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Innovation and Climate Change Mitigation Technology in the Asian and African Mining Sector: Empirical Analysis Using the LMDI Method

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Abstract: Technology plays an essential role as climate change becomes a growing concern worldwide. This article aims to examine the influence that innovation exerts on climate change mitigation technology (CCMT) in the African and Asian mining sectors. Data were collected from the World Intellectual Property Organization mining database. We conducted a decomposition analysis of patent families between 2011 and 2020 based on the Logarithmic Mean Divisia Index (LMDI) method. Findings revealed that African countries do not devote their innovation efforts to adaptive technologies, resulting in a mismatch between mining and access to technologies as the scope of R&D narrows. In Asia, the drive for innovation and technological efficiency is a tool to prevent economic damage and legitimize technological benefits as solutions for climate change mitigation technology. This outcome calls on political, national, and international governments to bridge the innovation gap to trigger a real shift from innovation to these technologies.

Keywords: mining; innovation; climate change mitigation technology; Africa; Asia

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1. Introduction

Mining industries have always been indispensable to the development of societies [1–6]. Mining activities are diversified and essential in producing materials, autonomy, buildings, public works, renewable energies, and batteries. Products manufactured by mining industries include gravel, iron, and aluminum [7–11]. Several researchers argue that mineral products are crucial to the supply strategy of any economy [12].

Whether through industrial exploitation or artisanal and small-scale mining, mineral production represents a significant part of the global economy. However, the production and sale of minerals impact the climate, an issue that pushes several countries to focus on innovation in the mining sector. For example, producing countries and boards have stepped up their efforts to prevent climate change by controlling the production of their minerals. To do it, the fight against climate change requires effective mitigation methods related to environmental stability [13]. The mining industry has a role in advancing technology [14–16] to reduce global warming to 2 °C and reduce carbon dioxide emissions. Some countries have implemented specific strategies to boost innovation and climate change mitigation technology.

On the one hand, public funding of research and development (R&D) through tax incentives or financing supports innovation in new technologies. In contrast, proliferation support policies to ensure deployment generally fall into the price- and quantity-based approaches [17–24]. Dissemination support policies encourage economic agents to adopt innovations through learning effects [24–27]. However, it seems necessary to study the effectiveness of the strategies implemented by the mining sector to better understand the mechanisms that deal with climate stability [28–33]. Case studies [34–39] or surveys [40–43] with or without statistical results have been developed to show the relationship between

Innovation and climate change mitigation and technologies. In the search for climate change mitigation technology, R&D also plays a crucial role in influencing the direction of innovation [16]. The authors [44–46] are the first to choose this direction. Despite some variability, the results suggest that the relationship between innovation and research and development (R&D) positively impacts technology by reducing technology costs [44,47–49], especially in the early stages of technological development [50].

The new strategies make it possible to do more with climate stability. Whether it is renewable energy or controlling logging, there could be an environmental effect. The challenge is bringing innovation into the process of climate change while promoting faster diffusion of innovation in the mining sector. WIPO global challenges program works with multiple stakeholders to address these challenges. In this context, WIPO member countries adopted an international protocol that provides the legal basis for the regional initiative against the exploitation of natural resources for economic development and global climate protection [51–53].

While progress has been made in the implementation and harmonization of legal instruments in Asian countries, the pace of implementation in African countries is different. Some have indeed made significant progress. However, others have not yet started the process. Several member states in African countries are still in the process of adopting national legislation that includes establishing a chain of custody systems and a framework for assessing mine sites. It is known that innovation is an essential objective of sustainable development and can help reduce the need for primary resources through change and other techniques adopted [3,54–57]. Thus, favoring the mining sector is essential to the first pillar of the global economy. The mining industry is a fundamental part of any mineral commodities strategy, supported by many countries, such as the G-20 countries and the European Commission, as part of their raw materials initiative. However, the analyses of refs [58–61] predict that the mining industry will not run out of ore deposits shortly. Still, the exploration process for these deposits could encounter problems regarding sustainable development goals and climate stability. The mining and metallurgical industry has been forced to bend to the need to change and improve to remain profitable and efficient for climate change. However, there are many expectations and challenges from various stakeholders, including the public sector and geographical and geological factors.

Indeed, production patterns in the natural resource industries influence the innovation landscape in the mining industry [62–65]. Researcher [66] finds a lack of studies in the field, leading to a deficit in the mining industry. According to the author [63], it is vital to understand the barriers and motivations for innovation in the mining industry, to predict stability and sustainability in the mining industry, and to promote best practices across mining operations. Authors [63,66,67] argue that companies need to understand their challenges in operating with their partners and how profitable they are when focusing on innovation or new technology. It is important to note that some climate change mitigation technologies have more significant incentives than others. They can help companies maintain a better perception of the public and community and only make their business more profitable [68].

The mining industry and the CCMT trace countries' innovation trends in the context of slowing down current challenges [69–71]. Intended to provide as complete a picture as possible of innovation, it includes measures of the environment, infrastructure, and knowledge creation in each economy. The high level of CCMT in mining in developed countries, especially Asian countries, and technological innovation lag in developing countries, particularly African countries, have called our scientific curiosity to study the factors to measure innovation in the mining industry and climate change. Our research found that previous studies analyzing patents in the mining sector have aligned with knowing the number of patent applications filed with the patent office. No previous research has examined the climate change mitigation technology (CCMT) in mining between Africa and Asia. Our paper, however, is the first to take this path that no one has yet taken.

Based on the decomposition method, we intend to fill this knowledge gap. Thus, our work focuses on specific categories of CCMT between 2011 and 2020. The continuation of our work, for example, our results, apply to decision-makers as they provide insight into the most effective policies and encourage the invention of specific CCMT categories in the mining sector of both continents. We focus on data collected from the World Intellectual Property Organization (WIPO) mining database to make a decomposing analysis of patents [72,73] to calculate economies of patent and privilege families, as indicated in our research framework. The aim is to show that the impact of the evolution of patent family demand in African and Asian countries between 2011 and 2020 can be given to various indicators. These indicators are measured using a proprietary breakdown analysis method to understand the data better.

This article aims to examine the influence that innovation exerts on climate change mitigation technology in the African and Asian mining sectors. The key questions are how much is climate mitigation technology a priority for climate change in Africa and Asia?

How can innovation drivers play a key role in climate change mitigation in Africa and Asia? We have divided the work into several sections to answer the research question. Thus, apart from Section 1, which includes the introduction, Section 2 consists of the literature review. It focuses on critical innovation features in the mining and metallurgy industries. The section also analyzes climate change mitigation. Section 3 details the methodology used for the analysis of the patent database. Section 4 discusses the results of the research and discussion. Section 5 includes the conclusion and policy recommendations.

2. Literature Review

In the course of its evolution, the mining sector, minerals, and metals have seen a metamorphosis within these activities. We were especially concerned about the number of patent applications per country or group. Thus, in this second section of our study, we will analyze in detail the vital information to understand the main indicators of the Innovation of CMT in the mining industries. In addition, this literature review is important and includes case studies, comparative analyses between several countries, and more theoretical work.

While metallurgical and mining companies have traditionally been less interested in innovation, service or manufacturing companies are making innovation an essential tool for their development. If metals and mining industries want to adapt to an increasingly advantageous and remunerative environment, they must solve their problems [65]. For example, the scarcity of mineral springs means that mineral resources are increasingly difficult to find and mineral reserves more difficult to discover [59,63,74]. In general, the manufacturing industry of a basic object has little or no impact on the price of the final object. As a result, producers strive to make their products more profitable by prioritizing innovation rather than trying to make their products different from others in the market. To do this, they try to innovate in their sector of activity by finding better natural resources to exploit, increasing production without increasing costs, and reducing fixed manufacturing costs [74].

