Beyond Supply Chains: A Just Mining Index for Assessing Critical Mineral Sources

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Abstract

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Critical minerals are essential to the success of the global energy transition, yet decisions about where and how they are sourced often prioritize supply chain security over human rights and environmental implications. Given these different dimensions, I construct an index using principal component analysis to aggregate multiple factors related to just critical mineral mining and refining: security, infrastructure, socio-economic resilience, quality of life, climate preparedness, and human rights at a national level. I address two research questions: 1) What are the national security, EEJ, and human rights implications of new possible rare earth element investments and partnerships? And 2) what are the major concerns with rare earth elements mining or production in countries selected as new partners highlighted by the index? Using data compiled between 2023 and 2025 from the Fragile States Index, the Global Health Security Index, the Notre Dame Global Adaptation Initiative, World Bank, World Health Organization, and other United Nations bodies, I calculated the Just Mining Index, which ranges from zero, having the least capacity to support just mining, to one, having the most capacity to support just mining. Findings reveal that very few of the 174 nations scored are presently able to provide the conditions necessary for 'just' mining. However, this does not mean that this capacity cannot be created. Rather, because variation across nations exists, there is an opportunity to design investments and partnerships accordingly, in ways that address and quantify the justice trade-offs in planning alternative mineral sources.

Table of Contents

List of Figures

List of Tables

I. Introduction

For many developed parts of the world, the use of fossil fuels is declining and the need to mitigate climate change is ushering in a new era of progress known as the "green energy transition". However, to achieve decarbonization, more materials will be needed to produce the technologies that will replace fossil fuels, including electric vehicles, electric grid systems, wind turbines, solar panels, and batteries. Some of the most important materials needed to accomplish this are called critical minerals, and they are essential to creating modern, efficient technology. According to the United States Department of Energy, critical minerals are defined as minerals that have a high risk of causing supply chain disruption and serve a necessary function in at least one energy technology (U.S. Department of Energy, 2025).

Currently, there are 60 minerals considered 'critical' which most notably include copper, cobalt, lithium, nickel, and rare earth elements (REEs) (defined in section 1.1) (USGS, 2026). Their critical status comes from the varying national security, economic, and geopolitical challenges in how they are sourced. In the past five years alone, critical minerals have played a key role in global politics, such as Russia's invasion of Ukraine, the United States' proposal to buy Greenland, and deadly protests in Central America (Beiser, 2024). As the "West's most serious strategic weakness in many years" (Economist, 2026), dependence on China for nearly all mineral processing capabilities has highlighted key gaps in American foresight and mineral policy. Decoupling the supply of mineral resources from China is now a top priority for America, but deciding which countries to source minerals from will determine its "green" future as well as its geopolitical placement, especially when it comes to REEs.

A dominant frame in the literature views REEs as a security issue, emphasizing supply chain concerns and geopolitical competition. The approaches to understanding REEs can be split into 1) securitization narratives that underscore threats to national security and 2) narratives that see the current REE landscape as a strategic opportunity.

The securitization approach perceives REEs as a geopolitical threat due to where reserves of REEs and production are located. Or rather, how the location of REEs could negatively impact security. China has the largest unmined deposits (44 million tons) and is also the largest producer of REEs (Depraiter and Goutte, 2023; Filipenco, 2025). Geopolitically, this presents significant challenges for the REE market and supply chain(s) as scholars argue that dependence on one nation for minerals increases vulnerability to supply shocks. This can be seen in China's mid-2010s REE export restrictions, which had severe impacts on the U.S. economy and highlighted a key area the U.S. left exposed to economic shocks (Mancheri, 2015). Securitization, as a frame for REEs, functions as a political tool in which urgency can spur policy intervention and supply diversification (Beiser, 2024; Garcia Torres, 2025). Assistant Secretary of Defense for Industrial Base Policy to the Biden Administration once emphasized the importance of a diversified REE supply using this lens: "Resilient supply chains are essential to this goal [modernizing the defense industrial ecosystem]. The U.S. can no longer afford to rely on overseas, single points of failure for critical components (Lopez, 2024)." In this way, China's dominance in the REE sector has become a significant theme across the literature and policy initiatives, reinforcing the connection between securitization and mineral dependency.

To address this dependency issue, the U.S. has made a number of agreements with the goal of increasing supply chain resilience. Bilateral agreements include the U.S. and Ukraine (Baskaran and Schwartz, 2025), Saudi Arabia (Baskaran, 2026), the United Arab Emirates (Embassy of the United Arab Emirates, 2026), the Democratic Republic of the Congo (U.S.

Department of State, 2025), and Japan (The White House, 2025). Multilateral agreements have also signaled the importance of cohesion in the "race for rare earths". The Minerals Security Partnership (MSP), for example, is an agreement and forum comprised of 15 nations with the goal of producing, processing, and recycling minerals "in a manner that supports the ability of countries to realise the full economic development benefit of their geological endowments" (International Energy Agency, 2025). The countries involved are highly industrialized, developed, and affluent, but most lack mineral production capacities and/or mineral reserves. Thus, the goal of this partnership is to spur mineral acquisition and trade. MSP partnerships include Australia, Canada, Estonia, Finland, France, Germany, Japan, Korea, Sweden, the United Kingdom, the United States, and the European Union.

However, China's mineral supply structure may have aspects other nations could learn from if looked at through a different lens of strategic opportunity. Park et al. (2023), for instance, note that the success seen in China's REE strategy stems from consistent, long-term investment and industrial policy. Rather than viewing China as solely risky and as the antithesis to American industry, this lens suggests that elements of China's strategy could be implemented in nations seeking to shift to more proactive REE policy (Park et al., 2023). However, both frames are similar in that they are positioned within an almost exclusively economic framework, prioritizing geopolitics and economic security above environmental and social concerns. Consequently, the scholarship on REEs using these frames lacks interrogation of localized impacts.

Reliance on the securitization narrative has been studied and critiqued by multiple scholars (Baranowski et al., 2025; Palle, 2021; Hine et al., 2023). Hine et al. (2023), for example argue that using a security frame increases the level of urgency around critical minerals and may encourage more rapid extraction with policy that lacks foresight or acknowledgment about socio-ecological impacts. The authors present a "counter-urgency" frame that sees critical minerals as a policy commons rather than something to securitize. Looked at through this lens, securitization is often used as a justification for creating "sacrifice zones" to preserve consumption-centric lifestyles.

While the securitization lens underscores important dynamics in how nations respond to the current REE landscape, it fails to account for the environmental, equity, justice (EEJ), and human rights vulnerabilities present in the REE supply chain. Tools to evaluate where critical mineral mining and processing should take place lack consideration of nations' capacities to provide and protect their communities. Given that U.S. policy on critical minerals and REEs is largely informed by a securitization lens, failing to address this gap could exacerbate issues in nations and communities that are part of the expanding supply chain. The limitations of using a threat-based lens far outweigh the benefits. A more comprehensive framework is needed that evaluates the conditions REE extraction and processing can occur in the least harmful ways.

The social and environmental tradeoffs of achieving the green energy transition and climate justice in meeting technological demands must be considered (Dolšak and Prakash, 2022). Despite critical minerals' contribution to green technology, mining them increases emissions, pollution, land degradation, and biodiversity loss which often leads to increases in social vulnerability in the communities hosting these operations (Kippenberg, 2024; Alfaro, 2022; Business and Human Rights Centre, 2026; Boafo and Arthur-Holmes, 2025). Importantly, mining operations that are not just may increase the likelihood of community grievances and governance issues, jeopardizing the reliability of mineral supplies. Given the growing demand for advanced technology like cellphones, solar panels, wind turbines, electric vehicles, and defense equipment, it is important for politicians, decision-makers, and industry leaders to make decisions that address not only national security but also environmental equity, justice, and human rights.

Existing approaches to securing the critical mineral supply chain, especially for REEs, largely ignore the social implications of mining and refining and instead focus on supply chain economics: what sources of minerals are the cheapest and most resilient in the face of market disruptions? Significant gaps are therefore present in how decisions are made regarding the supply chain despite increasing investment in domestic mining and processing (Baskaran, 2026; Lopez, 2024). To close this gap and capture these important issues, this paper constructs an index using principal component analysis to measure security, infrastructure, socio-economic resilience, quality of life, climate preparedness, and human rights. I examine two research questions: 1) What are the national security, environmental equity and justice (EEJ), and human rights implications of possible new rare earth element investments and partnerships? And 2) what are the core concerns with REE mining or production in countries identified as new partners?

II. Literature review

To first answer the question "what are the national security, environmental equity and justice (EEJ), and human rights implications of mining for rare earth elements?" I conducted a systematic search of the Science Direct database using the following keywords in combination: rare earth elements, human rights, supply chain, and security, which resulted in a total of 397 open-access research and/or review articles published between 2001 and 2025. The top three journals that consistently publish in this area are Resources Policy, Energy Research and Social Science, and The Extractive Industries and Society. Articles were included if they addressed environmental or social implications of mining, geopolitical competition for REEs, or supply chain risks. The number of articles using the specific combinations of keywords is presented below (Table 1).

A grey literature search was then conducted by first identifying U.S. government reports on critical minerals, followed by organizations that focus on the political and human rights implications of critical minerals sourcing. Finally, a book search was conducted across various bookselling platforms to identify more comprehensive, journalistic sources addressing the human rights and environmental concerns associated with critical minerals (Beiser, 2024; Kara, 2023; Hamouchene et al., 2023; Scheyder, 2025).

Table 1. Literature review search results in ScienceDirect

Journal	**Keywords**	**Results (#)**
Resources Policy	rare earth elements AND human rights	33
Resources Policy	rare earth elements AND supply chain	71
Resources Policy	rare earth elements AND security	56

Energy Research and Social Science	rare earth elements AND human rights	47
Energy Research and Social Science	rare earth elements AND supply chain	54
Energy Research and Social Science	rare earth elements AND security	50
The Extractive Industries and Society	rare earth elements AND human rights	32
The Extractive Industries and Society	rare earth elements AND supply chain	24
The Extractive Industries and Society	rare earth elements AND security	30

2.1 Rare Earth Elements

When REEs were discovered, they were given the title "rare" simply because they had never been seen (Science History Institute, 2025). However, today the term rare earth element does not stem from these minerals being rare in occurrence. In fact, REEs are found in most places around the world, but what makes them "rare" is that they are highly demanded. REEs have very specific, flexible properties that make them a key feature in many technologies, which mainly include magnetic, optical, luminescent, and thermal properties (Depraiter and Goutte, 2023). These properties make them highly useful in smartphone batteries, electric and hybrid vehicles, wind turbines, fighter jets, and even disc drives. Permanent magnets are perhaps the most widely known and important use of REEs. Of the 17 REEs, the U.S. has classified 7 "highly critical" and the other 10 a mix of elevated and moderate criticality (Mineral Resources Program, 2025).

Processing and refining REEs is expensive and economically inefficient due to the low concentration of deposits and difficulty in separating each element (Depraiter and Goutte, 2023). REEs are found together with other critical minerals of varying concentrations which makes it difficult to create a refining process that can separate each mineral. These issues are compounded by the fact that REEs have no viable mineral alternative and recycling technology is not yet advanced enough to be a more sustainable source (ibid).

These minerals also play a major role in both electric vehicle and wind turbine production and are therefore crucial in achieving the green energy transition. As wind and solar power continue to become the preferred electricity sources, REEs will only become more necessary (International Energy Agency, 2024). What makes this mineral group so important is its ability to transform mechanical energy into electrical energy via permanent magnets. Particularly, neodymium, praseodymium, dysprosium, and terbium are used in the creation of neodymium-iron-boron magnets (NdFeB). Neodymium and praseodymium aid in increasing magnetic strength, while the latter two contribute to resistance against demagnetization at high temperatures. These properties make REEs highly useful in technologies that heat up quickly or are subject to direct sunlight, like electric vehicle motors and wind turbines (Depraiter and Goutte, 2023).

REEs also play a crucial role in the defense sector, particularly in advanced technologies such as sonar, radar, laser guidance, and propulsion systems that ensure precision (Underwood and Soyocak, n.d.). For example, some U.S. Navy ships employ the AN/SPY-6 Air and Missile Defense Radar, a technology that would not be possible without REEs magnets and metallic properties (ibid). Permanent magnets made from REEs are used in large quantities in various other defense equipment on board military aircraft, submarines, and vehicles. The U.S. fighter jet F-35, for instance, uses nearly 900 pounds of REEs, a small number in comparison to the 5,200 pounds required for the DDG-51 Navy destroyer ship and 9,200 pounds for a single Virginia-class submarine (Lopez, 2024). The application of REEs in the defense industry is one key reason the U.S. and other nations value them so highly and, in turn, directly impacts the lengths nations are willing to stretch their supply chains to reduce dependency.

2.2 Rare Earth Scholarship

The current discourse around REEs is largely tethered to supply chain economics and geological placement, with little engagement on how mining these minerals impacts energy transition justice and human rights. Comprehensive publications on critical mineral mining impacts that examine environmental impacts and human rights typically focus solely on cobalt, lithium, and copper rather than REEs (Bhamra, 2024; Klinger, 2018). Research beyond the REE supply chain that examines the link between society and REE mining has yet to be fully considered (ibid), which can be attributed, at least in part, to the scientific nature of the scholarship around the subject of mining, despite its inherently political nature. Garcia Torres (2025), for instance, finds that the scholarly discourse around REEs heavily focuses on materials and planetary sciences, likely because deposits are increasingly being searched for and explored. A gap exists in the scholarship between the natural sciences and geological approach to REEs and the study of localized impacts. The analysis of publications included in this literature review indicates a need for a more strategic, comprehensive approach to the issue of REEs with more integration and engagement with the social sciences.

2.3 Just Energy Transition

Following Dolšak and Prakash's conceptualization climate justice, this study incorporates the three "faces" defined by the authors to inform the meaning behind "just". These include 1) unequal distribution of climate impacts and vulnerability and 2) the uneven distribution of costs brought on by the energy transition (Dolšak and Prakash, 2022). These aspects of justice are being increasingly discussed throughout the critical mineral and REE scholarship in an attempt to address the tension between the negative impacts of mining and the values of the green energy transition.

