**ANALYSIS OF SUPPLY DISRUPTION RISKS IN A SUPPLY CHAIN**

## 

## Seminar Report

Submitted by

**DARBAR VALI K**

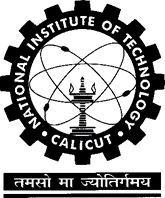
**(B190690ME)**

*in partial fulfilment of the requirements for the award of the degree of*

**Bachelor of Technology**

*in*

**MECHANICAL ENGINEERING**



### 

### Department of Mechanical Engineering

### NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

### NIT CAMPUS PO, CALICUT

### KERALA, INDIA 673601

### 

**ACKNOWLEDGEMENT**

I would like to express my special thanks to my guide Dr.Vinay V Panicker for their able guidance and support in selecting the journal papers and preparing the seminar presentation. I would also like to extend my gratitude to Dr – Shahana A, Callie W.B, Kim D.B the authors of the cited journal article Research – *Disruption risks to material supply chains in the electronics sector.*

I would like to extend my sincere gratitude to the Department of Mechanical Engineering and my institution for giving me this opportunity to commence this extensive study of subject matter and an opportunity to efficiently output it through valuable presentations and project works. I also wish to thank all the faculty in charge of the seminar, especially the one DR. ASHESH SAHA who conducted our seminars and gave support from their side.

I also acknowledge a deep sense of gratitude to my parents for being my constant support and motivation factor. I would also like to extend my gratitude to my teammates for their continuous support and understanding throughout the process.

DARBAR VALI K

**CERTIFICATE**

This is to certify that the report entitled “***ANALYSIS OF SUPPLY DISRUPTION RISKS IN A SUPPLY CHAIN***” is a bonafide record of the seminar presented by ***DARBAR VALI K (B190690ME)*,** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **MECHANICAL ENGINEERING** from the **National Institute of Technology Calicut.**

## **Faculty-in-charge**

(ME4097 - SEMINAR)

*Dept. of Mechanical Engineering*

**Professor & Head**

*Dept. of Mechanical Engineering*

*Place:* NIT Calicut

*Date:* 06-04-2022

Department seal

**ABSTRACT**

Electronic items are an important element of current civilization, but perhaps never more so than when the COVID-19 epidemic drove nearly every area of human interaction to go online. The pandemic, on the other hand, highlighted that supply chains that produce critical raw materials for electronics manufacture are becoming increasingly subject to social, geopolitical, and technical disturbances. These vulnerabilities are expected to intensify in the future as a result of global health crises, natural disasters, and global political instability, all of which will be compounded by imminent climate change impacts. This study explores potential supply chain disruption risks in the electronics sector by using metrics to capture supply, demand, socio-political, and environmental concerns in a multi-criteria framework for over 40 metals and minerals that provide crucial functionality to electronic products. The material risks differed depending on the possible nature of the disturbance, according to the findings. Precious metals such as gold, rhodium, platinum, and palladium, for example, faced the greatest risk in scenarios where disruptions resulted in price volatility or weakening of environmental standards. Cobalt, gallium, and important rare earth elements, on the other hand, posed the most risk in scenarios where supply interruptions resulted in supply strains or geopolitical conflicts. Because these metals are known for their energy-intensive manufacture and highly concentrated geographic production, recycling and supply chain diversification could help mitigate some of the highlighted hazards. Trade-offs between social, economic, and environmental elements are also considered in the study. Cobalt, for example, is a vital component in lithium-ion batteries, and its manufacturing concentration in the Democratic Republic of the Congo has substantial societal consequences. While shifting production to other countries may reduce these risks, it also raises new worries about economic and environmental consequences.