Innovation improves profitability prospects and technology deployment [75]. In contrast, refs [76–81] achieve the positive effects of these policies on renewable energy and technologies. Therefore, the results depend partly on the econometric model and the definition of the variables observed with greater precision in describing the strategy. Similarly, the lack of precision in technical characterization leads to trivial results. Refs. [82,83] conclude that technology has no impact on innovation when all technologies are considered. The reason is that "pricing" policies favor incremental innovation through learning by doing. In contrast, patents favor disruptive innovations because of the costs incurred by filing a patent and the possibility of using other means of protection for innovation [83].

Kleinman 2011 observes that countries with the most effective strategies all use guaranteed prices, while countries that use quota systems perform worse. Stern (2007) and others [20,78,84,85] concluded that the price mechanism has the potential to achieve a higher penetration rate. Renewable energy costs are lower than allowances and auction mechanisms. This is all the more relevant as they offer greater stability than quantitative policies [75,86].

However, according to refs. [87–89], natural resources are not necessary for most mining and metal business models in developed countries. Their countries have revolutionized their processing stages by using new technologies throughout the processing and mining of minerals. Developing countries, on the other hand, find it more difficult to develop their mining and metallurgical industries [90,91]. They are fortunate to have more natural resources than other countries but struggle to develop their sector due to a lack of technology and innovations and the lack of cohesion among stakeholders, and ineffective policies [92–94]. There are many indicators in the language of innovation to determine the growth of the mining industry: sales strategies, brands, intellectual property companies, and employee training. These innovation activities are fundamental for the development of brand value, the development of software, and the rental or purchase of goods, equipment, and facilities [95].

There is evidence that innovation in the process of combining products and services improves the productivity and sustainability of manufacturing companies. According to Lanciano [96], innovation is a significant challenge for competitiveness between enterprises and countries. It contributes to the collective reflection on the transformation of enterprises and productive systems.

Other surveys measure innovation in companies with indicators related to research and development (R&D) activities: research budgets, allocation of research and development (R&D) staff, and the number of patent filings [97]. The Time survey (Technology and Innovation in Craft Enterprises), carried out in 1997 and updated in 2002, shows the potential of innovation in the mining industry. Research conducted within the Network of Technological Universities initiated by the Ecole Supérieure des Métiers (ISM, 2005) shows that craftsmen acquire cognitive, managerial, social, and other knowledge through innovation [98–101]

Researchers [102,103] have studied the relationship between patents and R&D activity several times, and their results are similar to those of [104–108]. For these researchers, there is a reasonably strong relationship between innovation and manufacturing industries, between R&D and industries. This means that innovation can be a good indicator of industrial production in Africa and worldwide. This relationship is not only due to differences in size, as stated by [109], which represents patents and R&D. The same relationship, although statistically significant, is much weaker on the dimension of intra-firm time series. However, it is clear that when a company changes its strategy by privilege, R&D, and innovation, its number of patents also evolves in parallel.

Staying in the same direction, Seclen-Luna [110] surveyed 791 Peruvian manufacturing companies in 2021 and found that innovation positively impacted the company by privileged productivity and environmental performance. Similarly, Yurdakul and Kazan [111] surveyed 219 Turkish manufacturing companies in 2020 and found that sustainable innovation positively impacts pollution, resource use, and price reduction.

(OECD, 2016) believes that growth and development are closely linked to business, privileged activities, and technological innovation for climate stability. Countries that have managed to integrate into the economy have understood the importance of privilege and innovation in the industrial field for the well-being of all. According to the World Intellectual Property Organization (WIPO), the number of patent applications worldwide was 2 million before 2011, eventually reaching 3.2 million in 2019 (WIPO, Patents for Inventions, 2021).

Far more than double the number of patent filings, these numbers are impressive and reach a level called a "patent explosion!" but what I call "the innovative awakening" sparked by the awareness of a group of countries regarding the mining sector to fight climate change. Unlike other countries, African countries have missed the path to a knowledge-based economy by holding only 0.5% of the world's total patent applications.

Asian countries have successfully entered the knowledge economy, holding 80% of total applications (WIPO, patents, 2021). According to data from the World Intellectual Property Organization, the number of Asian patent applications is higher than the total number of patents in Africa and worldwide. According to the World Intellectual Property Organization, in the 1960s, Asia had almost the same level of technological development as African countries. From 2011–2020, it became the world's first patent holder for favoring innovation in the industrial field.

Fernandez [112] analyzed work on Chilean mining companies from 1970 to 2018. His research shows that the mining industry was failing in terms of innovation. Nevertheless, the number of patent filings has increased. The size and importance of a company are essential in determining whether a company is striving to innovate. Because of commercial and regulatory barriers, small businesses may be forced to rally on innovations, not technology, to come together with other companies.

Despite the advantages that mining companies can have, especially in increased patents, Ali and Ur Rehman [113], in a study in Pakistan, claim that mining companies are still not ready to innovate. The main reasons were the fear of losing one's job and the lack of training in the higher education system. Johnston and Nicolli [78,114] observe that commodity prices encourage technological innovation, while Rübbelke [85] found no effect on innovation in their study. According to the authors, this difference comes from the different maturity levels between the two factors. The closer the cost of the product is to the market price, the less continuous innovation effort is required [32,79,115,116]. Samer Fawzy was working on strategies for the mitigation of climate change. Most of the technologies are well-established and have an acceptable and controlled level of environmental protection addressed in the Kyoto Protocol and the Paris Agreement [16].

Many economic activities emit greenhouse gases: in particular, the industry sector accounts for around 19% and the transport sector around 13%. The correlation between the actors that determine the choice of action and their success is, at best, considered implicitly. Innovation, mining, and privilege indicate how various mitigation opportunities could contribute to reducing the temperature over time. In discussions about national and global climate policy, the European Parliamentary Research Service (EPRS) [117] adds that many technologies can remove CO_2 from the atmosphere. Compared with the usual greenhouse gas reduction technologies, the necessary mining technological innovation is an important parameter to consider. In this sense, most technology factors in climate mitigation use renewable energies for climate protection. Charlie Wilson analyzes various indicators of activity across the innovation system to assess climate change and finds that utilization technologies contribute to large potential emission reductions and provide social returns on investment [118]. Richard Newell proposes examining innovative trends and prospects for mitigating climate change to identify the actions needed to transform energy systems to stabilize greenhouse gases. It describes the main technical issues related to the development, diffusion, and adoption of climate change mitigation technologies. He examines the role of environmental and innovation policy measures in encouraging innovation and describes the conditions that trigger these advances [119].

Many countries are increasingly developing climate change mitigation plans and policies. These plans and policies are often focused on innovation. This approach to protecting the climate leads to a change in priority.

3. Materials and Methods

Understanding the nature of climate change mitigation technology is essential to determining the right way to promote invention and research in a given country. We chose Logarithmic Mean Divisia Index (LMDI) as the methodology for our work. LMDI is suitable for all situations; for example, the type and nature of the variables depend on the scope and study. Therefore, its fields of application are very diverse, such as industry [120,121], the residential sector [122], construction [123,124], agriculture [125], and transport [126–128].

Indeed, Patent trends have been used in decomposition methods to show which factors drive innovation, whether it is large-scale R&D or specific inventions [76,95,129–132].

