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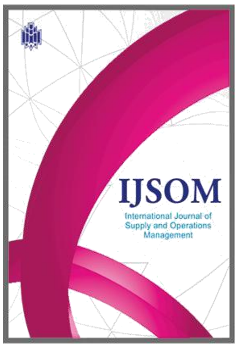

A Sustainability Model for Globalized Mining Supply Chain

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Abstract
New dynamics in consumer behavior demand a review of methods for the provenance of consumer products, especially the evolution of supply chains in the mining and manufacturing industry. This phenomenon has intrigued academic and corporate society to foster research in supply chain sustainability. Globalization has introduced complexities to the traditional implementation of mining supply chain networks that require quantification within a unified framework for commensurable qualitative analysis. Irrespective of valuable opportunity presented by the mining industry to benefit national economies and local communities, there are still however, environmental, and social impacts that beseech a global heed. A more systemic approach to conceptualize within the context of developing assessment tools is imperative This study investigates the effects of globalization on supply chain networks, while leveraging the Triple Bottom Line (TBL) theory to determine relationships with various sustainability dimensions as well as propose a practical mathematical model to estimate the impact of globalization on the traditional supply chain networks with respect to identified sustainability dimensions.

Keywords: Computational theory; Globalization; Sustainability assessment; Mining supply chain.

1. Introduction

The term globalization epitomizes varied implications. The definition of globalization we adopt is that of a phenomenon which explains the procedure of generating networks of associations among actors at intra- or multi-continental distances, facilitated through a variety of flows including people, data, capital, and commodities (Tang et al., 2020). Many have argued that such integration from a mining industry perspective, economically benefits developing countries as well as creates synergies across developed nations. Other philosophies maintain that this phenomenon may be the cause of aggravated inequalities across the globe and a contributor to contemporary issues of sustainability. Of course, the desired result of globalization for most people is one in which the global environment, society and economic system develops sustainably (Tang et al., 2020). Conversely, the sustainability of globalization may not flow in a similar way for all countries (Tang et al., 2020). The global economic system tends to favor developed countries in the globalization process considering all dimensions of sustainability. Hence, sustainability has become a sought-after topic throughout the world. Supply chain management on the other hand is generally defined as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole" (Mentzer et al., 2001). Therefore, the concepts of globalization and supply chain link up at the point where businesses operate on the international scale.

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Extending the supply chain globally gave rise to the term “Global supply chain” which can be described as being characterised by increased comlexity but also associated with increased level of value added activities (Gereffi et. al., 2005). Global supply chains play a critical role in many of the most pressing envirinmental stresss and social struggles identified by the United Nations’ Sustainable Developement Goals (Thorlakson et al., 2018). For this reason, there is an increase in the advocacy for voluntary practices by organizations to vet and improve activities from upstream supply counterparts. According to Thorlakson et al. (2018), a 2008 KPMG survey reported that over 90% of the world’s top 250 businesses employ some form of standard to regulate their suppliers’ social and environmental behaviours. Futhermore, the global effects of environmental problems, increasing ecological awareness, as well as more and more restrictive and complex environment protection legislation, the conditions of operating business activities changes too, especially in the power industry sector (Burchart-Karol et al., 2014). The need for leading-edge standards and models for assessments in this niche is ever-growing. A robust sustainability assessment tool for globalized mining supply chains can be achieved by advancing research efforts in global mining supply chain with a focus on fairness in reporting across mining organizations. This research goes beyond the traditional sustainability methods of assessment by first considering the effects of globalization on each dimension of sustainability based on Triple Bottom Line (TBL). Upon proper classification of these effects and taking into account overlaps across sustainability dimensions, a practical mathematical model is proposed, which uses a globalization effect score (GES) to estimate the impact of globalization on a mining supply chain network. The impact of this model at the global front resonates with evolving efforts in developing indices to quantify complex measures of sustainability in global mining supply chains.

The remainder of the paper is structured as follows. Section 2 provides a literature review that summarises and synthesises arguments and perspectives of related works in globalized minining supply chain sustainability. Section 3 identifies globalization effects in mininig supply chain networks from a TBL point of view. Section 4 introduces a conceptual framework upon which this research is predictated. In section 5 the proposed theoretical mathematical model is developed. Section 6 provides analyses and findings in validating the model, and discusses assumption, limitations and implications. And finally, section 7 concludes the study and suggests future perspectives.

