The Challenge and Opportunity of Integrating ESG–Sustainability Metrics into Strategic
Long Term Mine Planning

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Context & "Take – Aways"

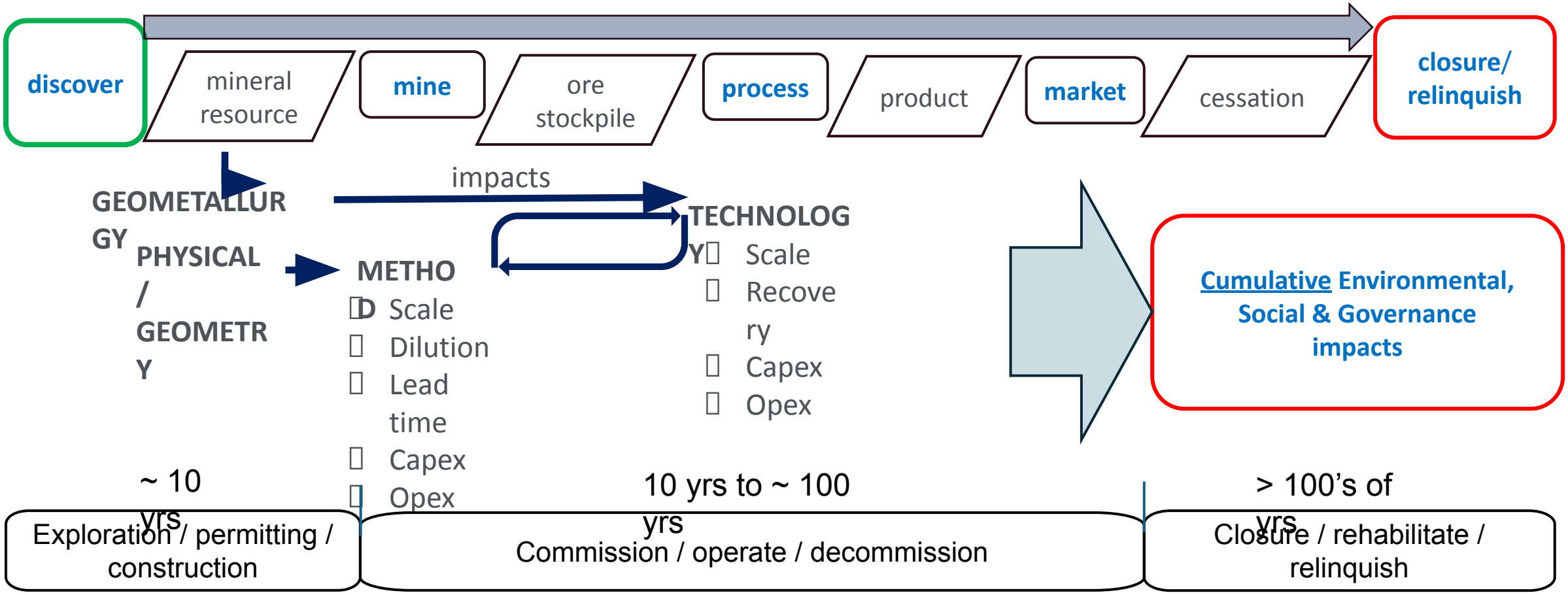
Context

- Mining is a **complex adaptive system** that operates at the intersection of natural and industrial ecosystems with society.
- Adaptive systems **evolve in response to internal and external influences** and exhibit emergent behaviour over time.
- Mining and beneficiation activities have **significant spatial and temporal impacts** on the environment and society.
- ESG–Sustainability demands **continuously adapt** to shifts in regulation, ecological concerns and social dynamics.
- Multi-generational sustainability **expectations will diverge** from initial business planning assumptions necessitating strategic **scenario driven, dynamic life of mine planning** to address evolving Reasonable Prospects of Eventual Economic Extraction (RPEEE) interpretation.