We use patents to measure innovation in the mining industry and climate change [69]. Of course, patents are not the only way to demonstrate the climate impact of innovation and technologies, but the advantage of these patents is that patent data are relatively easy to access and constitutes the output of the innovation process, unlike public spending on research and development (R&D), for example. In addition, international classifications may target specific technical areas. Many studies have triggered innovation adoption in the mining industry and climate change [78,79,114,133]. These studies show that innovation and CCMT positively impact low-quality patent filings. The number of patent applications does not affect growth or development. The reasons would be the misallocation of natural resources and the lack of expertise of countries that provide too much research effort in the mining sector. Figure 1 presents the research framework of our study. That is to say it traces the approach of our reasoning based on the discussion above. We argue that countries' commitment to innovation impacts climate change mitigation. Particular attention should be engaged to understand the determinants of innovation in the mining sector while considering the number of patents filed in the mining sector for the climate change mitigation

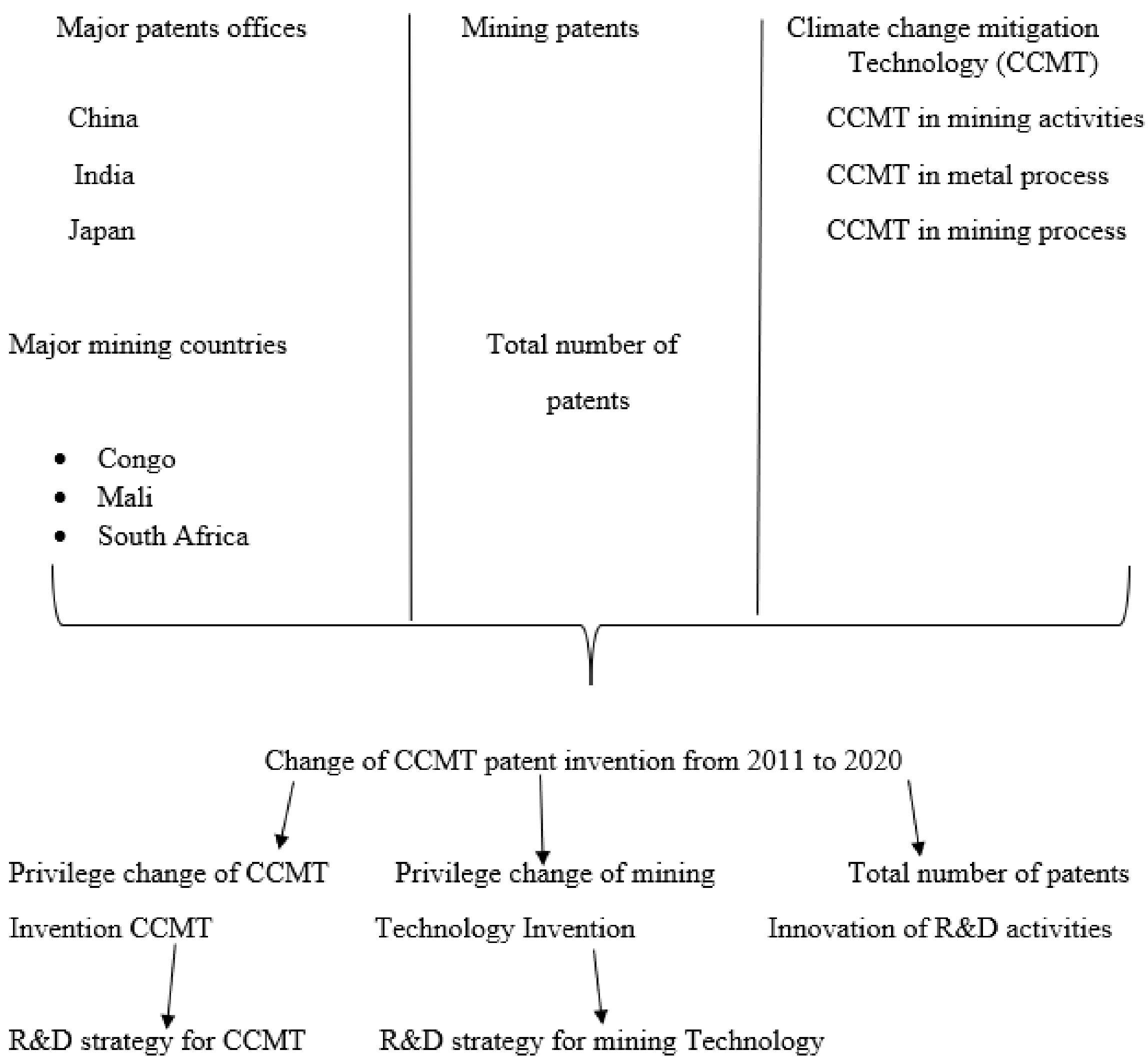


Figure 1. Research framework.

As mentioned above, we use a decomposition analysis based on the logarithmic mean of the Divisia Index (LMDI) to analyze the patent family to understand the drivers of innovation in the mining industry to the challenge of climate change in Asia and Africa. Additionally, it shows effective methods to promote sustainable technological development.

Regarding climate change, several aspects come into play in technology, innovation, prices, and the demand for minerals. Since late 1970, researchers have used a decomposition analysis technique to explain variations associated with climate change. This analysis is based on the equivalence presented below:

$$C = \forall \times \frac{C}{\forall} = \sum_i \forall \times \frac{\pi_i}{\forall} \times \frac{\epsilon_i}{\pi_i} = \sum_i \forall \times S_i \times I_i \quad (1)$$

C = Climate change
$\forall$= Total activity of mines
π_i = activity of the subsector
ϵ_i = Emissions from the subsector
S_i = Structural effect
I_i = effect of intensity

In general, the overall effect of activity ($\forall$) is a measure of countries' economic growth to develop policies that encourage research and development (R&D). In addition, estimates of activities vary from one sector to another. For example, activity in the residential sector is measured by usable area, while in the industrial or mining sector, activity is generally measured by the number of patents filed or by gross production. The structural effect (S_i) counts innovation in the economy's composition, such as the shift from a goods-producing industry to a service-producing sector. The intensity effect (I_i) measures the change in emissions intensity at the subsector level. This variable accounts for the impacts of changes in fuel composition and climate change improvements. With the LMDI method, the decomposition of climate change mitigation factors can be described by the following equations:

$$C_I - C_0 = \sum_i \frac{\epsilon_{iI} - \epsilon_{i0}}{\ln \frac{\epsilon_{iI}}{\epsilon_{i0}}} \times In \forall_I - In \forall_0 \; activity\ effect\ ,\ mines \quad (2)$$

$$+\sum_i \frac{\epsilon_{iI} - \epsilon_{i0}}{\ln \frac{\epsilon_{iI}}{\epsilon_{i0}}} \times \left(In \frac{\pi_{iI}}{\forall}_{iI} - In \frac{\pi_{i0}}{\forall}_{i0} \right) structural\ effect,\ mineral \quad (3)$$

$$+\sum_i \frac{\epsilon_{iI} - \epsilon_{i0}}{\ln \frac{\epsilon_{iI}}{\epsilon_{i0}}} \times \left(In \frac{\epsilon_{i0}}{\pi}_{iI} - In \frac{\epsilon_{iI}}{\pi}_{i0} \right) effect\ of\ climat\ change, metal \quad (4)$$

Several authors expressed different opinions on the LMDI method of patent decomposition. Thus, the work of Sánchez and Yamashita [57,65] and Fernandez [110,112,134] sheds light on how innovative players in the mining and mineral processing industries privilege the challenges of climate change. The authors' analyses also make practical recommendations to encourage technological development for sustainable operations. In addition, other researchers have developed more efficient methods to better exploit the technical benefits of patent data analysis [135,136].

For author Khramova [135], the Revealed Technological Advantage (RTA) and patent analysis are required methods for measuring the technological advantage of one country over another. It can only be seen that the factors that control and modify the number of patents are inconvenient to study in the variation of research development. Therefore, determining how the research development orientation of each CCMT has changed over time would be necessary to develop strategies to stimulate R&D [65].

Fujii [72] relies on the LMDI segmentation method [131] to perform a three-way decomposition of the hierarchy of patent family categories related to filed patent families. The log–normal relationship between the two different time points and their ratios was then calculated to understand the reason that determines the evolution of the number of patent families for each factor. This patented method of decomposition analysis has been applied in artificial intelligence [73], also in water treatment [72], and green technologies in the chemical industry [137].

