GeoPolRisk Assessment of Critical Minerals in Canada's Battery Supply Chain.

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Funded by the Collaborative Research and Training Experience in Sustainable Electronics and Eco-Design (CREATE SEED) and the Québec Circular Economy Research Network (RRECQ)

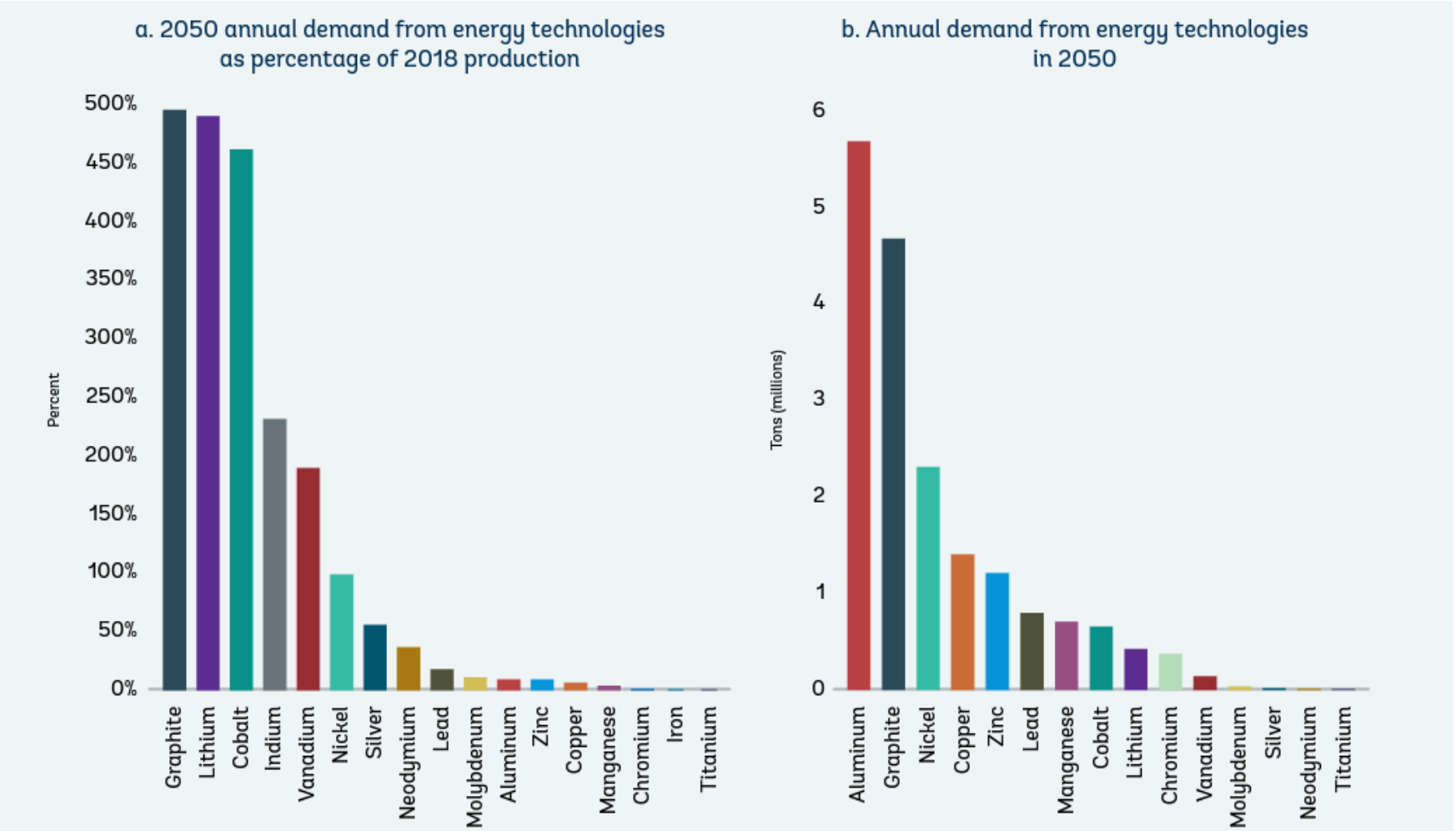
August 21, 2023

Agenda

1. Context
2. Research features
3. Literature Review
4. GeoPolRisk Method
    1. Contributions and Scenarios
5. Results
6. Conclusions and future research

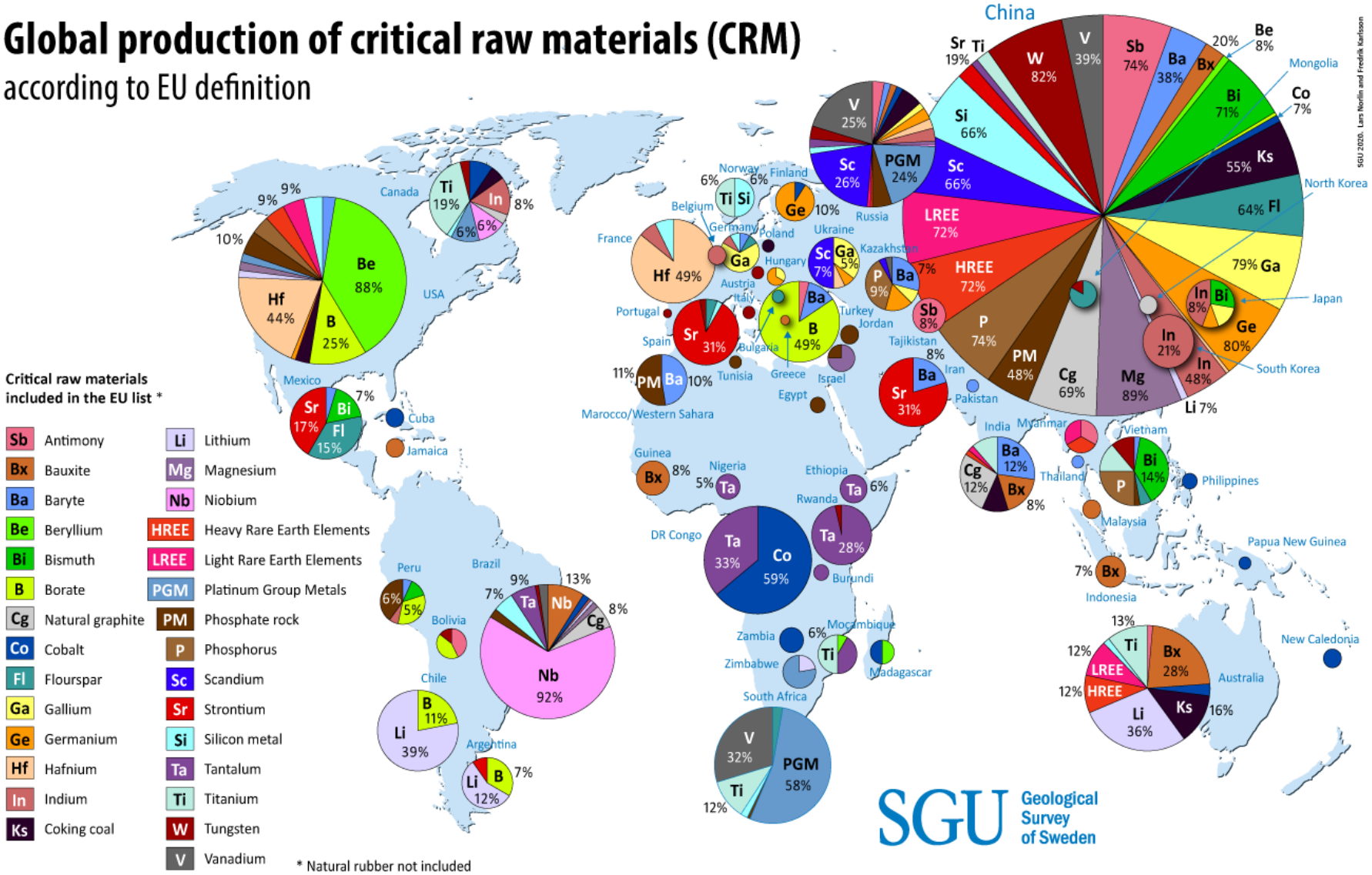
Critical minerals play an essential role to the energy transition

Batteries are key enablers for the energy transition which increase global demand



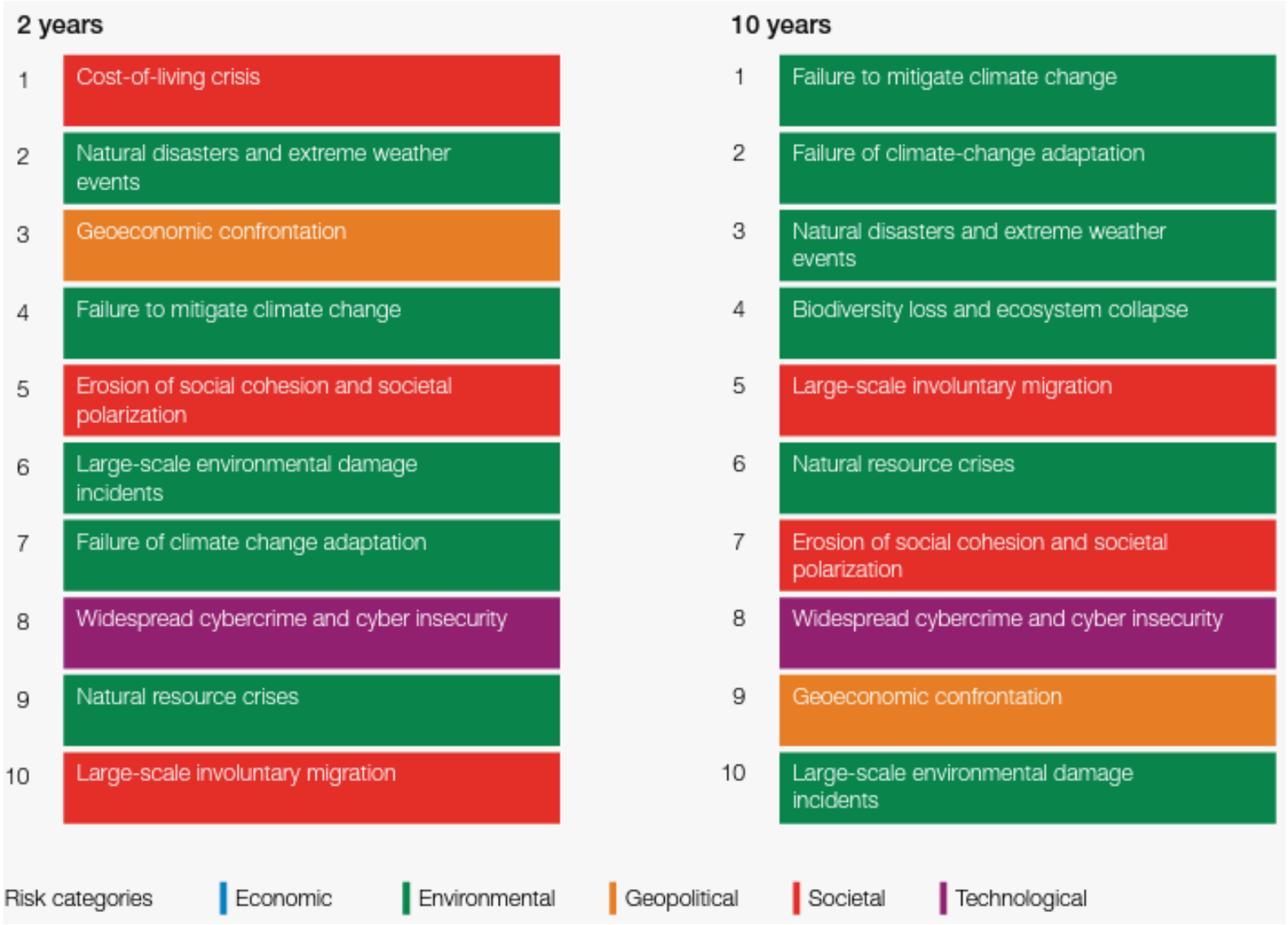
Source: Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition, World Bank, 2020.

Concentrated geographical distribution of critical minerals



Source: Critical Raw Minerals according to the present EU classification, Geological Survey of Sweden, 2020.

Emerging global environmental and social risk landscape



Source: World Economic Forum Global Risks Perception Survey 2022-2023

In the news

How Climate Change Is Disrupting the Global Supply Chain

The impact of the Covid pandemic on the global supply chain has been widely reported. But extreme weather, from floods to wildfires, is increasingly hammering ports, highways, and factories worldwide, and experts warn these climate-induced disruptions will only get worse.

