallurgical technologies. In addition, alliances focused on optimising logistics processes, improving supply chains and implementing unified resource management strategies have become widespread, which can significantly improve companies' operational efficiency.

It is difficult to overestimate the importance of strategic alliances for the sustainable development of the mining and metallurgical sector. They help to increase the adaptability of companies to dynamically changing economic and technological conditions, reduce risks and strengthen market positions. Innovative partnership projects make it possible to modernise production processes, which increases the competitiveness of alliance participants on a global scale. Moreover, cooperation in this format contributes to the optimisation of natural resources management and the reduction of negative environmental impacts, which is a key factor in the context of the modern course towards sustainable industrial development [Dunikov, 2017].

At the same time, the effectiveness of such forms of interaction will depend on the strategy for managing the relationships of the alliance participants.

3. Partnerships between coal and metal companies: an empirical analysis

The typology of relationship management strategies was first developed by W. Campbell, who identified three types of management strategies:

– a cooperative type of strategy, which involves focusing on long-term relationships, achieving alignment of objectives, building mutual trust and creating a mechanism for ongoing investment in relationship development;

- competitive type of strategy - focused on the competitive selection of partners (e.g. by price or speed of delivery) with the aim of increasing efficiency indicators;

- team type strategy - exerting pressure on the network partners of the strongest participant to achieve the required supply parameters [Campbell, 1985].

In this study, we surveyed 173 participants in coal mining and metals alliances to identify clusters of companies that characterise established partnerships between companies in these sectors.

The k-means method described in [Trachuk, Linder, 2018] was used for the analysis.

Binary values of the component characteristics were used to analyse the strategies used:

- typology of relationship management strategies according to the groups identified:
  – cooperative type (if yes - 1, if no - 0);
  – competitive type (if yes - 1, no - 0);
  – team type (if yes - 1, no - 0);
- quality of relationships:
  – trust between partners (if yes - 1, if no - 0);
  – satisfaction with relationships (if yes - 1, no - 0);

Table 3
Characteristics of clusters by type of partnerships established between companies in the coal mining and metallurgic sectors

Clusters by type of partnership established	Number of companies in the cluster	Main characteristics	Dominant type of relationship management strategy
Cluster 1: Partnerships for economic benefit	54	Dominance of a large customer or supplier. The main objective is to increase economic efficiency: to increase profits and reduce costs as a result of the relationship.	Competitive
Cluster 2: Innovative and technical cooperation partnerships	38	The main objective is innovative partnership, knowledge exchange, technical and technological cooperation to improve the level of technologies used. Regular improvement of technical and research skills of employees	Competitive
Cluster 3: Partnerships to co-create value	29	The main objective is to create joint value for the consumer and increase market share. Coordinating marketing and product strategies	Cooperative
Cluster 4: Opportunity-driven partnerships	24	The main objective is to create new opportunities for the company, such as entering new markets, achieving sustainable development goals and providing preferential investment opportunities.	Team
Cluster 5: Relationship-based partnerships	28	The main objective is to achieve better results in the area of supplier and consumer relations.	Cooperative

Source: compiled by the authors.

- knowledge sharing and joint problem solving (if yes - 1, no - 0);
- alignment of objectives (if yes - 1, no - 0);
- presence of sustainable development objectives (if yes - 1, no - 0);
- joint creation of innovations (if yes - 1, no - 0);
- commitment to relationships (if yes - 1, no - 0);
- effectiveness of communication (if yes - 1, no - 0);

• economic characteristics of the relationship:

- optimal allocation of resources (if yes - 1, no - 0);
- increase in profit as a result of investing in relationships (if yes - 1, no - 0);
- cost reduction as a result of relationship building (if yes - 1, no - 0).

The hierarchical cluster analysis model was used to determine the clusters. The formula used to determine the distances between clusters was:

$$d_{ij} = \sum x_{ik} - x_{jk}\text{right}|, \quad (1)$$

where d – distance between characteristics, x_i – highlighted relationship characteristics, k – number of companies surveyed.