In particular, refs [123] demonstrate that the decomposition analysis method of technological inventions helps to find the main factors that determine innovation, whether to privilege particular technological inventions or economies of scale in R&D activities. Therefore, the patent decomposition analysis studied by [137] has the advantage of saving the amount of purity in obtaining the privilege of the invention from patent data by controlling the scale effect [26]. To this end, our analysis of decaying CCMT patents will be based on our use of three factors: Privilege, Mining, and Innovation.

The indication "privilege" includes the number of patent families relative to CCMT via the wide variety of patent households inside the mining or metallurgical area. This provision will increase provided that the range of patents related to climate change mitigation technology (CCMT) will develop faster than the wide variety of patent families inside the mining and metallurgical industry.

The indicator "privilege" includes the number of patent families relative to the CCMT divided by the number of patent families in the mining, mineral, or metallurgical sector. This provision increases provided that the number of patents related to CWTC increases faster than the number of patent families in the mining, mineral, or metallurgical industries. This means that inventors focus their research resources on inventions related to CCMT.

By "mining" indicator, as Yamashita [65] was able to define, it is the number of mining, mineral, and metal patent families divided by the total number of patent families to give the share of all mining patents, minerals, and metals. This measure will grow while the wide variety of patent families grows faster than the entire range of patent families. They indicated inventors focus their research assets on the mining, minerals, and metals companies.

Finally, the "innovation" index is defined as the total number of patent families [65]. It is, therefore, an innovation in R&D activity. Generally, active research and development efforts typically contribute to new technologies' invention [1]. Thus, the total number of patent families reflects active search efforts. Innovation increases with the total number of patent families. As the innovation index increases, the number of patent families related to CCMT increases with the number of innovations in total R&D activity. The number of CCMT patent families (CCMT) can be divided using the number of minimum patent families, minerals and metals patent mining, and the total number of patent families, as shown in the equation below.

$$CCMT = \frac{CCMT}{P_a M_a} \times \frac{P_a M_a}{Total} \times Total \tag{5}$$

$$= Privilege \times M_a \times Total$$

$$P_a = (\text{Patent}),\ M_a = (\text{Mining})\ P_i = (\text{Privilege}).$$

The evolution of the CCMT patent family will be considered from a specific period or year called ($CCMT^t$), which will be rated t + 1 ($CCMT^{t+1}$). So, by adding this variation of the CCMT patent family to our fourth equation, it would be rewritten as follows:

$$\frac{CCMT^{t+1}}{CCMT^t} = \frac{P_i^{t+1}}{P_i^t} \times \frac{M_a^{t+1}}{M_a^t} \times \frac{Innovation^{t+1}}{Innovation^t} \tag{6}$$

A natural logarithmic function is obtained after the transformation of Equation (6), resulting in Equation (7) represented in this form:

$$In\left(CCMT^{t+1}\right) - In\left(CCMT^t\right) = In\left(\frac{P_i^{t+1}}{P_i^t}\right) + In\left(\frac{M_a^{t+1}}{M_a^t}\right) + In\left(\frac{Innovation^{t+1}}{Innovation^t}\right) \tag{7}$$

Once the transformation of Equation (7) is obtained, the two forms of Equation (7) are multiplied to form equation $\Pi_t^{t+1} = \frac{CCMT^{t+1} - CCMT^t}{In\left(CCMT^{t+1}\right) - In\left(CCMT^t\right)}$, (8) below.

$$CCMT^{t+1} - CCMT^{t} = \exists CCMT^{t,t+1} = \Pi_t^{t+1}\, In\left(\frac{P_i^{t+1}}{P_i^{t}}\right) + \Pi_t^{t+1}\, In\left(\frac{M_a^{t+1}}{M_a^{t}}\right) + \Pi_t^{t+1}\, In\left(\frac{Innovation^{t+1}}{Innovation^{t}}\right) \quad (8)$$

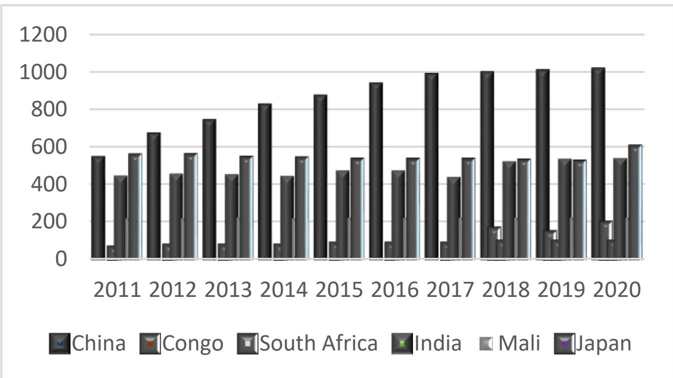
Thus, the evolution of the number of patent families in CCMT (∃CCMT) was broken down according to the evolutions of Privilege (Phase 1), Mining (Phase 2), and Innovation (Phase 3) to estimate the number of patents disclosed by CCMT. This technique of factorization of the logarithmic mean divisor index (LMDI) of Ang [131].

4. Results and Discussion

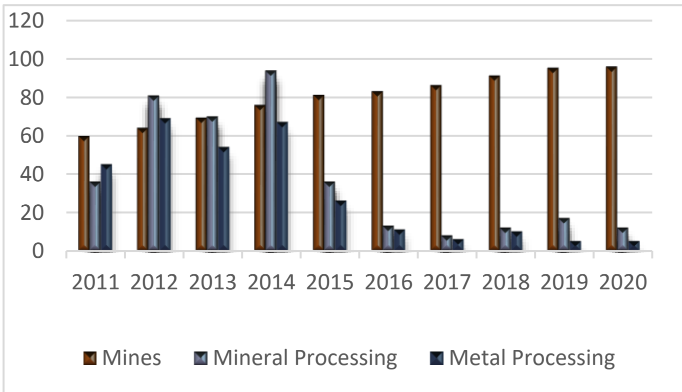
Description of the Six Countries and Patent Family Filings at WIPO

For this paper, it is reasonable to use patent family data from the World Intellectual Property Organization (WIPO) mining database [138] to identify CCMT technologies using the patent classification combination.

To carry out this work, we focused on three types of CCMT: (a) CCMT associated with mining/mining, (b) CCMT associated with mineral processing, and (c) CCMT related to metal processing see Equations (2)–(4). Then, we filter CCMT patent holders focused on the patent descriptions provided by Daly [138], as we can see in the following countries. Concerning the analysis of patent families discussed in this article, Figure 2A,B details the patent data from the World Intellectual Property Organization (WIPO) mining database. Moreover, if we look at the evolution of the number of patent families related to the CCMT filed between 2011 and 2020, we see a steady increase. Figure 2 provides an exciting beginning point for analysis, further discussion, and insight into CCMT trends in the mining, minerals, and metals industry. Figure 2A shows a significant increase in the number of patents in Asian countries (China, India, and Japan). The patent family has been filled, and African countries have maintained steady growth. Figure 2B shows the most considerable evolution of metalworking CCMT patent during the reference period.