BY JACQUES LESLIE · MARCH 10, 2022

An oil refinery flooded by Hurricane Ida at Belle Chasse, Louisiana, on September 3, 2021. PO2 RYAN DICKINSON / U.S. COAST GUARD / ALAMY LIVE NEWS

Shipping containers stranded in floodwaters at the harbor in Riesa, Germany. THOMAS PETER / REUTERS / ALAMY STOCK PHOTO

The Economic Times

Climate change will reshape global supply chains — it can reduce welfare on Earth by 20%: Ivan Rudik

The Guardian

Yes, the climate crisis is raising your grocery bills

Droughts, fires, floods, heatwaves – they're all contributing to our supply-chain problems and brutal inflation.

Apr 28, 2023

The New York Times

Climate Change Could Worsen Supply Chain Turmoil

What does this entail for Canada?

Canadian EV supply chain leadership

#2

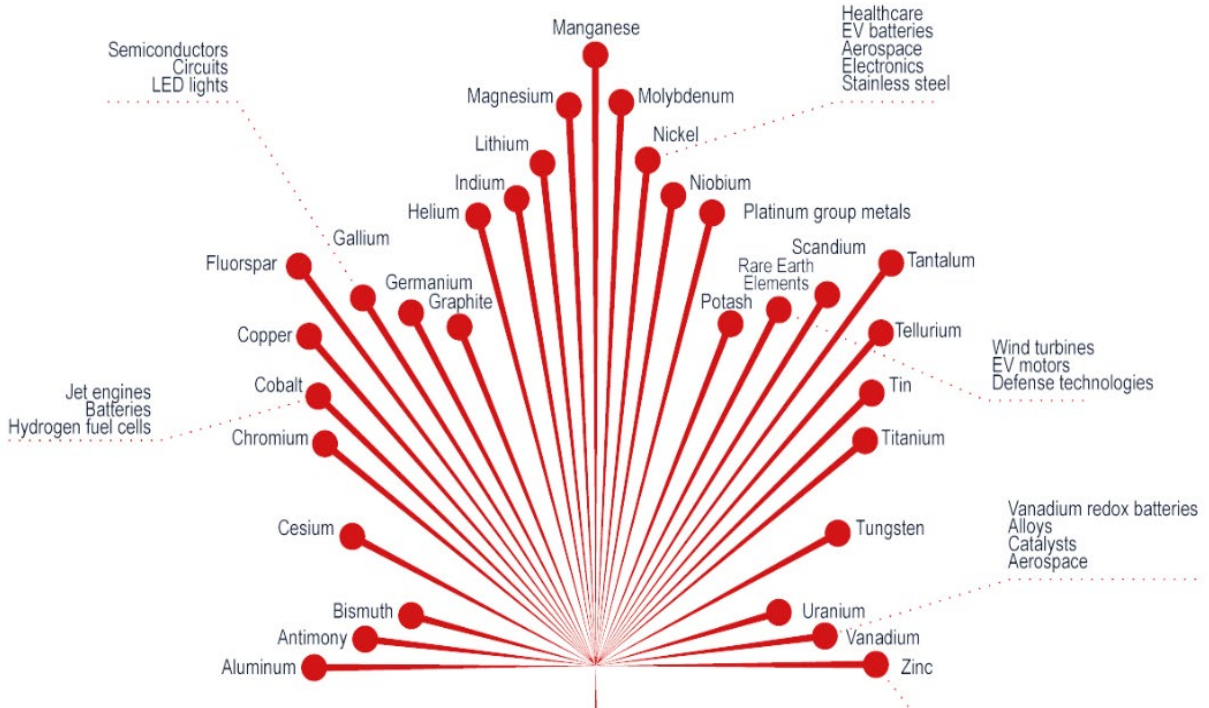
in the world for global lithium-ion battery supply chain

#4

globally for raw material capacities

TOP 10

producer of nickel, cobalt, graphite and aluminum



Source: Invest in Canada, EV supply chain, 2022 ;

Geopolitical Risk Assessment for Critical Minerals - research features

- **GeoPolRisk method –** provides country-specific supply risk characterization factors rather than global values
  - Focus on factors of trade partner as a source of supply risk
  - First presented by Gemechu et al. (2015)

- Adaptation of the *GeoPolRisk Method* to **include Environmental, Social and Governance** (ESG) factors

- **Hypothesis:**

  1. The integration of ESG factors into the *GeoPolRisk Method* enhances the robustness of the indicator, providing a more comprehensive understanding of CM supply disruption probability

  2. The shift to HHIexp improves risk probability assessment of multiple supply-chain stages

Geopolitical Risk Assessment for Critical Minerals - research features

- **Relevance**:
  - Strategic planning: Considers availability and accessibility at the design stage
  - Informs policy making in the energy transition
  - Improves risk management and enhances trade relationships
  - Social and environmental factors affect geopolitical changes (expected and unexpected)

- **Contribution**:
  - Integrated approach accounting for rising environmental and social risks expected to increase in magnitude and frequency
  - Enables analysis of trade flows through a risk probability lens

Life Cycle Analysis logic

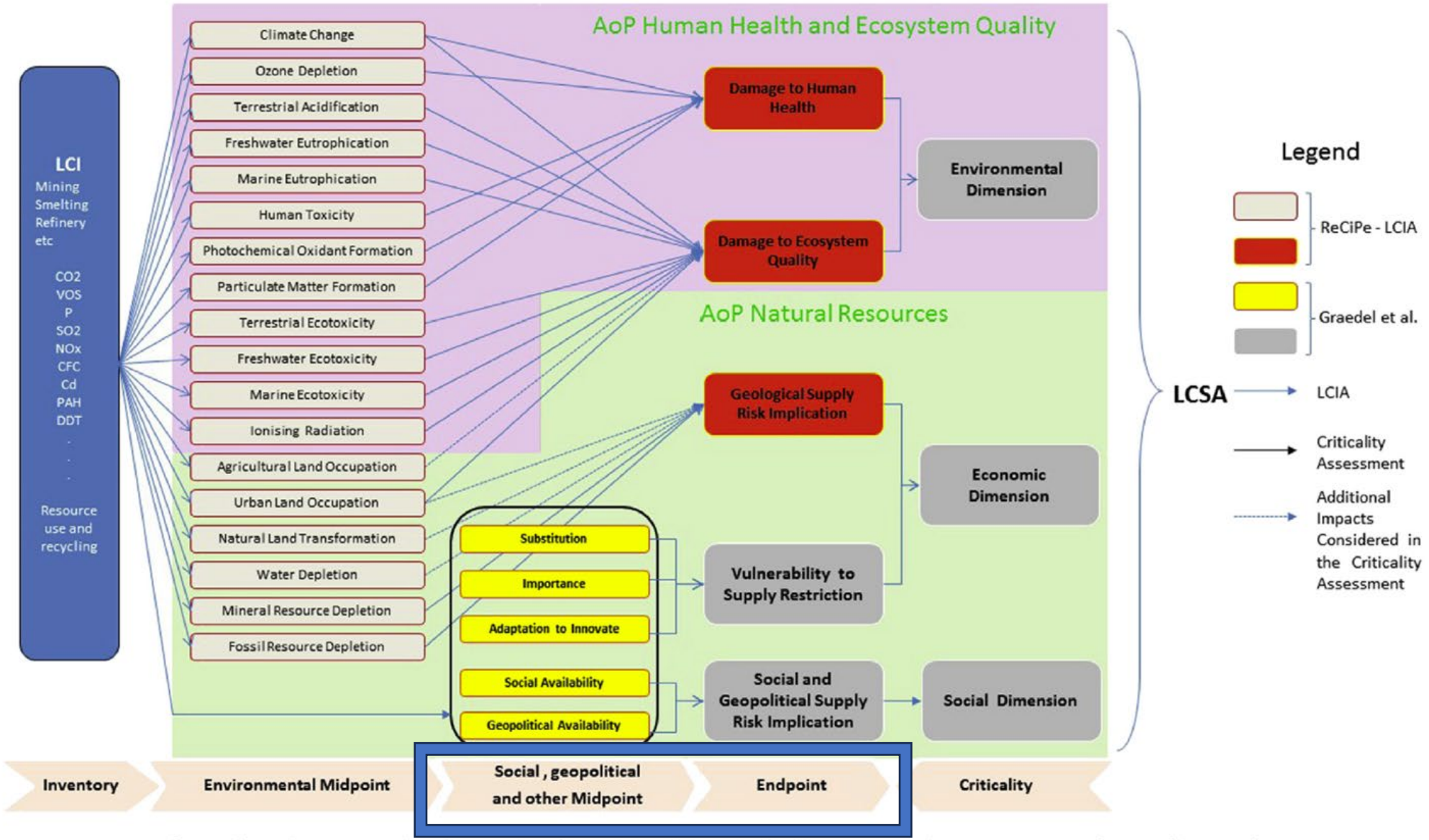


Fig. 1. Schematic representation of integration of Graedel et al. (2012) criticality assessment into LCA context under LCSA framework.

GeoPolRisk Method in the Literature

Geopolitical-related supply risk assessment as a complement to environmental impact assessment: the case of electric vehicles

June 2015 · The International Journal of Life Cycle Assessment 22(1)

DOI:10.1007/s11367-015-0917-4

LCIA OF IMPACTS ON HUMAN HEALTH AND ECOSYSTEMS | Open Access |
Published: 11 February 2020

Mineral resources in life cycle impact assessment: part II – recommendations on application-dependent use of existing methods and on future method development needs

Markus Berger, Thomas Sonderegger, Rodrigo Alvarenga, Vanessa Bach, Alexander Cimprich, Jo Dewulf, Rolf Frischknecht, Jeroen Guinée, Christoph Helbig, Tom Huppertz, Olivier Jolliet, Masaharu Motoshita, Stephen Northey, Claudia A. Peña, Benedetto Rugani, Abdelhadi Sahnoune, Dieuwertje Schrijvers, Rita Schulze, Guido Sonnemann, Alicia Valero, Bo P. Weidema & Steven B. Young

An improved resource midpoint characterization method for supply risk of resources: integrated assessment of Li-ion batteries

Article | Full-text available | Mar 2022

Jair Santillan Saldivar · Eskinder Gemechu · Stéphanie Muller · [...] · Guido Sonnemann

Raw material criticality assessment as a complement to environmental life cycle assessment: Examining methods for product-level supply risk assessment

WILEY

April 2019 · Journal of Industrial Ecology 23(4)

ELSEVIER

Resources, Conservation and Recycling

Volume 164, January 2021, 105108

Full length article

How recycling mitigates supply risks of critical raw materials: Extension of the geopolitical supply risk methodology applied to information and communication technologies in the European Union

Jair Santillán-Saldivar [a b c], Alexander Cimprich [c], Noor Shaikh [c], Bertrand Laratte [d e f], Steven B. Young [c], Guido Sonnemann [a b]

GeoPolRisk method: Baseline

- Developed by Gemechu et al. (2015)
- Assesses the supply disruption probability of resources in the life cycle impact assessment (LCIA)
- Considers the concentration of production as a factor in supply risk.
- Focuses on the geopolitical stability risk of the trade partner where minerals are produced

$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_{i} \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}}$$

Source: Anish Koyamparambath, Jair Santillán-Saldivar, Benjamin McLellan, Guido Sonnemann, Supply risk evolution of raw materials for batteries and fossil fuels for selected OECD countries (2000–2018), Resources Policy, Volume 75, 2022, 102465, ISSN 0301-4207

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- **From the importing country's perspective**
- **Probability of disruption at the (upstream) supply source**

Source: Anish Koyamparambath, Jair Santillán-Saldivar, Benjamin McLellan, Guido Sonnemann, Supply risk evolution of raw materials for batteries and fossil fuels for selected OECD countries (2000–2018), Resources Policy, Volume 75, 2022, 102465, ISSN 0301-4207

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Herfindahl-Hirschman Index

$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_{i} \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}}$$

- **Measure of market concentration $(\sum s^2)$ of producing countries**
- **The closer a market is to a monopoly, the higher the market's concentration**
- **Data obtained from US Geological Survey (USGS) and World Data Mining (WDM)**

Source: Anish Koyamparambath, Jair Santillán-Saldivar, Benjamin McLellan, Guido Sonnemann, Supply risk evolution of raw materials for batteries and fossil fuels for selected OECD countries (2000–2018), Resources Policy, Volume 75, 2022, 102465, ISSN 0301-4207

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Geopolitical (in)stability of country *i*