**Keywords:** Electronics Sustainability , COVID-19,Supply chain risks ,Social hotspots, Multi-criteria analysis

**CONTENTS**

**List of Figures ii**

**List of Tables iii**

**1 Introduction 1**

**2 Literature Review 2**

**3 Method**   **3**

3.1 Identifying supply chain disruption risks 3

3.2 Mapping risks to electronics materials 7

3.3 Applying multi-criteria ranking to identify material hotspots 9

3.4 Exploring potential risk mitigation strategies 10

**4 Results and Discussion 12**

4.1 Key material hotspots 12

4.2Recycling as a pathway to reduce disruption risks 13

4. 3Supply chain diversification as a pathway to reduce disruption risks 13

4.4 Potential tradeoffs from changing material supply chains 14

4.5 Conclusion 15

**References 16**

i

**LIST OF FIGURES**

3.1 Conceptual framework of the methods applied to model risks of supply chain disruption and to identify strategies for mitigating these risks in the electronics sector.

ii

**LIST OF TABLES**

#### 3.2 Material scope.

#### 3.3 Disruption scenario descriptions and weightings.

iii

**CHAPTER 1**

**INTRODUCTION**

The way society works, learns, and distributes news and pleasure has been altered by information and communication technology. In times of crisis, when commonplace technological products become the lifeline of human interaction, the relevance of these technologies is never more apparent. During the COVID-19 global epidemic, this role became especially obvious. Individuals and organizations – from governments and colleges to corporations and nonprofits – resorted to electronic technology for communication, education, and home-based labor when physical "distancing" became necessary. Online schools and family relationships were hosted on smartphones and PCs, while TV and movie viewing on streaming media devices reached new heights. Laptops, webcams, and microphones were in such high demand for schools and home offices that the used electronics market exploded as shop inventories couldn't keep up with demand.

However, at a period when electronic gadgets were especially important for pandemic response, the worldwide supply chains required to manufacture these devices began to be strained owing to manufacturing and mining disruptions.

All of these reasons point to the fact that the stresses on material supply networks encountered during the COVID-19 epidemic are merely a foreshadowing of future bottlenecks and vulnerabilities in the electronics industry. Increased frequency and severity of catastrophic natural disasters as a result of climate change would increase the risk of material disruptions while also increasing the burden on supply chains to assure access to energy and sanitation systems, which rely on many of the same materials.

Two critical knowledge gaps must be addressed in order to attain these objectives. To begin, we must comprehend the nature and scope of key supply chain hazards related to electronic materials. Second, a variety of tactics can be utilized to reduce supply chain risks, but it's uncertain which will provide the most value in real-world scenarios.

1

**CHAPTER 2**

**LITERATURE REVIEW**

→ The study of risk and criticality of materials used in a range of applications was the focus of the literature review to identify metrics.

→ The parameters for demand risks were chosen based on their capacity to capture the market pull for a certain material, as evidenced by literature showing how demand fluctuations can ripple up the supply chain.

→ The literature yielded specific indicators capable of capturing these direct and indirect hazards, which were grouped into four risk categories: supply, demand, sociopolitical, and environmental (Supplemental Information (SI) Figure S1

→ The study of risk and criticality of materials used in a range of applications was the focus of the literature review to identify metrics. In the following sections, you'll find more information about each of these topics.

→ Literature has established that reserves, ore quality, depletion index, and byproduct output are all factors in supply risk.

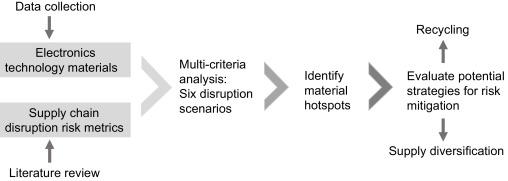
## 

## 

## 2

## **CHAPTER 3**

**METHODS**

* The study's overall purpose was to examine material supply chain risks in the electronics industry in the case of a disruptive event, such as the COVID-19 pandemic. The methodology is conceptualized and consists of four steps: 1) putting together a list of essential measures that can be used to quantify the risks associated with the electronic material supply chain;2) Product material profiles and data compilation are used to map these risks to electronics materials.3) identifying material hotspots under baseline (normal operation) and interruption (COVID-19) situations using multi-criteria rankings;and 4) investigating possible solutions for reducing the dangers associated with material-hotspots.