The result of the analysis was the identification of five clusters based on the type of partnership structure and the strategy implemented to manage them (Table 3).

It can be concluded that most companies aim to gain economic benefits from their relations with partners. In second place are the objectives of S&T cooperation, which is explained by the companies' desire to also achieve efficiency indicators through the introduction of new technologies, both in new products and services and in their own business processes. For example, the partnership between ArcelorMittal and Nippon Steel led to an 8% increase in the efficiency of production processes through the introduction of advanced technological solutions [Zhang et al., 2021].

The remaining three clusters - partnerships for joint value creation, partnerships for new opportunities and partnerships for relationships - have roughly the same distribution of companies and are aimed at developing long-term relationships to open up new opportunities, such as entering foreign markets through partnering, creating joint value for customers to increase market share and stable relationships with multiple suppliers and customers.

Thus, in the coal mining and metallurgy sector, partnerships aimed at economic benefits and partnerships aimed at scientific and technological cooperation predominate. In this regard, in order to achieve the effectiveness of the partnerships created to achieve the SDGs, it is necessary to develop mechanisms aimed at increasing the effectiveness of the implementation of joint technologies and economic efficiency.

4. Achieving technological and economic efficiency of partnerships in the coal and metallurgical industries

4.1. Technological integration of the coal and metallurgical sectors

Modern technologies allow coal mining and processing processes to be optimised, which in turn improves the quality of the final metallurgical product. For example, the use of thermocoke, obtained from lignite and thermal coal, opens up new opportunities for metallurgical plants. Thermocoke has high strength and chemical purity, making it an excellent alternative to traditional coke and providing more stable conditions for metallurgical processes [Teece, 1986].

Hydrogen is also becoming increasingly important in the steel industry, especially as part of the transition to cleaner technologies. Its use as a reducing agent in place of carbon allows a significant reduction in carbon dioxide emissions. Hydrogen can be used in the direct reduction of iron ore, opening up new horizons for sustainable steelmaking. In combination with thermocoke, it can help steelmakers achieve higher standards of environmental safety and efficiency, an important step towards reducing the industry's carbon footprint.

The integration of the coal and steel sectors not only reduces the cost of transporting and storing raw materials, but also opens up new opportunities for more efficient resource management. This interaction makes it possible to optimise logistics processes, which in turn leads to a significant reduction in time and financial costs. Joint efforts in research and development can become a catalyst for the creation of innovative technologies that will not only improve the environmental performance of both industries, but also help to reduce carbon emissions, which is extremely important in the context of global climate change. In addition, such technologies can minimise negative environmental impacts, promote sustainable development and preserve natural resources for future generations. The integration of these sectors is therefore a strategic step towards a more sustainable and environmentally friendly future.

Hydrogen iron production, which is being actively developed in a number of countries, promises to revolutionise the industry by providing cleaner and more efficient steelmaking processes.

Plasma arc furnaces are also an innovative solution for the metallurgical industry. These furnaces allow high temperatures to be achieved and provide more precise control over the melting and alloying of metals. The use of plasma technologies can lead to a reduction in energy costs and an improvement in the quality of the final product, making them attractive for implementation in modern production.

The combination of thermocoke, hydrogen technologies and plasma arc furnaces opens up new horizons for the sustainable development of metallurgy, reducing the negative impact on the environment and increasing the efficiency of production processes.

Partial coal gasification plants are characterised by significantly lower costs compared to full gasification plants. This advantage is due to a simpler process diagram, fewer stages and reduced gas cleaning requirements. According to the author of the paper [Islamov, 2017], the use of such units is particularly promising for coals with a high content of volatile substances, as this allows the most efficient extraction of thermal coke at minimal cost.

One of the key benefits of thermocoke is its ability to reduce the carbon footprint of metallurgical operations by 20-30% compared to traditional methods.