2. Literature Review

A lot of studies in sustainability involve the identification of conditions under which supply chain can be perceived as responsible and sustainable. To investigate these conditions, we review the Triple Bottom-Line (TBL) theory. The TBL theory introduces the notion that sustainable organizations must go beyond traditional and financial bottom-lines in their evaluation process. This evaluation process should include social, environmental, and economic dimensions. In a broader context, the dimensions are sometimes referred to as 3P’s, people, planet, and profit. TBL is a societal and ecological agreement between community and businesses (Jackson et al., 2011). A multifaceted approach that asserts evaluation and reporting will increase transparency across the mining supply chain and alleviate stakeholder concerns on issues of sustainability. On the other hand, the stringent way TBL based assessments are conducted may appear challenging within corporate circles in the mining industry and consequently lead to a reluctance in mainstream adoption of TBL tenets. The tendency of such resistance is natural, especially given the risk of eminent changes in corporate policies and the possibility of overhauling existing processes throughout the value chain. Nevertheless, the struggle to retain all resources possible for future generations while still utilizing enough to survive today must be part of the evolutionary process into sustainability (Jackson et al, 2011).

The mining supply chain is extensive and can be explored in several ways. A global mining supply chain can be defined as network of integrated facilities designed to convey ore products from mines and processing plants, through a variety of modals including roads, ducts, railways, rivers, and oceans, to metal processing customers, which can be located at significant geographic distances (Pimental et al., 2010). Figure 1 illustrates a typical global supply chain.

Traditionally, the mining industry can be split into 4 sub-sectors namely,

1. Energy minerals
2. Metallic minerals
3. Construction minerals, and
4. Industrial minerals.

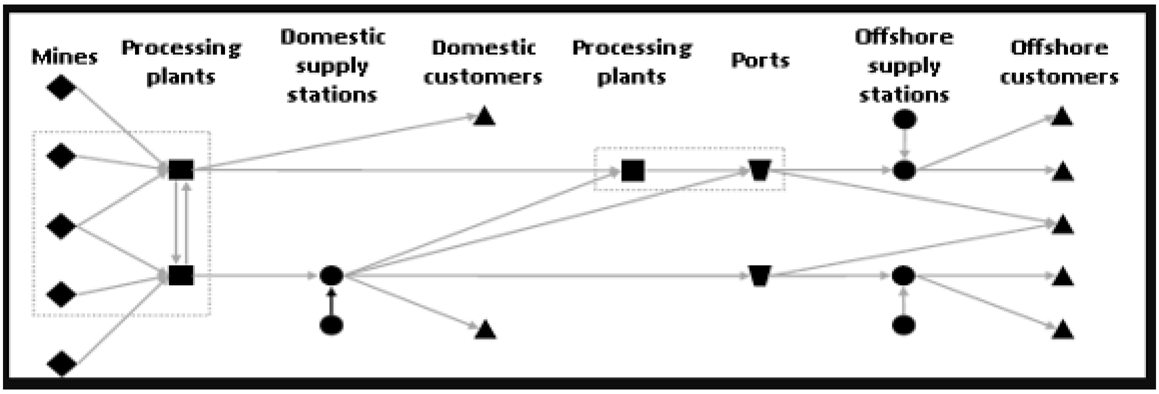

Figure 1. Global mining supply chain (Adapted from Pimental et al., 2010)

Although these four sub-sectors share many common characteristics regarding sustainability issues, they are also quite different (Azapagic, 2004). However, the fundamental differences among these mining sub-sectors are not considered in this research. According to Azapagic (2004), over 80 mineral commodities are produced by the mining and minerals sector, which is quite significant. A significant amount of natural deposits is situated in developing countries across the world. Nonetheless, the presence of substantial sources of wealth does not necessarily translate to economic prosperity, especially in less developed and developing countries. In spite potential economic benefits presented to developing nations by the mining enterprise, Hoffmann et al. (2018), raised the issue of challenges which could accompany these opportunities. Developing countries are often characterized by vulnerable infrastructures, especially in the regulation and enforcement of government policies. This is evident in World Bank’s classification of nations. According to Fantom and Serajuddin (2016), the world bank used an income classification to group countries for analytical purposes into 4 categories namely, high, upper-middle, lower-middle-, and low income countries. The gross domestic product (GDP) alongside political stability and other indices, is an important measure that is factored in this categorization. Apart from geo-political ramifications, there are other critical activities in the mining supply chain that are prone to issues of sustainability, and particularly in the upstream segment. These activities are embedded in the prospecting, exploring, mining, and extracting phases of the value chain. Although most research on mining supply chain sustainability at the global scale focus primarily on the upstream segment, both midstream and downstream segments also present opportunities as well as complexities to the overall supply chain network. Consequently, sustainability concerns diffuse through the supply chain from upstream through the final point of consumption. Environmental concerns become paramount, especially during transportation. The expansion of transportation networks within remote and urban areas, improves the performance of economic activities as well as social pursuits. However, excessive infrastructure construction could put huge pressure on the natural ecological environment when meeting the need for economic development and social improvement (Wang et al., 2018).