Several publications highlight the environmental and social harms caused by various critical mineral mining projects targeting lithium, cobalt, and copper (Sefa-Nyarko, 2026; Mangani et al., 2025; U.S. Department of Labor, 2024; Amnesty International, 2023). As previously mentioned, REEs are crucial to the structure of many technologies that will enable green energy (Depraiter & Goutte, 2023), but there are deep social and environmental contradictions in achieving decarbonization. Mining is set to take place and increase in countries that are already struggling in terms of security, infrastructure, socio-economic resilience, quality of life, climate preparedness, and human rights, making the feasibility and success of the energy transition inherently about justice: who benefits and who continues to sacrifice?

While many publications are thorough in their analysis of the economic implications of not diversifying or expanding operations, they often fail to account for environmental equity, justice, human rights, conflict, colonial legacies, and public health disparities that could be exacerbated by the current extractive system. For example, the Center for Strategic International Studies released a study entitled “Critical Minerals and the Future of the U.S. Economy” in February, 2025. In fact, scholars have found that efforts to decarbonize require actions that increase emissions, chemical pollution, and inequality. This tension is often referred to as the “energy transition paradox,” whereby the advancement of long-term societal goals intensifies environmental degradation (Boafo and Arthur-Holmes, 2025). Emphasizing this point, United Nations Assistant Secretary-General Ligia Noronha notes that “while energy transition minerals can help usher in the clean energy age and opportunities for development…the urgency and scale of demand could also lead to exploitation, human rights violations and environmental destruction (UNEP, 2024).” The report also fails to mention ‘justice’ of any kind, and any information on conflict is solely related to the importance of U.S. defense systems, not the prevention of conflict in mineral rich nations.

The few times human rights are mentioned, it is only to say that violations have occurred in the mineral mining industry. The report does not discuss how to protect human rights or prevent future violations moving forward (Baskaran and Wood, 2025). There has yet to be a comprehensive publication on REEs that attempts to mitigate the impacts of REE mining on vulnerable populations while simultaneously addressing ways that nations and industries can move forward and advance technology. The literature highlights that these areas are deeply overlooked in mining policy and practice despite being relevant to past and present harms.

Some frameworks, like the Initiative for Responsible Mining Assurance (IRMA) or the Responsible Mining Index, attempt to address the social consequences of mining. However, each of these organizations targets individual companies rather than governance and structural inequities. IRMA, for instance, is a voluntary organization that certifies companies based on “environmentally and socially responsible” standards. Its broad standards detail objectives about legal compliance, community engagement, due diligence, human rights, environmental and social impact assessments, resettlement, and community consent, among others (IRMA, 2018). However, despite IRMA’s multinational scope and observer status in various United Nations bodies, only 118 sites of an estimated 12,876 (ICMM, 2025) across 35 countries are certified through IRMA’s framework (IRMA, 2025). This bottom-up approach to responsible mining assurance is crucial, but must incorporate the state’s role in creating reliable governance for responsible mining. As IRMA’s law and policy director put it, while “voluntary initiatives can complement laws and their implementation, creating market incentives for mine sites to go beyond legal compliance… they can never replace the critical role of governments to establish rules for all operators to follow, monitor implementation of those rules, and enforce compliance through appropriate incentives and penalties (ibid).” Thus, the voluntary nature of IRMA certification and its focus on individual companies neglects the importance of the state in holding its mining sector to such standards.

In many of the same ways, the Responsible Mining Index (RMI) approaches responsible mining from the bottom up by scoring individual companies on the extent to which they disclose environmental, social, and governance (ESG) issues and policies to the public (World Resource Forum, 2025). Of the 25 countries scored by the RMI, none have acceptable scores when it comes to indicators of community wellbeing, human rights, working conditions, environmental responsibility, gender, mine lifecycle management, and climate change emissions measuring (ibid). Both the RMI main report and findings are, however, brief and fail to deliver a detailed analysis of each company or the implications of results (World Resources Forum Findings, 2025).

Supply chain opacity, as well as tensions with China, create multiple constraints in improving the mining industry because both hinder proactive decision-making. These constraints linger throughout the supply chain, making the processing and transformation of REEs another concern. For example, artisanal mining in Myanmar supplies China with many of the minerals it processes as its own (Fishbein and Naw, 2025). This has contributed to immense environmental degradation, the exacerbation of conflict, and increased air pollution within Myanmar, with its population taking the brunt of negative impacts. The way governments and scholars discuss the challenges of REEs as an almost exclusively supply chain issue fails to acknowledge the equity and justice dimensions of extractive modes of production (Johnson et al., 2020; Kramarz et al., 2021). There are clear tradeoffs seen here and emphasized by the 'green energy bargain', the idea that transitioning to low-carbon energy sources will be just as, if not more, materially intensive than fossil fuels, leading to increased environmental degradation (Brown, 2024).

The tension between the goals of advancing technology and achieving decarbonization on the one hand and the means of getting there on the other has the potential to undermine a truly just transition. For many nations, scholars, and industries, the ends justify the means. However, the belief that green energy will solve many of the problems society is experiencing due to climate change is fundamentally flawed. I argue that the means of mitigating and adapting to climate change must be based on solutions that do not impose disproportionate costs on countries where citizens already experience high levels of impacts or are not able to secure a high quality of life and human rights protection. When it comes to deciding where to source REEs or invest in their production, it is crucial to acknowledge the past and present harm of human rights violations, environmental degradation, community access to public services, and overall state stability. Repeating the past under the guise of green energy will not solve the issues that underpin climate change. A new, updated framework is needed for sourcing REEs beyond what the "just transition" describes.

III. Methods

This research applies principal component analysis to 22 variables (Table 2) to construct an index measuring security, infrastructure, socio-economic resilience, quality of life, climate preparedness, and human rights to better capture the conditions necessary for 'just' critical mineral mining. This study employs the definition of climate justice conceptualized by Dolsak and Prakash (2022), which means that the distribution of costs and benefits of the energy transition is equitable, with no additional harm imposed on communities by critical-mineral mining and refining activities. Table 2, included below, lists each variable used to create the index. One asterisk indicates that a regular normalization formula was used to scale indicators from 0 (lowest/worst) to 100 (highest/best). Two asterisks indicate that normalization required scale reversal to align variable direction. Additional variable details are included in the subsequent section.

Table 2. Variables Table

Variable name	***Question and scale***	***Source***
Security_apparatus**	Scored 0-100 where high security capacity = 100.	Fragile States Index (FSI)
Group_cohesion**	Scored 0-100 where high levels of group cohesion = 100.	Fragile States Index (FSI)
Nonillicit_activity*	**Variable incorporates three aspects: 1) likelihood that terrorist attacks will cause disruption, 2) level of illicit arms flows, and 3) risk of organized criminal activity to the government or businesses in the country.** Scoring banded into quintiles from no threat (100) to very high threat (0)	Global Health Security Index (GHSI) – original data from Economist Intelligence
Lack_of_conflict*	**Is this country presently subject to an armed conflict, or is there at least a moderate risk of such conflict in the future?** Scoring banded into quintiles from no armed conflict exists (100) to territorial conflict (0)	Global Health Security Index (GHSI) – original data from Economist Intelligence
Legitimacy**	Scored 0-100 where high perceived legitimacy = 100.	Fragile States Index (FSI)
Road_adequacy*	**What is the risk that the road network will prove inadequate to meet needs?** Scoring banded into quintiles from Very low = 100 Low = 74 Moderate = 50 High = 25 Very high = 0	Global Health Security Index – original data from Economist Intelligence (GHSI)
Airport_adequacy*	**What is the risk that air transport will prove inadequate to meet needs?** Scoring banded into quintiles from Very low = 100 Low = 74 Moderate = 50 High = 25 Very high = 0	Global Health Security Index – original data from Economist Intelligence (GHSI)
Power_adequacy*	**What is the risk that power shortages could be disruptive?** Scoring banded into quintiles from Very low = 100 Low = 74 Moderate = 50	Global Health Security Index – original data from Economist Intelligence (GHSI)

	High = 25 Very high = 0	
Disaster_recovery*	**What is the risk that the economy will suffer a major disruption owing to a natural disaster?** Scoring banded into quintiles from Very low = 100 Low = 74 Moderate = 50 High = 25 Very high = 0	Global Health Security Index – original data from Economist Intelligence (GHSI)
Economic_equality**	Scored 0-100 where high economic equality = 100.	Fragile States Index (FSI)
Public_services**	Scored 0-100 where high access to public services = 100.	Fragile States Index (FSI)
Adult_literacy	Adult literacy rate, population 15+ years, both sexes (%)	United Nations Development Programme (UNDP); United Nations Educational, Scientific and Cultural Organization (UNESCO); Economist Impact
Gender_equality	UNDP Gender Inequality Index score	United Nations Development Programme (UNDP); Economist Impact
Poverty_gap	Poverty headcount ratio at US$1.90 a day (2011 PPP) (% of population)	World Bank; Economist Impact
Social_insurance	Coverage of social insurance programs (% of population) Scored in quartiles (0–3, where 3 = best)	World Bank; Economist Impact calculations
Life_expectancy	Total life expectancy (years)	United Nations; World Bank, UNICEF; Institute for Health Metrics and Evaluation (IHME); Central Intelligence Agency (CIA) World Factbook
Water_access	Percentage of homes with access to at least basic water infrastructure	UNICEF; Economist Impact
Sanitation_access	Percentage of homes with access to at least basic sanitation facilities	UNICEF; Economist Impact
Gov_health_expend	Domestic general government health expenditure per capita, PPP (current international $)	WHO Global Health Expenditure database
Adapt_capacity**	The availability of social resources for sector-specific adaptation. In some cases, these capacities reflect sustainable adaptation solutions. In other cases, they reflect capacities to put newer, more sustainable adaptations into place.	Notre Dame Global Adaptation Initiative (NDGAI)
Climate_sensitivity**	The extent to which a country is dependent upon a sector negatively affected by climate hazard, or the proportion of the population particularly susceptible to a climate change hazard.	Notre Dame Global Adaptation Initiative (NDGAI)

Human_rights**	Scored 0-100 where low human rights concerns = 100.	Fragile States Index (FSI)
NOTES:	*** = regular normalization formula** $$X' = \frac{GHSI_x - GHSI_{min}}{GHSI_{max} - GHSI_{min}} * 100$$	**** = reversed normalization formula** $$X' = \frac{FSI_{max} - FSI_x}{FSI_{max} - FSI_{min}} * 100$$ $$X' = \frac{NDGAI_{max} - NDGAI_x}{NDGAI_{max} - FSI_{min}} * 100$$

3.1 Variables

3.1.1 Security

REE supply is highly sensitive to state stability. Unstable regions can disrupt mineral extraction and trade, creating uncertainty for entities relying on secure sources (Dou et al., 2023; Council on Foreign Relations, 2025). State stability directly impacts the profitability of companies and the availability and accessibility of many commodities and services (International Energy Agency, 2025; Dou et al., 2023). Weak domestic institutions are also shown to increase the risk of conflict, crime, and policy inconsistency, all of which contribute to the reliability of supply chains.

To capture these risks, the JMI includes measures that address a state's ability to protect itself (*Security_apparatus*), non-illicit activity and organized crime risks (*Nonillicit_activity*), and the lack of conflict in a state (*Lack_of_conflict*), which have each been shown to disrupt both mineral supply chains and community stability (Church & Crawford, 2018). Additionally, indicators measuring group cohesion (*Group_cohesion*) and legitimacy (*Legitimacy*) are included because low levels of trust in the government and cohesion between groups increase the likelihood of protests, conflict, and project delays or cancellations (Marin and Palazzo, 2024; Møller, 2019). However, measures that were negative in the original data sources were reversed to reflect high security rather than high instability. Taken together, these measures capture the range of institutional stability that is necessary to consider for mining investment and production.

3.1.2 Infrastructure

Infrastructure stability and low levels of disaster risk are also drivers of supply chain resilience. Failures in transportation networks, energy systems, and disaster response can negatively impact mineral supply chains by hindering extraction and export (Teshima et al., 2026; Heydari et al., 2025). However, despite their importance to resilient systems, environmental disasters and infrastructure failures are less frequently addressed in assessments and policy (Heydari et al., 2025). The JMI accounts for these risks by including measures of natural disaster recovery (*Disaster_recovery*), adequacy of road and air transport infrastructure (*Road_adequacy* and *Airport_adequacy*), and electricity adequacy (*Power_adequacy*). Together, these indicators represent the structural capacity of a nation to provide reliable and resilient production and extraction environments.

3.1.3 Socio-economic resilience

Despite the many benefits associated with mining critical minerals, there are significant concerns with how such activities can exacerbate socioeconomic situations. Long-term exposure to socio-economic risks increases community vulnerability to inequities, harsh labor conditions, and exploitation (Berthet et al., 2024). Research conducted in Latin America and Africa highlights that mining can exacerbate economic inequality and social harm, including gender-based violence against women (Buss, 2018).

To account for these risks, the JMI integrates measures of economic equality (*Economic_equality*), gender equality (*Gender_equality*), and adult literacy (*Literacy*). Literacy is included in socio-economic resilience because the ability of workers to read safety information and employment contracts impacts their rights and safety (Masuku, 2024).

The JMI includes a measure of social insurance (*Social_insurance*), which reflects the percent of a population covered by social insurance programs. In a development context, this reflects the capacity of a government to provide population protection "against life-course and employment-related hazards that threaten acceptable levels of well-being; supporting their productive capacity; and facilitating their full participation in society (Ali, 2023)." The existence of social insurance and high percentage of coverage indicates that workers would be better protected in hazardous environments, like those associated with mining.