The direct reduction of iron ore using thermocoke is an innovative approach that offers a significant reduction in energy costs - 15% compared to traditional processing methods. This significant improvement is achieved through the high reactivity of the thermocoke, which interacts effectively with the iron ore. As a result, iron is extracted from the ore without the need for additional steps, which are usually associated with significant energy costs.

The use of thermocoke in metallurgy contributes to a significant reduction in carbon dioxide emissions. Coal products play a key role in this industry as they are used by both coking plants and thermal power plants [Belozertsev, Belozertseva, 2023, p. 2]. In 2022, companies using thermocoke reduced CO_2 emissions by 1.2 million tonnes, which highlights the environmental benefits of this technology and its contribution to achieving sustainable development goals.

The economics of using thermocoke are confirmed by a 10% reduction in steel production costs. This is achieved by using cheaper raw materials and reducing energy costs. Thus, the introduction of thermocoke into production processes helps to increase the competitiveness of metallurgical enterprises [Dunikov, 2017].

Technologies based on the use of thermocoke are already being actively used by companies in Germany and China. These companies provide successful examples of the integration of thermocoke into production processes, which confirms both the efficiency and the prospects of this technology. According to Islamov, 'the most effective foreign development is the technology of Salem Corporation, implemented at the level of an industrial plant with a capacity of 105 thousand tonnes per year in Germany and Canada' [Islamov, 2010, p. 8]. This underlines the high level of implementation of thermocoke in modern production systems.

4.2. Hydrogen production from coal for direct reduction of iron ore

Hydrogen production from coal is a complex technological process based on coal gasification. In this process, coal is thermally treated in the presence of oxygen and water vapour, resulting in the formation of synthesis gas containing hydrogen and carbon monoxide. Gasification allows the efficient use of low-grade coal, which is usually unsuitable for traditional application methods, making the process more versatile and cost-effective. Coal gasification can be used to produce hydrogen and synthesis gas, which in turn helps to reduce the carbon footprint [Nefedov et al., 2008, p. 2].

Hydrogen is produced from coal by complete gasification, which involves the thermal decomposition of coal at temperatures up to 1300°C and limited oxygen content. This process produces synthesis gas, the main components of which are hydrogen, carbon monoxide and small amounts of methane. In the first stage, the syngas undergoes multi-stage purification to remove impurities such as hydrogen sulphide and carbon dioxide, which increases the efficiency of the subsequent hydrogen extraction. This is done using advanced technologies such as membrane processes, absorption processes and cryogenic units.

In addition, coal gasification is associated with the implementation of carbon capture, use and storage (CCUS) technologies that reduce the carbon footprint of the process. For example, carbon dioxide released during gasification can be captured and used to produce synthetic fuels or stored in geological formations.

One of the key environmental benefits of using hydrogen in metallurgy is the significant reduction in carbon dioxide emissions. The use of hydrogen in the iron ore reduction process can reduce CO_2 emissions by 60-70% compared to conventional methods. This is particularly relevant in the context of the global fight against climate change and the desire for carbon neutrality. At the same time, it is important to consider that 'the main trend in the global electricity industry of the 21st century is the transition to coal as a fuel' [Nefedov et al., 2008, p. 2]. The transition to hydrogen technologies can be an important step towards reducing dependence on coal and reducing the negative impact on the environment.

An example of successful implementation of the technology is China, which is actively developing coal gasification. By 2023, more than 400 plants using this technology will be operating in the country. European Union projects such as HYBRIT are exploring the possibility of using hydrogen from coal for metallurgical purposes.

Another example is South Korea, which is implementing coal gasification projects to reduce carbon emissions and improve the efficiency of energy systems. The country is actively developing carbon capture and storage (CCS) technologies to minimise the negative impact on the environment.