Consumers and shareholders expectation are ever-changing. There is an increased awareness of negative environmental impact which is typical of the manufacturing and the mining industry. Consumers are now looking beyond the usual key performance indicators like on-time delivery, pricing, reliability, and quality. There is an ongoing gradual change in perspective, globally, which now includes environmental responsibility in the measurement and determination of sustainability. An example of this change is the increase in the amount of boycott of consumer products from manufacturers in mining supply chains involved in unethical procurement practices. Responsible sourcing across mining supply chain is now a prominent pursuit. Nonetheless, it is not uncommon for certain organizations in the global mining supply chain to focus attention exclusively on strategic suppliers. Other organizations focus on key suppliers based on production criticality and significant spend for their certification programs. These actions are not sufficient, especially when contemporary reporting tools, which are the only avenue to vet sustainability present varied limitations. The Global Reporting initiative (GRI) guidelines have emerged as an important instrument used by firms to structure the content of sustainability reporting (Yang, 2019). The GRI is an independent non-profit, multi-stakeholder standard that helps organizations globally to understand and communicate their impact on issues around the social and environmental dimensions of sustainability. This standard tool cannot, however, account for all peculiarities of the mining industry (Dialga, 2019). According to Young et al. (2014), despite evidence of tracking and identifying the provenance of minerals and metals commodities dating back to the early 2000’s, the phenomenon of formal certification in the mining and metals sector in an organized scheme has only recently been brought to the limelight. Since most of these certification programs focus on the mining organization exclusively, they may not necessarily apply to the entire supply chain. The increased complexity presented by the global mining supply chain due to its extensiveness, inhibits challenges in tracking and traceability. Manufacturers and distributors of commodities further downstream do not have the visibility to lower-tier suppliers. Moreover, their power over suppliers diminishes as the distance upstream the supply chain increases (Young et al., 2019) Corporate Social Responsibility (CSR), which unifies the economic, social, political, and environmental responsibilities of an organization, especially within globalized supply chains has a mandate to address relationships between businesses and society. Airike et al. (2016), contended that CSR should not be limited to its political obligation in creating value across the supply chains, but also to assure good governance and moral responsibility. A recent study on CSR, emphasizes the importance of a collective approach when addressing complex social responsibility issues that reach beyond traditional company boundaries (Airike et al., 2016). In a case study that reviewed two large mining corporations namely, Alcoa and Rio Tinto, it was revealed that the implementation of sustainable strategies at Rio Tinto generated higher-level economic performances as well as impacted overall operations in preceding years. Through these improvements in operational efficiency over the last decade, they have been able to shift economic contributions from payments to suppliers to more value-add payments, which include payments to employees, governments, and investors (Shrivastava and Vidhi, 2020). In fact, these actions have questioned the perceived overhead in terms of cost, which is often associated with sustainability implementations by mining organizations.

Land use is a preeminent issue affecting the social dimension of sustainability in the mining industry. Disputes over land often occur between mine management and community groups (Hilson, 2002). Conflicts are common among key stakeholders who aspire for alternative use of land due to varied concerns. As an attribute that cuts across environmental and social dimensions, resolutions around issues of land use must be appropriately addressed.

3. Globalization effect on mining supply chain sustainability

It is impractical to conduct a holistic sustainability study in the mining supply chain without considering globalization as a driver. Therefore, a systematic approach to this investigation entails specific review of the literature to uncover globalization effects. The effects would be classified according to TBL dimensions to provide a framework upon which a subsequent conceptualization is actualized. Enormous evidence of economic benefits in the mining enterprise both in developed and developing nations has been established throughout existing literature. While a good number of industrialized countries profit from raw mineral and metal extracts to fuel their manufacturing economies, others such as Australia and Canada are heavily invested in global mining economics. On the other hand, a good number of developing countries realized remarkable economic development through mining pursuits as well. According to Walser (2002), countries such as Peru, Chile, Ghana, Botswana, Mali, Ghana, Papua New Guinea, and others have had significant economic impacts from the mining enterprise. Walser (2002) further revealed three important elements that follow globalization alongside the dominance of market economy including:

i. The creation of global capital, goods, and service markets
ii. The creation of global communication and information space
iii. The emergence of global values