Trade partner *i*

$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_{i} \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}}$$

- **Measured by the World's Bank Worldwide Governance Indicator - Political Stability and Absence of Violence and Terrorism (WGI-PV)**
  - **Lower values signify increased political stability of a country**
  - **Min – Max Normalized**

Source: Anish Koyamparambath, Jair Santillán-Saldivar, Benjamin McLellan, Guido Sonnemann, Supply risk evolution of raw materials for batteries and fossil fuels for selected OECD countries (2000–2018), Resources Policy, Volume 75, 2022, 102465, ISSN 0301-4207

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$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_{i} \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}} \rightarrow \mathbf{F = \sum f}$$

Imports of mineral *A* from trade partner *i* to importing country *c*

Domestic production of mineral *A* in the importing country *c*

Total imports of mineral *A* to the importing country *c*

Source: Anish Koyamparambath, Jair Santillán-Saldivar, Benjamin McLellan, Guido Sonnemann, Supply risk evolution of raw materials for batteries and fossil fuels for selected OECD countries (2000–2018), Resources Policy, Volume 75, 2022, 102465, ISSN 0301-4207

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Imports of mineral *A* from trade partner *i* to importing country *c*

Data obtained from UN Comtrade

Total imports of mineral *A* to the importing country *c*

Domestic production of mineral *A* in the importing country *c*

Data obtained from USGS and WDM

Source: Anish Koyamparambath, Jair Santillán-Saldivar, Benjamin McLellan, Guido Sonnemann, Supply risk evolution of raw materials for batteries and fossil fuels for selected OECD countries (2000–2018), Resources Policy, Volume 75, 2022, 102465, ISSN 0301-4207

First contribution: **GPRS 1**

- Change of HHI_{PROD} → HHI_{EXP}
- Captures the contribution of intermediary trade partners, not only producers

$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_{i} \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}}$$

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$$GeoPolRisk_{AC} = HHI_{EXP} * \sum_{i} \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}}$$

- **Measure of trade concentration $(\sum s^2)$ of <u>exporting</u> countries**

Second contribution: **GPRS 2**

- Keeps HHI_{PROD} from the baseline assessment
- Introduces the ESG_i variables as weighting factors for each trade partner

$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_i \frac{g_i * f_{AiC}}{P_{AC} + F_{AC}}$$

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Second contribution: GPRS 2

- Keeps HHI_{PROD} from the baseline assessment
- Introduces the ESG_i variables as weighting factors for each trade partner

ESG factors of country *i*

$$GeoPolRisk_{AC} = HHI_{PROD} * \sum_{i} \frac{ESG_i * f_{AiC}}{P_{AC} + F_{AC}}$$

- **Data obtained from the Notre Dame Global Adaptation Initiative (ND-GAIN)**
  - **Ecosystem services, Human Habitat, Infrastructure, Economic readiness, Governance readiness, Social readiness**
- **Min – Max Normalized**

Extension : GPRS 3

- Keeps HHI_{EXP} + ESG_i
- Assess both factors interacting together
- Combines both contributions

$$GeoPolRisk_{AC} = HHI_{EXP} * \sum_i \frac{ESG_i * f_{AiC}}{P_{AC} + F_{AC}}$$

Minerals assessed

- Cobalt
- Cadmium
- Cobalt
- Lead
- Magnesium
- Silver
- Lithium
- Iron
- Nickel
- Copper
- Graphite
- Rare Earth Element

Canada minerals' supply risk Case Study: Results

Sensitive to risks associated to a high concentration in production in few countries

More responsive to mineral's trade quantity availability and trade partner diversification

$$GeoPolRisk_{AC} = HHI * \sum_{i} \frac{ESG_i * f_{AiC}}{P_{AC} + F_{AC}}$$

Canada minerals' supply risk Case Study: Results

Cadmium
Cobalt
Lead
Magnesium
Rare Earth

Graphite

Silver
Lithium
Iron
Nickel
Copper

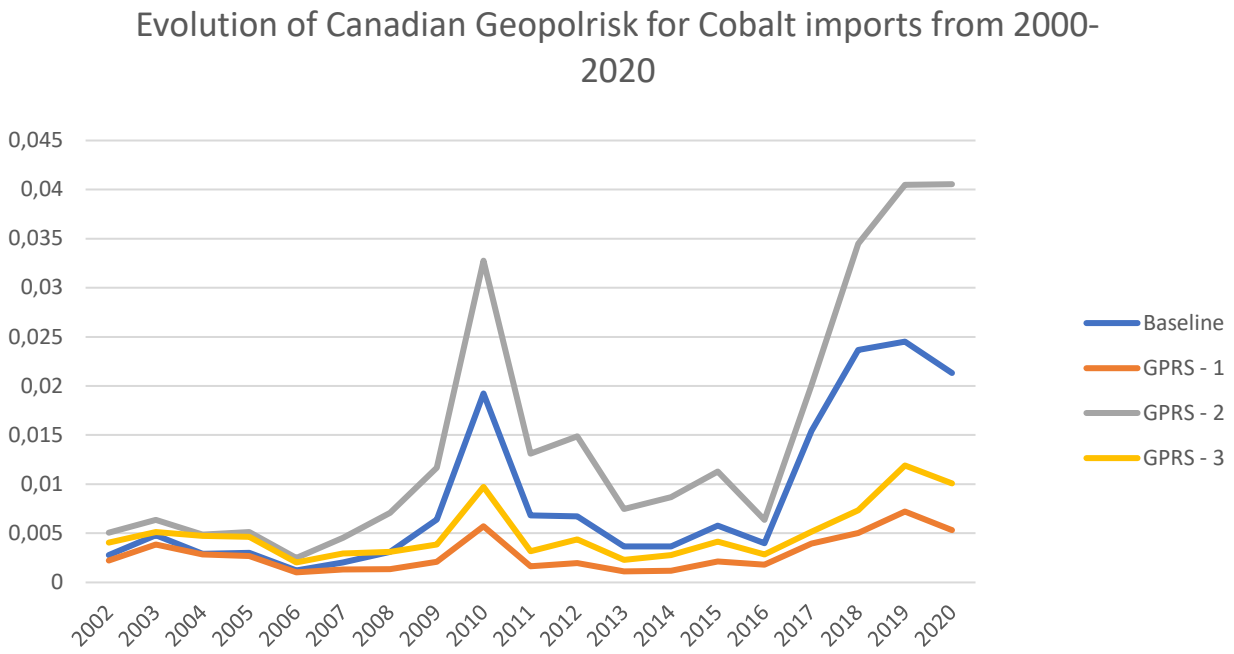
$$GeoPolRisk_{AC} = HHI * \sum_{i} \frac{ESG_i * f_{AiC}}{P_{AC} + F_{AC}}$$

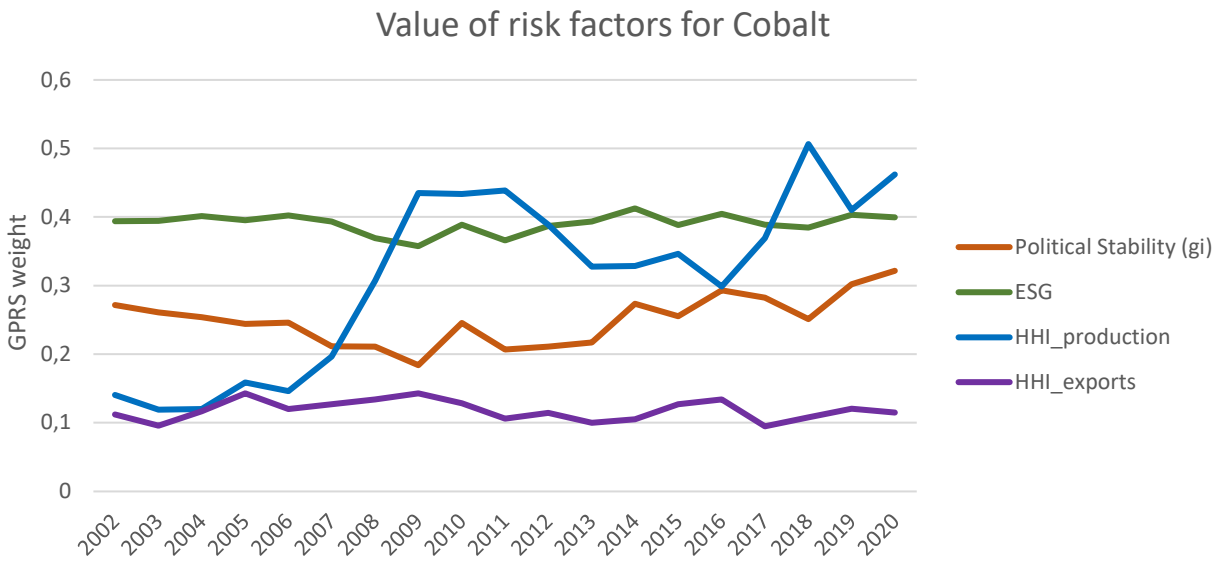
Canada minerals' supply risk Case Study: Results

Supply disruption factor from environmental and social sources are more relevant

$$GeoPolRisk_{AC} = HHI * \sum_i \frac{ESG_i * f_{AiC}}{P_{AC} + F_{AC}}$$

Canada minerals' supply risk Case Study: Results





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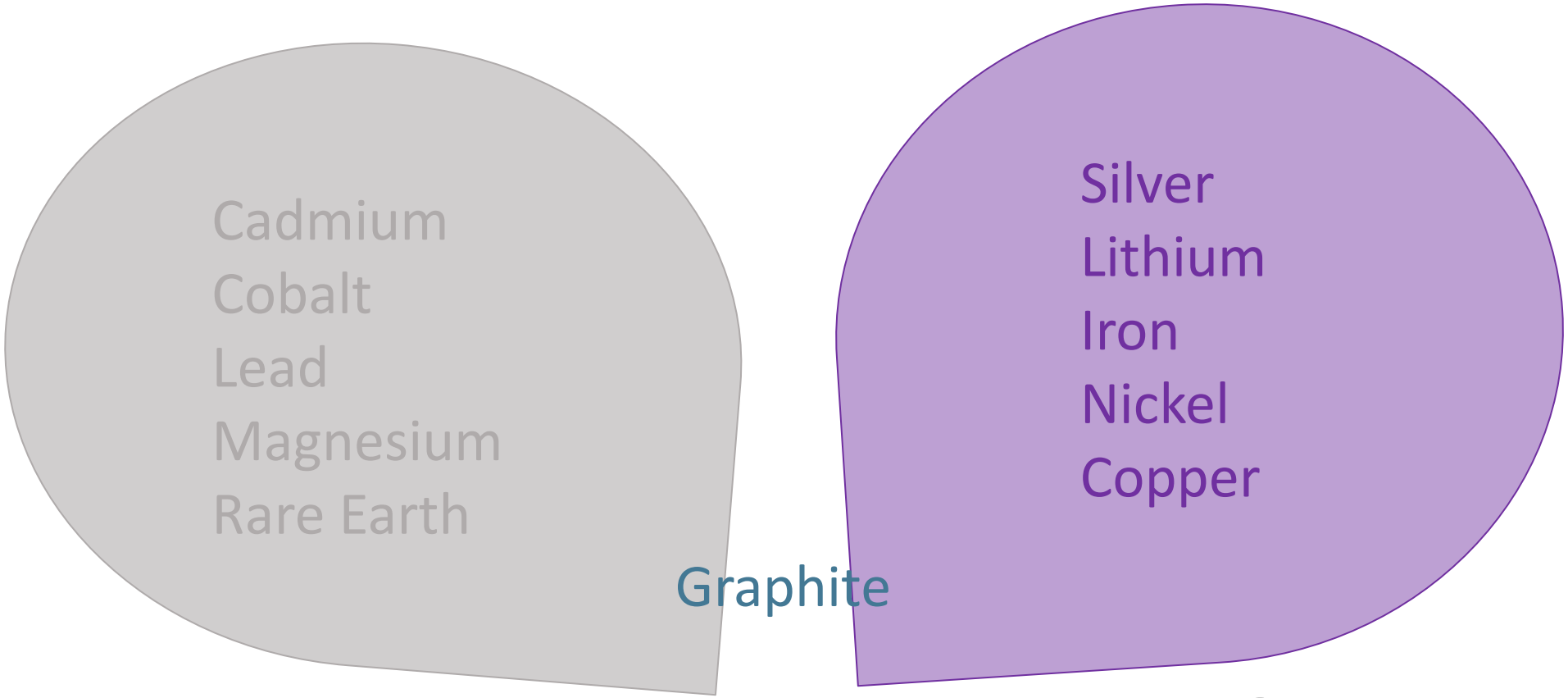