(**A**)

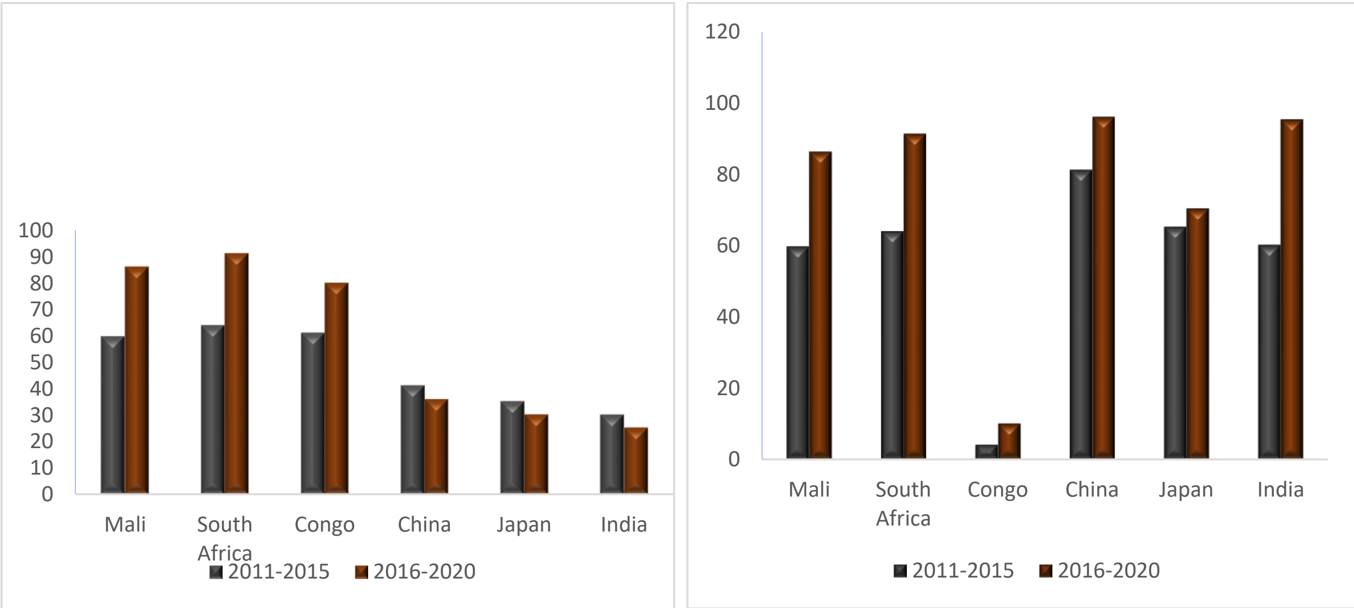


(**B**)

Figure 2. The curve of CCMT associated with patent families filed between 2011 and 2020. (**A**) The curve of CCMT by Country (**B**) the curve of CCMT by technology. Source: World Intellectual Property Organization (WIPO).

For Fernandez 2021 [134], the strength of the patent family grouping and the number of patents filed in several countries for the same invention indicates innovation, profitability, and technological maturity. According to the author [139], the number of patent families filed in a country significantly impacts the complexity of its economy. It has been observed that since 2014, the number of patent families in the mining and metallurgical industries has been steadily increasing in Asian countries due to the evolution of refining technology, exploration, and environmental technologies Fernandez, 2020 [112].

Comparing Figure 3A,B, we find that it can be seen that mineral-producing countries generally play a very important role in economic development. These countries can develop new comparative advantages and move up, as the researchers [140–142] say, because patent growth theory suggests that Africans can influence a country's long-term growth potential. As a result, the proportion of mining patents has risen over the years.



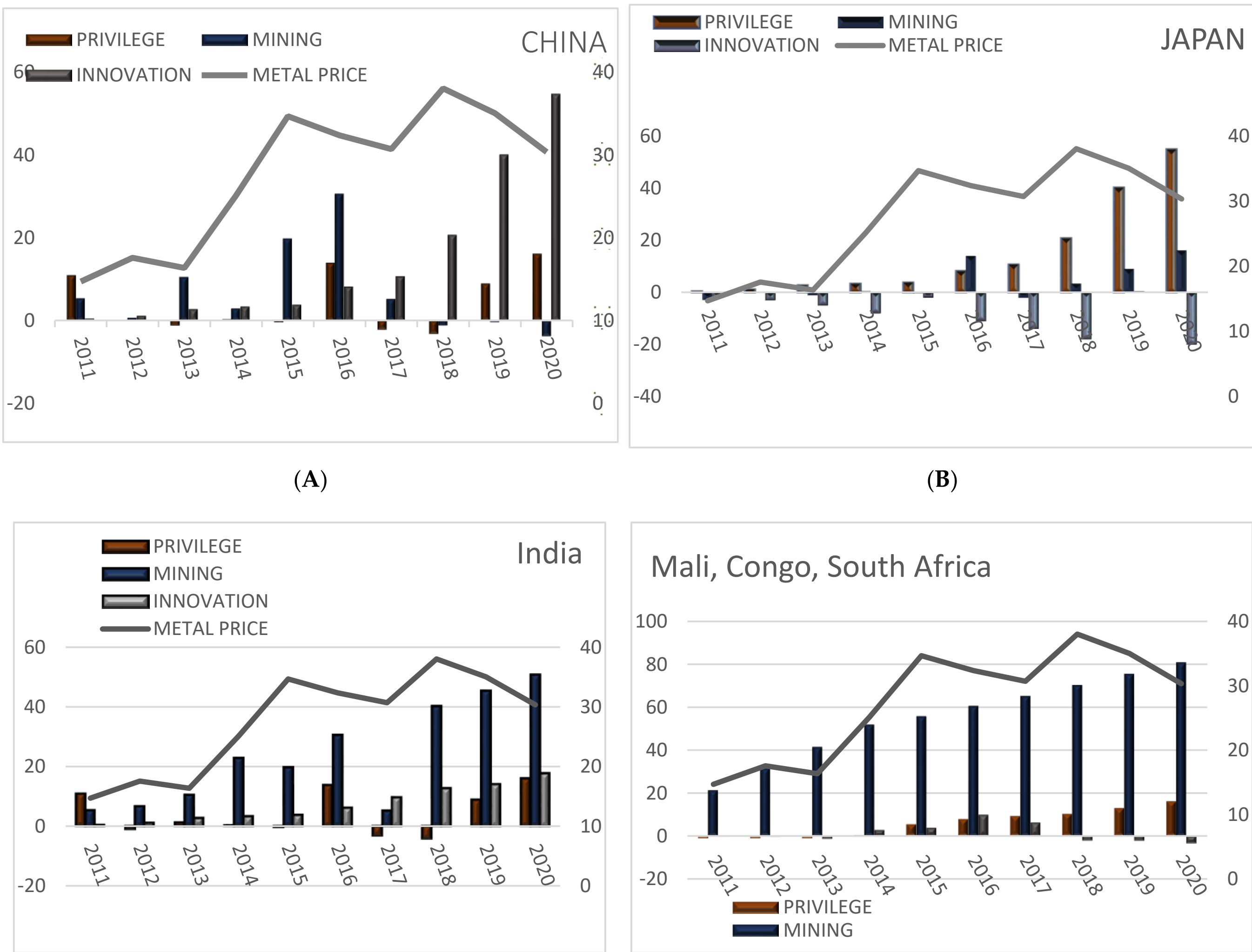
(A) (B)

Figure 3. (**A**). Ratio Mining Total, (**B**). Ratio CCMT Mining. Source: World Intellectual Property Organization (WIPO).

As countries that are relatively more specialized in high-tech products and have a higher index of technological specialization will export relatively more [143], there is no difference in the relationship between CCMT-linked and mining patents. Our results join the authors Daly and Yamashita [65,138], who show that a patent family is a series of related patent applications filed in one or more countries to protect their inventions. They also prove that applicants often file patent applications in multiple countries, raising concerns about some multiple registrations that prompt WIPO to develop indicators related to the first filed patent families, defined as a set of priority claims or privileges. A patent family includes both patent and design patent applications. To avoid a counting overload, the appropriate Offices shall deal with patent families as a single entity unless otherwise specified.

Figure 4A–D show CCMT techniques identified using a combination of patent classification as core indicators from our search. Cooperatives involved in mineral processing and CCMT associated with metal processing. Then, we described this study's target countries and regions, starting with those with the highest patent filings where mining is active. Figures show the results of the patent data collected for the decomposition analysis of the CCMT in the mining and metals industry between 2011–2020. Indeed, Figures 4–8 are fundamental figures to our research. Indeed, according to IMF 2020 data on metal prices, Figures 4–8 show the decomposition analysis results in regions where mining is practiced as a primary and non-primary economic activity.