The mining sector has also been credited with bringing in a significant amount of foreign exchange earnings, employment opportunities, mineral royalties, employee income taxes as exemplified in Ghana's mining industry, although the flexibility in mining laws and policies have also been cited as a contributor in this case according to Amponsah-Tawiah and Dartey-Baah (2011). Economic sustainability comprises several factors including income, income growth, monopoly power, competition, and trade from a globalization standpoint. The environmental and social dimensions are severely impacted by globalization. Organizations are moving from the conservative approach which focuses mainly on economic and environmental aspects of sustainability. The incorporation of social factors in recent years have become evident. Mancini and Sala (2018) evoked several key components such as demography, human rights, income, employment, education, security, land use, health, and safety in a review, as aspects of social sustainability.

Table 1. A summary of globalization effects on sustainability dimensions (Adapted from Njualem and Ogundare, 2021)

Economic Dimension	Social Dimension	Environmental Dimension
Trade	Security	Air Pollution
Competition	Education	Water Quality
Income	Employment	Biodegradation
Economic Growth	Land Use	Transportation
	EHS	
	Human Rights	

4. A concept for sustainability in globalized supply chains

The core of this research aspires to qualify a global mining supply chain as sustainable. The conception of a robust assessment tool for sustainability in the globalized mining supply chain inquires further on appropriate variables for appraisal. The current literature reveals convincing evidence that globalized mining supply chain sustainability is influenced by factors listed in Table 1. These variables are also not restricted to a one-to-one relationship with specific dimensions of sustainability but to an extent present dimensional overlaps as illustrated in Figure 2. The conceptual framework establishes the bases for the development of a quantitative model.