3.1 In the electronics industry, a conceptual framework for the approaches used to predict supply chain disruption risks and create ways for managing these risks.

**3.1 Identifying supply chain disruption risks**

Metrics capable of capturing direct and indirect risks to electronics material supply chains were defined based on elements previously shown to be relevant to supply disruption risks in general and to the electronics sector in particular in previous literature. For example, due to the abrupt halt or changes in mining, processing, and manufacturing activities, the immediate impact on a material supply chain is experienced in both demand and supply. A mismatch in demand and supply that may arise as a result of such disruptions can have an economic impact in the form of price spikes and volatility, which can spread disruptive events up and down the supply chain.

3

The physical availability of a material, as well as whether it is mined directly or as a by-product of other metal ores, has an impact on its ability to scale up production and supply to meet increased demand.The immediate consequences of sudden disruptions in supply and demand may be magnified by geopolitical difficulties if material sourcing is dependent on a few nations and there are border closures or labor disruptions, such as those connected to measures to limit the spread of the COVID-19 outbreak. Increased material supply to meet demand during the recovery period of an economy would worsen extra socio-political and environmental risks associated with material manufacturing.

The physical availability of a material is determined by available resources as well as the capacity to obtain the item from those resources. Literature has established that reserves, ore quality, depletion index, and by product output are all factors in supply risk.

The global reserve is the working inventory of commercially extractable mineral commodities (GR). The United States Geological Survey (USGS) published data for the year 2019, which is expressed in metric tons. Individual world REE reserves were determined using total REE reserves. Scientists studied data from China's Bayan Obo mine in the case of REEs. The USGS released global REO (Rare Earth Oxide) reserves, as well as the content. Scientists studied data from China's Bayan Obo mine in the case of REEs. The USGS reported (percentage) of each REE in its REO ore.

Lower concentrations indicate more scarce and/or distributed materials that require more energy or expense to extract, whereas higher concentrations indicate more scarce and/or dispersed components that require more energy or expenditure to extract. Except for REEs, data was acquired from the literature for all elements.

Based on research indicating how unexpected changes in demand can ripple up the supply chain, the indicators related with demand risks were chosen based on their capacity to capture the market pull for a certain material. Unless otherwise stated, the data in this section was mostly derived from the USGS. SI Table S1 summarizes the data.

The overall global production of a material to meet demand in all sectors is referred to as annual mining production (AP). Annual production data has been used in the literature to forecast material supply and demand limitations. For most elements, data was obtained from the USGS for the year 2019 and reported in metric tons. The British Geological Based recommendation annual output figures for individual REEs (2011). The percentage of total material produced annually that is used in electronic technologies is known as consumption by the electronics sector (EC). The information came from the USGS and Graedel et al (2015b). It's worth noting that the source data includes

4

all hardware, including electric apparatuses, inserted electronic parts, (for example, electric engines), and customer gadgets. Value (P) is a market request pointer for a possibly scant asset. The information is for the year 2019 and is given in US dollars per kilogram of material.

Cost unpredictability (PV) was determined as a 7-year coefficient of change in a material's yearly normal estimating. Connection among's request and value unpredictability of materials has been recently settled . This measurement was created involving yearly cost information from the USGS for the years 2013 to 2019.\ Because of the fluctuated spatial grouping of metal assets, creation frameworks are scattered all through few nations. Geographic fixation can restrict admittance to certain assets, regardless of whether they are genuinely accessible, because of political or financial variables in the creating nation or in import-subordinate nations. A few measures on international risks have been created, with an attention on provincial creation fixation. The information in this segment was for the most part gathered or determined from the USGS, and it is summed up in SI Table S3.