3.1.4 Quality of life

Although many nations may hold vast reserves of REEs, it is not always the case that their people have the means of a stable quality of life that meets their basic needs. REE mining is known to produce toxic waste that impacts waterways and degrades land (Wang et al., 2024). Both of which negatively impact quality of life by decreasing the availability and accessibility of drinking water for communities (Mangani, 2025). To address these concerns, the JMI includes measures that address access to public services (*Public_services)*, water (*Water_access*), and sanitation (*Sanitation_access*) to understand the constraints within a nation that may be impacted by further mining operations.

As discussed above, mining is a dangerous, hazardous sector (Mangani, 2025). If a mine is built, expanded, or invested in, health constraints should be considered to prevent issues and attempt to improve situations for possible workers and their communities. Two measures, life expectancy (*Life_expectancy*) and government health expenditure (*Gov_health_expend*) are included in the JMI to capture these risks.

3.1.5 Climate preparedness

Mining is costly to the environment, not only in terms of land degradation and water pollution, but also in how it significantly contributes to climate change by releasing greenhouse gases into the atmosphere (Azadi et al., 2020) that increase global warming and weather extremes. It may be counterproductive to prop up REE extraction and production in nations unable to adapt to further temperature increases, land degradation, and pollution. Therefore, any investment or partnership must consider a nation's capacity for sectors and citizens to adapt to the adverse and extreme impacts of climate change at the local level. Two measures are used to assess these capacities: 1) the availability of sector-specific resources for adaptation

(*Adaptive_capacity*) and 2) the extent to which the population or sector is vulnerable to climate hazards (*Climate_sensitivity*).

3.1.6 Human rights

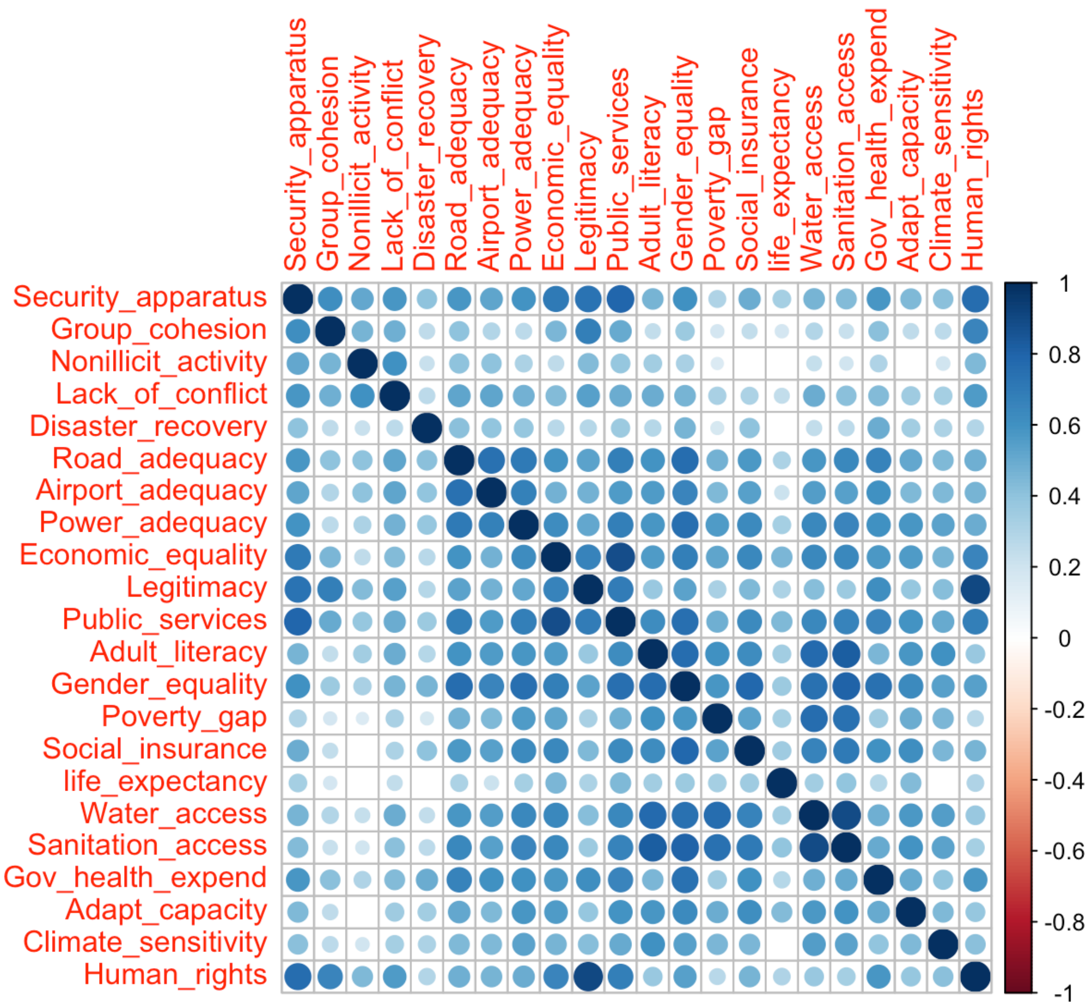
While overall economic improvements can often be seen in communities where mining takes place, human rights violations are common (Kippenberg, 2024; Alfaro, 2022; Business and Human Rights Centre, 2026). In fact, 47% of critical mineral mines worldwide have had one or more allegations of human rights abuse cited against it (Business and Human Rights Centre, 2025). Thus, how well a nation protects citizens' social and political human rights (*Human_rights*) must be considered an important qualifier of mining investment and/or partnership. The Universal Declaration of Human Rights states that no person, group, or nation has "any right to engage in any activity or to perform any act aimed at the destruction of any of the rights and freedoms set forth herein (United Nations, 1948)." Thus, ensuring the protection and freedoms afforded to potential employees and affected communities through human rights is necessary.

3.2 Principal Component Analysis (PCA)

Many variables that capture the above concepts are correlated and therefore present challenges with double-counting or overrepresenting certain aspects of just mining. The figure below depicts the correlation matrix for variables included in the Just Mining Index (JMI). Many indicators show moderate to strong positive correlations, particularly between human rights, gender equality, economic equality, water access, sanitation access, and adequacy of public services.

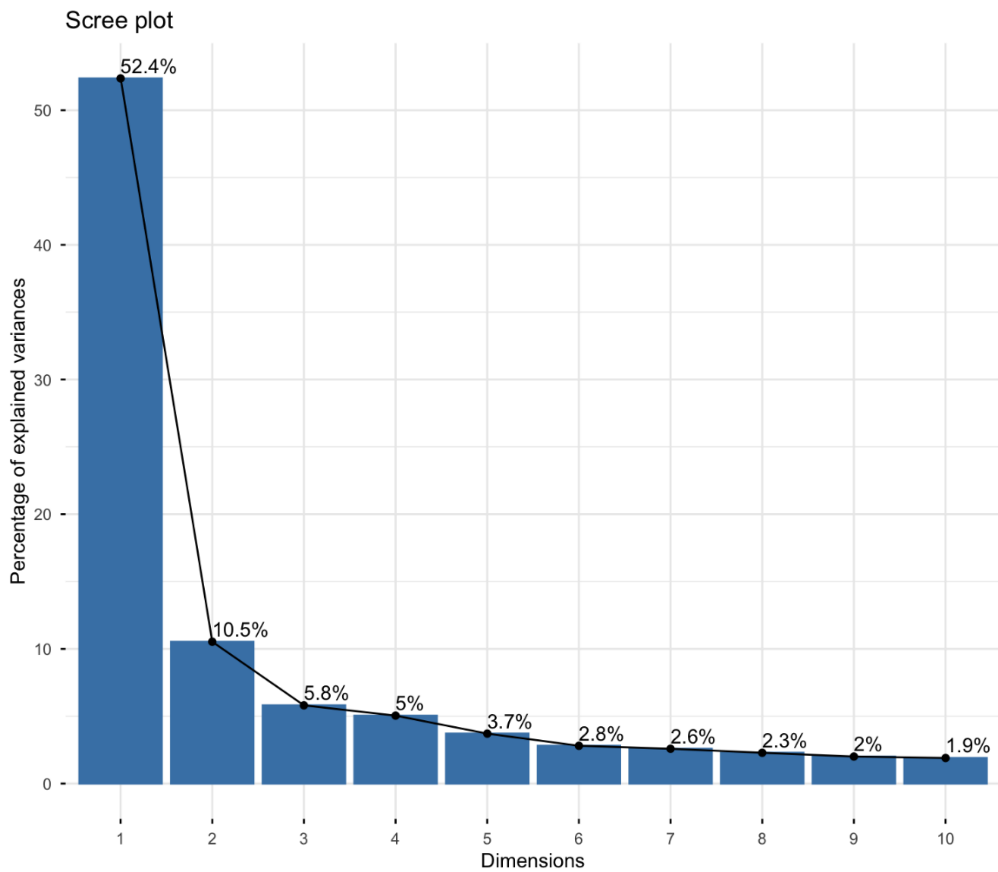
The fact that these correlations exist indicates the overlapping nature of development and institutional capacity. While other indices like the Fragile States Index capture nations' capacity to cope with pressure, they do not explicitly capture mining-relevant dimensions (e.g. social protection and climate adaptation capacity) despite some variables being strongly correlated. The JMI is designed to capture conditions that would support just, environmentally conscious extraction and refining. To address the issue of correlation between variables, this study employs Principal Component Analysis (PCA) to preserve shared variance and prevent double-counting.

Figure 1. Correlation matrix - all variables



The JMI is created using principal component analysis (PCA) following Ko et al. (2022) and is applied to normalized indicators (scaled 0-100) using the first principal component (PC1). PC1 explains the most variance, 52.4%, while the additional components explain only 1-10% (Figure 2). PCA creates uncorrelated "buckets" (indices) that extract the dominant structures underlying the data.

Figure 2. Percentage of variance explained by PCs 1 to 10



It can also be argued that the best way to create a principal component (PC) index is to add PCs together weighted by their eigenvalue (eigenvalue-proportional weights) (Praus, 2019). However, this method falls outside the framework of PCA because it creates a new axis that does not fit within the hierarchy of PCs (Jolliffe, 2002; Abdi & Williams, 2010; Härdle & Simar, 2019). In other words, eigenvalue-proportional weighting produces a value that is a combination of PCs and not an interpretable PC itself. Further, eigenvalue proportional weighting does not maximize the variance explained despite what is implied by PC summation (Australian Bureau of Statistics, 2021 Strang, 2016). Therefore, by using the first principal component to create the JMI rather than the weighted sum of multiple PCs or separate variables, the JMI fits squarely within the PCA framework and maximizes the variance explained between all linear combinations.

The following formula explains how the JMI is created. PC1 is used to weight the data to generate the final JMI scores (Appendix 1). $Index_i$ denotes the value for each country i. The index for country i is the sum of the products of all variables and the loading weight of variable j on the first principal component.

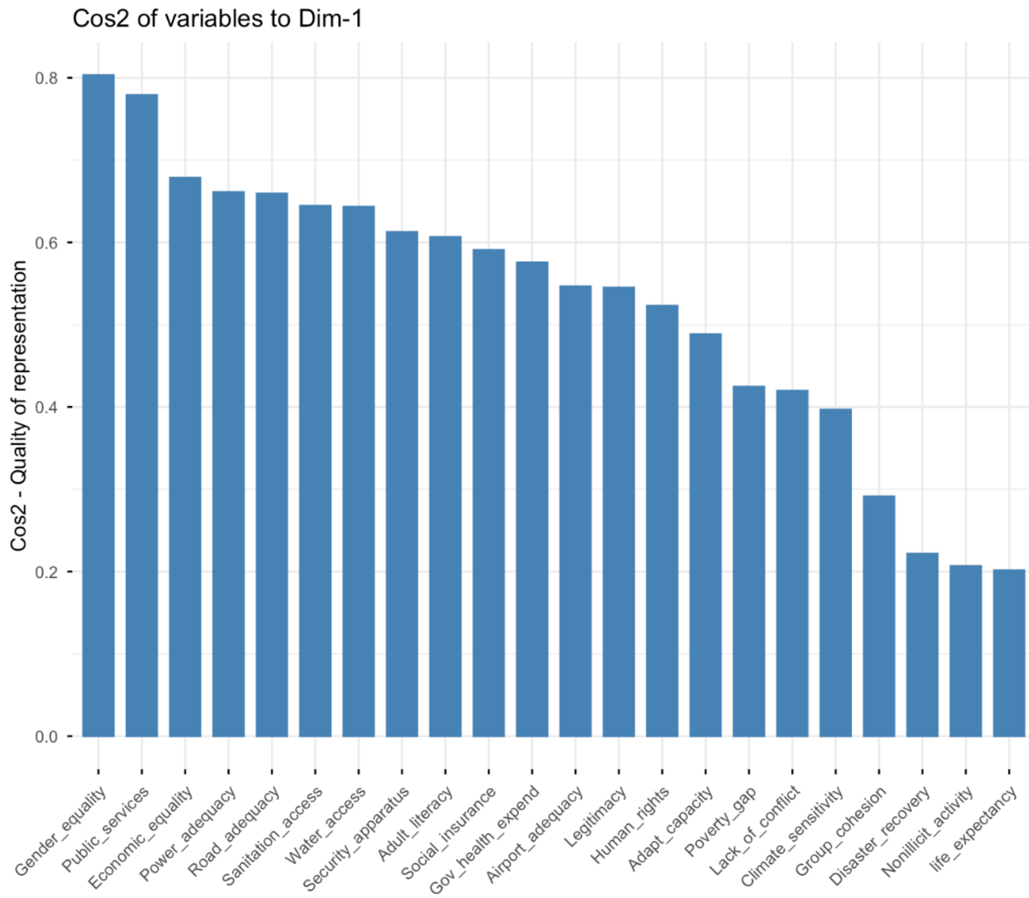
$$Index_i = \sum_j (\text{PC1}\ loading_j \times x_{ij})$$

Figure 3 explains how well each variable is represented in the first principal component (PC1) by the sum of least squares (Cos^2). Cos^2 reflects the driving structure of variables by measuring the proportion of variance explained by each component. Higher values mean that a given variable follows the same linear structure of PC1, while lower values show less alignment with PC1's structure. In this analysis, most variables have values greater than 0.5, underscoring social and infrastructure development as the main dimension. Importantly, adaptive capacity loads moderately strongly on PC1, highlighting that the availability of sector-specific adaptation resources is also a prominent development measure. The variables that contribute most to the underlying structure of PC1 (gender equality, adequacy of public services, economic equality, infrastructure adequacy, sanitation access, and water access) are measures that contribute to "social progress and better standards of life", a definition of development used by the United Nations in tandem with economic growth or GDP (UN General Assembly, 1958).