Coal gasification research is also underway in Australia, where new methods are being developed to use coal in a cleaner way. For example, the GASGAS project aims to develop more efficient gasification processes that can be integrated into existing energy systems.

These examples demonstrate the potential of technology and its importance in achieving sustainable development.

4.3. Hydrogen for plasma arc furnaces

Plasma arc furnaces are an innovative solution in the metallurgical industry to achieve high temperatures for metal processing. These devices use plasma generated by an electric arc to melt and process materials. The technology has become widely used in recent years due to its versatility and ability to process different types of raw materials.

The use of hydrogen in plasma arc furnaces offers significant advantages over traditional methods. First of all, it reduces carbon dioxide emissions by 90%, which helps to improve the environmental situation. In particular, the use of hydrogen to reduce iron oxides can significantly reduce environmental pollution [Boranbaeva et al., 2020, p. 2].

Despite the initial cost of implementing hydrogen technologies, the economic benefits are clear in the long term. According to studies, the transition to hydrogen technologies can increase costs by 20%, but thanks to lower carbon taxes and increased energy efficiency, the payback period is short. In addition, such investments help to strengthen the market position of companies.

An example of the successful implementation of hydrogen technologies is the Hybrit project in Sweden, where hydrogen is used to produce steel with a minimal carbon footprint *ArcelorMittal* is actively investing in the development of hydrogen technologies with a view to integrating them into its production processes.

Another interesting example is the H2GreenSteel project in Sweden, which aims to produce carbon-neutral steel using hydrogen produced from renewable energy. This project also includes the construction of a new plant that will use hydrogen instead of coal in the production process. In Germany *Thyssenkrupp* is working on a project to use hydrogen to replace coal in blast furnaces, significantly reducing CO_2 emissions.

In Australia *Fortescue Metals Group* is developing an initiative to produce green hydrogen for use in the mining industry, which could also reduce its carbon footprint.

These examples demonstrate the potential of hydrogen technologies in the metals industry and other sectors, highlighting their importance in achieving sustainable development and reducing environmental impact.

Most foreign researchers and experts at the European Institute of Plasma Metallurgy support the method of using plasma arc furnaces with hydrogen as the main energy source. This approach allows a significant reduction in carbon emissions, while offering high energy efficiency and versatility in processing different metals. This technology is suitable not only for the production of cast iron, but also for the manufacture of a wide range of commercial ferrous metallurgy products, including slabs, rolled products, high-strength alloys, machine parts and specialised structures for the aerospace and automotive industries. Research shows that the implementation of this technology can become the basis for the creation of a carbon-neutral metallurgical industry. International projects such as the Fraunhofer Hydrogen Initiative and experiments with hydrogen plasma in Germany and Sweden confirm its potential and necessity for the future sustainable development of the industry. This process requires significant capital investment, which is the main obstacle to its widespread adoption. The high cost of creating infrastructure, upgrading equipment, and the need to develop hydrogen logistics and supply networks are significantly slowing the pace of adoption of this technology in industry.

In modern industrial clusters, coal mining and metallurgical companies form a symbiotic relationship aimed at optimising resource consumption and minimising operating costs. Coal mining, as a supplier of critical raw materials, ensures the stability of the production cycles of metallurgical plants, which in turn transform raw materials into high value-added products (steel, alloys). This collaborative model, reinforced by the integration of technological and financial players, creates a synergy that reduces market volatility. Technology companies that provide digital platforms for monitoring ESG indicators and financial institutions that finance infrastructure projects act as catalysts for the stability of alliances [Potapov, Pinchuk, 2006].

The declared transition to a hydrogen economy is causing structural shifts in traditional alliances. Coal mining companies, faced with a decline in demand for coal, are forced to diversify their activities through the introduction of carbon capture and storage (CCUS) technologies and the production of blue hydrogen. The metallurgical sector is reorienting itself towards direct reduction of iron (DRI) technologies using H_2, which requires investments of $1.2-2 billion to modernise a plant. One example is the HYBRIT project (Sweden), where the replacement of coke with hydrogen has reduced the carbon footprint by 90%.