Topographical grouping of creation (HHI) measures how thought a material's creation is in a couple of countries, which could compound inventory gambles in the event that a nation confines or can't keep up with supply, for instance, because of exchange guidelines, political hindrances, or interruptions (like the COVID-19 pandemic or catastrophic event). The Herfindahl-Hirschman Index (HHI), a factual proportion of market focus, was utilized to decide the topographical grouping of result (Brown, 2018).

Utilizing a public activity cycle evaluation (S-LCA) of work freedoms, wellbeing and security, administration, local area framework, and common liberties in the nation of material creation, the social areas of interest (SH) score measures social dangers of material creation. These boundaries may connected with apparent dangers assuming that they impede material creation, yet they additionally may present aberrant dangers to firms worried about general assessment and ruckus when basic liberties infringement are found. The Social Hotspots Database (SHDB) was utilized to ascertain this measurement, which was determined utilizing an effect appraisal strategy that similarly weighted risk classifications (Social Hotspot 2019). The value, GTAP (Global Trade Analysis Project) classification, and geological circulation of creation are utilized to compute an asset's social areas of interest.The potential for major ecological ramifications associated with energy use, contamination discharge, and waste creation are additionally qualities of material extraction activities (Tost et al., 2018). These outcomes may not comprise an immediate risk to material accessibility, but rather they in all actuality do reflect mining tasks' drawn out reasonability, particularly considering diminishing outside conditions and expanded public examination of inventory network liability.

5

Each of the indicators described below adopts a life cycle approach, accounting for both direct material extraction impacts as well as any upstream implications connected to the production of energy, chemicals, infrastructure, and other extraction process inputs.The metrics are based on life cycle impact assessment methods that are often used to calculate a material's environmental footprint (Nuss and Eckelman, 2014). SI Table S4 contains data for each metric. These effects were computed in SimaPro8 using data from the ecoinvent 3.5 database processes and life cycle inventory data (see SI Table S5).

The greenhouse gas impact of the supply chain is quantified using the global warming potential (GWP), which combines greenhouse gas emissions from extraction of raw material (e.g., from combusting fuels for energy and transportation) as well as upstream energy activities. The 100-year IPCC global warming potentials (IPCC 2013 GWP 100a V1.00) methodology was used to calculate this metric, which was reported in kg CO2-eq per kg of material generated. Established GWP values for individual REEs were obtained from the literature. The main energy flows for material extraction are reflected in cumulative energy demand (CED), which includes both direct energy inputs and upstream primary energy associated with manufacturing energy carriers. This measure was calculated using the Cumulative Energy Demand impact assessment method and expressed in MJ-eq per kg of material produced.

**3.2. Mapping risks to electronics materials**

The aforementioned metrics were applied to a wide range of materials utilized in the electronics industry, with a focus on metals and minerals that have supply chains that are vulnerable to these hazards. Bill of materials data from product disassembly (Babbitt et al., 2020) and a study of previous studies on materials in electronics were used to define common materials found in electronics. The list of critical items to be included in the study scope was determined by conducting a literature search on the recycling potential of electronics, particularly complicated components such as printed circuit boards, display units, and batteries.

6

Base metals, valuable metals, technological metals, rare earth elements (REEs), and hazardous metals are among the electronic materials considered in this study's scope. Because of its importance in the creation of lithium-ion batteries and the possibility for future supply disruptions, graphite, a non-metal, is also mentioned. Three of the six platinum group metals (PGMs) and seven of the seventeen rare earth elements (REEs) were removed from the study due to a lack of data and minimal utilization in electronics. The SI file contains the raw data for each of the metrics aligned to each of the materials (Tables S1-S4).

|  |  |
| --- | --- |
| **Category** | **Materials** |
| Base metals | Al, Cu, Mg, Fe, Ni, Zn, Ti |
| Precious metals | Au, Ag, Pd, Pt, Rh |
| Technology metals | Sb, Ba, Co, Ga, Gr[\*](https://www.sciencedirect.com/science/article/pii/S0921344920305632), In, Li, Mn, Ta, Te, Sn, V |
| Rare earth elements | La, Ce, Pr, Nd, Eu, Sm, Gd, Y, Tb, Dy |
| Hazardous metals | Pb, Hg, Cr, Cd |