For that, Figure 4A shows the results of the patent office's decomposition analysis of the Asian countries, mainly China. The result indicates that the CCMT patent family increases with the renewal of innovation R&D activities. Many reasons could justify this increase. Among these reasons, two main ones have been retained. First, the simplification of the law provided for companies concerning patent applications [144,145]. Secondly, the improvement of technology transfer, the National Plan for Scientific and Technological Development in the medium and long term, and the contribution of university R&D activities [146]. However, in Figure 4B, the opposite is observed in Japan. Thus, the privilege and mining factors increased climate change mitigation technology (CCMT) patents in the country, although the innovation indicator negatively affected the level of patents in 2011 and 2020. This analysis suggests that the focus of research has shifted to the rise of CCMT technology as the scope of Japanese R&D activities has narrowed. India's Figures 4C,D share a common trend of increasing mining and a sharp expansion in privilege CCMT.



(**A**) (**B**) (**C**) (**D**)

Figure 4. CCMT techniques identified using a combination of patent classification by countries. (**A**) CCMT techniques combination in China (**B**) CCMT techniques combination in Japan. (**C**) CCMT techniques combination in India (**D**) CCMT techniques combination in Africa. Source: World Intellectual Property Organization (WIPO).

Figure 5 shows roughly the results of the analysis of the decomposition of patents by the number of patents and the trends in metal prices, according to the International Monetary Fund, 2020, in regions where mining is a leading economic activity.

In addition, Figures 4–8 suggest that adaptation has been marked by an awareness of climate change [147,148]. This increases the development of the CCMT and leads to an increase in the demand for CCMT. Because several countries have agreed to sign a climate agreement to reduce greenhouse gas emissions has two degrees. This observed growth testifies to the importance all these countries attach to the proper functioning of the climate and economy. Therefore, companies can derive many future benefits from acquiring CCMT patents, including royalties and the assignment of patent rights. In addition, it was observed that the R&D strategy varied from country to country. As a result, the innovation factor has also changed depending on the country.

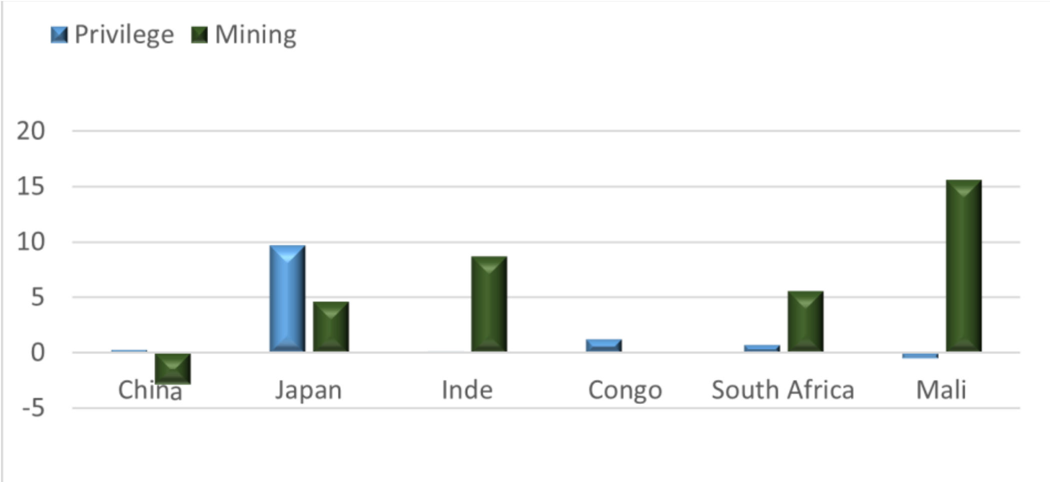


Figure 5. Decomposition analysis of the CCMT in the mining and metals industry between 2011–2020. Source: World Intellectual Property Organization (WIPO).

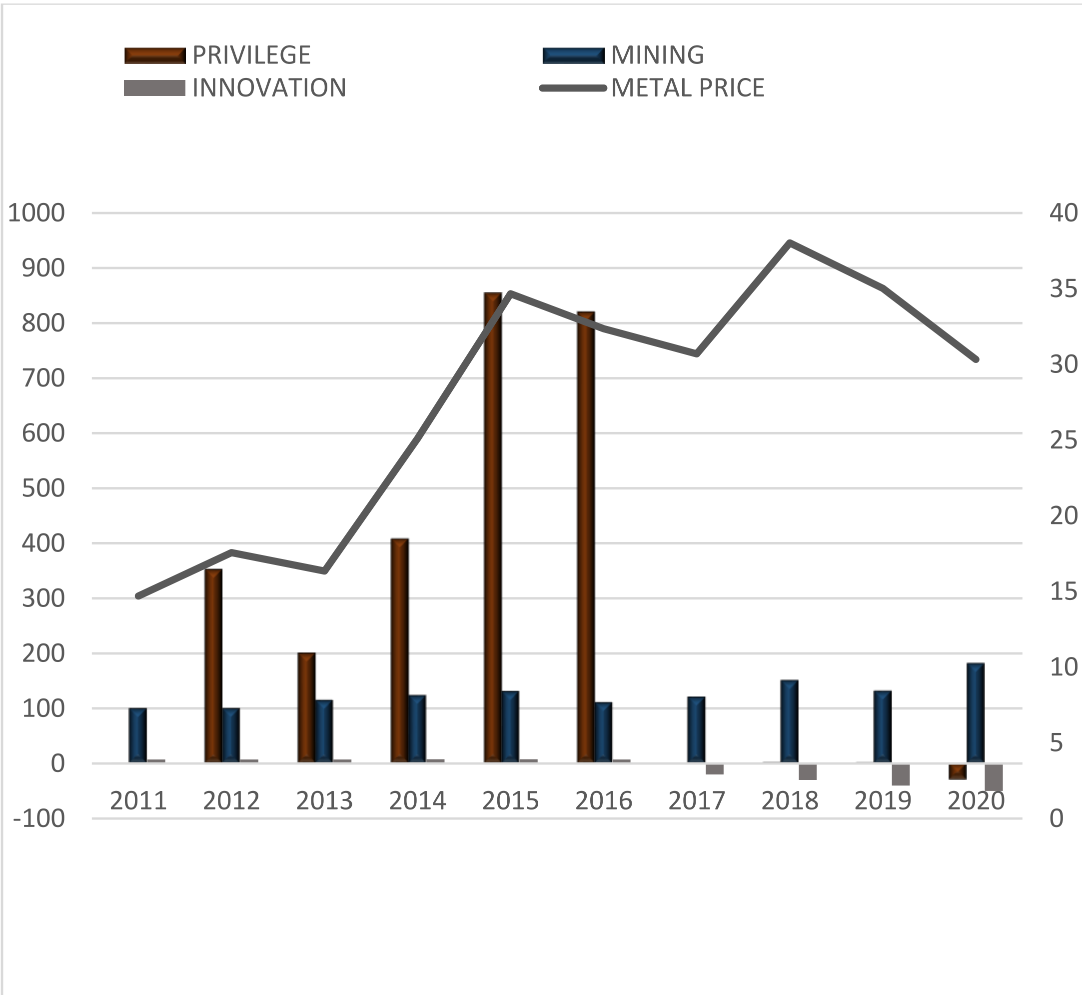


Figure 6. The results of the analysis of the decomposition of patents by the number of patents and the trends in metal prices in the Congo. Source: World Intellectual Property Organization (WIPO).