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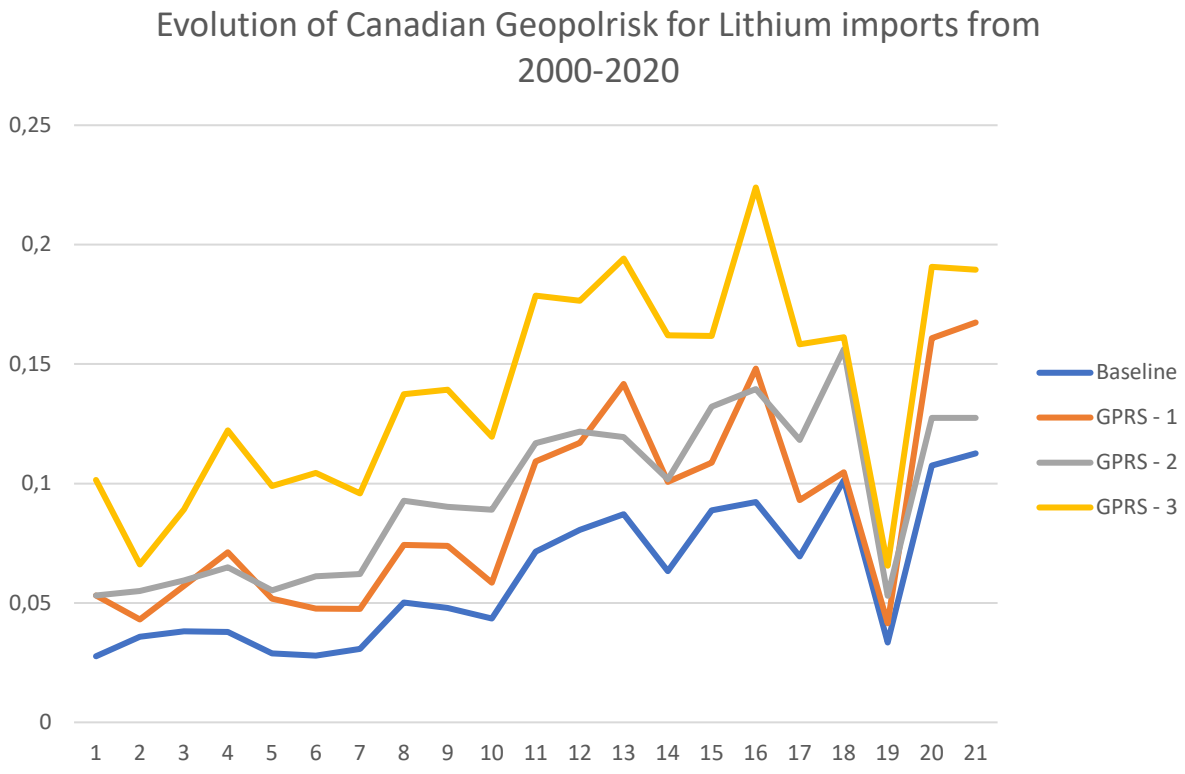

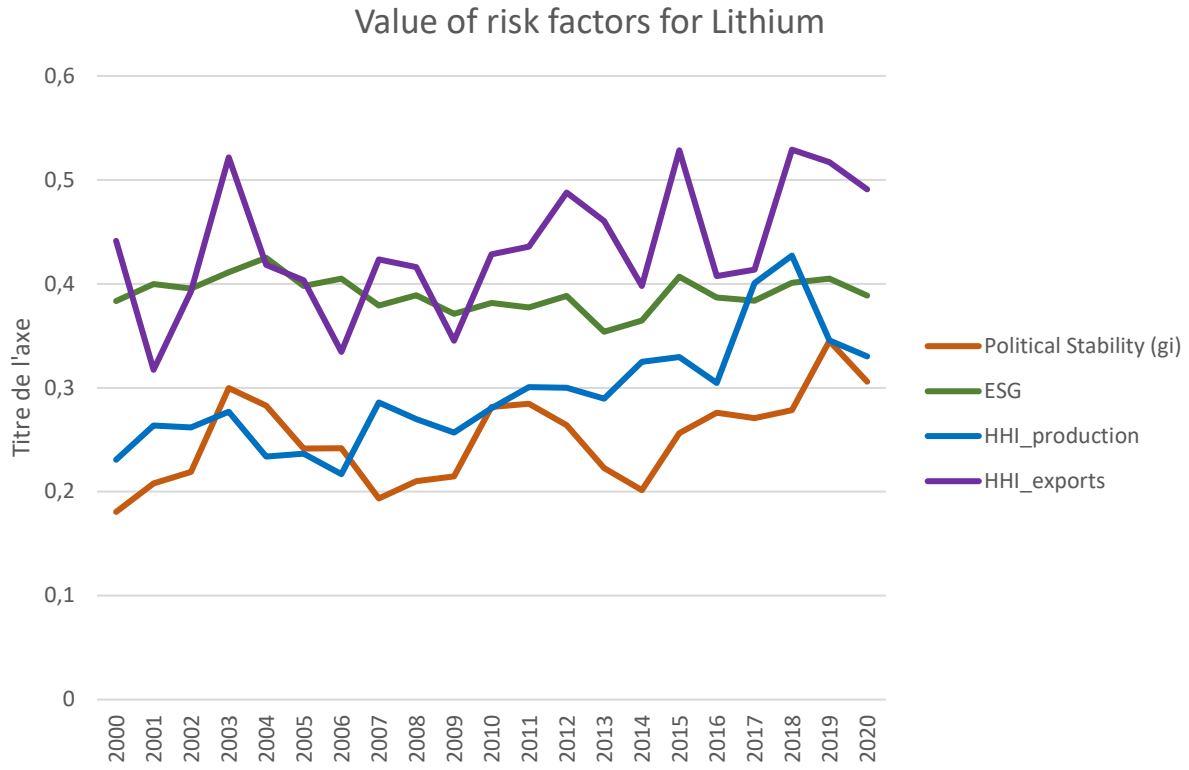

Correlation and Opportunity

	Economic (ESG)	Governance (ESG)	Social (ESG)	Ecosystems (ESG)	Habitat (ESG)	Infrastructure (ESG)	Political Stability (gi)
Economic (ESG)	1						
Governance (ESG)	0.60678648	1					
Social (ESG)	0.70343872	0.78711357	1				
Ecosystems (ESG)	0.3103538	0.69987865	0.54505448	1			
Habitat (ESG)	0.50340697	0.50341847	0.56533286	0.55735095	1		
Infrastructure	0.12768858	0.04448071	0.19527062	-0.1376586	-0.0650527	1	
Political Stability (gi)	0.49940527	0.88459528	0.62869881	0.56712748	0.31318455	-0.066674	1

Conclusion and future of research

- This tool includes environmental and social disruptive factors that are expected to become more frequent and severe in the geopolitical landscape, aligning with the goals of international Agreements.
- Assesses the supply probability disruption of resources for a sustainable design
- The risk assessment expands from focusing on the concentration of production to encompassing distributed risks throughout the intermediate stages of the supply chain.
  - Opens the conversation to explore trade partners
  - Further opportunity to assess geopolitical risk along the supply chain to guarantee access and sufficiency for the global energy transition

Conclusion and future of research

- Leverage Methods: Utilize various methodologies like the Gravity model to better understand the flow of exports and trade relationships between countries.
- Risk Assessment: Conduct comprehensive risk assessments to identify vulnerabilities in international trade dynamics.
- Diversification Strategies: Investigate the potential benefits of export diversification as a risk mitigation strategy against geopolitical and economic uncertainties including recycling.
- Resilience Against Uncertainties: Examine how diversification and optimal trading partnerships can bolster economic resilience, offering avenues for future stability in international commerce.

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UNIVERSITÉ D'INGÉNIERIE

GeoPolRisk Assessment of Critical Minerals in Canada's Battery Supply Chain.

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MERCI !

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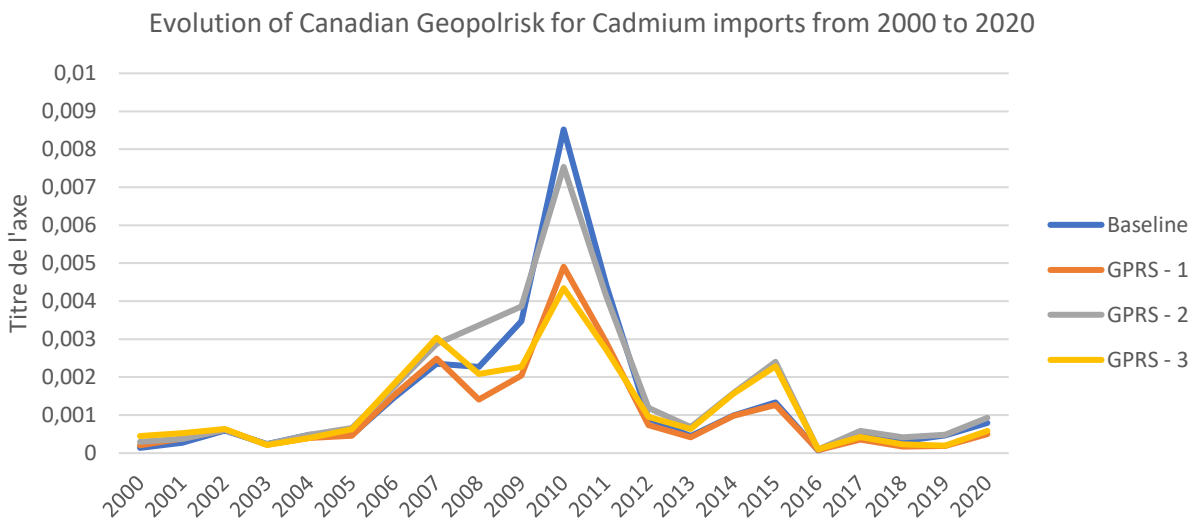
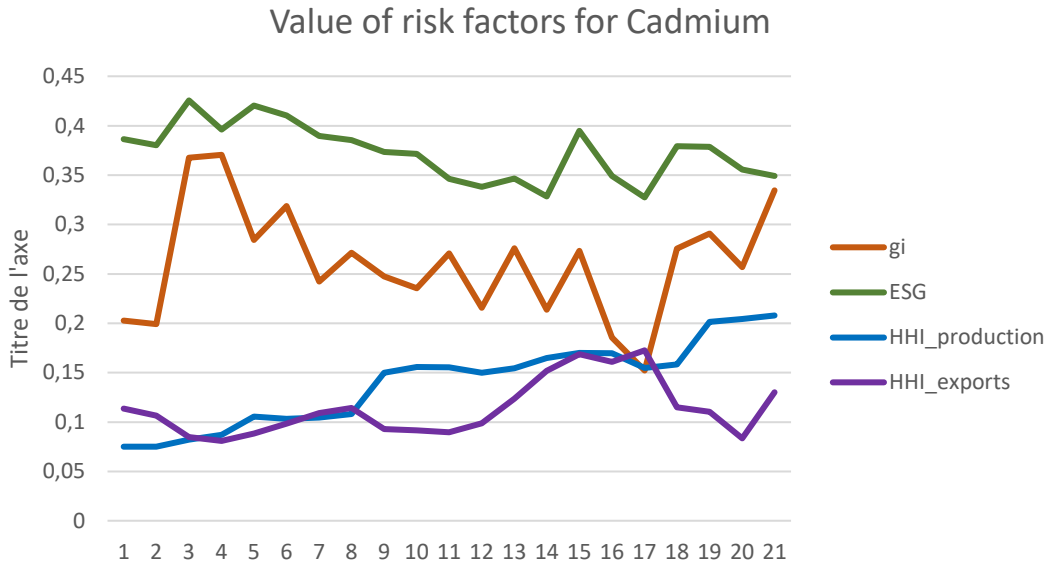
UNIVERSITÉ D'INGÉNIERIE