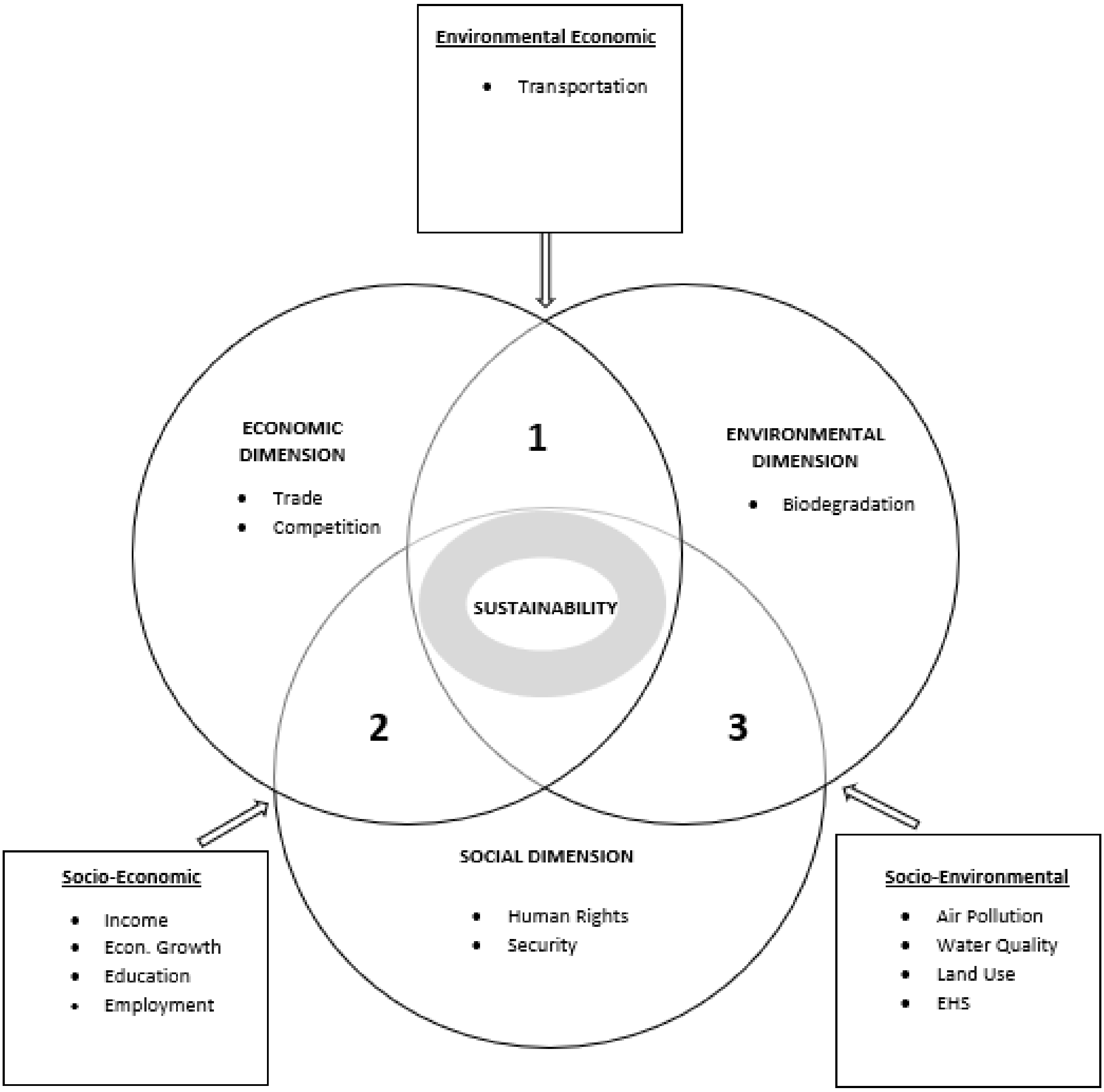

Figure 2. Conceptual framework

5. Methodology

This section introduces the adopted methodology to estimate the impact of globalization on the mining supply chain networks. A theoretical mathematical model is developed based on the conceptual framework on Figure 2. The model validates against actual GDP data from countries with significant mining activities and supply chain networks. The final output of the model yields a Globalization Effect Score (GES), which reflects the impact of globalization on a particular instance of a mining supply chain (Njualem and Ogundare, 2021). Banwarth-Kuhn and Sindi (2020) supported the suitability of mathematical models to study the sensitivity of an output of interest with respect to increasing or decreasing amounts of other factors. To realize ordinal relationships in the proposed model, the captured variables assign discrete values. A summarized score for each dimension of sustainability would easily be determined as a function of low-level factors (Njualem and Ogundare, 2021). An informal definition of the scores is given and followed by a closed form relation of secondary and primary factors which are tuned by α_0 and α_1 respectively.

Economic Dimension Score **(EDS)** =

$$f\begin{pmatrix}Trade\ (t_1), Competition\ (c), Income(i), \%Economic\ Growth\ (e_1), Education\ (e_2), Employment\ (e_3), \\ Transportion\ \ (t_2)\end{pmatrix}$$

EDS = $\alpha_0(t_1\ \times c \times i\ \times e_2 \times e_3 \times t_2)^{1/6} +\ \alpha_1\, e_1$ (1)

Social Dimension Score **(SDS)** = $f\begin{pmatrix}Income\ (i), Security(s), Education(e_2), \\ Human\ Rights\ (h)\end{pmatrix}$

SDS = $\alpha_0(i\ \times s\ \times e_2)^{1/3} +\ \alpha_1\, h_1$ (2)

Environmental Dimension Score **(EVS)** =

$$f\ (Air\ Pollution\ (a), Water\ Quality(w), Biodegradability(b), Land\ Use(l), Transportation(t), EHS(e_4))$$

EVS = $\alpha_0(w\ \times b\ \times l \times t_2 \times e_4)^{1/5} +\ \alpha_1\, a$ (3)

We introduce a Globalization Effect Score (GES) which intrinsically harmonizes the volume density of the economy with environmental and social factors.

$$GES = [\frac{1}{3}(EDS^{-1} + SDS^{-1} + EVS^{-1})]^{-1} \quad (4)$$

Aparently, sustainability dimension score changes depending on the supply chain under investigation. Njualem and Ogundare (2021) developed the tables below to explain the calculation of the scores using discrete values that encapsulate ordinal relationship between the realizations of each decision variable (factor).

Table 2. Ordinal Trade Score

Score	Description
1	Low Trade Activity
2	Average Trade
3	High Trade

Table 3. Ordinal Competition Score

Score	Description
1	No Marketplace Competition / Government Controlled
2	Government Controlled & Restricted Market
3	Semi-free Market
4	Free Market

Table 4. Ordinal Income Score

Score	Description
1	Income Below Poverty Line
2	Income at Poverty Line
3	Income above Poverty Line

Table 5. Ordinal Economic Growth Score

Score	Description
0	<1% Econ. Growth
1	1-5% Econ. Growth
2	6-10% Econ. Growth
3	11-15% Econ. Growth
4	16-20% Econ. Growth
5	>20% Econ. Growth

Table 6. Ordinal Security Score

Score	Description
1	No Security
2	Low Security
3	Medium Security
3	High Security

Table 7. Ordinal Education Score

Score	Description
1	No Primary Education
2	Some Primary Education but no Secondary Education
3	Some Secondary Education but no College Education
4	College Graduate
5	Post Graduate Degree Holder