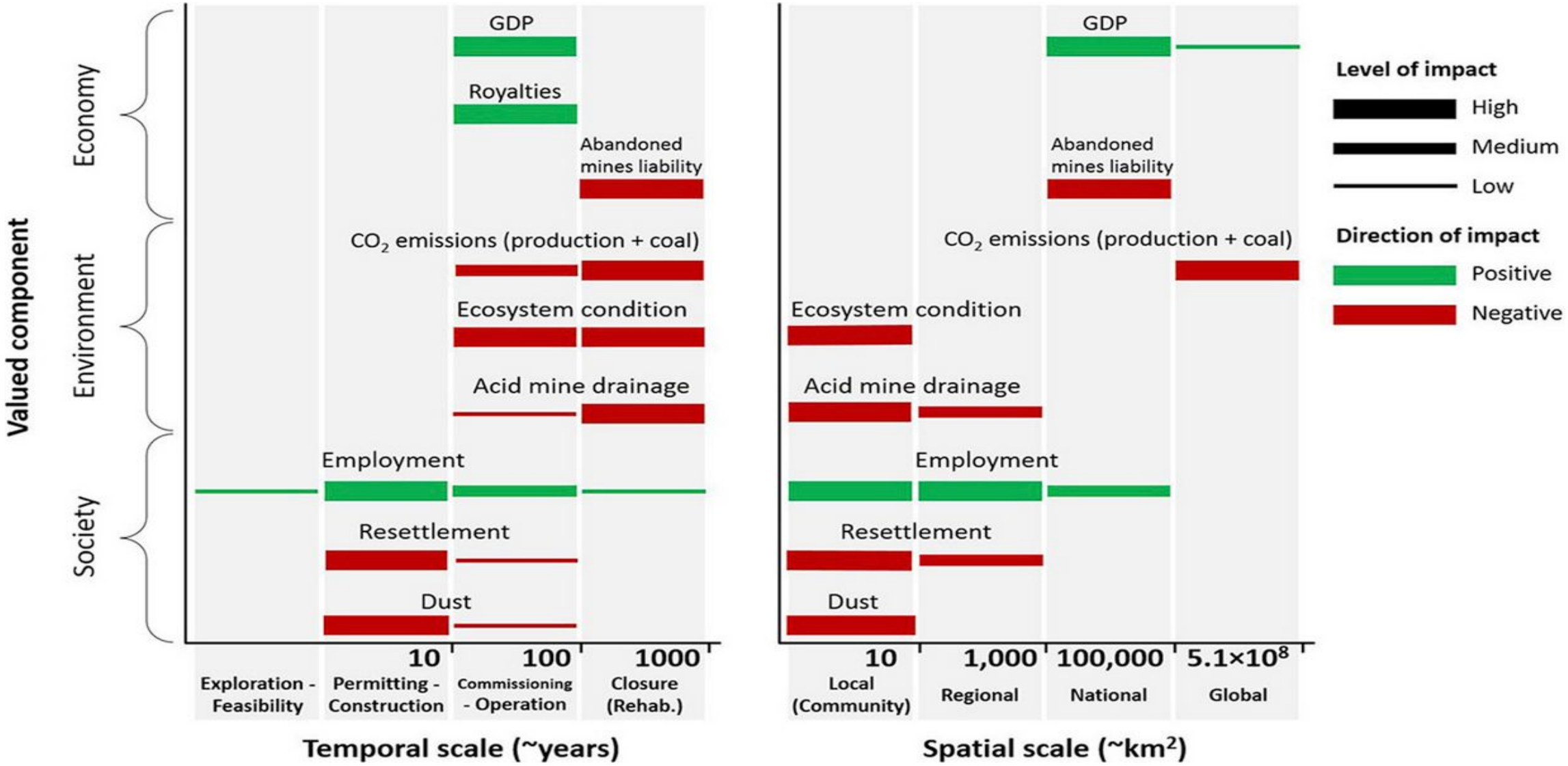
Take-aways

- **Identification, quantification and inclusion of ESG-S criteria,** at an **appropriate estimate level,** in **life of mine planning and optimization** is necessary to address closure and relinquishment risk.
- Acknowledgement of **spatial and temporal** impacts, through **scenario based planning**, can identify likely business operating envelopes and enable value optimization.