Although some scholars are less than enthusiastic about the use of indices due to concerns about oversimplification and arbitrary weighting (Parulo et al., 2018; Greco et al. 2019), I argue that indices offer a point for further exploration into given contexts. It is never enough to take an index score at face value. Every nation, community, and person is different and comprised of countless realities. It is therefore impossible for one number to account for such diversity of experience.

However, for the purpose of creating one measure that encompasses security, infrastructure, socio-economic resilience, quality of life, climate preparedness and human rights, the JMI offers a new way of thinking about investment and where it should take place. Furthermore, this study contributes to the body of literature on the negative impacts of mining by focusing specifically on rare earth elements. It must also be noted that the goal of this study is not to deter mineral partnership or investment in nations that receive lower scores, but to highlight factors that could be exacerbated by creating or expanding mining operations if not carefully managed.

Figure 3. Quality of variable representation of PC1



Further, the most prominent variables shown on PC1 (gender equality, public services, economic equality, power and road adequacy, sanitation access, and water access) tend to be structural, improving over the long-term as opposed to variables that have lower Cos^2 scores (Figure 3). It is important to note that variables that load "weakly" on PC1 (<.5) are not unimportant but are simply not aligned with the variance structure of PC1. Overall, this suggests that variance between countries is most driven by levels of socio-economic resilience and infrastructure rather than poverty gaps within countries, lack of conflict, group cohesion, disaster recovery, illicit activity, and life expectancy.

Given that investment decisions are often made based on export controls and conflict-related supply chain risk metrics (International Energy Agency, 2025; U.S. Department of State, 2026), this finding suggests that a nation's development stage and capacity before, during, and after the implementation of mining projects is crucial to consider alongside geopolitical and economic growth models. Because the structural and social conditions of a nation affect mining project feasibility and community responses to potential negative impacts of extraction, the JMI becomes a useful tool for informing U.S. mineral partnerships. In the following sections, I examine the JMI's regional distribution as well as how the JMI can be applied to new REE partnerships.

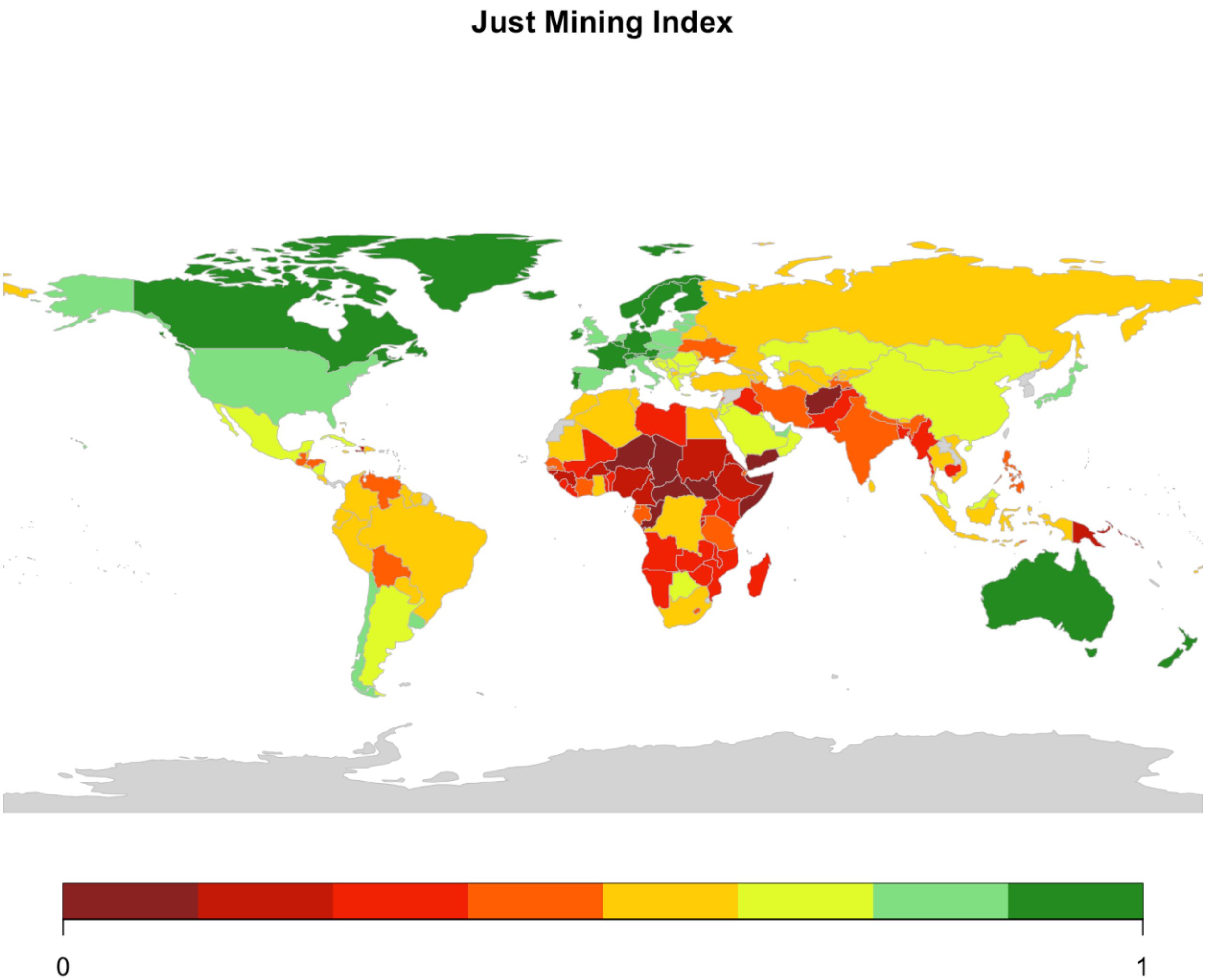
IV. Results

4.1 Mapping and applying the Just Mining Index

The Just Mining Index is constructed using normalized PC1 scores on a scale of 0 to 1, where 1 indicates the highest observed level of security, infrastructure, socio-economic resilience, quality of life, climate preparedness, and human rights, with a score of 0 indicating the lowest observed levels in the index. Scale breaks are evenly distributed by increments of 12.5. The colors of the map range from dark red (lowest JMI scores) to dark green (highest JMI scores). The following map provides high-level results from the Just Mining Index. Country-specific scores (Appendix 1) and disaggregated variables (Appendices 2-4) are provided for closer analysis of each nation's score. Overall, very few nations are currently able to support the necessary conditions for 'just' mining, that is, mining that does not increase exposure to negative impacts and equitably distributes the costs of extraction or refinement.

In the effort to decouple from China, as is the imperative of geopolitics and U.S. foreign policy, many nations are looking for alternative sources of REEs, and it is important to understand if these alternatives sacrifice justice or shift burdens to other nations in the name of energy transition. As will be demonstrated in the subsequent section, the impact of supply diversification may come at the expense of justice and shift social, economic, and environmental burdens to nations ill-equipped to handle the consequences of mineral extraction or refinement.

Figure 4. Just Mining Index – country scores



Geographically, Figure 4 shows regional clustering in areas where security, infrastructure, socio-economic resilience, quality of life, climate preparedness, and human rights are lacking. The distribution of the map reflects the varieties of development, socio-economic, and institutional capacities. Importantly, this variation persists within regions, highlighting the need to tailor investments and partnerships accordingly. These findings suggest that the conditions for just critical mineral extraction are unevenly distributed and must be accounted for in decisions about where and how to mine.

The JMI is meant to be applied to contexts where critical mineral mining, production, and refinement are relevant and used by decision-makers implementing or investing in these projects. It must be noted that a low score does not imply that mining projects will fail, but that structural and normative conditions may prevent effective regulation of the possible harms caused by mining. The scores attributed to each nation are not static, unmovable prescriptions but rather points for further inquiry and discussion about how to improve situations. Thus, the conditions that support just partnership and investment can be created and strengthened.

4.2 Diversification abroad: selected FORGE country partnerships

As previously discussed, the need to diversify the REE supply chain away from China is a top priority for the U.S. government for reasons ranging from national security and defense to green energy (U.S. Department of State, 2026; The White House, 2024, The White House, 2025). China's JMI score is 0.62 (Appendix 1), influenced by high levels of infrastructure development and literacy coupled with low levels of perceived legitimacy, access to services, economic equality, and human rights protections (Appendix 2).

While the goal of diversification is to disperse the concentration of the REE supply chain, the JMI shows that not all shifts away from China are "better", nor perfect, when it comes to impacts on communities. For instance, a large part of the U.S. critical minerals strategy relies on increasing resilience of domestic mineral supply chains (Export-Import Bank of the United States, 2026; U.S. Department of Energy, 2025), but with a score of 0.86, concerns are still present despite being an improvement from China (0.64). As previously mentioned, the U.S. is looking to expand domestic and international mining and refining, but the JMI highlights that human rights protection, gender equality, legitimacy, and illicit activity are key factors that negatively influence the U.S.'s JMI score (Appendix 4). So, although decoupling from China may improve national security, some moves away from China may sacrifice justice, a number that can be quantified by comparing nations' scores.

More recently, the United States created the Forum on Resource Geostrategic Engagement (FORGE), aiming to increase collaboration at the "policy and project levels to advance initiatives that strengthen diversified, resilient, and secure critical minerals supply chains" (U.S. Department of State, 2026). The FORGE collaboration is meant to build upon the MSP by broadening membership, tightening focus on market instruments, and aligning mineral policies and projects across states. Notably, all 17 members of the MSP have signed onto the FORGE partnership, marking a plurilateral shift in U.S. mineral policy away from the United States' recent bilateral lean (Baskaran and Schwartz, 2026).

Table 2 below depicts the values of the Just Mining Index to assess 8 out of the 10 new U.S. partnerships announced at the FORGE Moratorium based on the viability of REE deposits and/or relevance to the refining process: Argentina, Ecuador, Guinea, Morocco, Peru, the Philippines, the United Arab Emirates, and Uzbekistan (U.S. Department of State, 2026). Table 2 shows that although most of the recent partnerships have geological conditions that may be associated with REEs (i.e., Argentina, Ecuador, Guinea, Morocco, Peru, the Philippines, and Uzbekistan), the governance and infrastructure issues within each nation may present high risks to project implementation and community harm. On the other hand, although the United Arab Emirates lacks REE deposits and reserves, it represents a strategic investment in downstream REE production that carries hidden risks and vulnerabilities associated with its extractive industry. The chart below (Table 2) includes the U.S. and China as case comparisons. In the subsequent section, the JMI is unpacked to identify key areas of concern within nations identified as new U.S. partners.

Table 3. New U.S. Partnerships for REEs listed by JMI score

Countries	***Just Mining Index***
The United States	**0.86**
China	**0.64**

United Arab Emirates	0.80
Argentina	0.71
Morocco	0.60
Ecuador	0.56
Peru	0.54
Uzbekistan	0.50
Philippines	0.45
Guinea	0.23

United Arab Emirates (0.80)

Despite lacking mineral resources, the United Arab Emirates (UAE) is strategically positioning itself as a processing and refining alternative to China (Wajid, 2025; Meridith, 2025; Ardemagni, 2025; Mining SEE, 2025) and important FORGE partner country for the United States. The country is expanding its mineral assets by investing in mineral projects in Africa and South America, with the goal of becoming a key hub in the mineral supply chain (Wajid, 2025). The UAE has a JMI score of 0.80 with high levels of access to public services and infrastructure adequacy. However, perceptions of legitimacy and protection of human rights are notable concerns (see Appendix 4). In fact, the U.S. Department of State notes credible cases of enforced disappearances, repression of persons from other countries, arbitrary arrest and detention, restrictions in freedom of expression, and restrictions on workers' freedom of association (U.S. Department of State, 2024). The report goes so far as to highlight that the government failed to take "credible steps or actions" to find and hold officials accountable for these abuses (ibid). Furthermore, immigrants form over 95% of the UAE's working population (Fargues et al., 2019) and are largely employed in the construction and oil sectors (Wright, 2021). While worker protections do exist for UAE citizens, they do not for foreign workers in these industries (U.S. Department of State, 2024). The expansion of the REE processing industry here highlights concern over how migrant workers will be treated and if conditions from other extractive industries will be mirrored rather than improved.

Argentina (0.71)

Argentina is not a current REE producer; however, the country is expanding its critical mineral policy via bilateral and multilateral agreements (e.g., FORGE) and by implementing new investment incentives for mining projects (Albe and Tobin, 2024). U.S. Secretary of State Marco Rubio notes that the partnership with Argentina is both about the resources it possesses as well as its "production expertise" (U.S. Mission Argentina, 2026). Argentina has a JMI score of 0.71, higher than the average (0.54) but not without concerns. According to Appendix 2, there are risks of illicit activity from non-state actors, infrastructure inadequacy, and the exacerbation of inequality should mining activities expand. Environmental issues related to the impacts of mining on water pollution and access are likely (Business and Human Rights Centre, 2026). In fact, vulnerabilities related to water pollution are already being seen. Due to new critical mineral mining opportunities, the country has proposed limiting its glacier protection laws to the detriment of water access. Glaciers are a key source of drinking water in Argentina, but according to the president, the law protecting them "unnecessarily limits mining and other economically important activities (Orfila, 2026)." Coupled with concerns over infrastructure adequacy, illicit activity, and inequality, sourcing minerals from Argentina presents a moderately high risk to both the supply chain and communities.