ADDITIONAL SLIDES / ANNEX

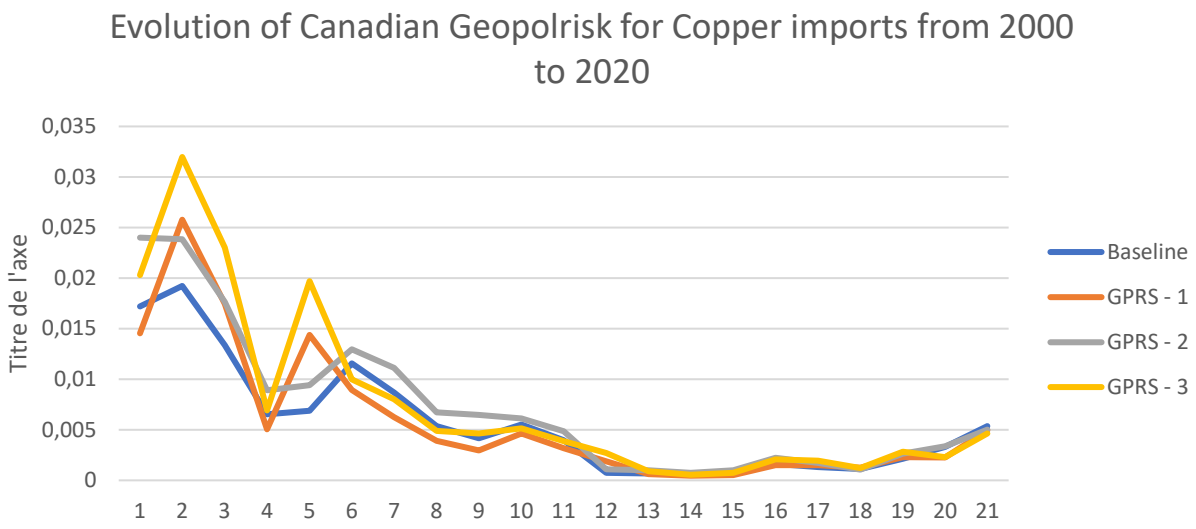
Sector	Exposure Component	Sensitivity Component	Adaptive Capacity Component
Ecosystem services	Projected change of biome distribution	Dependency on natural capital	Protected biomes
	Projected change of marine biodiversity	Ecological footprint	Engagement in International environmental conventions
Human Habitat	Projected change of warm period	Urban concentration	Quality of trade and transport-related infrastructure
	Projected change of flood hazard	Age dependency ratio	Paved roads
Infrastructure	Projected change of hydropower generation capacity	Dependency on imported energy	Electricity access
	Projection of Sea Level Rise impacts	Population living under 5m above sea level	Disaster preparedness
Component	**Indicators**		
Economic Readiness	Doing business		
Governance Readiness	**Political stability and non-violence (g_i)** Control of corruption Rule of Law Regulatory quality		
Social Readiness	Social inequality ICT Infrastructure Education Innovation		

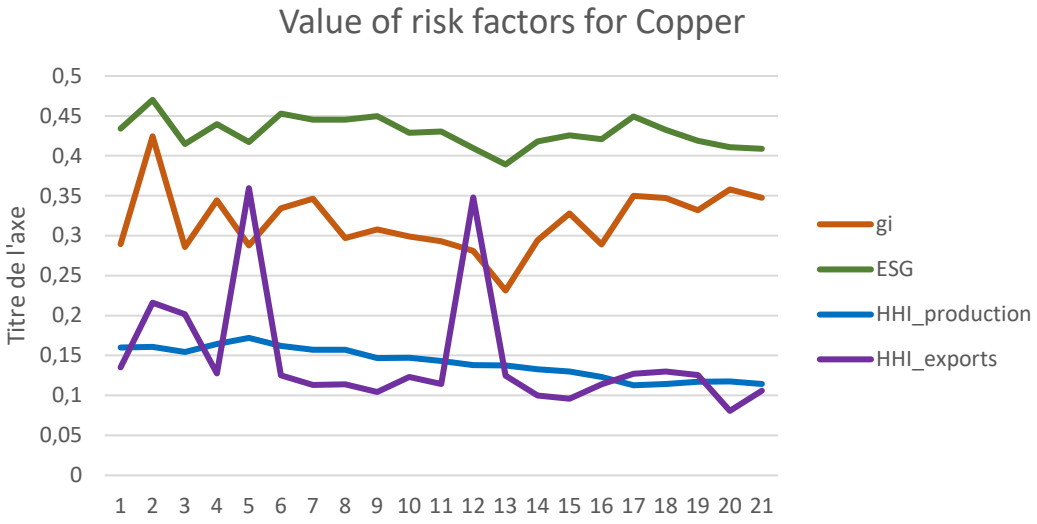
Cadmium


Evolution of Canadian Geopolrisk for Cadmium imports from 2000 to 2020
Titre de l'axe
0,01
0,009
0,008
0,007
0,006
0,005
0,004
0,003
0,002
0,001
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Baseline
GPRS - 1
GPRS - 2
GPRS - 3

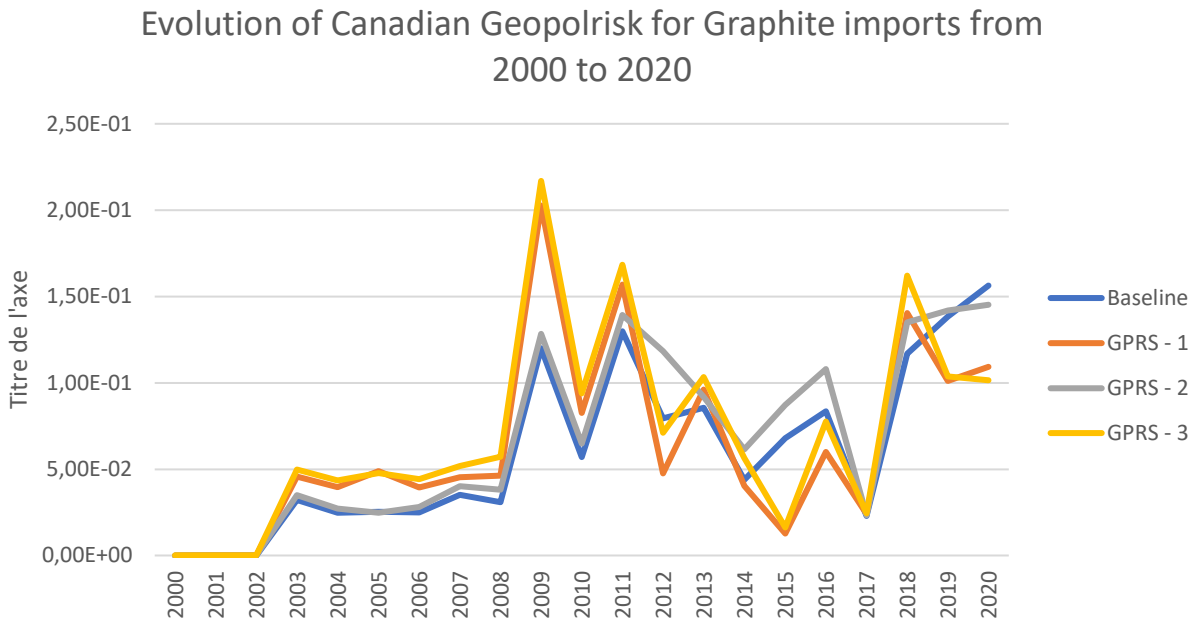

Value of risk factors for Cadmium
Titre de l'axe
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
gi
ESG
HHI_production
HHI_exports

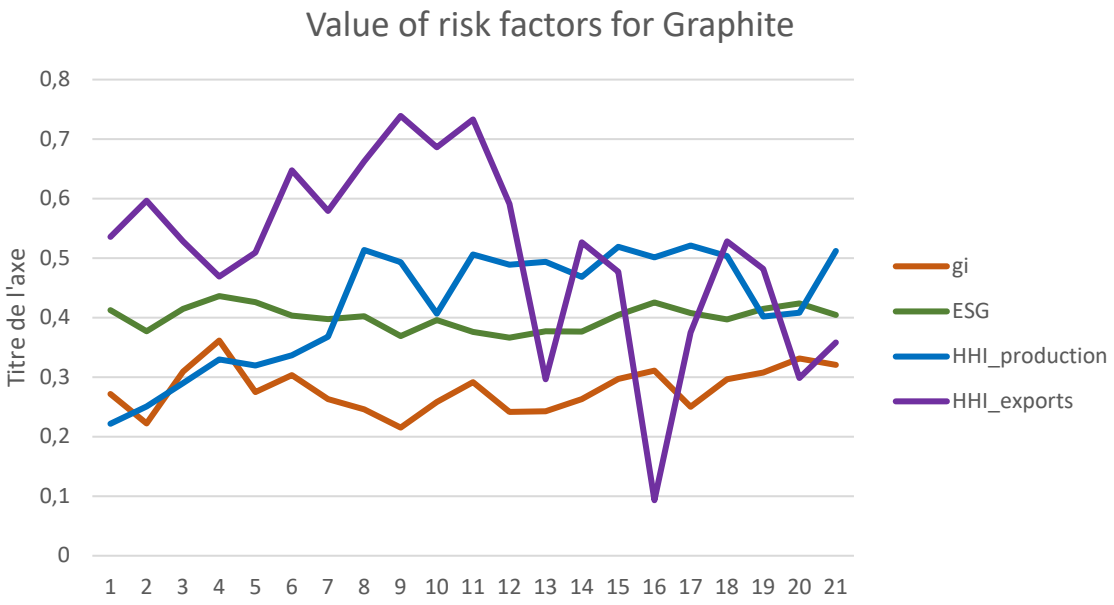
Copper


Evolution of Canadian Geopolrisk for Copper imports from 2000 to 2020
Titre de l'axe
0,035
0,03
0,025
0,02
0,015
0,01
0,005
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Baseline
GPRS - 1
GPRS - 2
GPRS - 3


Value of risk factors for Copper
Titre de l'axe
0,5
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
gi
ESG
HHI_production
HHI_exports

Graphite


Evolution of Canadian Geopolrisk for Graphite imports from 2000 to 2020
Titre de l'axe
2,50E-01
2,00E-01
1,50E-01
1,00E-01
5,00E-02
0,00E+00
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Baseline
GPRS - 1
GPRS - 2
GPRS - 3