Mining activities: integrated from discovery to relinquishment = Cumulative ESG-S Impacts



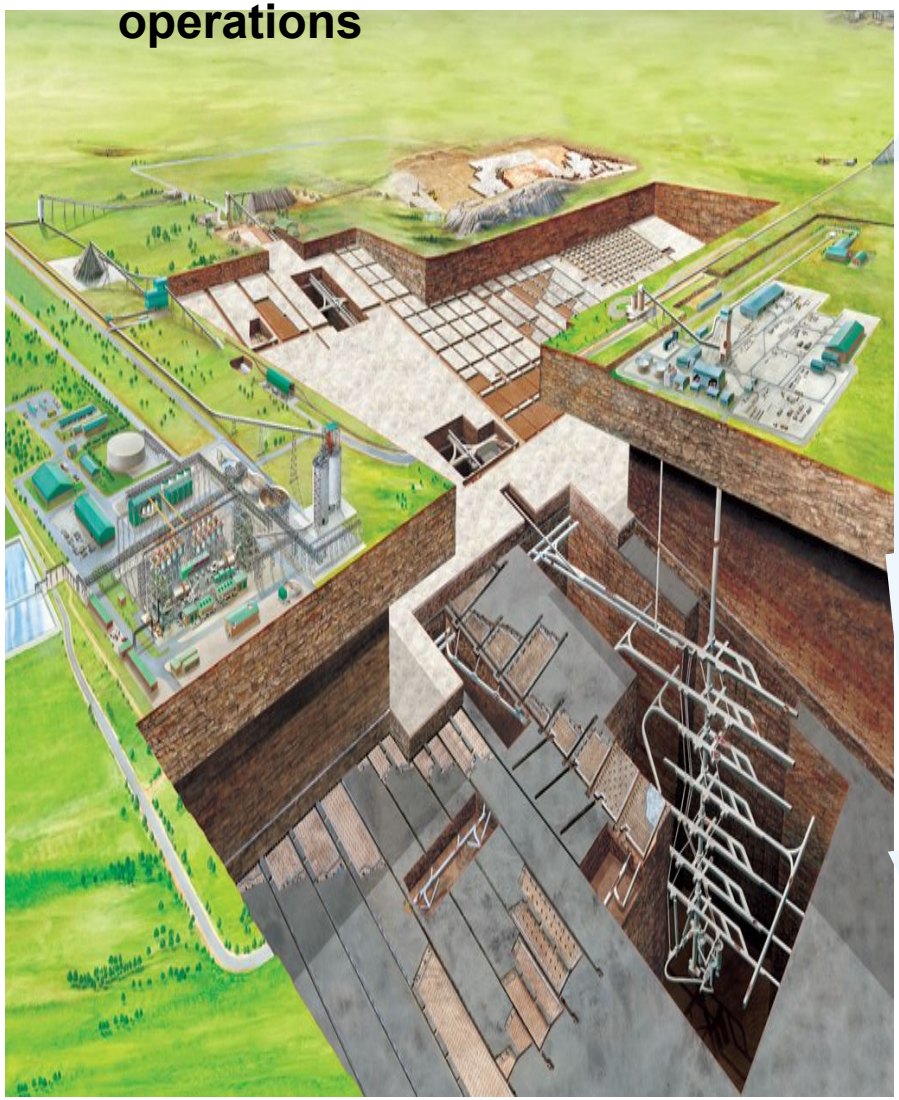
Mining activities - Temporal & Spatial impacts over Life of Mine



Lechner, A.M. et al (2017) – Challenges of integrated modelling in mining regions to address social, environmental and economic impacts