Morocco (0.60)

Morocco’s REE potential is two-fold. First, the country’s geological structure is favorable to high-grade deposits, of which many REEs have already been located (ONHYM, n.d.) Secondly, due to Morocco’s vibrant phosphate industry and the subsequent waste it produces, REE recovery from phosphates has been found to be effective and capable of producing significant minerals (Hak et al., 2023). Morocco’s JMI score is 0.60 and is associated with low levels of group cohesion and gender equality, as well as a high possibility of economic disruption due to disaster and a moderate likelihood of disruption caused by road and power inadequacy (Appendix 3). However, key environmental and human rights issues persist as phosphate mining is known to produce significant pollution and cause harm to human health in Morocco (Bourazza et al., 2025; Raji and Nadir, 2023). Advancement in REE recovery from phosphates is likely, and therefore increases the potential that further pollution will occur.

Ecuador (0.56)

Although Ecuador’s mining sector has historically focused on gold, copper, and silver (International Trade Administration, 2025), modern technology is making the identification of REEs in Ecuador more feasible (Cotrina-Teatino, 2025). Ecuador has a JMI score of 0.56, which is largely attributed to low levels of road infrastructure, access to public services, protection of human rights, and equality (Appendix 2). Already, the impacts of critical mineral mining have negatively impacted community health, access to services, and equality. In fact, both the Ministry of the Environment and the Ministry of Women and Human Rights were eliminated and forced to consolidate into the Ministry of Energy and Mines (Aguilar, 2025). Although this decision intends to spur private investment, notable concerns arise over the protections and oversight mechanisms now not in place to help regulate environmental degradation and human harm. Furthermore, Ecuador also experiences high levels of illegal mining that often leads to conflict (Ortiz-T, 2025). The expansion of critical mineral mining and/or processing in the country may heighten the tension between these issues.

Peru (0.54)

Peru’s rare earth deposits are a largely untapped resource despite the country’s rich mineral resources (Solar, 2025). Recent discoveries of both light and heavy REEs have increased Peru’s investment potential (Rivera et al., 2022). Peru has a JMI score of 0.54, which can be attributed to low access to services and sanitation, equality, and group cohesion (Appendix 4). Illicit non-state actor activity and perceptions of illegitimacy are also notable issues (Appendix 4). The intersection of mining and these concerns is substantial. Not only does Peru have a long history of illegal mining for critical minerals that continues to negatively impact Amazonian communities and the environment, but violence among miners is common and persists across regions (Zadeh, 2025). U.S. mining companies have also long been criticized for dumping toxic mining waste into the ocean and bays, negatively impacting marine ecosystems, livelihoods, and resources of communities (Orihuela, 2024; Alfaro, 2022). Failing to account for past harms while pursuing accountable prevention of future harm has thus far failed to happen in Peru’s mining sector, and with new projects expected to break ground or expand in the coming years (Alfaro, 2022; Radwin, 2026), it is likely that REE mining will exacerbate already fragile conditions.

Uzbekistan (0.50)

Uzbekistan is on the verge of a major REE mining boom (Baskaran and Aubakirov, 2025). With the recent discovery of 14 deposits and the establishment of Central Asia's first research center dedicated to REEs, the country is attracting the attention of many nations looking to diversify their REE supplies (Cekuta et al., 2024). Uzbekistan has a JMI score of 0.50, which largely underscores extremely low levels of infrastructure adequacy, economic equality, and human rights protection (Appendix 4). The U.S. Department of State notes that the country's "weak rule of law and a lack of transparency allowed human rights abuses" to persist (U.S. Department of State, 2024). Concerns over the expansion of mining for REE are therefore high and tied to the perception that the country may not have the capability to manage resources or industrial growth effectively (Ruzmatov, 2025). Water pollution in Uzbekistan has already negatively impacted public health and agriculture due to waste runoff (ibid), and with the expansion of the REE industry, it is likely to remain an issue if not properly addressed by future project implementers. Thus, although Uzbekistan is becoming an important incubator for REE expansion in Central Asia, the likelihood of exacerbating water scarcity and pollution issues is high.

The Philippines (0.45)

The Philippines is a large source of minerals, particularly nickel, copper, and gold (IUCN, 2023). However, the geological potential of REEs is high and comparable to China, Turkey, and other well-endowed nations (Gibaga et al., 2022). The Philippines' JMI score of 0.45 indicates the existence of many issues. Notable concerns with infrastructure, access to public services and sanitation, disaster recovery, perceptions of government legitimacy, and human rights protection (Appendix 4) may present issues with REE sourcing. Beyond the persistent land and water pollution inflicted on indigenous land by mining (IUCN, 2023), serious social concerns are also caused by and exacerbated by the presence of mines. The U.S. Department of State recognizes many of the above issues, noting instances of "arbitrary or unlawful killings; disappearances; torture or cruel, inhuman or degrading treatment or punishment; arbitrary arrest or detention; serious abuses in a conflict; unlawful recruitment or use of child soldiers by terrorists and groups in rebellion against the government; serious restrictions on freedom of expression and media freedom (U.S. Department of State, 2024)." In fact, environmental activists and human rights workers have long been targets of abuse and accusations of terrorism (Amnesty International, 2025), with accounts that these workers are often "harassed, threatened, and even killed (IUCN, 2023)." Therefore, holding the government and industries accountable for environmental degradation and human rights abuses associated with mining may be difficult in this context. Overall, while the political environment in the Philippines may be conducive to the cheap extraction of REEs, there are many high-risk elements to sourcing and expanding projects in the region.

Guinea (0.23)

Guinea is a recently formed democracy and is noted to be Africa's fastest-growing economy, largely due to its mining sector (Gowling WLG, 2026; Critical Minerals Africa Group, 2025). With abundant natural resources and prime geology for the increased discovery of REEs (via bauxite), Guinea is on track to become a key player in the global REE supply chain (Critical Minerals Africa Group, 2025). However, despite its economic development, the nation receives the lowest JMI score out of the U.S.'s new FORGE partnerships (0.23). Guinea's score can be attributed to several factors related to a lack of access/adequacy of services, water, and infrastructure, as well as concerns with legitimacy, human rights, and equality (Appendix 3). According to Human Rights Watch, a major issue with mining in Guinea is that the government's focus on industry growth "has too often taken precedence over the protection of the environment and human rights (Human Rights Watch, 2018)." In fact, the main impacts of mining in Guinea are land degradation and water pollution (Dibattista et al., 2023). Coupled with the severe water and sanitation access issues already present in the country (Appendix 3), this raises concerns about the increase of mining activities further deteriorating the situation.

V. Conclusion

Critical minerals are an essential component in modern technologies and achieving a low carbon future. However, mining for these and other critical minerals is materially intensive and poses significant social and environmental risks if decisions about where and how to mine are not more carefully considered. Current frameworks for "responsible" and "sustainable" mining lack substance and are too broad to truly encompass the various realities of resource-rich communities. The Just Mining Index fills this gap by offering a more comprehensive framework to guide mineral sourcing decisions that include factors that impact both mineral supply chains *and* communities.

Findings show that not only are the conditions for just mining are unevenly distributed but few nations have the very few nations are currently able to support the necessary conditions for 'just' mining. The JMI highlights that mining investment and partnership between countries must be designed with their specific challenges in mind. Blanket policies and initiatives that are intended to protect the environment and communities from the impacts of mining will not suffice. Instead, specificity between mining companies, governments, health ministries, environmental advocacy groups, scientists, and community members must be intricately involved with the process of increased or continuing mining operations.

Notably, the JMI is meant to be applied to contexts where critical mineral mining, production, and refinement are relevant and used by decision-makers implementing or investing in these projects. The JMI framework allows decision-makers to identify which aspects of a partnership need attention. A low score does not imply that mining projects will fail, but that structural and normative conditions may prevent effective regulation of pollution and community impacts. Further, the JMI also allows decision-makers to understand how much is being sacrificed in terms of justice in the just transition.

Future research should use a smaller unit of analysis to assess the localized impacts of critical mineral mining, as this study focused exclusively on the national level. Ultimately, the Just Mining Index highlights that the positive phrase 'resource-rich *country*' may mask the negative impacts on the smaller unit, the resource-rich *community*. Understanding this distinction, pulling the focus down to where, how, and for whom extraction is taking place should guide the just energy transition and all decisions related to critical mineral mining.

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Appendix

Appendix 1. JMI scores by country

Rank	Countries	PCA_Index_raw	JMI
1	Norway	431.905	1.000
2	Austria	430.645	0.997
3	Switzerland	425.425	0.983
4	Luxembourg	420.725	0.970
5	Finland	419.128	0.966
6	Iceland	418.467	0.964
7	France	414.030	0.953
8	Greenland	411.288	0.945
9	Denmark	410.209	0.942
10	Canada	409.053	0.939
11	Sweden	408.106	0.937
12	Germany	404.498	0.927
13	New Zealand	399.308	0.913
14	Belgium	397.593	0.909
15	Slovenia	397.397	0.908
16	Portugal	397.146	0.908
17	Australia	392.545	0.895
18	Ireland	387.859	0.883
19	Estonia	384.144	0.873
20	Singapore	379.163	0.860
21	United States	378.613	0.858
22	Japan	369.126	0.833
23	Czech Republic	368.994	0.833
24	Qatar	368.964	0.833
25	Slovak Republic	368.818	0.832
26	Lithuania	365.660	0.824
27	Uruguay	364.434	0.821
28	South Korea	361.107	0.812
29	Spain	361.046	0.812
30	Poland	359.390	0.807
31	Italy	359.122	0.807
32	Latvia	357.919	0.804
33	United Kingdom	356.425	0.800
34	United Arab Emirates	355.239	0.796
35	Hungary	345.091	0.769

36	Chile	341.923	0.761
37	Netherlands	340.916	0.758
38	Bulgaria	336.121	0.746
39	Barbados	334.554	0.741
40	Romania	330.499	0.731
41	Oman	329.295	0.728
42	Brunei	328.270	0.725
43	Mexico	325.675	0.718
44	Cyprus	324.906	0.716
45	Israel	324.540	0.715
46	Grenada	322.308	0.709
47	Argentina	320.893	0.705
48	Kuwait	319.788	0.702
49	Seychelles	316.871	0.695
50	Mongolia	315.614	0.691
51	Kazakhstan	313.434	0.685
52	Montenegro	310.675	0.678
53	Cuba	309.898	0.676
54	Greece	307.974	0.671
55	Antigua and Barbuda	303.210	0.658
56	Malaysia	301.660	0.654
57	Croatia	300.872	0.652
58	Samoa	300.762	0.652
59	Cape Verde	298.208	0.645
60	China	295.638	0.638
61	Trinidad and Tobago	295.353	0.637
62	Jordan	292.784	0.631
63	Botswana	292.643	0.630
64	Albania	292.588	0.630
65	Serbia	292.335	0.629
66	Saudi Arabia	291.762	0.628
67	Bosnia and Herzegovina	290.858	0.625
68	Nicaragua	290.857	0.625
69	Bahrain	287.933	0.618
70	Belarus	284.405	0.608
71	Fiji	284.148	0.608
72	Jamaica	283.618	0.606
73	Maldives	282.678	0.604
74	Tunisia	282.259	0.603

75	Morocco	280.439	0.598
76	Brazil	278.563	0.593
77	Macedonia	275.524	0.585
78	Azerbaijan	274.811	0.583
79	Dominican Republic	274.294	0.581
80	Bahamas	273.862	0.580
81	Costa Rica	273.612	0.580
82	Kyrgyz Republic	273.359	0.579
83	Moldova	272.092	0.576
84	Malta	271.318	0.574
85	Turkey	270.114	0.570
86	Suriname	268.733	0.567
87	Thailand	266.783	0.562
88	Ecuador	266.772	0.562
89	Turkmenistan	266.011	0.559
90	Georgia	265.120	0.557
91	Mauritius	264.925	0.557
92	Indonesia	264.553	0.556
93	Sri Lanka	264.466	0.555
94	Vietnam	263.703	0.553
95	El Salvador	263.020	0.552
96	Algeria	262.996	0.551
97	Paraguay	262.361	0.550
98	Russia	262.246	0.549
99	Belize	260.640	0.545
100	Armenia	260.372	0.545
101	Peru	259.287	0.542
102	Ghana	258.937	0.541
103	Egypt	258.763	0.540
104	Bhutan	253.622	0.527
105	Colombia	252.130	0.523
106	South Africa	251.780	0.522
107	Mauritania	250.722	0.519
108	Democratic Republic of the Congo	246.817	0.509
109	Guyana	246.664	0.508
110	Uzbekistan	244.929	0.504
111	Bolivia	243.281	0.499
112	India	240.460	0.492

113	Equatorial Guinea	238.300	0.486
114	Sao Tome and Principe	237.887	0.485
115	Cote d'Ivoire	237.847	0.485
116	Ukraine	234.423	0.476
117	Gabon	227.957	0.458
118	Nepal	226.558	0.455
119	Philippines	224.684	0.450
120	Lesotho	224.395	0.449
121	Tajikistan	219.352	0.436
122	Iran	217.967	0.432
123	Lebanon	216.857	0.429
124	Micronesia	211.458	0.415
125	Venezuela	205.809	0.400
126	Timor Leste	205.039	0.398
127	Gambia	204.613	0.396
128	Senegal	202.371	0.390
129	Guatemala	199.345	0.382
130	Tanzania	197.802	0.378
131	Djibouti	197.195	0.377
132	Honduras	196.735	0.376
133	Namibia	196.229	0.374
134	Solomon Islands	194.281	0.369
135	Libya	192.816	0.365
136	Rwanda	189.424	0.356
137	Mozambique	187.525	0.351
138	Cambodia	187.026	0.350
139	Benin	186.127	0.347
140	Zambia	180.748	0.333
141	Iraq	180.254	0.332
142	Togo	176.633	0.322
143	Bangladesh	174.939	0.318
144	Madagascar	174.760	0.317
145	Uganda	170.799	0.307
146	Pakistan	170.556	0.306
147	Myanmar	169.292	0.303
148	Angola	165.482	0.293
149	Mali	164.933	0.291
150	Comoros	163.617	0.288
151	Sierra Leone	163.524	0.287