Table 8. Ordinal Employment Score

Score	Description
1	Unemployed
2	Part-Time Employment
4	Full Time Employment

Table 9. Ordinal Land Use Score

Score	Description
1	Strict Land Use Policy
2	Moderate Land Use Policy
3	Lax Land Use Policy

Table 10. Ordinal Human Rights Score

Score	Description
0	Pervasive Human Rights Violation
1	No Human Rights Violation

Table 11. Ordinal Air Pollution Score

Score	Description
6	Good Air Quality (Index level 0 – 50)
5	Moderate Air Quality (Index level 51 – 100)
4	Air Quality Unhealthy for Sensitive Groups (Index level 101 – 150)
3	Unhealthy Air Quality (Index level 151 – 200)
2	Very Unhealthy Air Quality (Index level 201 – 300)
1	Hazardous Air Quality (Index level 301 and higher)

Table 12. Ordinal Water Quality Score

Score	Description
5	Category 1: Meets tested standards for clean waters
4	Category 2: Waters of concern
3	Category 3: Insufficient data
2	Category 4: Impaired waters that do not require a Total Maximum Daily Load (TMDL)
1	Category 5: Polluted waters that require a water improvement project

Table 13. Ordinal Biodegradability Score

Score	Description
1	Non-Biodegradable
5	Biodegradable

Table 14. Ordinal Transportation Score

Score	Description
1	No Accessibility to Transportation
2	Low Accessibility to Transportation
3	Medium Accessibility to Transportation
4	High Accessibility to Transportation

Table 15. Ordinal EHS Score

Score	Description
1	Loosely Enforced
2	Strictly Enforced

6. Analyses and Findings

In this section the proposed mathematical model introduced in the previous section will be validated. The results will be evaluated and discussed. The validation process is supported by an analysis of mining supply chains stemming from prominent countries where mining activities in the globe are prevelent. To better understand this phenomenon from a diversified front, the world bank's classification of countries as previuosly indicated is leverged. The use of the world bank's datasets has become highly diserable. Over time it has become part of the developement discourse, and academia and the news media frequently find it a useful benchmark to analyze development trends (Fantom and Serajuddin, 2016).

Five countries were selected for each income category, and evaluated based on the 14 primary variables that were captured in the model. This amounted to a total of 20 mining countries that were used in the analyses. It is important to note that these countries are assummed to be primary hosts of upstream mining activities within their supply chain networks. The assessment led to score assignments using table 2 through table 15. Applying the developed model to the data, EDS, SDS, and EVS scores were computed, as well as the globalization effect score (GES) for each mining supply chain network scenario. Table 16 below shows a summary of GES score calculations on all the mining supply chain networks. Meanwhile, figure 3 shows the relationship between GES and 2021 GDP per capita for each involving mining host country.

Using descriptive statistics, table 17 below summarizes the average GDP per capita as well as the average GES score for each income group. These consolidated values strongly suggests a correlation between GDP and GES. However, it is important to note that when comparing 2 mining supply chain networks, one cannot directly infer that the host mining country with the higher GDP will definitely have a better GES performance. This can be established by looking at GDP and GES scores of both Sweden and the United States in table 16. Sweden with a GDP per capita of $58,100 has a better GES score of 0.97 than the United States, which has a higher GDP per capita of $69,231. The details indicate that Sweden performed better in terms of air pollution than the United States. Hence, the model algorithm penalizes mining supply chains that fall short of critical environmental attributes. On the other hand, this experience is replicated within mining supply chains stemming across income groups. This is an important finding especially when considering the spotlighted globalization effects on sustainability in upper-middle, lower-middle and low income countries. Apparently, it can be demostrated by 2 comparisons, including Guinea vs. Uzbekistan and Ghana vs. Botswana as depicted in table 16. Based on these comparisons, Guinea has a higher GES score than Uzbekistan, although the world bank's classification puts Uzbekistan in a higher income echelon. Similarly, Ghana, a lower-middle income country seems to have a better GES performance than Botswana, however, the later is rated as an upper-middle income country.