Mining - impact indicators – a simple example

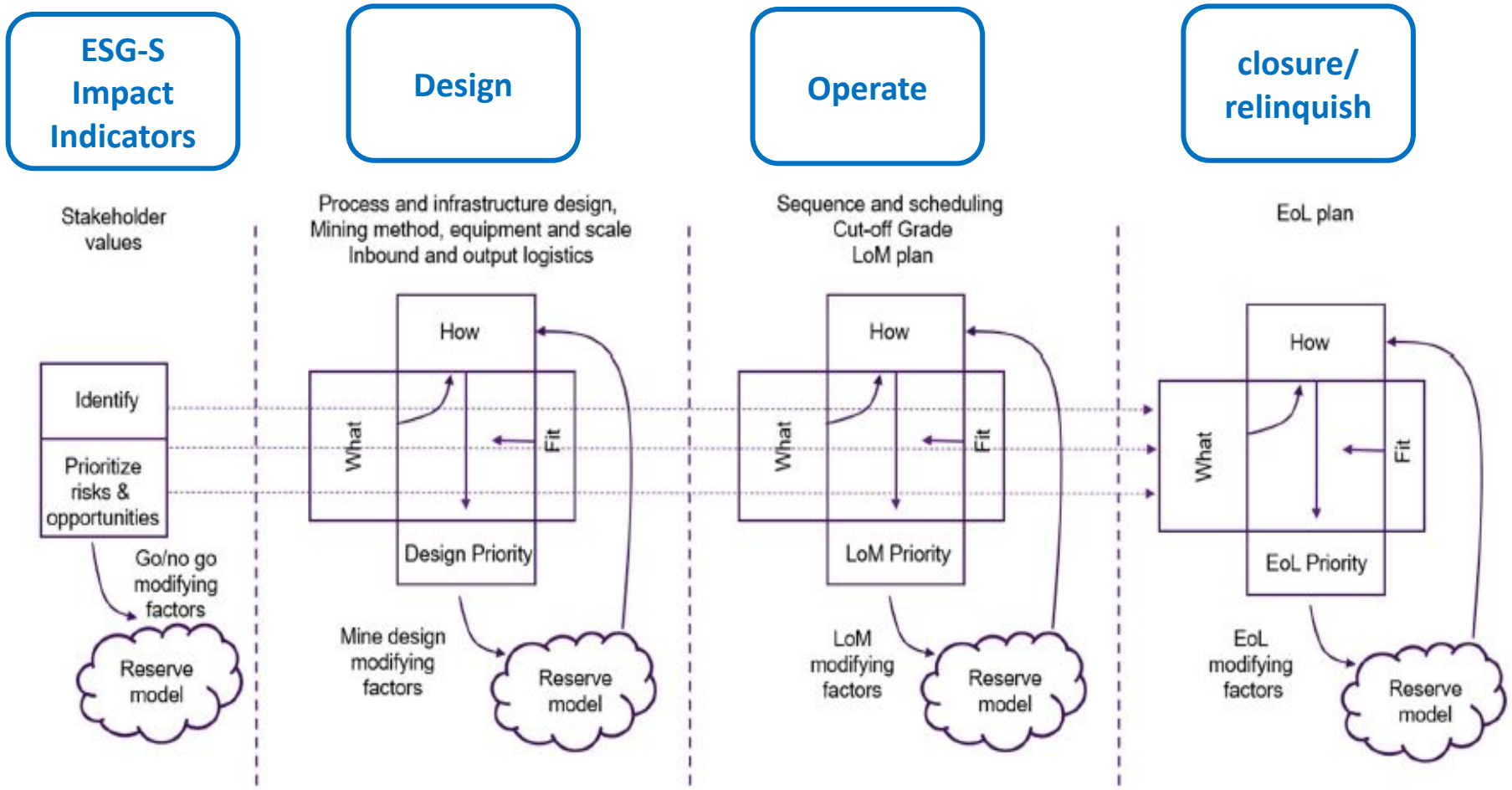
Mining & Processing operations



environmental & social impact		aspect	indicator
e.g. vegetation	Species viability	ECOSYSTEM HEALTH	Biodiversity
	Erosion		Genetic diversity
			??
e.g. de-watering	Ground water contamination	WATER RESOURCES	Water quantity
	Flooding		Water quality
			??
e.g. blasting	Dust/noise, vibration	COMMUNITY, HEALTH, SAFETY, LIVELIHOODS	Health
e.g. Employment	Variability		Disease
e.g. air pollution			Demographics
			??