Value of risk factors for Graphite
Titre de l'axe
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
1
2
3
4
5
6
7
8
9
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14
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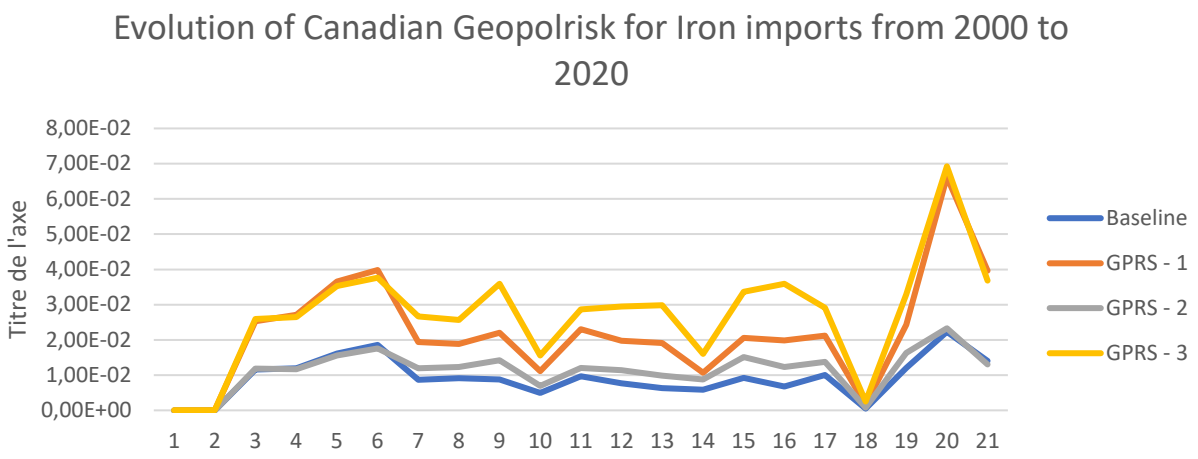
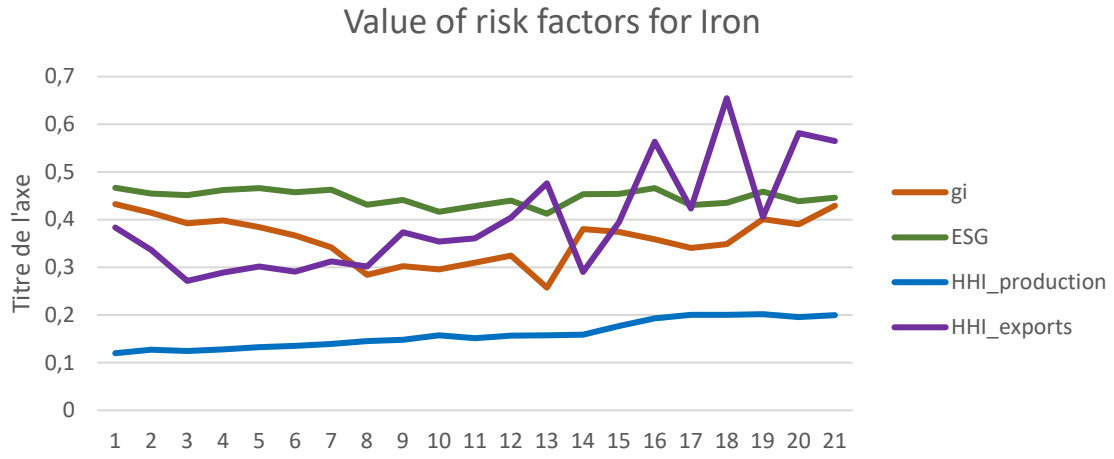
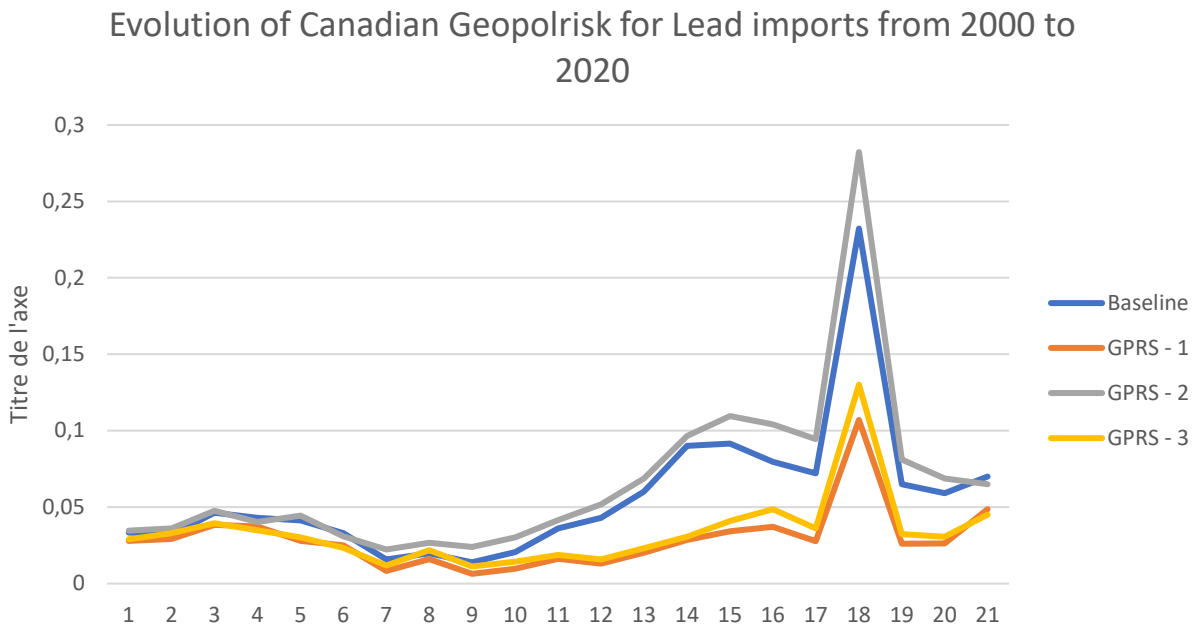
20
21
gi
ESG
HHI_production
HHI_exports

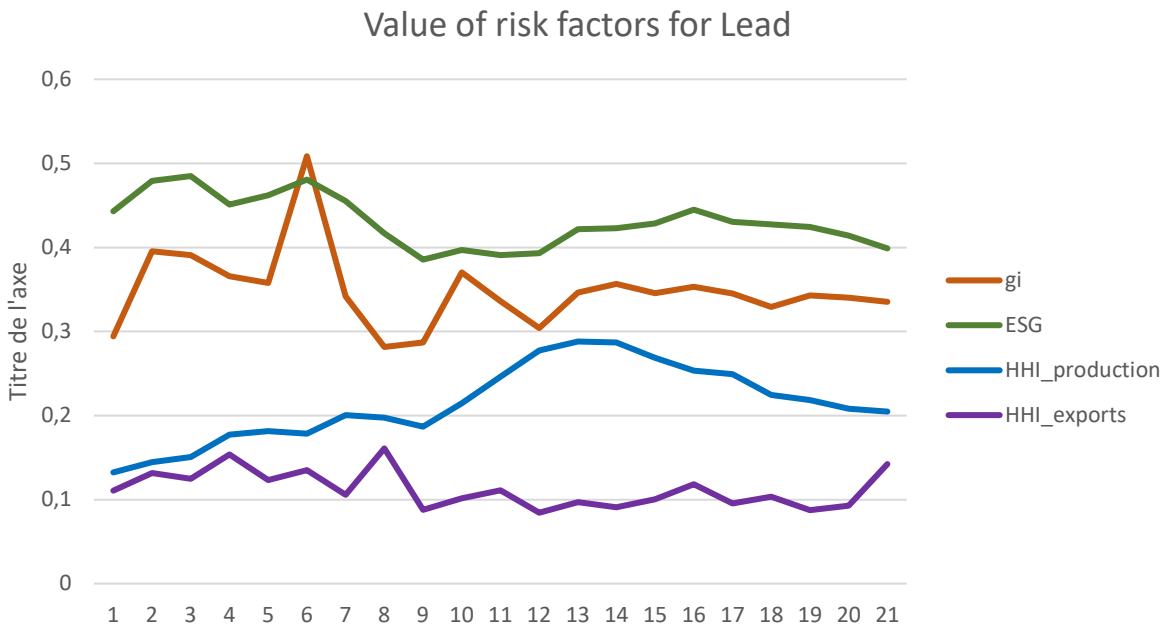
Iron


Evolution of Canadian Geopolrisk for Iron imports from 2000 to 2020
Titre de l'axe
8,00E-02
7,00E-02
6,00E-02
5,00E-02
4,00E-02
3,00E-02
2,00E-02
1,00E-02
0,00E+00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Baseline
GPRS - 1
GPRS - 2
GPRS - 3

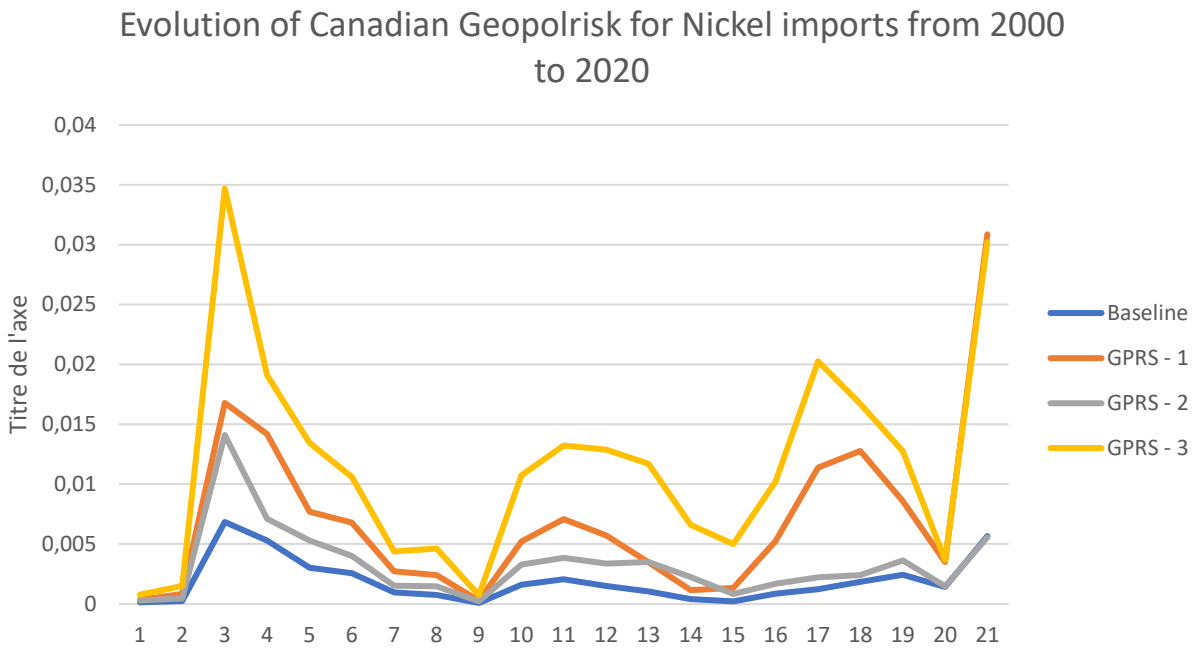

Value of risk factors for Iron
Titre de l'axe
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
gi
ESG
HHI_production
HHI_exports

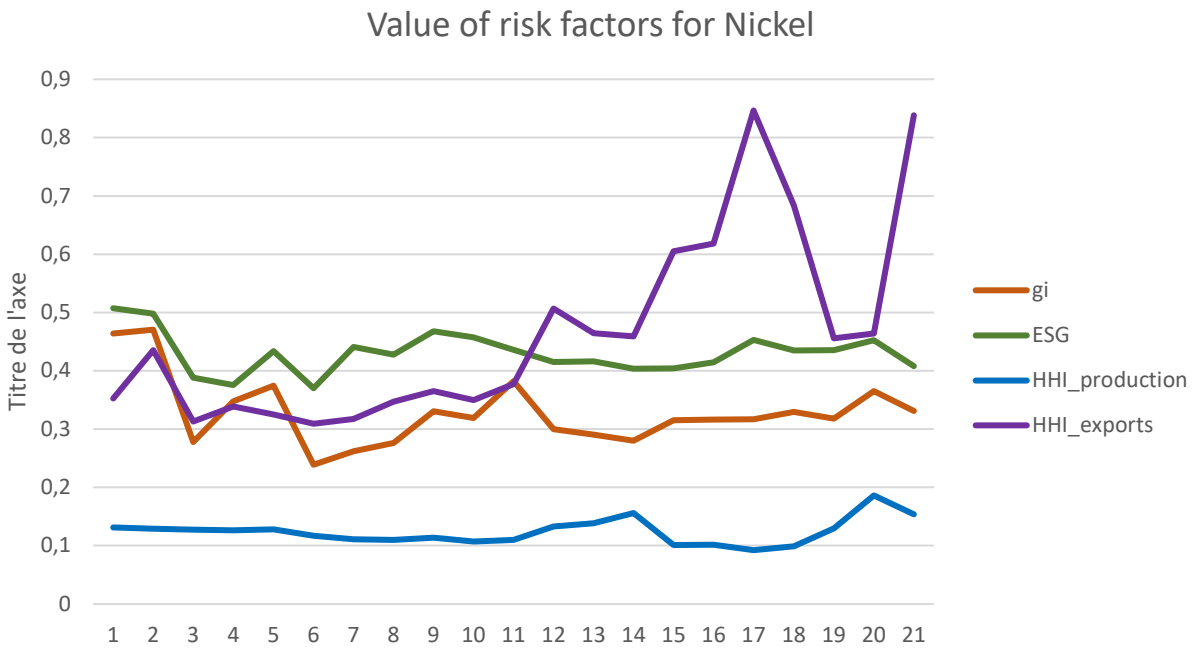
Lead


Evolution of Canadian Geopolrisk for Lead imports from 2000 to 2020
Titre de l'axe
0,3
0,25
0,2
0,15
0,1
0,05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Baseline
GPRS - 1
GPRS - 2
GPRS - 3