### **Tab. 3.2 Material scope.**

### 

### 

### 7

### **3.3. Applying multi-criteria ranking to identify material hotspots**

The measurements delivered from this examination were parametrized for all materials to distinguish potential "areas of interest," or districts of worry, inside every one of the 16 gamble classes. These unique outcomes were then consolidated to deliver a typical record that might be utilized to recognize materials with the most serious peril potential and convey really those discoveries to the right gatherings. To unite different pointers into a solitary arranged list, a multi-measures choice examination technique was utilized (Kalbar et al., 2017). We embrace the TOPSIS strategy (Technique for Order Preference by Similarity to Ideal Solution) to address practically identical multi-standards choice investigation for fundamental materials in this review (Niero and Kalbar, 2019). More or less, the TOPSIS strategy works out a positioning score (FSi) for all materials I = 1 to m) in light of all defined measurements (j = 1 to n) utilized in the review.

|  |  |  |
| --- | --- | --- |
| **Scenario** | **Description** | **Metric Weightings** |
| Baseline | The electronics industry's long-term future is threatened by supply, demand, geopolitical, and environmental challenges. | All 16 metrics were given equal weighting (6.25 %). |
| 1 | SUPPLY CANNOT MEET HIGHER DEMAND: Due to the closure of mining sites and metal processing facilities, pandemic mitigation measures (lockdowns) result in increased demand for electronics and decreased production of needed materials. | Metrics that capture the physical availability of products, such as global reserves, ore concentration, index of depletion, and production percent as a by product, were given a higher weighting (20%). The consumption of the electronics sector is weighted at 15%; the remaining 5% is distributed among all other measures. |
| 2 | ECONOMIC VOLATILITY IS CAUSED BY DEMAND FLUCTUATION: Pandemic lockdowns cause economic downturns, which are followed by material spikes once economies reopen, resulting in price increases.  8 | Price, price volatility, and electronic industry consumption, all of which are related to material demand, were given a larger weighting (20%). The remaining 40% is distributed evenly across all other measures. |
| 3 | GOVERNMENTS HAVE THE ABILITY TO OVERREACH WITH PANDEMIC. In countries with political instability and governance challenges, government overreach leads to domestic conflicts, resulting in societal dangers such as forced labor, layoffs, bad working conditions, and worker disease.. | Metrics that represent social risks, such as socio-political weighted HHI and social hotspots, were given a higher weighting (20%). The consumption of the electronics sector is weighted at 15%; the remaining 45 percent is distributed among all other indicators. |
| 4 | GEOPOLITICAL TENSIONS ARE CAUSED BY PANDEMIC. Lockdowns, border restrictions, and travel bans have an impact on global trade relations and metal flows. | Geographic production concentration and import reliance (from a US perspective) measures were given a higher weighting (20%). The consumption of the electronics sector is weighted at 15%; the remaining 45 percent is distributed among all other indicators. |
| 5 | ENVIRONMENTAL CONCERNS TAKE A BACK SEAT DURING PANDEMIC. When countries struggle to keep their economies afloat, environmental rules take a back seat, exacerbating the dangers of material manufacture. | Environmental criteria such as supply chain GWP, CED, MRD, and ecotoxicity were given a higher weighting (20%). The consumption of the electronics sector is weighted at 15%; the remaining 5% is distributed among all other measures. |

Tab.3.3 Descriptions and weightings for disruption events.