spatial & temporal metrics over Life of

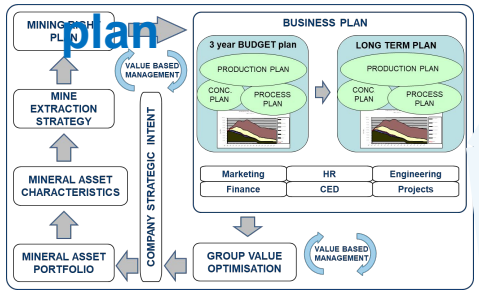
Integrated mine design, planning and execution – ESG-Sustainability & modifying factors



Adapted from Nehring, M. & Knights, P. (2024)- "A Systems Engineering Approach to Incorporate ESG Risks and Opportunities in Early Stage Mine Design and Planning

Integrated mine design, planning and execution – ESG-S & Mineral Resource block model

Life of mine plan



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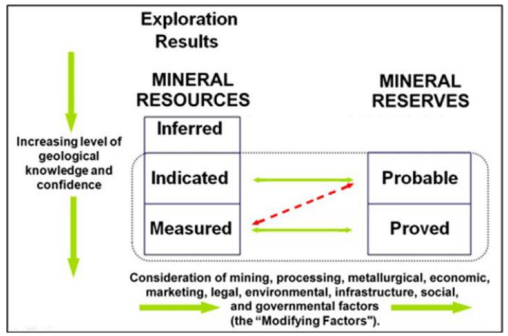

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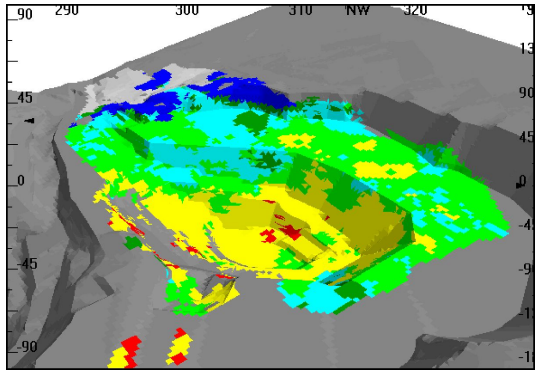
Modifying factors



Resource Block model

environmental & social impact | aspect | indicator

e.g Vegetation loss	Species viability	ECOSYSTEM HEALTH	Biodiversity
			Genetic diversity
	Erosion		??
e.g. De-watering	Ground water contamination	WATER RESOURCES	Water quantity
			Water quality
	Flooding		??
e.g. Blasting	Dust/noise, vibration	COMMUNITY, HEALTH, SAFETY, LIVELIHOODS	Health
			Disease
	Employment variability		Demographics
e.g. Air pollution			??

1

spatial & temporal metrics

Integrated mine design, planning and execution – Block model and ESG-S impact indicators

Example: energy demand for mining and recovery, based on geometallurgy domains, linked to SO_2 emissions, impacts, mitigation, cost, location and time