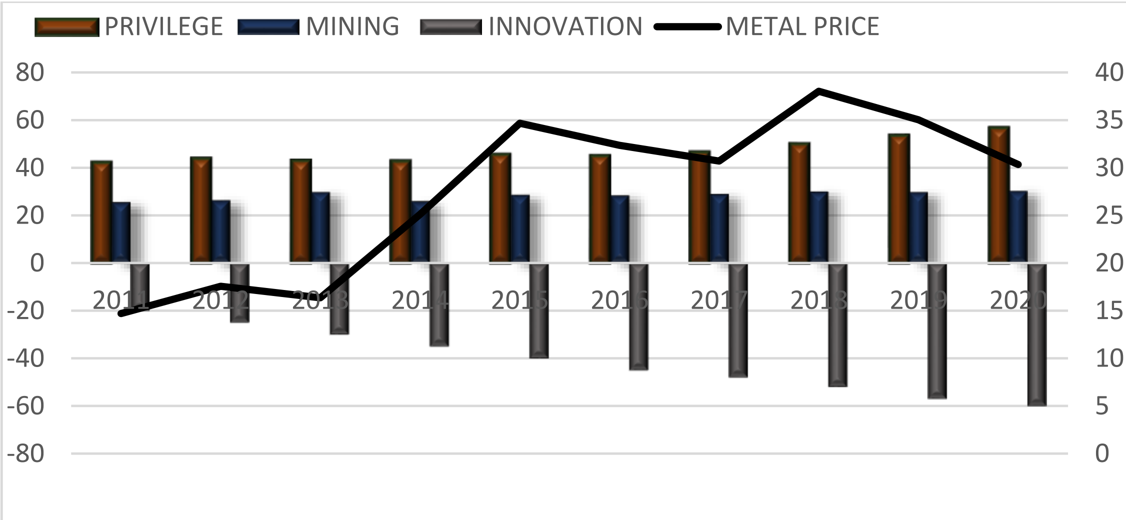


Figure 7. Analysis of the decomposition of patents by the number of patents and the trends in metal prices in Mali. Source: World Intellectual Property Organization (WIPO).

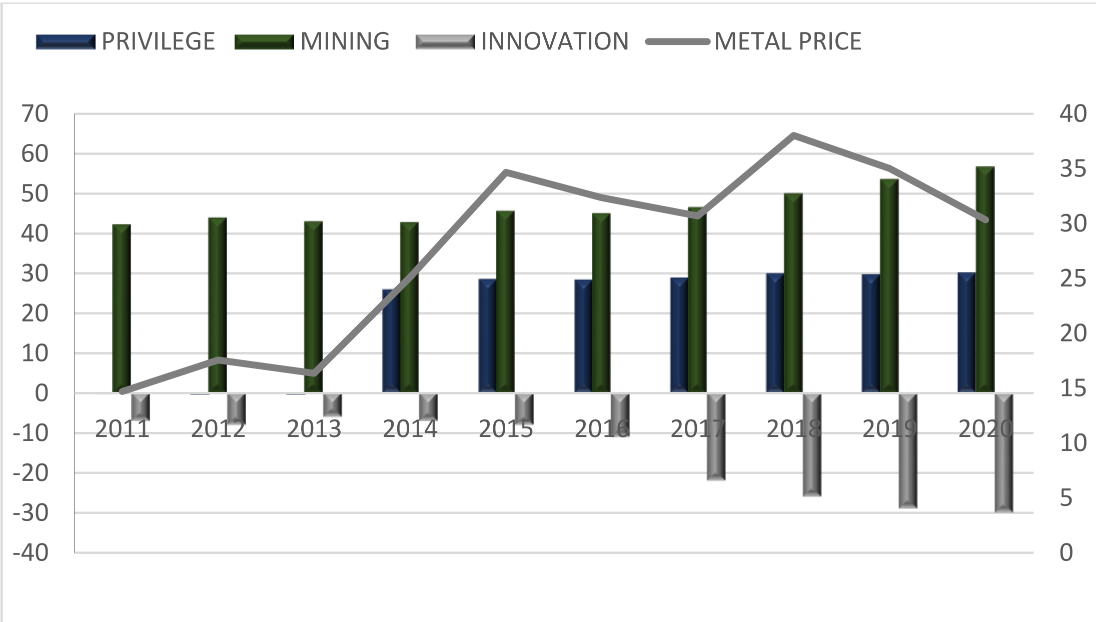


Figure 8. Analysis of the decomposition of patents by the number of patents and the trends in metal prices in South Africa. Source: World Intellectual Property Organization (WIPO).

Since 2011, the mining indicator has kept its growth, especially for countries such as Congo and Mali. One of the reasons is indeed the rise in world metal prices. According to the International Monetary Fund [149], the rise in metal prices has been particularly pronounced for a natural resource caused by China's strong demand and consumption of raw materials. China's global awakening has increased the demand for minerals and encouraged the mining industry to develop technologically. Figure 5 shows a more detailed analysis by explaining how rising metal prices predicted an increase in the mining factor and is heavily dependent on mining in South Africa. Figure 5 shows the decomposition factors studied between 2011–2020. The results show different trends between countries on the impact of the privilege, mining and innovation factors. Indeed, the evolution of patents related to CCMT in countries such as India, Congo, and Mali is mainly associated with the mining factor. In China, on the other hand, this development is caused by an increase in the total number of patents granted, as we can see with the Innovation indicator. However, total R&D spending in Japan and Africa has fallen significantly.

Thus, it results in two cases. In the first case, it results in a negative ∃CCMT, while in the second case, ∃CCMT remains positive. Indeed, the fall in their investments in R&D had been replaced by patents linked to the CCMT. This proves that the Privilege factor is positive. There was also an overall decline in patents in Mali with a negative Privilege factor. This decline suggests a lack of commitment to innovation associated with CCMT. The number of patents granted by this society decreased from one year to the next. According to Francis (2015), foreign inventors often provide innovation in the mining industry. This shows that foreign companies strongly influence Mali mining patents and that the decline in the privilege of CCMT is also strongly influenced by patent applications filed by foreign companies. This result refers us to the conclusion obtained by Yamashita and Watson [65,150].

Another approach, analyzed in Figure 6, is to show the analysis of the decomposition of patents by the number of patents and the trends in metal prices in the Congo between variables. These results indicate that privilege is the most important factor than innovation. Since it defines most strategies and solutions at least cost. Then, Mining presented an important share, linked to most of the strategies adopted for metal prices.

Figure 7 Analysis of the decomposition of patents by the number of patents and the trends in metal prices in Mali

It can be seen that Mali's innovation is not a priority for the country. The focus is more on mining and privilege.

Finally, Figure 8. Analysis of the decomposition of patents by the number of patents and the trends in metal prices in South Africa. The paper shows that South Africa's priority is mining when dealing with climate change. The country presents a shrinking result of the innovation factor. The country does not prioritize innovation in its mining development strategy. Hence, to achieve the fixed objectives of climate mitigation, it must prioritize innovation more than other factors.

The highest participation and role of the mining factor means that there are still substantial investments in mining and metals. However, CCMT's commitment to innovation has shifted towards purely different technologies. China is orienting its position for innovation in the mining sector towards other areas, but the mining industry remains welded by the CCMT.

For other countries, we observed an increase in ∃CCMT due to similar contributions from privilege, mining, and innovation. Comparing the involvement of several factors of countries, taking into account the privilege factor, Asia holds the largest share. Taking mining into account, most countries have achieved positive results. This partly reflects the importance of this country's mining and metals sectors. In addition, by observing the innovation factor, we see that most countries have negative values. This trend may indicate that R&D investments in these countries and patent filings mainly outside their countries of origin have not moved. On the other hand, Asian countries show an almost different trend from African countries. Asia privileges technology and supports innovation, which is why its case differs from all other African countries.