Previously supportive technology companies are becoming key players by developing hydrogen cycle solutions, from high-efficiency electrolysers to cryogenic storage systems.

Modern operating models for coal mining and metallurgical companies have historically been based on exploiting hydrocarbon resources, optimising profitability by scaling production and minimising operating costs. However, increasing regulatory pressure and changing stakeholder expectations in the context of the ESG agenda are initiating a structural restructuring of these industries.

The transformation of the energy base in favour of hydrogen is associated with capital-intensive investments in infrastructure (electrolysers, storage systems) and R&D. According to the model presented in [Bolshakov, Tuboltsev, 2023], the cost of creating a hydrogen hub with a capacity of 1 million tonnes per year is $3-4 billion. However, the long-term payback is ensured by:

– reducing carbon payments (in the EU, the price per tonne of CO_2 will exceed €100 in 2024);
– premium pricing for green steel (+15-20% of market value);
– access to green finance (the volume of global ESG funds exceeded $5 trillion in 2023) [Bolshakov, Tuboltsev, 2023].

Implementing hydrogen solutions, such as replacing natural gas with H_2 in direct reduction of iron (DRI) processes, requires overcoming technological barriers. A study [Bolshakov, Tuboltsev, 2023] shows that the transition to hydrogen in blast furnaces reduces productivity by 12-18% due to the need to reconfigure temperature regimes. To minimise losses, companies are implementing hybrid models combining hydrogen with biomethane (case of SSAB, Sweden). In parallel, the role of CCUS technologies is growing: projects such as

Nord Stream - Hydrogen in the Russian Federation aim to capture up to 50 million tonnes of CO_2 per year by 2030 [Knelts, 2022].

Industry pioneers such as *Thyssenkrupp*, are already implementing projects to replace 40% of coke in blast furnace production with hydrogen and have invested €2 billion in creating hydrogen clusters. In Russia, Severstal has launched a pilot DRI plant with a capacity of 1.5 million tonnes per year and predicts a 65% reduction in its carbon footprint by 2026. However, as [Knelz, 2022] points out, only 8% of Russian metallurgical companies have approved decarbonisation plans, reflecting institutional delays.

The transition to hydrogen business models requires companies to balance operational resilience with innovative aggression. Strategies must be integrated:

– phased replacement of assets, taking into account technological maturity;
– participation in public-private partnerships to reduce investment risks;
– development of cross-sector alliances (energy + logistics + IT).

As the authors [Bolshakov, Tuboltsev, 2023] summarise, ‘the success of decarbonisation will be determined not so much by technology as by the ability of companies to turn institutional constraints into competitive advantages’.

5. Development of partnerships in the coal mining and metallurgical industries

The decarbonisation of industry, driven by the climate agenda, is reconfiguring the principles of forming strategic alliances in the coal mining and metallurgical sectors. As noted in [Adams et al., 2024], 78% of industrial companies have included hydrogen initiatives in long-term strategies, highlighting the need to move from competition to collaboration. A key trend is the creation of hybrid consortia that bring together traditional players (*Anglo American, Glencore*) and technology start-ups (*H2Pro, Sunfire*), which allows for the diversification of R&D risks and accelerates the commercialisation of solutions [Friedman et al., 2019].

The declining share of coal in the global energy mix (from 27% in 2022 to 15% in 2040, according to the IEA) is forcing coal producers to rethink their operating models. Adaptation strategies include:

– production of blue hydrogen using CCUS technologies (the Kuzbass Clean Coal Project with the potential to capture 10 million tonnes of CO_2 per year);
– integration into hydrogen clusters (BHP’s partnership with Fortescue Future Industries to export H_2 to Asia);
– implementation of circular models (reclamation of mines for renewable energy installations).