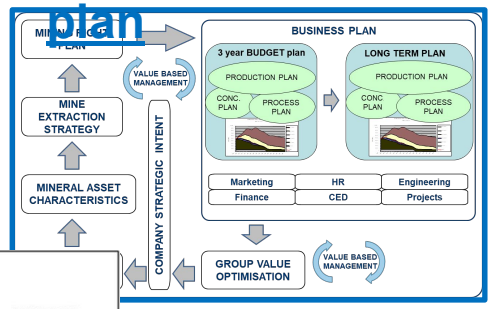
Block Model: (domains) 1 .. n

Parameter: energy (kWhr/t) .. …

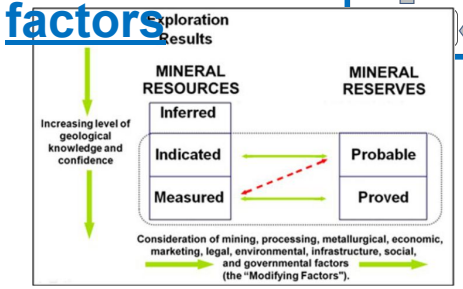
Energy demand: (kW) .. …

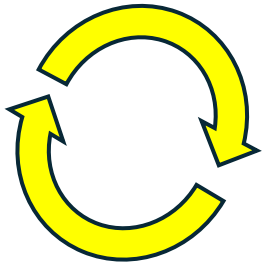
Emissions (SO_2) .. …

Life of mine plan



Modify factors





Impact

Environment Water & Soil acidification Infrastructure corrosion

Social Community health

-ve Outcome

Reduced Crop yields

Shortened lifespan

Respiratory disease Neurological effects

Mitigation

Water treatment Soil remediation

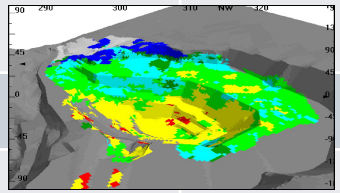
Infrastructure replacement

Medical treatment / devices Compensation

Block Model

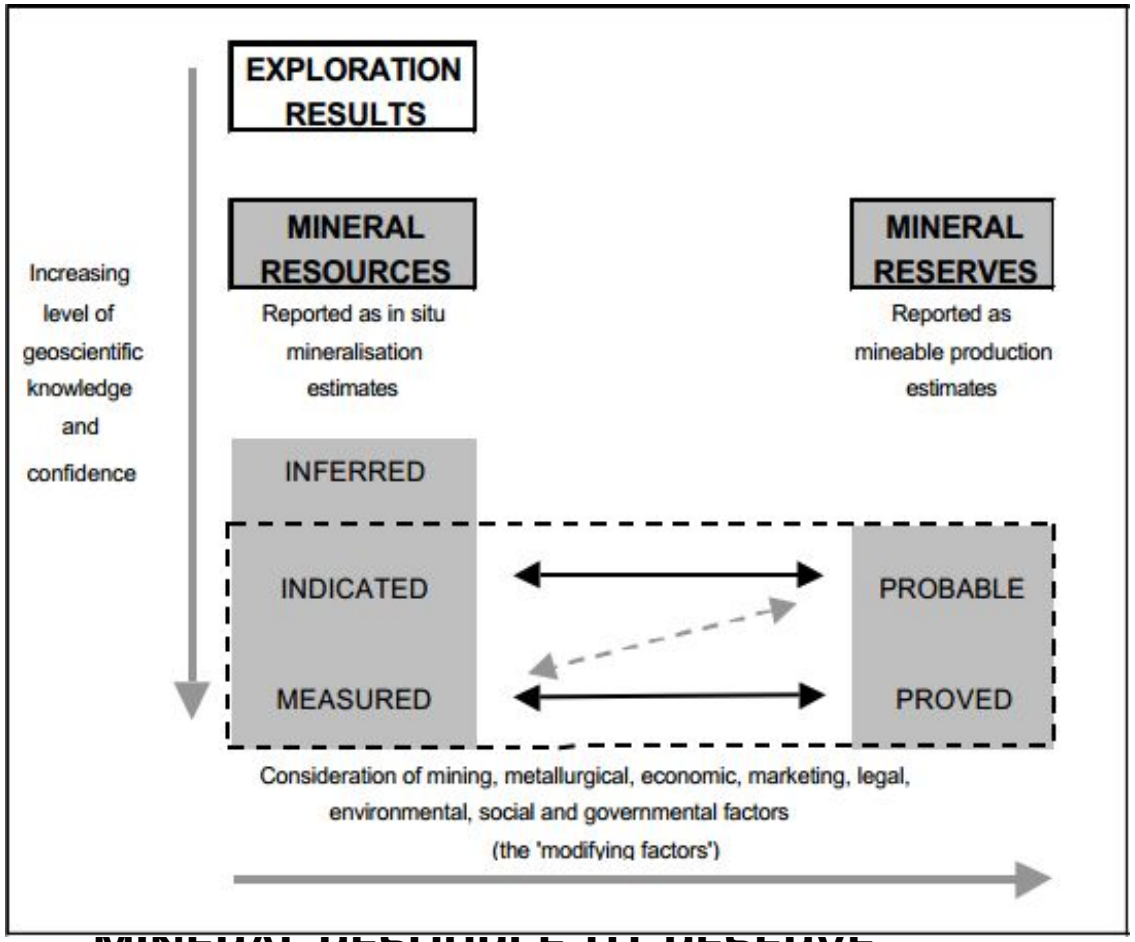
Environmental (rating: $/t) 1 = xx/t n ….