Table 16. Summary table of GES score calculations on mining supply chain networks

Entity	Country of entity	2021 GDP per capita in USD	Trade Score	Competition Score	Income Score	Economic Growth score	Security Score	Education Score	Employment Score	Land Use Score	Human Rights Score	Air Pollution Score	Water Quality Score	Biodegradability Score	Transportation Score	EHS Score	EVS	SDS	EDS	GES
Mining SC 1	United States	$69,231/00	3	3	3	5	3	3	4	2	1	2	5	1	4	2	2/201	2	4/151	0/837
Mining SC 1	Canada	$43,100/00	3	3	3	5	3	3	4	2	1	3	5	1	4	2	2/701	2	4/151	0/9
Mining SC 1	Sweden	$58,100/00	3	3	3	5	3	3	4	1	1	4	5	5	4	2	3/443	2	4/151	0/97
Mining SC 1	Australia	$56,100/00	3	3	3	4	3	3	4	2	1	3	5	1	4	2	2/701	2	3/651	0/874
Mining SC 1	Poland	$17,400/00	3	2	2	4	2	3	2	1	1	3	5	5	4	2	2/943	1/645	3/285	0/799
Mining SC 2	China	$8,840/00	3	3	2	5	2	3	2	2	0	3	3	1	4	2	2/584	1/145	3/875	0/659

Table 16. Continued

GES	0/799	0/51	0/693	0/595	0/691	0/568	0/397	0/395	0/342	0/304
EDS	3/225	2/645	2/52	1/794	2/391	2/453	1/061	1/707	1/561	1
SDS	1/645	0/794	1/221	1/13	1/294	1	0/794	0/63	0/5	0/5
EVS	2/996	3/11	4/413	4/201	3/913	2/822	3/134	2/803	3/487	3/487
EHS Score	2	2	2	2	2	1	2	2	1	1
Transportation Score	3	3	3	2	2	2	1	2	1	1
Biodegradability Score	5	1	5	5	5	1	5	5	5	5
Water Quality Score	4	3	3	2	3	2	2	3	2	2
Air Pollution Score	3	4	6	6	5	4	4	3	5	5
Human Rights Score	1	0	1	1	1	0	0	0	0	0
Land Use Score	2	3	2	2	3	3	3	2	3	3
Employment Score	2	2	2	2	2	1	1	1	1	1
Education Score	3	2	3	2	2	2	2	2	1	1
Security Score	2	1	1	1	2	2	2	1	1	1
Economic Growth score	4	3	3	2	3	3	1	2	2	1
Income Score	2	2	1	1	1	2	1	1	1	1
Competition Score	2	2	2	1	2	2	1	1	1	1
Trade Score	3	3	2	2	2	3	1	2	2	1
2021 GDP per capita in USD	$11,100/00	$15,000/00	$7,080/00	$6,700/00	$1,960/00	$4,450/00	$1,260/00	$1,680/00	$2,450/00	$420/00
Country of entity	Brazil	Chile	South Africa	Botswana	Ghana	Indonesia	Zambia	Bangladesh	Uzbekistan	Congo
Entity	Mining SC 2	Mining SC 2	Mining SC 2	Mining SC 2	Mining SC 3	Mining SC 3	Mining SC 3	Mining SC 3	Mining SC 3	Mining SC 4

Table 16. Continued

Entity	Country of entity	2021 GDP per capita in USD	Trade Score	Competition Score	Income Score	Economic Growth score	Security Score	Education Score	Employment Score	Land Use Score	Human Rights Score	Air Pollution Score	Water Quality Score	Biodegradability Score	Transportation Score	EHS Score	EVS	SDS	EDS	GES
Mining SC 4	Afghanistan	$570/00	1	1	1	1	1	1	1	3	0	5	2	5	1	1	3/487	0/5	1	0/304
Mining SC 4	Sierra Leonne	$630/00	1	1	1	1	1	2	1	3	0	4	2	5	1	1	2/987	0/63	1/061	0/349
Mining SC 4	Guinea	$1,000/00	1	1	1	1	1	2	1	3	0	5	3	5	1	2	3/73	0/63	1/061	0/357
Mining SC 4	Central African	$382/00	1	1	1	1	1	1	1	3	0	5	2	5	1	1	3/487	0/5	1	0/304

*Mining SC 1: Upstream in High Income Country
*Mining SC 2: Upstream in Upper-Middle Income Country
*Mining SC 3: Upstream in Lower-Middle Income Country
*Mining SC 4: Upstream in Low Income Country

Table 17. Summary table of GDP and GES score averages based on income group

Group	GDP Average	GES Average
High Income Country	$48,786/20	4/378827
Upper-Middle Income Country	$9,744/00	3/255986
Lower-Middle Income Country	$2,360/00	2/987251
Low Income Country	$600/40	1/619278