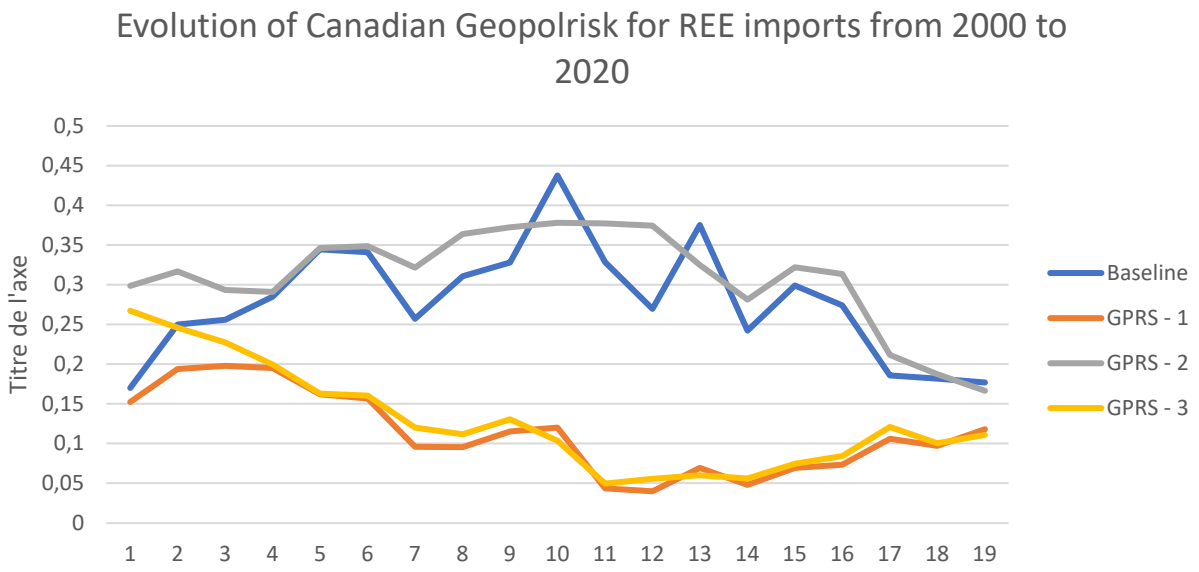

Value of risk factors for Lead
Titre de l'axe
0,6
0,5
0,4
0,3
0,2
0,1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
gi
ESG
HHI_production
HHI_exports

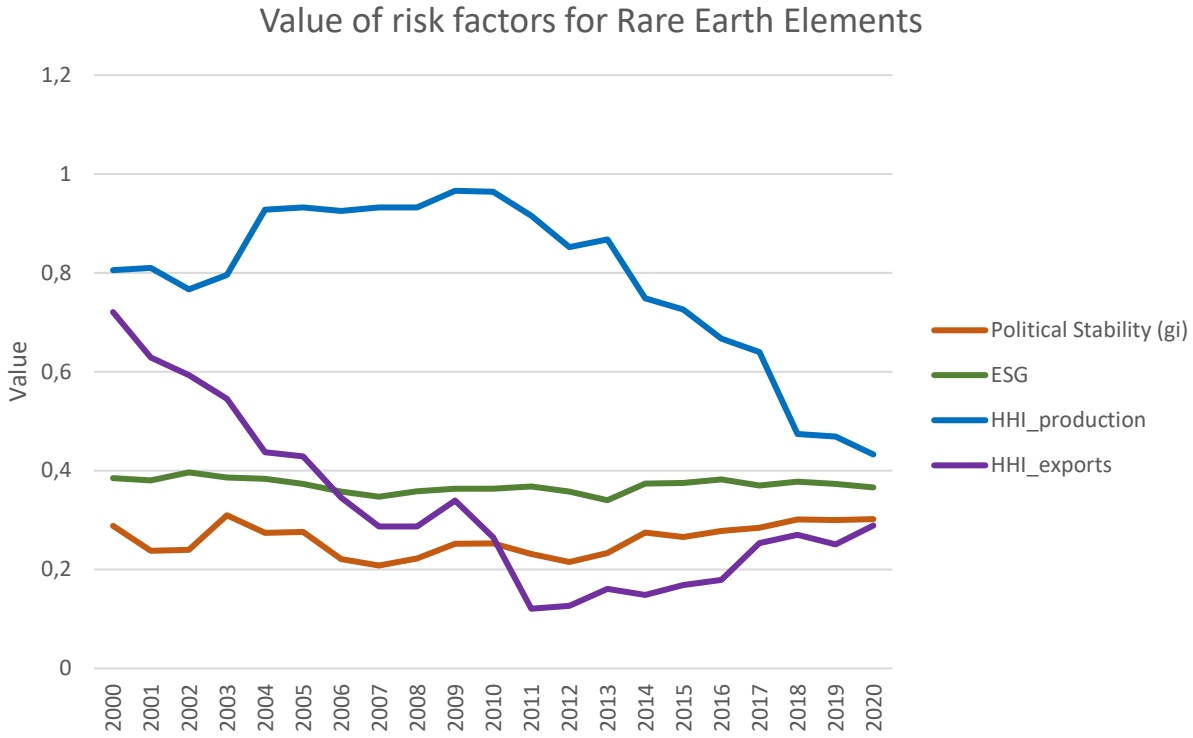
Nickel


Evolution of Canadian Geopolrisk for Nickel imports from 2000 to 2020
Titre de l'axe
0,04
0,035
0,03
0,025
0,02
0,015
0,01
0,005
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Baseline
GPRS - 1
GPRS - 2
GPRS - 3

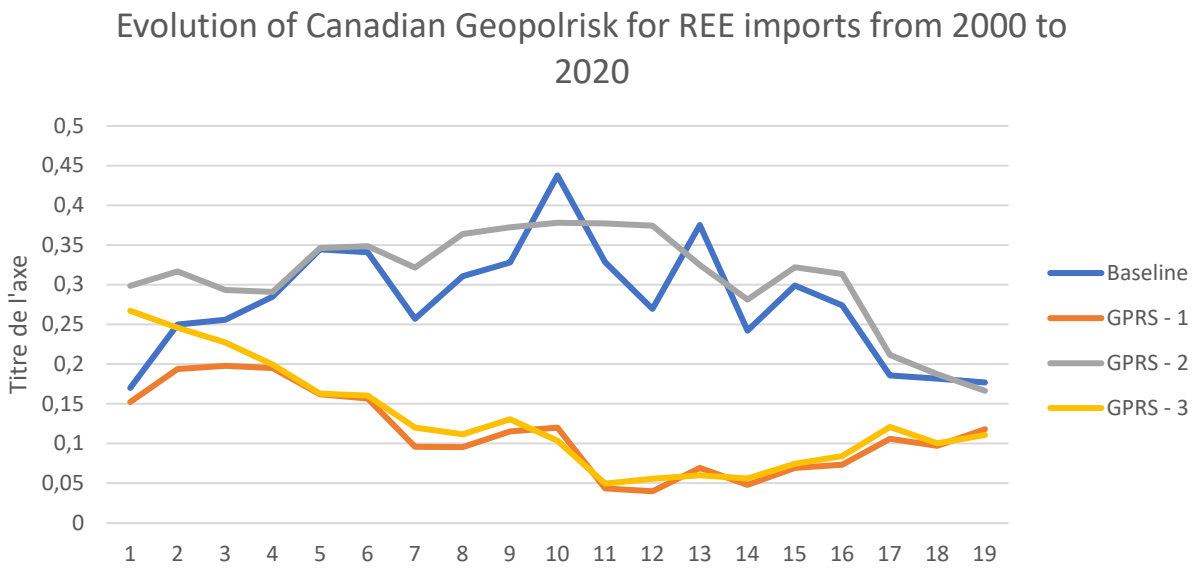

Value of risk factors for Nickel
Titre de l'axe
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
gi
ESG
HHI_production
HHI_exports