152	Zimbabwe	163.190	0.286
153	Kenya	161.047	0.281
154	Malawi	159.408	0.276
155	Liberia	156.781	0.269
156	Papua New Guinea	143.716	0.235
157	Nigeria	143.668	0.235
158	Cameroon	142.798	0.232
159	Eritrea	140.751	0.227
160	Haiti	138.398	0.221
161	Guinea	137.721	0.219
162	Sudan	128.788	0.195
163	Burundi	126.889	0.190
164	Ethiopia	123.505	0.181
165	Burkina Faso	117.463	0.165
166	Guinea Bissau	109.543	0.144
167	Niger	100.041	0.119
168	Yemen	94.859	0.105
169	Afghanistan	91.571	0.096
170	Congo Republic	83.538	0.075
171	Somalia	73.646	0.049
172	Chad	71.884	0.044
173	Central African Republic	71.494	0.043
174	South Sudan	55.311	0.000

Appendix 2. Indicator scores

Countries	Security_apparatus	Group_cohesion	Nonillicit_activity	Lack_of_conflict	Disaster_recovery	Road_adequacy	Airport_adequacy	Power_adequacy	Economic_equality	Legitimacy	Public_services	Adult_literacy	Gender_equality	Poverty_gap	Social_insurance	life_expectancy	Water_access	Sanitation_access	Gov_health_expend	Adapt_capacity	Climate_sensitivity	Human_rights
Afghanistan	8.2	17	0	0	25	0	0	0	13.2	4.1	3.2	26.6	32.5	92.4	0	31.9	47.1	39.4	0.1	27.387	40.13	12.2
Albania	56.1	59.6	50	100	25	25	50	25	82.9	52	68.1	97.6	75.3	99.5	66.7	70.1	86.7	98.6	6.4	58.728	76.94	68.4
Algeria	45.9	26.6	50	75	75	25	50	50	57.9	24.5	56.4	76.1	49.1	99.5	66.7	65.3	91	87.6	10.8	53.803	74.86	26.5
Angola	37.8	10.6	50	75	50	25	50	25	6.6	20.4	13.8	56.2	32.1	39.2	33.3	21.8	28.4	46.5	1.1	18.259	73.54	36.7
Antigua_Barbuda	53.1	63.8	83.3	100	0	75	75	50	59.2	68.4	68.1	98.7	63.1	99.2	33.3	65.8	96.2	87.5	13.3	37.569	64.52	60.2
Argentina	61.2	71.3	41.7	100	75	50	50	50	51.3	69.4	64.9	98.8	60.2	98.7	66.7	64.8	98.5	93.6	20.9	63.025	80.45	77.6
Armenia	46.9	28.7	33.3	25	25	25	25	50	86.8	40.8	64.9	99.6	72.1	99.5	100	60.5	100	94.1	2.1	60.387	73.14	45.9
Australia	83.7	74.5	50	100	50	75	100	75	84.2	99	88.3	99.9	91.7	99	100	81.8	100	100	59.4	82.023	98.52	82.7
Austria	90.8	70.2	91.7	100	100	100	100	100	88.2	95.9	91.5	99.9	95.5	99.5	100	78.9	100	100	73.8	85.283	80.9	98
Azerbaijan	45.9	34	58.3	25	75	50	75	75	67.1	7.1	51.1	99.7	64.4	100	100	54.8	87.4	92.9	2.8	52.963	57.82	24.5
Bahamas	55.1	80.9	75	100	0	50	50	0	56.6	86.7	50	99.9	60.4	99.2	33.3	57.2	99.8	95.5	17.2	0	67.41	53.1
Bahrain	51	1.1	50	50	100	75	75	50	43.4	20.4	80.9	96.8	78.7	100	66.7	66.5	100	100	19.7	62.084	39.41	16.3
Bangladesh	31.6	7.4	33.3	75	0	25	25	25	46.1	22.4	25.5	66.4	37.4	93.1	0	53.3	96.7	44.6	0.2	20.684	36.64	26.5
Barbados	60.2	80.9	91.7	100	0	75	75	75	52.6	90.8	70.2	99.5	72.5	99.2	33.3	71.8	99.2	98.1	9.2	73.537	61.93	73.5
Belarus	41.8	42.6	41.7	50	75	50	25	50	82.9	9.2	80.9	99.7	89.7	100	100	58.4	95.9	98.7	13.6	73.037	74.44	20.4
Belgium	75.5	68.1	50	100	100	75	100	75	94.7	95.9	83	99.9	99	99.7	100	78.7	100	100	70.4	80.131	61.93	88.8
Belize	31.6	52.1	66.7	75	0	50	50	25	78.9	70.4	51.1	91.9	55.6	97.2	66.7	59.3	98.3	87.9	5.9	41.251	47.62	42.9
Benin	51	76.6	66.7	100	100	25	50	25	21.1	48	19.1	25.9	27.7	43	33.3	23.7	45.9	10	0.2	12.111	26.42	40.8
Bhutan	77.6	2.1	58.3	100	0	25	25	100	69.7	73.5	50	57	49.9	99.5	0	51	97	67.6	4.3	38.899	66.03	48
Bolivia	51	30.9	58.3	75	50	25	50	50	23.7	35.7	42.6	90.3	48.7	95.7	33.3	50.4	89.7	58.2	6	30.754	70.65	46.9
Bosnia_Herzegovina	60.2	22.3	58.3	75	25	25	25	75	75	39.8	64.9	96.1	84.3	100	66.7	66.8	95.2	96.1	15.6	60.165	84.57	59.2
Botswana	66.3	66	91.7	100	100	75	75	25	38.2	76.5	40.4	84.2	46.4	90.1	0	45	85.6	76.3	14.4	29.608	66.72	48
Brazil	41.8	22.3	41.7	100	100	25	50	50	39.5	34.7	33	91.2	56.2	95.9	66.7	62.5	98.7	88.3	10.9	64.61	89.72	26.5
Brunei	65.3	23.4	100	100	100	75	75	75	31.6	20.4	88.3	96.4	75.3	99.5	33.3	62.6	100	98.5	31.9	41.425	77.62	34.7
Bulgaria	63.3	62.8	66.7	100	75	50	50	75	59.2	69.4	68.1	97.9	77.3	99	100	60.5	100	85.8	16.1	66.03	78.98	70.4
Burkina_Faso	5.1	39.4	33.3	0	75	25	0	25	11.8	29.6	13.8	24.3	27.9	71.5	0	22.8	15.3	13.2	0.7	13.047	67	29.6
Burundi	25.5	34	50	50	25	25	25	0	28.9	7.1	22.3	59.3	39.4	20.9	0	23.1	36.7	42	0.2	18.387	42.48	13.3
Cambodia	39.8	45.7	66.7	75	0	25	25	25	39.5	8.2	30.9	74.9	45.2	90.3	0	45.8	66	56.6	0.9	26.106	56.39	16.3
Cameroon	22.4	19.1	50	25	25	25	50	0	26.3	8.2	17	70.5	33.6	78.6	0	16.7	36	34.7	0.1	20.018	67.72	26.5
Canada	77.6	84	50	100	100	100	75	75	89.5	99	91.5	99.9	94.2	99.7	100	79.6	100	100	65.7	89.657	100	82.7
Cape_Verde	62.2	79.8	75	100	25	50	100	50	59.2	69.4	50	83	58	98.2	33.3	54.6	80.3	72.6	4	43.019	65.69	81.6
Central_African_Republic	25.5	19.1	33.3	0	0	0	50	0	0	6.1	0	19.4	19.1	16.5	33.3	0	34.8	20.6	0	8.622	40.99	13.3
Chad	16.3	12.8	33.3	50	0	25	25	0	11.8	13.3	4.3	0	16.7	61.3	0	3.2	0	1.1	0.1	0	37.01	19.4
Chile	62.2	58.5	50	100	50	50	100	75	60.5	60.2	68.1	96	68.5	99.5	100	74.4	100	100	20.1	71.18	84.32	68.4
China	55.1	36.2	75	100	25	75	75	75	40.8	19.4	55.3	95.9	84.2	99.7	66.7	65.3	89.7	84.5	9	64.812	77.54	6.1
Colombia	35.7	28.7	25	50	25	25	50	75	40.8	51	45.7	93.7	53.1	95.7	33.3	66.4	97.2	89.7	14.1	49.876	92.36	27.6
Comoros	48	47.9	58.3	75	25	0	25	0	17.1	19.4	24.5	47	30.6	82.7	0	30.9	68.8	31.2	0.1	32.583	48.37	40.8
Congo_Republic	17.3	2.1	41.7	0	75	0	0	0	10.5	6.1	8.5	70.4	22.5	0	0	20.7	7.5	14.4	0	18.219	49.54	10.2
Costa_Rica	39.8	7.4	50	100	100	25	75	50	25	9.2	12.8	97.3	68.9	98.5	33.3	74.6	100	98.7	16.6	62.268	54.87	31.6
Cote_dIvoire	70.4	79.8	41.7	75	75	25	50	50	55.3	89.8	61.7	32	30.6	75.1	33.3	12.6	56.7	27	0.8	26.167	83.01	86.7
Croatia	37.8	34	50	75	25	75	75	100	27.6	30.6	19.1	98.8	89.3	99.2	100	69	100	97.3	26.8	66.11	59.73	34.7
Cuba	84.7	59.6	91.7	100	25	25	25	25	84.2	79.6	78.7	99.7	65.4	97.2	33.3	70.8	93.9	93.2	38.4	46.454	65.53	84.7
Cyprus	70.4	75.5	50	50	100	75	75	50	73.7	22.4	57.4	98.3	93.9	100	66.7	76.6	100	100	19.2	65.537	74.08	40.8
Czech_Republic	72.4	57.4	91.7	100	75	75	75	75	69.7	62.2	74.5	99.7	87.5	100	100	71.7	100	100	43.2	81.508	65.22	69.4
Democratic_Republic_Congo	84.7	62.8	66.7	75	50	25	75	25	97.4	67.3	78.7	74.6	32	60.8	33.3	31.4	57.2	14.1	0.7	1.948	88	84.7
Denmark	93.9	72.3	66.7	100	100	75	75	75	96.1	100	91.5	99.9	99.6	99.7	100	76.9	100	100	83.5	81.795	72.35	99
Djibouti	51	42.6	58.3	50	50	50	50	50	28.9	11.2	22.3	41.8	30.6	85.8	33.3	37.6	61.2	61.4	1.1	23.976	42.35	24.5
Dominican_Republic	49	56.4	58.3	100	25	50	75	25	61.8	50	35.1	92	47.8	99.7	33.3	57.6	96.2	83.5	7.7	44.824	67.79	59.2
Ecuador	39.8	42.6	41.7	75	0	50	75	75	43.4	35.7	45.7	92.7	55.8	97.5	33.3	65.6	91.7	88	8.4	46.233	69.56	55.1
Egypt	27.6	23.4	66.7	75	25	50	75	100	64.5	15.3	45.7	62.9	48.2	98.5	66.7	52	100	94.8	2.9	68.219	37.7	11.2
El_Salvador	43.9	45.7	33.3	100	25	25	50	75	55.3	43.9	43.6	85.8	54.8	99.2	33.3	55.5	97.3	87.4	6.4	44.454	70.97	41.8
Equatorial_Guinea	44.9	19.1	66.7	75	75	50	50	50	26.3	2	14.9	93.6	41.8	92.1	33.3	15.3	43.1	64.3	2.3	128.247	82.79	21.4
Eritrea	43.9	12.8	66.7	25	75	25	25	25	22.4	3.1	22.3	69.9	30.6	51.1	0	35.9	34.8	20.6	0.1	5.311	24.69	11.2
Estonia	87.8	33	91.7	100	75	75	75	75	84.2	94.9	89.4	99.9	93.2	99.5	100	69.5	100	100	30.6	66.899	92.82	86.7
Ethiopia	21.4	10.6	58.3	0	25	25	50	50	19.7	20.4	11.7	38	40.9	76.1	0	36.7	4	0	0.2	0	55.88	15.3
Fiji	39.8	50	83.3	100	25	75	75	50	60.5	42.9	64.9	98.8	59.8	99.7	33.3	39.7	91.4	95.7	4.3	21.537	57.92	51
Finland	84.7	100	66.7	100	100	100	75	100	100	100	98.9	99.9	98.4	99.7	100	79	100	100	60.1	45.91	89.85	99
France	73.5	33	66.7	100	100	100	100	100	85.5	90.8	92.6	99.9	98.2	100	100	81.7	100	99.7	66.2	97.045	78.82	91.8
Gabon	21.4	72.3	75	100	50	0	25	25	44.7	14.3	31.9	80.3	37.6	98	33.3	36.6	78.1	43.7	4.9	89.974	75.18	37.8
Gambia	46.9	75.5	58.3	75	100	25	50	25	40.8	39.8	23.4	36.7	26.9	94.1	0	24.4	65.2	34.8	0.3	32.043	46.77	30.6

Appendix 3. Indicator scores (cont'd)