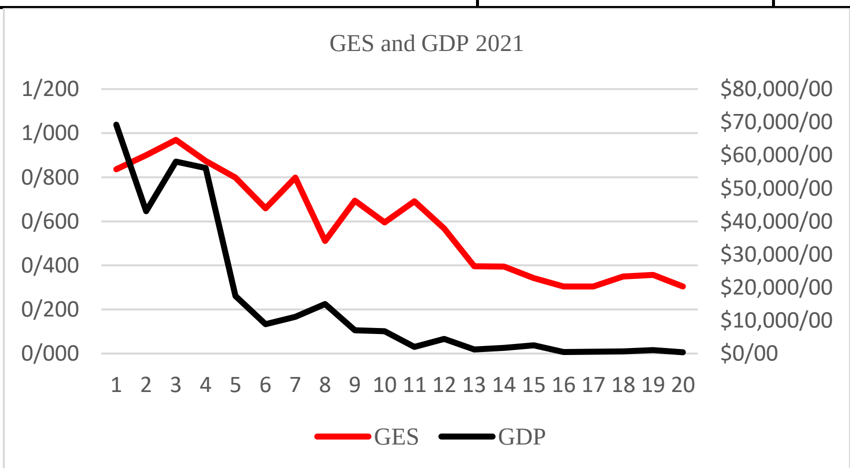

Figure 3. GES vs. 2021 GDP per capita

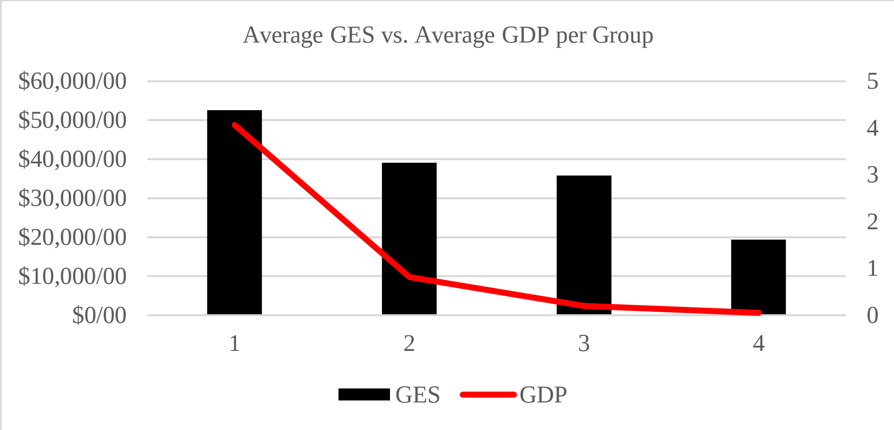

Figure 4. Average GES vs. Average 2021 GDP per capita per group

7. Conclusion

This research aimed at proposing a practical model to assess sustainability in globalized mining supply chains. Globalization contributes immensely to issues around sustainability. In consequence, the research considered globalization effects as primary factors to develop the proposed model. The TBL theory underpins this trajectory by associating the three dimensions of sustainability with various globalization effects. Establishing this relationship is critical, given the extensive nature of globalized mining supply chains. Subsequently, an informal quantitative framework, simplified for practical considerations presents, while accounting for overlapping factors across economic, social, and environmental dimensions. The proposed model is based on computable dimension scores (EDS, SDS and EVS) as functions of discrete random variables resulting in the Globalization Effect Score (GES) as a pragmatic measure for globalized mining supply chain sustainability. Assignment of ordinal scores against globalization effects (factors), according to categories listed in tables 2 through 13, typically will vary from one mining supply chain to the other. Further analyses made it possible to compare the model-based GES results with 2021 GDP per capita for 20 mining countries around the globe. Careful selection of these mining countries according to world bank's income-based classification of nations, accounted for comprehensive data in the analyses. In accordance with the results, there is a perceived correlation between GES and GDP, however, a determination of the impact of globalization on mining supply chain sustainability cannot rely solely on GDP per capita of the host mining country.

The findings of this research contribute to the collective research effort in assessing supply chain sustainability in the mining industry. Specifically, it bridges the gap in the literature by establishing globalization as a key component in the assessment process. Alongside these informed perspectives, the integrated approach applied in the proposed mathematical model will be useful in guiding researchers and providing practical insights to practitioners across public and private sectors. Future study directions may involve case studies, where detailed examination conducts across all echelons of a globalized mining supply chain. Such studies will help address a critical limitation of this research that has to do with the assignment of ordinal scores to various primary variables considered by the model. Assigning ordinal scores that to a greater extent considers globalization effects in the midstream and downstream supply chain will tremendously improve the model and generate a more comprehensive GES outcome. Comparative studies with other sustainability assessment tools discussed in this research are also suggestive.

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