### **3.4. Exploring potential risk mitigation strategies**

After identifying the material hotspots for each scenario, potential risk-mitigation measures were investigated. Supply chain diversification, recycling, material substitution, stockpiling, and regulatory adjustments such as system response time reduction and mineral tax implementation have all been advocated as risk mitigation techniques in previous research (Sprecher et al., 2017a, Sprecher et al., 2017b). Using the TOPSIS framework, the potential for risk reduction through two of these techniques, recycling and supply diversification, was investigated for important material hotspots. Because the focus here is on unexpected disruptions, such as the COVID-19 pandemic, methods that would strengthen the supply chain and help meet short-term demand were prioritized.

9

## It's hard to survey reusing conceivable outcomes quantitatively in light of the fact that information on hardware materials is not many and questionable. Thus, the gamble alleviation capability of reusing was examined by assessing the improvement in a material's gamble score in the standard situation for different reused content in the inventory network: Current reused content (low gauge) from writing (Graedel et al., 2011), and high/hopeful reused content of half in material stockpile. To display the advantages of reusing, the four natural measurements (GWP, CED, MRD, Etox), as well as the Index of Depletion, Mine Production, Price, Price Volatility, Social Hotspots, and Import Reliance, were discounted relatively to the reused content rate to mirror the decrease in essential inventory required. For every one of the situations (Table 2), the five most serious gamble materials were surveyed for reusing upgrades.

## Involving REEs as a contextual analysis, the gamble alleviation capability of production network broadening was explored. The ability to give a broadened inventory network to a given still up in the air by its actual accessibility (saves) and the framework to extricate and refine it in different regions. As a result, the stock variety study was done by modifying the commitment of existing REE maker nations to creation. In this situation, the adjustment of TOPSIS risk score for unmistakable REE areas of interest is examined in a situation where the United States and other REE maker nations keep on growing their creation at the rate found as of late, however China's yearly creation stays static. The boundaries for HHI, WGI-PSAV weighted HHI, Social Hotspots score, and US Import Reliance are recalculated for the new creation dispersion in the inventory variety situation.

## 

## 

## 

## 

## **1****0**

## CHAPTER 4

**RESULTS**

The study's main finding is the identification of materials to be concerned about in terms of supply chain vulnerabilities that may arise as a result of abrupt interruptions like the COVID-19 pandemic. The sections that follow go over these findings in detail, as well as suggested measures for reducing supply chain risks and increasing supply chain resilience in the electronics industry.

### **3.1. Key material hotspots**

Inventory network chances are evaluated utilizing 16 measurements got from earlier examination, which incorporate stock, request, sociopolitical, and ecological factors, and are parametrized for metals commonly utilized in electronic gear. Material areas of interest are portrayed on a hotness map (Fig. 2) by revealing relative gamble inside specific standards. The inventory network results related with valuable metals are featured specifically by these discoveries and the pattern multi-rules investigation (Fig. 3A). Low saves and mineral focuses, as well as a weighty dependence on side-effect creation, all add to supply issues for these metals (Alonso et al., 2008; Hao et al., 2019). On a for each kg premise, valuable metals have significant ecological ramifications, like an Earth-wide temperature boost potential and energy and mineral necessities. These outcomes can be ascribed to both actual accessibility and strategic boundaries: metals in low overflow require more energy and assets to separate, and are regularly portrayed by high market costs, which are figured into life cycle information (ecoinvent) financial designation techniques used to demonstrate natural effects. Thus, gold, silver, and platinum bunch metals (PGMs) have been displayed to address "areas of interest" of production network risk in typical conditions. Accordingly, long haul supportability in the gadgets business will require proceeding with endeavors to lessen valuable metal use and further develop reusing to foster an auxiliary material stockpile.