Countries	Security_apparatus	Group_cohesion	Nonillicit_activity	Lack_of_conflict	Disaster_recovery	Road_adequacy	Airport_adequacy	Power_adequacy	Economic_equality	Legitimacy	Public_services	Adult_literacy	Gender_equality	Poverty_gap	Social_insurance	life_expectancy	Water_access	Sanitation_access	Gov_health_expend	Adapt_capacity	Climate_sensitivity	Human_rights
Gambia	46.9	75.5	58.3	75	100	25	50	25	40.8	39.8	23.4	36.7	26.9	94.1	0	24.4	65.2	34.8	0.3	32.043	46.77	30.6
Georgia	54.1	29.8	50	50	25	25	50	75	67.1	23.5	69.1	99.5	60.6	96.9	66.7	56.8	99	90.2	5.3	24.63	72.81	54.1
Germany	75.5	69.1	83.3	100	100	75	100	75	85.5	96.9	92.6	99.9	94.1	100	100	76.7	100	100	81.4	55.089	68.83	94.9
Ghana	64.3	73.4	58.3	75	75	25	50	50	32.9	68.4	37.2	73	36.8	88.3	100	30	71	12.2	1	89.997	61.25	66.3
Greece	70.4	62.8	41.7	100	0	50	50	50	78.9	45.9	57.4	97.3	89.3	99	100	79.2	100	100	20.8	45.47	69.66	61.2
Greenland	93.9	72.3	66.7	100	100	75	75	75	96.1	100	91.5	99.9	99.6	99.7	100	76.9	100	100	83.5	87.607	72.35	99
Grenada	56.1	63.8	83.3	100	0	75	50	75	61.8	67.3	61.7	98.2	63.1	97.2	33.3	76.9	94.4	91.8	4.5	81.795	79.83	84.7
Guatemala	42.9	5.3	25	25	0	25	75	25	43.4	30.6	37.2	75.9	42.9	93.4	33.3	53.5	92	63	2.9	50.321	66.19	21.4
Guinea	13.3	4.3	58.3	75	75	0	0	0	27.6	6.1	8.5	12.5	30.6	73	0	58.1	38.5	16.8	0.2	52.641	53.23	27.6
Guinea_Bissau	24.5	61.7	50	50	0	0	25	0	9.2	12.2	9.6	30	30.6	18.6	33.3	22.9	46.3	14.4	0.1	17.755	30.64	37.8
Guyana	38.8	42.6	83.3	100	0	25	50	25	77.6	58.2	46.8	81.5	42.9	97.2	66.7	14.2	94.2	85.6	5.4	11.191	63.22	64.3
Haiti	30.6	40.4	66.7	75	0	0	25	0	5.3	0	1.1	50.7	26.9	79.6	0	46.4	44.4	29.9	0.2	40.886	55.39	8.2
Honduras	35.7	53.2	50	75	0	25	50	0	34.2	33.7	26.6	85.8	44.5	82.7	0	29.7	93	80.7	2.4	18.775	62.04	22.4
Hungary	86.7	70.2	66.7	100	50	100	75	75	88.2	41.8	79.8	98.8	72.3	99.2	100	60.9	100	98.9	25.1	42.523	60.71	46.9
Iceland	99	98.9	91.7	100	75	75	75	100	100	98	100	99.9	97.5	100	100	63.6	100	99.8	72.4	72.559	84.57	100
India	43.9	14.9	41.7	50	25	50	50	50	47.4	56.1	31.9	67.1	41.8	88.3	66.7	82.1	89.6	56.9	1.2	84.536	65.72	24.5
Indonesia	52	31.9	66.7	75	50	25	50	75	67.1	53.1	46.8	94.5	48.1	98.7	33.3	45.4	83.9	71.8	3.1	44.128	79.79	33.7
Iran	33.7	2.1	33.3	50	0	50	50	25	64.5	5.1	66	81.3	42.9	99.7	66.7	51.1	93.7	88.4	13.3	48.922	72.42	0
Iraq	28.6	20.2	0	25	0	0	25	0	48.7	17.3	21.3	81.5	36.9	99.2	66.7	64.7	95.9	94.7	5.8	50.625	49.37	25.5
Ireland	83.7	98.9	75	75	100	75	75	75	94.7	99	85.1	99.9	93	99.7	100	48.2	97.3	91.5	74.9	60.068	74.94	86.7
Israel	65.3	25.5	41.7	75	0	50	75	100	73.7	53.1	87.2	99.9	92.1	100	66.7	80.5	100	100	35.6	86.554	62.08	61.2
Italy	55.1	66	33.3	100	75	75	50	50	80.3	84.7	68.1	99	96	97.2	100	82	100	99.8	46	92.144	69.78	93.9
Jamaica	30.6	88.3	50	100	25	50	50	50	53.9	62.2	35.1	84.7	53.8	99	33.3	83.5	86.1	87.2	6.2	86.167	62.83	51
Japan	83.7	85.1	66.7	100	50	75	75	75	80.3	99	90.4	99.9	92.2	99.5	66.7	58.9	100	100	65.1	54.742	63.9	73.5
Jordan	58.2	14.9	41.7	75	75	50	75	50	68.4	32.7	58.5	97.7	45.8	100	66.7	85.8	99.8	98.1	6.2	90.121	49.62	30.6
Kazakhstan	64.3	26.6	41.7	100	75	50	75	75	92.1	19.4	67	99.7	79.2	100	66.7	59	94.4	98.8	8.1	67.329	82.13	32.7
Kenya	31.6	20.2	25	50	50	0	25	0	23.7	26.5	24.5	76.2	36.3	70.2	0	55.6	33.5	23.8	1.2	73.175	54.55	40.8
Kuwait	80.6	52.1	75	100	100	75	75	25	60.5	31.6	74.5	95	73.9	100	66.7	37	100	100	55.5	34.971	64.3	29.6
Kyrgyz_Republic	48	16	58.3	75	75	25	50	50	61.8	18.4	51.1	99.5	56.8	99.7	66.7	61.7	80.9	97.3	1.8	72.292	75.9	37.8
Latvia	84.7	23.4	83.3	100	75	75	75	75	71.1	86.7	74.5	99.9	83.4	99.2	100	40.4	99.3	92.5	19.4	73.028	71.93	84.7
Lebanon	25.5	16	33.3	25	0	25	75	0	32.9	23.5	28.7	93.7	59.2	100	66.7	60	89.4	99.5	9.3	67.108	59.15	32.7
Lesotho	45.9	72.3	66.7	75	25	50	50	25	22.4	56.1	27.7	69.9	36.1	75.6	0	71.2	49.6	38.7	3	53.442	67.23	52
Liberia	35.7	56.4	58.3	75	75	0	25	0	19.7	40.8	12.8	33.5	23	63.1	0	2.5	56.7	10.6	54.6	26.601	33.42	28.6
Libya	8.2	27.7	25	0	100	25	0	0	31.6	7.1	24.5	91.9	83.1	99.7	66.7	29.8	99.2	100	0	25.439	58.27	6.1
Lithuania	82.7	76.6	66.7	100	75	100	75	75	69.7	89.8	70.2	99.7	89.1	98	100	54.4	97.5	93.9	26.1	32.242	71.68	83.7
Luxembuourg	99	89.4	66.7	100	100	100	100	100	94.7	100	91.5	99.9	94.9	99.5	100	62.5	100	98.5	88.3	64.973	59.88	91.8
Macedonia	29.6	51.1	50	100	50	50	50	50	27.6	2	24.5	97.2	63.1	95.2	100	80.6	90.2	100	10.5	85.346	73.98	7.1
Madagascar	63.3	47.9	50	75	0	0	25	25	67.1	58.2	64.9	67.6	30.6	1.5	0	62.5	26	3.5	0.4	50.116	43.16	76.5
Malawi	42.9	62.8	83.3	100	0	25	50	0	5.3	32.7	7.4	51.2	27.5	24.2	0	37.9	49.9	20.6	0.5	8.401	50.21	43.9
Malaysia	61.2	61.7	83.3	75	100	50	100	75	23.7	28.6	22.3	93.4	70.3	100	33.3	30	96.2	100	10.4	17.392	84.86	53.1
Maldives	56.1	54.3	50	75	50	25	50	75	72.4	38.8	70.2	98.2	58.6	100	0	63.4	100	100	17.4	65.402	66.21	28.6
Mali	55.1	68.1	33.3	25	0	25	0	25	89.5	34.7	52.1	17	19.8	59.8	0	70.6	65.7	34.9	0.3	45.95	56.22	30.6
Malta	3.1	14.9	75	100	100	25	75	75	31.6	13.3	11.7	92.9	80.2	99.7	100	16.6	100	100	42.5	9.99	59.09	24.5
Mauritania	86.7	83	66.7	75	75	0	25	25	88.2	75.5	90.4	40.2	26.9	96.4	33.3	81	53.1	44.8	1.1	85.469	4.4	68.4
Mauritius	46.9	18.1	83.3	100	50	50	75	50	23.7	23.5	20.2	91.2	58.3	100	66.7	32.5	100	96.2	10.2	13.454	65.75	31.6
Mexico	89.8	45.7	16.7	75	100	50	50	75	78.9	77.6	74.5	94.1	62.7	98.7	66.7	59.1	100	91.5	9.1	61.298	91.23	67.3
Micronesia	20.4	37.2	41.7	100	0	50	50	25	46.1	36.7	34	61.8	41.8	86	33.3	60.6	66.2	88.3	1.8	57.11	0	48
Moldova	73.5	62.8	66.7	75	50	25	25	25	31.6	63.3	43.6	99.2	76	100	100	40.9	83.6	75.2	4.6	53.786	51.08	67.3
Mongolia	59.2	43.6	91.7	100	100	50	75	50	78.9	57.1	60.6	97.9	64.2	99.7	100	51.9	74	55.8	5.2	44.811	73.2	65.3
Montenegro	71.4	76.6	58.3	75	50	50	50	50	55.3	61.2	56.4	98.5	89.7	99.2	100	46.1	96.7	98.7	17.6	64.529	60.8	57.1
Morocco	64.3	6.4	50	75	25	50	75	50	86.8	63.3	69.1	66.3	42.9	99.5	66.7	65.5	79.8	88.5	3.1	58.996	69.69	73.5
Mozambique	61.2	17	50	50	50	50	50	25	60.5	32.7	55.3	49.4	33.2	27.2	33.3	64.6	28.2	24.1	0.3	28.621	47.85	50
Myanmar	35.7	22.3	50	25	0	0	50	25	2.6	24.5	6.4	68.6	47.1	99.5	33.3	20.1	71.5	62.2	0.7	28.575	68.89	31.6
Namibia	7.1	2.1	75	100	0	75	75	25	27.6	5.1	8.5	89.1	46.9	87.8	0	38.4	72.6	29.7	6.9	36.186	59.52	4.1
Nepal	62.2	60.6	58.3	75	25	0	50	25	32.9	70.4	33	58.7	44.9	92.4	33.3	28.9	83.1	59.8	0.7	27.993	63.05	76.5
Netherlands	49	7.4	66.7	100	75	75	100	100	56.6	37.8	34	99.9	99.5	99.7	100	48.3	100	98.6	62.8	98.364	37.25	40.8
New_Zealand	86.7	73.4	91.7	100	25	75	100	75	96.1	100	96.8	99.9	88	99.5	100	79.3	100	100	51.7	93.468	85.32	96.9
Nicaragua	88.8	84	75	50	25	25	25	50	85.5	99	93.6	77.6	47.6	98	33.3	79.4	71	73.2	4.8	47.044	66.09	96.9
Niger	48	38.3	41.7	0	0	0	25	0	34.2	7.1	36.2	16.5	23.5	65.1	0	58.7	19.2	6.9	0.4	6.676	31.22	24.5
Nigeria	10.2	23.4	41.7	25	75	25	25	0	21.1	33.7	4.3	37.1	30.6	68.2	0	25.2	54.2	34.8	0.5	20.429	68.36	32.7

Appendix 4. Indicator scores (cont'd)