Climate scarcity, the main obstacle to economic development, recognizes the real stakes through long-term prevention measures. The country's future depends on real social projects that consider the country's ecological and economic situation. The present study analyzes the determinants of climate change mitigation technology (CCMT) patent families granted by patent offices in Asia and Africa. Between 2011 and 2020, contributed to the existing literature by (a) discussing Asia–Africa trends in mining innovation based on R&D expenditures and patent families; and (b) privileging innovation in the mining sector for a better climate future. The main conclusions show that the LMDI method has been able to further elucidate the determinants of documentation of patent trends and provide essential information on sustainability factors in the mining industry [66]. This patent analysis also shows that indicators of the evolution of CCMT patents vary from country to country. Then, there was an evolution of CCMT patents linked to a growing R&D on mining technologies in Asia. Regarding Africa, it remains to be believed that they are focusing more on mining and not on CCMT as the scope of research and development (R&D) narrows.

Even though African countries are developing a low rate of mining patent filings, they have become more active in exploration and innovation in the mining sector. Several surveys of innovation in the mining sector show that mining and other economic sectors differ in how the benefit of innovation is perceived.

Thus, awareness of global climate stability has brought out the need for its benefit and has increased the number of patent families in all mining, minerals, and metallurgy industries related to CCMT [57,112,134]. Therefore, the selected countries can benefit from their innovation advantage to change government policy to address CCMT-related challenges to control climate change. Such a policy would benefit developing countries and many other countries globally [66,110,113].

5. Conclusions and Policy Recommendation

Climate change often causes adverse effects on human health and natural ecosystems, environmental, social, and economic impacts. These represent a real challenge for socio-economic development prospects. Congo, South Africa, and Mali are highly dependent on mining. China, Japan, and India are mining economic powers contributing more to the mining factor. Being a major mining country does not replace emission reduction measures in the fight against climate change. The majority of African countries show a narrow score for the innovation factor. Nations do not prioritize innovation in their mining development strategy. Hence, to achieve the fixed objectives of climate mitigation, they must prioritize innovation more than other factors.

We are fortunate to draw inspiration from many examples from Asian countries such as China, which has more than a decade of experience in the field of climate change tenure. No need to wonder where to start and how to go about it, betting on mining is an essential starting point to get started. Faced with this situation, the deep commitment of other countries to mining technological innovations is a solution to address climate mitigation. The Chinese CCMT patent family increases with the renewal of innovation research and development (R&D) activities. This analysis suggests that the focus of research has shifted to the rise of CCMT technology as the scope of Japanese R&D activities has narrowed. India shares a common trend of increasing mining and a sharp expansion in privileged CCMT. In Africa, foreign companies strongly influence mining patents, and the decline in the privilege of CCMT is also strongly influenced by patent applications filed by foreign companies. This patent analysis also shows that indicators of the technology innovation of CCMT patents change from country to country. The development of CCMT patents has been linked to increasing R&D on mining technologies in Asia.

Regarding Africa, it remains to be believed that they are focusing more on mining and not on CCMT as the scope of R&D narrows. The question of patent families has proved crucial, as Africa is rich in natural resources but poor in innovation strategy. What exposes it has several challenges that prevent the CCMT from being stable.

As a result of our study's analysis, the drivers of innovation in the mining sector now seem to be the preferred solution to climate change in Africa and Asia. Whether the breakdown of patents has made it possible to understand the research priorities towards technology innovation in the CCMT of the countries chosen to face climate change. As there is a strong correlation between innovation, R&D, CCMT management, and the economic growth of a country, this article addresses the issue of government contribution with a legal perspective and sustainable prospects in the mining sector.

5.1. Policy Recommendations

The results of the study suggest several policy implications that could help governments and policymakers encourage innovation in the mining sector. To minimize the negative consequences of climate temperature increases in Africa and Asia. The factors of innovation influencing the mining sector studied indicate the particular relevance of climate adaptation for the environmental sustainability of the selected countries.

According to our study, governments of both groups of countries are advised, especially African governments, to encourage exploration investment. Especially since exploration investments can be considered as research and development investments since mining companies can explore reserves once deposits are discovered, and exploration contracts are formalized to support climate change mitigation objectives. Including investments in the mining sector could reduce the ecological footprint of both continents. In both countries, mining innovation takes companies' efforts concerning patents into account. Since patents are an explicit reason for innovation, governments must take initiatives to make the mining sector more capable of climate stability. In addition, Africans are major mining countries, and natural resources could be an essential step toward CCMT's innovation. Based on evidence that patents can reveal trends to assess innovation in the mining industry, authorities should prioritize changing interest in the MTCC and increasing the number of mining-related patents. Mining industries that file and use patent offices should receive special rewards. The number of patent filings could be achieved by increasing investment in research and development in countries. Governments should encourage public and private partnerships to emphasize the importance of strong government policy to support innovation. Because our analysis shows that Asian countries (China) benefit from their innovations.

This study calls for the development of renewable energy technologies to better control climate change. The study makes a case for prioritizing the development of renewable resources to maintain environmental sustainability. In mining, prioritizing low-emission practices is a potential way to achieve ecological sustainability. Climate change mitigation technology remains a major challenge for developed and developing countries. Priority change is needed for the sustainable development of nations. Because environmental degradation would prevent economic growth, good governance should regulate the mining sector. Because institutional responsibility is essential, a country's central entity should promote accountability and strategic planning within companies. The authorities should also promote environmental technologies in mineral exploration. In this regard, the study suggests that policymakers should encourage the sustainable use of energy for better climate quality.

Human resources are also recommended for the development of CCMTs. The authorities should strengthen and improve their education and health systems. As we all know, engaging in education and health is a process that leads to human capital development. Therefore, increasing investment in human development is important to raise awareness of climate health protection because it allows everyone, whether entrepreneurs or individuals, to learn more about environmental conservation.

Countries with a deficit result have increased their research and development in mining and CCMT. To grow their economies, they have abused the ecological resources that contribute to their growth. On the other hand, other countries such as China have seen their research and development activities increase first thanks to the strengthening of the Paris Agreement on environmental protection, the Kyoto Protocol, and the United Nations Sustainable Development Goals (SDGs). Then, for privileged the innovation of the CCMT and to privilege the agreements to the mining technology. In the first case, they need to demand technological innovations that will allow them to thrive while maintaining the relationship between innovation, CCMT, and R&D granted to the mining industry. In other words, deficit countries must adopt sustainable practices and energy-saving measures.

China stands out among countries with a significant number of patents because of its unique strategy in patent development, innovation, and mining technology. China is an Asian country that has experienced a rapid economic boom while using its mining sector well. It has proven its commitment to reducing carbon emissions while preserving R&D and innovation activities in CCMT. Additionally, by remaining in the environmental struggle. This credit goes to the public's intellectual maturity and the government's efficiency, which has enabled the country to ensure that businesses and individuals play a vital role in the innovation process in CCMTs.

Africa and other countries should use China as a model. Several of them face two challenges: (A) develop policies and programs aimed at climate change mitigation technology and metal pricing to ensure sustainable investments in research and development; (B) join China and the rest of the world in combating climate change. Additionally, ultimately restore global climate stability. The government must develop business management strategies that are key to sustainable innovation.

5.2. Limitations

The conclusions drawn are not without limitations. The lack of large data sets limits on research and some other determinants of climate change mitigation, such as performance, environmental safety, capacity building, and technology development transfer. The results of this study are based on Africa and Asia; an in-depth detailed analysis of a single continent would bring a new dimension to research. Future research should look at other factors proposed by Figueido and Piana regarding the holistic proxy of innovation by combining them with the decomposition technique to understand better the relationship between innovation and climate change mitigation technologies. Future research should also look at the role of businesses and governments in the innovation process related to climate change mitigation technologies in Africa's mining sector proposed by Sanchez and Hartlieb. This analysis could reveal information to improve political and government strategy.

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