Social (rating: $/t) 1 = xx/t n ….

Location	Timing	Cost
		$/t
		$/t
		$/t
		$/t

Public reporting codes e.g. SAMREC …Mineral Resource to Reserve modifying factors

- ESG-Sustainability factors require inclusion at early-stage Minerals Resource definition to acknowledge Reasonable Prospects of Eventual Economic Extraction (RPEEE).
- Conversion of Mineral Resources to Mineral Reserves requires that ESG **modify factors** are estimated at the same level of accuracy as other project elements over **anticipated spatial and temporal impact zones** viz
  - Pre-Feasibility (±15% to ±25%)
  - Feasibility ((±10% to ±15%)
- This **requires spatially and time dependent ESG economic attributes for orebody geozones coupled to scenario based planning.**



MINERAL RESOURCE TO RESERVE CONVERSION

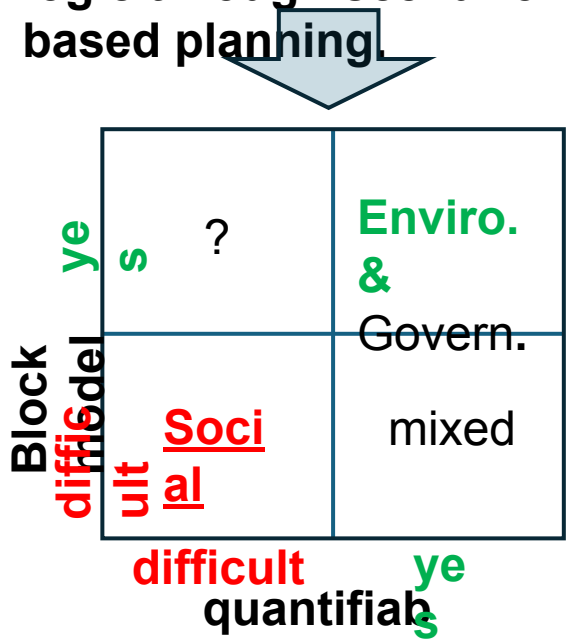
THE SOUTH AFRICAN CODE FOR THE REPORTING OF EXPLORATION RESULTS, MINERAL RESOURCES AND MINERAL RESERVES (THE SAMREC CODE), 2016 EDITION