The metallurgical sector is demonstrating an unprecedented pace of implementation of hydrogen technologies. *ArcelorMittal* pilot project in Gentach (Belgium) to replace 30% of coke with H_2 has reduced emissions by 1.5 million tonnes of CO_2 per year for an investment of €1.2 billion. However, the energy intensity of the processes remains a key barrier: the production of 1 tonne of green steel requires 4.5 MWh of electricity, compared to 0.8 MWh for the traditional method [Polevanov, 2020].

The formation of a global hydrogen infrastructure is accompanied by regional asymmetry:

- The EU emphasises standardisation (CertifHy 2.0) and the creation of ‘hydrogen valleys’ (HyDeal Ambition, 67 GW by 2030);
- Asia focuses on import corridors (Japan - Australia, $3.5bn investment);
- The Russian Federation develops export-oriented clusters (Sakhalin-2, potential 100 thousand tonnes of H_2 per year).

The International Energy Agency predicts that by 2050, 60% of hydrogen projects will be implemented through transnational alliances, which will require harmonisation of regulatory regimes.

The transition to hydrogen as a primary energy source requires significant changes in the technology and infrastructure of coal mining and metallurgical companies. Achievements to date, such as a 95% reduction in CO_2 emissions through the use of hydrogen in metallurgy, represent an important step forward. At the same time, the studies carried out indicate the need for further developments for the full implementation of hydrogen technologies. This is due to the need to improve the efficiency of existing processes and to adapt them to new conditions. In [Polevanov, 2020, p. 4] it is noted that ‘a leap in energy efficiency is accompanied by increased requirements for energy production in general and its electrical form in particular’.

The main areas of research in this field are the development of more efficient technologies for the production and storage of hydrogen and the creation of an infrastructure for its transport. It is also important to investigate how hydrogen technologies can be integrated into existing production chains of metallurgical and coal mining companies in order to minimise transition costs and ensure the sustainability of new processes. [Vorobyov, Vorotnikov, 2022] emphasise that ‘European leadership in hydrogen and fuel cells will play a key role in creating high-quality jobs, from strategic research and development to manufacturing and crafts’.

The successful implementation of hydrogen technologies is expected to lead to a significant reduction in the carbon footprint of the coal mining and metallurgy industry, contributing to the fulfilment of international environmental commitments. Research shows that carbon-free energy in commercial transport can be achieved by 2050, which will lead to cost reductions [Vorobyov, Vorotnikov, 2022, p. 4]. In addition, this will create new opportunities for cooperation between companies in the form of strategic alliances, which in turn will accelerate the development of innovation and increase the competitiveness of industries in the global market.

Conclusion

This study provides a comprehensive assessment of the changes occurring in the strategic alliances of coal mining and metallurgical companies in the context of the transition to hydrogen as a key energy resource. The current structure of the alliances, their dynamics and the impact of hydrogen energy on the interaction of the participants have been analysed. The prospects and challenges associated with the companies' adaptation to the new energy reality were considered.

Based on the analysis, it can be concluded that the transition to hydrogen has a significant impact on strategic cooperation in the mining and metallurgy industry. Companies are forced to review their strategies, implement innovative technologies and adapt to new conditions, which requires significant investments and coordination of efforts. These changes contribute to the creation of more sustainable and environmentally oriented interaction models, which are important for the future development of the industries.

Future research perspectives include the investigation of specific technologies and business models that facilitate successful adaptation to the hydrogen economy. It is also important to continue to analyse the role of international cooperation and government support in developing strategic alliances. These aspects can have a significant impact on the effectiveness of the transition to hydrogen and the strengthening of the competitive position of companies.

The study of changes in the strategic alliances of coal mining and metallurgical companies during the transition to hydrogen highlights the importance of strategic planning and an innovative approach in the context of global change. The findings may be useful for practitioners and researchers, as well as for the formulation of sustainable development policies aimed at reducing the carbon footprint and increasing the efficiency of industries.

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