### 

### **11**

### **3.2. Recycling as a pathway to reduce disruption risks**

Acquiring materials from auxiliary sources, for example, shut circle gadgets reusing or open-circle product markets, might be a method for reducing financial and ecological expenses while additionally enhancing supply chains and diminishing international and social dangers related with disturbances like COVID-19. The gamble moderation potential for reusing specific metals was examined for two situations: low (range determined by Graedel et al. (2011)) and high (50%) reused content, and the outcomes were contrasted with the benchmark TOPSIS score for zero reused content. Reusing offers the best potential to bring down perils for valuable metals, with up to a 30% increment in registered risk scores among the material areas of interest, as indicated by the discoveries (Table 3). This improvement is for the most part because of the ability to limit natural outcomes and expenses while likewise reducing supply limitations somewhat. Other material areas of interest, like REEs, indium, cobalt, and gallium, have more modest reusing benefits since gambles are all the more intently attached to local fixation, shortage, and high use in hardware, factors that are less modified by reused content. See that these discoveries are for altering reused content for a solitary material at a time; because TOPSIS scores are determined on a relative premise, results might shift while changing different numbers.

### **3.3. Supply chain diversification as a pathway to reduce disruption risks**

The findings also suggest that supply chain diversity could be a viable solution to the disruption risks identified. Given the small number of nations that now supply electronics materials, expanding supplies is very important (Figure S2). Over 75 percent of worldwide production for more than half of the commodities analyzed is concentrated in just three countries. However, nearly all commodities have more than 50% of their production limited to one or two countries, with China typically being the largest producer. China's refinery capacity for numerous technology-critical minerals, such as cobalt, is also expanding (Gulley et al., 2019).

Due to a local disruptive event in the source country, concentrated production and refining can result in considerable price increases (Leader et al., 2019). Further than the disruption risks highlighted here, diverse supply chains will help long-term availability and sustainability of these commodities, for example, by constructing extraction and refining facilities with lower environmental consequences or in places with less sensitive ecosystems.

12

### **3.4. Potential tradeoffs from changing material supply chains**

Despite the fact that store network changes and creation enhancement are hypothetically achievable, high monetary expenses, administrative constraints, hindrances to working out new mining foundation, and other innovative impediments all substitute the method of such a progress for hardware materials. For instance, every individual component exists in fluctuating focuses in topographical stores in countries with known loads of REEs (Goodenough et al., 2018), and a substitute store may not be to the point of satisfying need for a given REE in a particular hardware application. Moreover, as displayed in Fig. 5, changing worldwide stockpile chains might present unexpected social and ecological worries, as shown by country-explicit qualities for common social (Social Hotspots) and natural (GWP) pointers (information gave in SI Tables S7 and S8).

13

**CONCLUSION**

→ The COVID-19 outbreak has brought to light the weak connections in global supply networks for the first time. For material supply chains in the electronics sector, multi-criteria analysis was utilized to predict potential supply, demand, social, economic, geopolitical, and environmental hazards, both during normal operation and from sudden interruptions anticipated during a global health crisis.

→ In settings where disruptions amplify economic instability of commodity markets or environmental pressures of material extraction, precious metals are at high risk.

→ Diversifying manufacturing worldwide and enhancing secondary resources accessible through recycling can help to build a more robust supply chain.

Reduced consumption of high-risk materials will be required for long-term supply chain sustainability and resilience, which will be achieved through lower-impact production infrastructure, material substitution, and, eventually, widespread material circularity through product reuse and recycling.

Therefore, technology alone wasn't enough to create a secondary supply chain.

New advancements, together with enhanced understanding of supply chain vulnerabilities, are essential for reducing material supply chain risks, allowing electronics to continue to deliver on their promise of social cohesiveness even in times of global crisis.

14

**REFERENCES**

[1] Shahana A, Callie W.B, 2021. Disruption risks to material supply chains in the electronics sector, Conservation and Recycling, Vol. 167, 105248

[2] Kim D.B, Catherine D, Jonas O.J, Nico V, 2021. Vaccine supply chains in resource-limited settings: Mitigating the impact of rainy season disruptions, European Journal of Operational Research

[3] Tat-Dat B, Feng M.T, Ming-Lang T, Raymond R.T, Krista D.S.Y,2021. Sustainable supply chain management towards disruption and organizational ambidexterity: A data driven analysis Sustainable Production and Consumption, Vol. 26, Pages 373-410

15