Countries	Security_apparatus	Group_cohesion	Nonillicit_activity	Lack_of_conflict	Disaster_recovery	Road_adequacy	Airport_adequacy	Power_adequacy	Economic_equality	Legitimacy	Public_services	Adult_literacy	Gender_equality	Poverty_gap	Social_insurance	life_expectancy	Water_access	Sanitation_access	Gov_health_expend	Adapt_capacity	Climate_sensitivity	Human_rights
Norway	90.8	72.3	83.3	100	100	75	100	100	100	100	98.9	99.9	99.1	99.5	100	52.7	100	99	100	100	92.88	100
Oman	80.6	68.1	58.3	100	75	100	75	50	67.1	26.5	76.6	95	66.5	100	66.7	81.9	88.2	100	26	42.69	67.06	34.7
Pakistan	21.4	5.3	16.7	25	0	25	50	25	56.6	20.4	25.5	47.4	36	98.7	33.3	67.8	87.6	57.4	1	44.679	33.24	22.4
Papua_New_Guinea	30.6	48.9	66.7	75	25	0	50	0	18.4	43.9	8.5	50.6	11.8	62.3	0	69.7	4.3	6.1	1.1	14.323	42.05	30.6
Paraguay	46.9	55.3	83.3	75	25	25	50	50	35.5	35.7	48.9	93.2	44.2	99.2	33.3	31.3	100	90	6.9	57.329	84.15	48
Peru	43.9	16	33.3	75	25	50	50	100	44.7	23.5	33	92.8	56.8	98.2	33.3	58.3	86.9	73.1	8.2	46.002	86.28	42.9
Philippines	12.2	33	66.7	50	0	25	50	25	59.2	35.7	40.4	97.7	51.3	96.9	33.3	64.8	91	75.5	2.1	52.451	63.86	28.6
Poland	86.7	52.1	58.3	100	100	50	75	75	89.5	67.3	77.7	98.3	89.6	99.5	100	50	100	99.8	24.6	77.765	81.44	60.2
Portugal	100	91.5	75	100	50	100	75	100	84.2	93.9	80.9	95	94.5	99.5	100	67.8	100	100	34.2	89.872	69.36	88.8
Qatar	94.9	75.5	91.7	75	100	75	100	100	48.7	36.7	78.7	91.6	79.3	100	66.7	77.9	100	100	40.6	82.956	61.05	49
Romania	85.7	46.8	66.7	100	50	50	75	75	67.1	60.2	56.4	98.5	65	96.9	100	74.6	100	84	21.5	58.823	67.4	57.1
Russia	14.3	18.1	33.3	25	50	25	75	75	55.3	7.1	56.4	99.6	72.6	100	100	61.6	96.8	90.7	15.1	78.88	93.11	6.1
Rwanda	45.9	9.6	66.7	75	50	25	25	25	23.7	34.7	38.3	65.5	52.9	46.8	33.3	54.2	31.5	64.7	0.8	24.679	45.83	35.7
Samoa	68.4	44.7	91.7	100	25	75	50	50	72.4	63.3	57.4	98.8	59	99.7	66.7	43.4	97.3	99.1	4.3	32.771	49.49	61.2
Sao_Tome_Principe	57.1	57.4	75	100	50	25	50	0	31.6	66.3	38.3	90.7	36	66.7	33.3	55.7	75.6	38.9	1.5	32.234	49.08	74.5
Saudi Arabia	53.1	0	41.7	75	50	75	75	75	63.2	25.5	69.1	94	76.5	100	66.7	47.4	100	100	37.7	42.203	70.02	22.4
Senegal	55.1	47.9	66.7	75	25	25	50	25	40.8	28.6	24.5	38.1	39	66.7	33.3	60.6	69.7	48.2	0.5	23.62	46.84	54.1
Serbia	57.1	18.1	50	75	25	50	75	75	67.1	39.8	68.1	98.5	84.3	91.6	100	40.6	77.6	98.5	15.1	44.603	67.27	66.3
Seychelles	52	62.8	83.3	100	0	100	75	75	55.3	69.4	84	94.7	63.1	98.7	0	63.1	95.4	100	19.8	54.216	61.18	58.2
Sierra_Leone	44.9	43.6	58.3	75	25	25	25	25	25	44.9	13.8	26.9	23.8	70.2	33.3	54.7	36.7	9.2	0.3	7.637	44.09	48
Singapore	100	74.5	100	100	100	100	100	100	71.1	64.3	98.9	96.5	96.5	99.5	33.3	4.1	100	100	38.4	82.279	64.53	55.1
Slovak_Republic	92.9	46.8	58.3	100	75	50	75	100	94.7	72.4	81.9	99.9	80.8	96.9	100	82.9	100	98.8	29.6	67.552	64.32	79.6
Slovenia	100	73.4	83.3	100	75	75	75	100	84.2	88.8	84	99.6	96	100	100	66.8	100	100	39.3	78.701	75.74	90.8
Solomon_Islands	54.1	46.8	75	100	0	0	25	25	26.3	41.8	19.1	84.7	30.6	82.7	0	78.1	48.3	28.6	1.4	21.923	30.31	58.2
Somalia	3.1	6.4	25	0	0	0	0	0	3.9	3.1	5.3	41.8	32.9	51.1	0	54.7	22.7	33.8	0	11.124	21.57	13.3
South_Africa	37.8	41.5	58.3	100	75	50	75	25	32.9	42.9	34	83.3	51.7	84.5	0	11.6	89.6	74.6	10.4	47.557	73.88	50
South_Korea	89.8	75.5	91.7	50	50	75	75	100	81.6	80.6	84	99.9	97.4	99.7	66.7	30.2	100	100	32.2	84.319	84.37	69.4
South_Sudan	0	9.6	16.7	25	0	0	0	0	9.2	1	2.1	5.8	30.6	48.9	0	81.5	3.3	4.4	0.1	0	0	12.2
Spain	74.5	21.3	50	100	100	100	100	75	77.6	40.8	72.3	97.9	95.4	98.7	100	13.1	100	100	43.2	90.658	70.88	80.6
Sri_Lanka	35.7	16	41.7	75	50	75	50	75	42.1	25.5	45.7	89.6	57	99.7	33.3	83.7	84.1	96.5	3.6	43.236	63.38	19.4
Sudan	7.1	0	50	0	25	0	50	25	6.6	5.1	10.6	49.4	34.4	92.9	66.7	65.6	35.8	32	1.1	20.278	16.42	7.1
Suriname	70.4	22.3	75	100	0	0	25	75	64.5	60.2	59.6	92.8	46.3	97.2	66.7	33.6	94	84.2	13.3	50.8	74.01	59.2
Sweden	83.7	72.3	75	100	75	100	100	75	90.8	95.9	96.8	99.9	99.6	99.7	100	51.3	100	100	85.2	80.566	86.51	83.7
Switzerland	90.8	83	91.7	100	100	100	100	75	88.2	100	92.6	99.9	100	100	100	81.3	100	100	43.5	95.317	85.14	99
Tajikistan	49	28.7	58.3	50	0	25	25	0	67.1	5.1	59.6	99.7	57.3	97.7	66.7	51.8	70.5	97.8	1.1	64.215	64.5	17.3
Tanzania	58.2	46.8	58.3	75	75	25	50	25	23.7	34.7	20.2	71.6	37	59.5	0	49.4	29.9	24.6	0.7	25.92	60.31	48
Thailand	23.5	29.8	75	75	50	50	50	50	69.7	24.5	70.2	92	57.3	100	66.7	33.4	100	99.8	9.4	56.972	55.66	25.5
Timor_Leste	48	52.1	75	75	25	0	50	0	46.1	55.1	33	58.9	41.8	88.8	0	65.9	65.7	50.4	3.6	0	58.8	59.2
Togo	45.9	28.7	66.7	75	100	0	50	25	15.8	25.5	22.3	53.3	33.6	47.3	0	45	43.8	9.6	0.2	15.784	60.72	34.7
Trinidad_Tobago	24.5	63.8	50	100	50	50	50	75	53.9	69.4	63.8	98.3	64	99.2	33.3	21.7	98.7	93.9	17.7	48.039	89.77	63.3
Tunisia	34.7	27.7	41.7	75	75	50	75	75	69.7	42.9	54.3	73	67	100	66.7	56.2	95.5	91.2	8.9	59.312	58.95	30.6
Turkey	37.8	4.3	33.3	50	50	50	100	50	28.9	26.5	54.3	95.1	66.4	100	66.7	64.8	99.8	98.1	15.5	62.508	75.42	23.5
Turkmenistan	59.2	46.8	66.7	100	25	25	25	50	52.6	2	66	99.6	63.1	98.5	66.7	67.3	99.7	99.7	3.9	59.959	56.12	18.4
Uganda	36.7	18.1	58.3	75	75	25	50	25	22.4	19.4	24.5	69.8	38	66.7	0	41.7	17.2	12.2	0.3	26.455	42.14	27.6
Ukraine	3.1	26.6	33.3	0	50	25	50	50	61.8	37.8	31.9	100	69	100	100	27.8	91.4	96.9	5.5	66.153	75.12	25.5
United_Arab_Emirates	81.6	77.7	50	100	75	100	100	100	85.5	36.7	87.2	91.2	90.5	100	66.7	51.3	98.3	99.6	28.1	62.323	60.89	35.7
United_Kingdom	72.4	37.2	66.7	75	50	75	50	75	75	68.4	81.9	99.9	89.7	99.7	100	68.3	100	100	62.4	91.274	85.15	72.4
United_States	57.1	36.2	41.7	100	75	75	100	100	71.1	59.2	86.2	99.9	81.8	97.7	100	77.8	100	100	92.1	90.45	90.12	58.2
Uruguay	67.3	80.9	66.7	100	100	75	75	75	75	98	71.3	98.3	70.1	100	66.7	70.3	100	97.4	27.1	63.184	79.08	62.2
Uzbekistan	48	47.9	50	75	75	25	25	0	56.6	9.2	67	100	66.6	44.5	66.7	68.2	98	100	2.9	74.483	44.76	26.5
Venezuela	36.7	36.2	50	25	75	25	0	0	31.6	4.1	17	96.3	47.2	81.9	33.3	51.3	94.5	94.4	3.1	55.1	78.64	14.3
Vietnam	69.4	47.9	83.3	100	25	25	50	25	75	21.4	69.1	93.6	65.2	99	33.3	52.8	92.9	83.1	3.4	50.293	52.21	28.6
Yemen	19.4	8.5	0	0	0	0	0	0	22.4	2	3.2	41.8	0	89.3	33.3	61.5	41.1	56.5	0	11.522	41.41	7.1
Zambia	62.2	36.2	75	100	25	25	50	25	6.6	32.7	25.5	82.9	36.9	21.9	0	36.3	35.3	20.8	1.3	40.228	60.37	18.4
Zimbabwe	19.4	42.6	50	50	25	50	50	0	17.1	9.2	16	85.5	38.8	76.3	0	29.2	42.1	31.5	0.9	42.331	45.5	21.4

Appendix 5. R Code

```
# TITLE: 4.29 Mining Justice Index based on variables scaled 0-100

library(tidyverse)
library(readr)
library(dplyr)

########################## Correlation Matrix #################################

# Import data
data2 <- read_csv("Variables2.csv")

# look at the structure
str(data)

cor_matrix2 <- cor(
  data2,
  use = "pairwise.complete.obs",
  method = "pearson"
)

cor_matrix2

round(cor_matrix2, 2)

library(corrplot)

corrplot(
  cor_matrix2,
  method = "color",
  col = colorRampPalette(c("#b2182b", "white", "#2166ac"))(200),
  type = "upper",
  order = "hclust",
  addCoef.col = "black",
  number.cex = 0.4,   # smaller numbers
  tl.cex = 0.7,       # slightly smaller labels
  tl.col = "black"
)

library(Hmisc)

cor_results2 <- rcorr(as.matrix(data2))

cor_results2$r   # correlations
cor_results2$P   # p-values
```

```
# hides insignificant values
corrplot(
  cor_results2$r,
  p.mat = cor_results2$P,
  sig.level = 0.05,
  insig = "blank"
)

########################## Principal Component Analysis ######################
PCA2 <- read_csv("Variables2.csv")

PCA_results2 <- prcomp(PCA2, scale = TRUE)
# Shows loadings
PCA_results2

# Gives information (sd, prop of var, cumulative prop) about PCs 1-22
output_PCA2 <- princomp(PCA2)
summary(output_PCA2)

# gives eigenvalues (look at greater than 1)
PCA_results2$sdev

# install.packages("factoextra")
library(factoextra)

#PC1 explains 52% of the variance
fviz_eig(PCA_results2, addlabels = TRUE)

# Cos2 plot
fviz_cos2(PCA_results2, choice = "var", axes = 1)
# The code above computed the squared cosine value for each variable
# with respect to the first principal components.
# From the graph, gender equality, public services, economic equality, and infrastructure
# are the top 5 variables with the highest cos2, thus contributing most to PC1.
# (Followed by sanitation access and water access)

library(tidyverse)

#Creating weights using PC1
weights <- data.frame(
  variable = colnames(X),
  final_weight = PCA_results2$rotation[, 1]
)

view(weights)
```

```
df <- read_csv("PCA_variables2.csv")


#file country names separately
countries <- df$Countries

#define PCA loadings
loadings <- data.frame(
  variable = c(
    "Security_apparatus","Group_cohesion","Economic_equality","Legitimacy",
    "Public_services","Human_rights","Nonillicit_activity","Lack_of_conflict",
    "Road_adequacy","Airport_adequacy","Power_adequacy","Disaster_recovery",
    "Adult_literacy","Gender_equality","Poverty_gap","Social_insurance",
    "life_expectancy","Water_access","Sanitation_access","Gov_health_expend",
    "Adapt_capacity","Climate_sensitivity"
  ),
  PC1 = c(0.2306151,
         0.1590251,
         0.1339469,
         0.1908595,
         0.1387429,
         0.2392303,
         0.2178329,
         0.239554,
         0.2426911,
         0.2175209,
         0.2600575,
         0.2294709,
         0.2640573,
         0.1919805,
         0.2264453,
         0.1322497,
         0.2363221,
         0.2365295,
         0.2235244,
         0.205889,
         0.1855769,
         0.2130788)
)

weights <- loadings %>%
  select(variable, PC1) %>%
  rename(final_weight = PC1)

view(weights)
```

```
# keep only indicator variables used in PCA
X <- df %>%
  select(all_of(weights$variable))

# weights into vector
w <- setNames(weights$final_weight, weights$variable)

# raw index
df$PCA_Index_raw <- as.numeric(as.matrix(X) %*% w)

#rescale 0-1
df$JMI <-
  (df$PCA_Index_raw - min(df$PCA_Index_raw)) /
  (max(df$PCA_Index_raw) - min(df$PCA_Index_raw))

# Final index scaled 0-1

JMI_index <- df %>%
  select(Countries, PCA_Index_raw, JMI) %>%
  arrange(desc(JMI))

print(JMI_index)

view(JMI_index)

############################## MAP PC1 JMI #################################

# TITLE: All country map - PCA scores

library(tidyverse)
library(ggplot2)
library(rworldmap)
library(readr)

read_csv("JMI_final 4.27.csv")
JMI2 <- read_csv("JMI_final 4.27.csv")

JMI_final2 <- JMI2

view(JMI_final2)

sPDF <- joinCountryData2Map(JMI_final2
                            , joinCode = "NAME"
                            , nameJoinColumn = "Countries")
```

```
verbose=TRUE

par(mai=c(0,0,0.2,0),xaxs="i",yaxs="i")


# install.packages("countrycode")
library(countrycode)

JMI_final2$ISO3 <- countrycode(
  JMI_final2$Countries,
  origin = "country.name",
  destination = "iso3c"
)

sPDF <- joinCountryData2Map(
  JMI_final2,
  joinCode = "ISO3",
  nameJoinColumn = "ISO3"
)

sPDF@data <- sPDF@data[, !duplicated(names(sPDF@data))]

palette(
  c(
    "brown4"
    ,
    "red3"
    ,
    "red"
    ,
    "orange"
    ,
    "yellow"
    ,
    "lightgreen"
    ,
    "forestgreen"
  )
)

mapCountryData(
  sPDF,
  nameColumnToPlot = "JMI",
  mapTitle = "Just Mining Index",
  catMethod = "fixedWidth",
  numCats = 8,
```

```
  colourPalette = palette(),
  missingCountryCol = "lightgray"
)
```