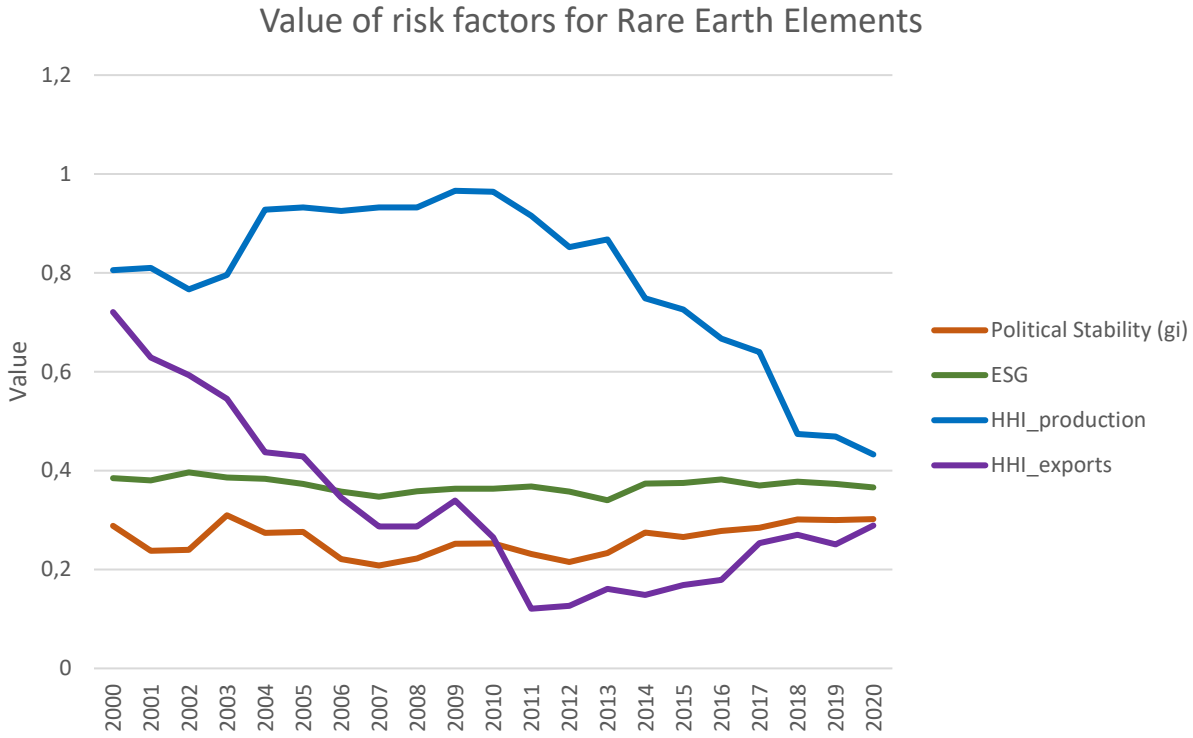
Rare Earth Elements





Rare Earth Elements

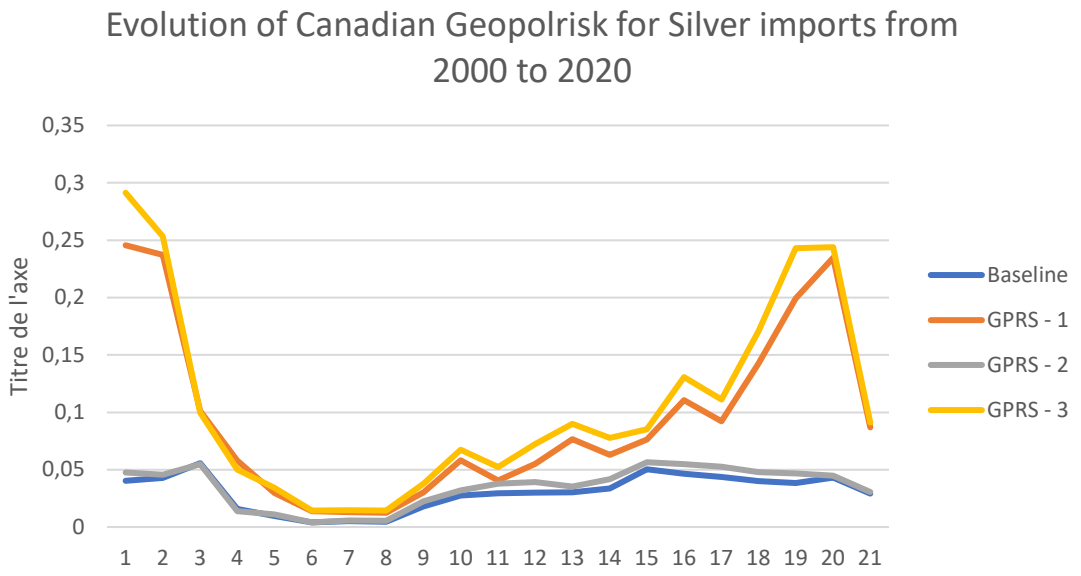


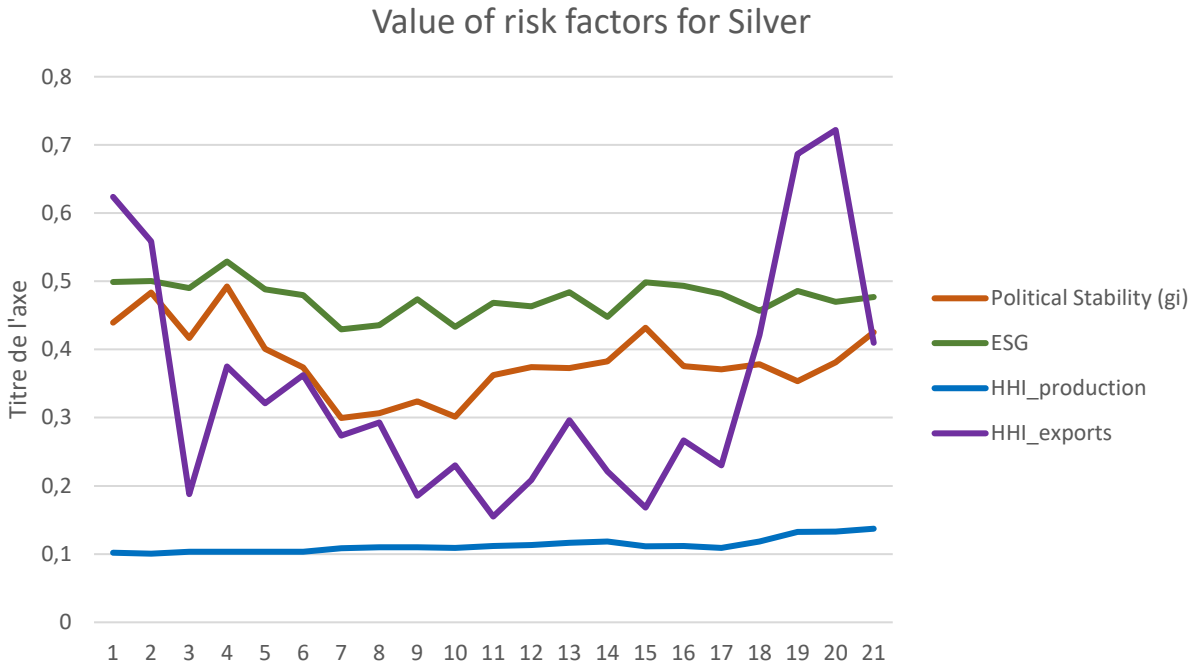


Correlation between ESG variables

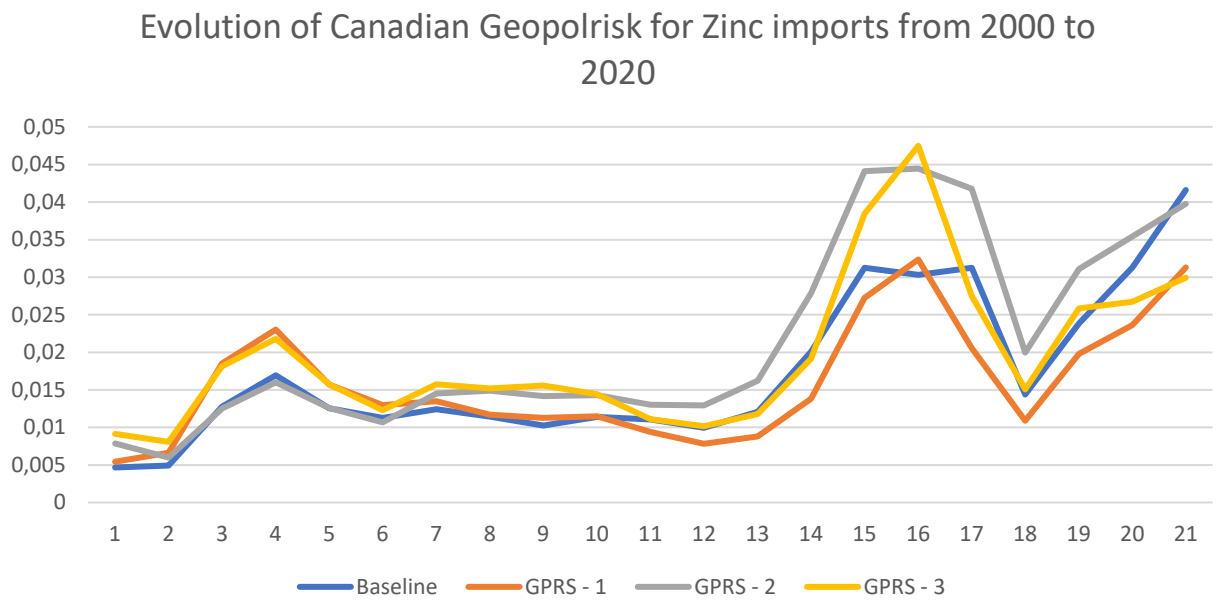
	Economic (ESG)	*Governance (ESG)*	*Social (ESG)*	*Ecosystem (ESG)*	*Habitat (ESG)*	*Infrastructure (ESG)*	*Political Stability (gi)*
Economic (ESG)	1						
Governance (ESG)	-0.5171369	1					
Social (ESG)	0.57417706	-0.3459661	1				
Ecosystem (ESG)	-0.5244986	0.38120004	-0.4345919	1			
Habitat (ESG)	-0.5190792	0.49586416	-0.7913486	0.56873747	1		
Infrastructure (ESG)	0.44497253	-0.1026641	0.4040341	-0.2046098	-0.4261189	1	
Political Stability (gi)	0.54996097	0.06275121	-0.0695191	-0.2448643	0.10698423	0.22593262	1

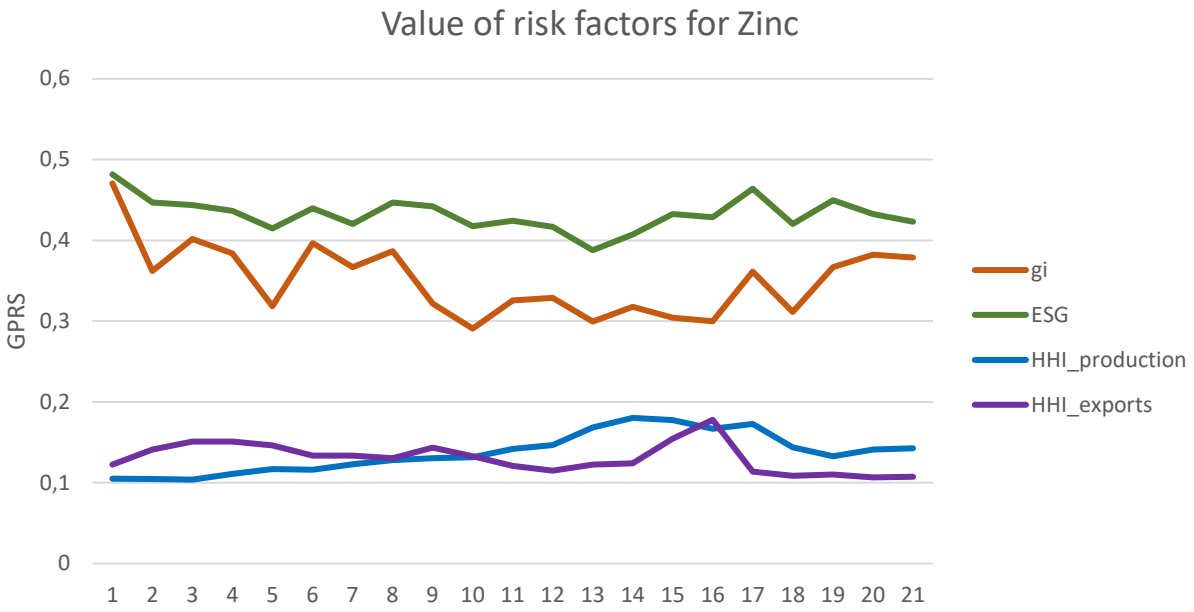
Silver


Evolution of Canadian Geopolrisk for Silver imports from 2000 to 2020
Titre de l'axe
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Baseline
GPRS - 1
GPRS - 2
GPRS - 3

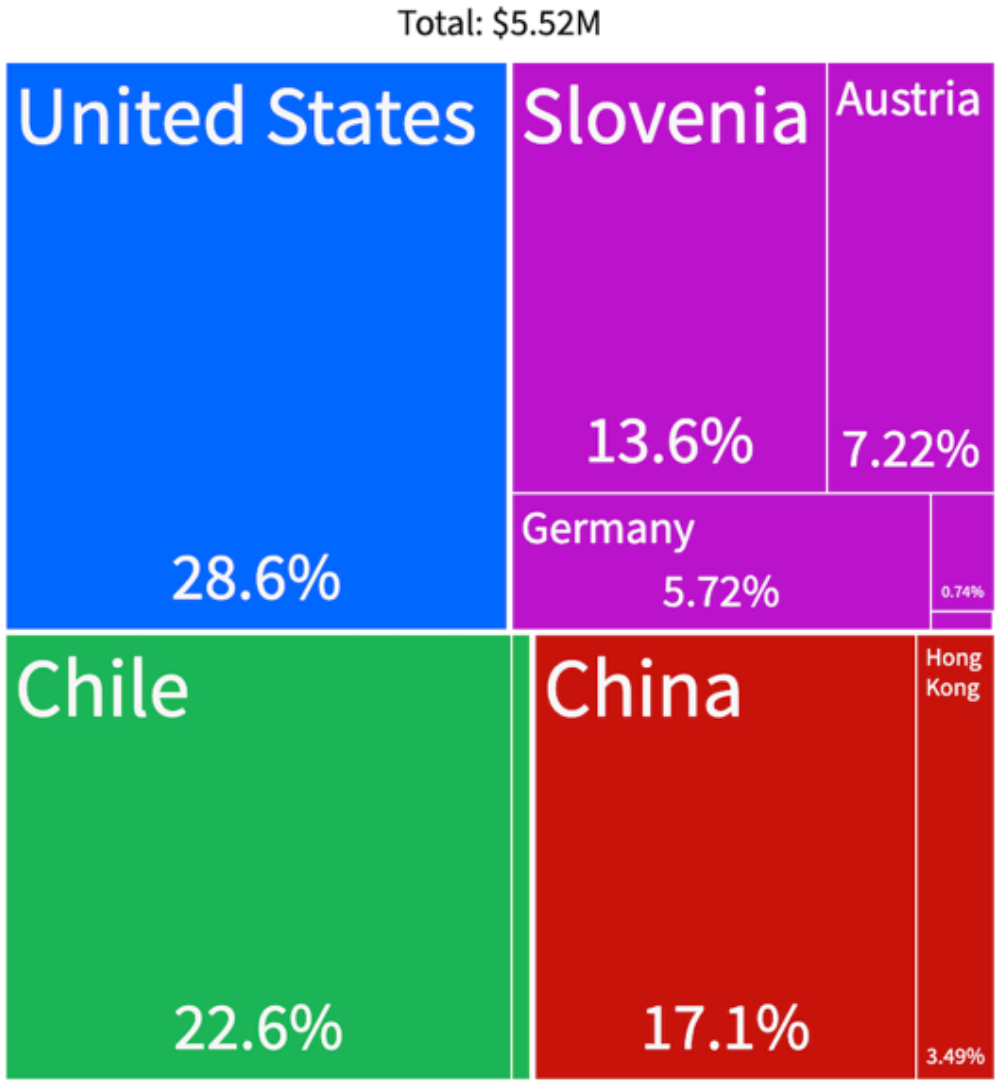

Value of risk factors for Silver
Titre de l'axe
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Political Stability (gi)
ESG
HHI_production
HHI_exports

Zinc


Evolution of Canadian Geopolrisk for Zinc imports from 2000 to 2020
0,05
0,045
0,04
0,035
0,03
0,025
0,02
0,015
0,01
0,005
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Baseline
GPRS - 1
GPRS - 2
GPRS - 3


Value of risk factors for Zinc
GPRS
0,6
0,5
0,4
0,3
0,2
0,1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
gi
ESG
HHI_production
HHI_exports

Zinc Exporters of lithium carbonate to Canada for 2020, (OEC, 2023)



Comparison of methodologies

Supply risk factor	GeoPolRisk	ESP	ESSENZ
Political stability	Worldwide Governance Indicators (WGIs): 90% confidence intervals (World Bank 2018)	Worldwide Governance Indicators (WGIs): 90% confidence intervals (World Bank 2018)	Worldwide Governance Indicators (WGIs): 90% confidence intervals (World Bank 2018)
Production (primary)	USGS mineral commodity summaries (USGS 2016) or similar: no uncertainty information	USGS mineral commodity summaries (USGS 2016) or similar: no uncertainty information	USGS mineral commodity summaries (USGS 2016) or similar: no uncertainty information
Commodity trading	UN Comtrade (United Nations 2018): no uncertainty information	Not applicable	Not applicable
Inventory flows	Case specific; depends on data sources	Case specific; depends on data sources	Case specific; depends on data sources
Substitutability	Ordinal ranking of "closest substitute" performance (Graedel et al., 2015b): qualitative discussion of uncertainty	Not applicable	Not applicable

Comparison between GeoPolRisk, ESP and ESSENZ, Cimprich, 2019.