ESG-Sustainability – Stakeholder value drivers

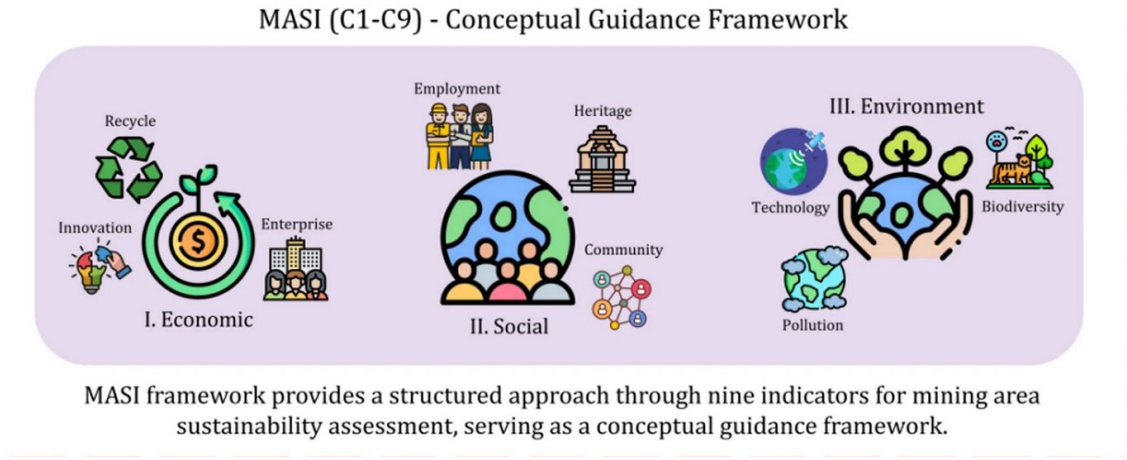
- **Environment** (GHG emissions; biodiversity; water use and access; water quality; air quality; noise; non-mineral waste and recycling; tailings and mineral waste).
- **People** (culture and heritage; land access and resettlement; meaningful participation; mutual benefits).
- **Workforce** (occupational health and wellbeing; inclusion and diversity; skills, training and career development).
- **Local communities** (livelihoods and mutual benefit; community education; community health and safety; human rights and governance; meaningful participation).
- **Customers** (commercial license to operate; security of supply; product quality and consistency; opportunity for growth; product stewardship and trust; circularity).
- **Suppliers** (commercial license to operate; Supplier capacity building; product stewardship and trust; circularity).
- **Government** (tax and royalty contribution; regional employment opportunities; regional development).
- **Shareholders** (growth; returns; risk and opportunity).

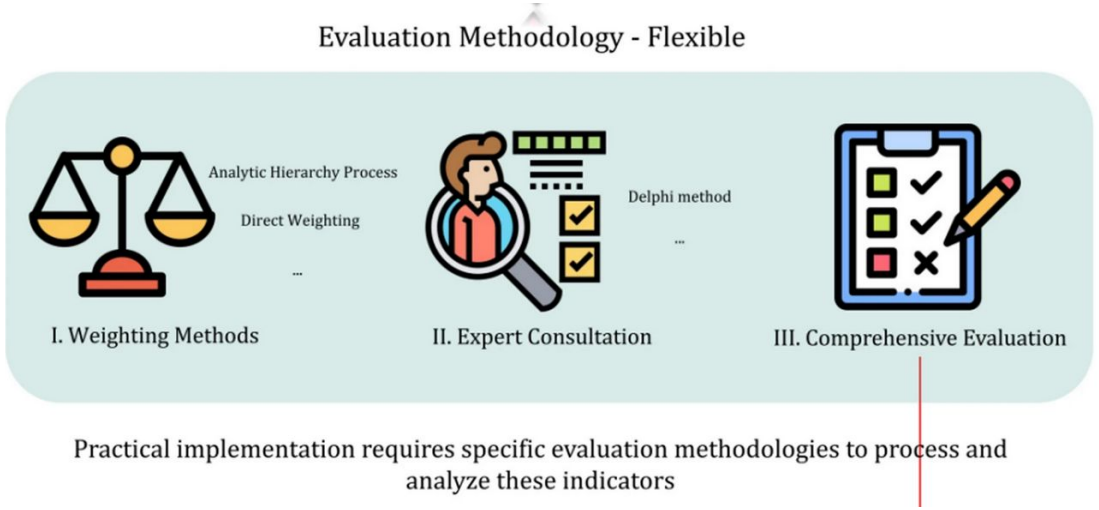
Need to re-think:

- **Identification & prioritisation logic for ESG impacts**
- **Impact quantification logic and associated mitigation estimates.**
- **block model integration, and**
- **Spatial and temporal impact logic through scenario based planning.**



Example methodology: Mining Area Sustainability Index (MASI)





Adapted from Haoxuan Yu, et al (2024) – "Elevating community well-being in mining areas: the proposal of the mining area sustainability index (MASI)

Comment

- This work analyses and prioritises indicators based on impact but **lacks linkages to mine planning and optimization processes.**
- **Tangible uncertainties** ("known unknowns" – recognized uncertainties where outcomes cannot be predicted with sufficient certainty) and usually excluded from planning risk assessment e.g. evolution of environmental awareness and activism, social response to post closure obligations, regulatory change, innovation in remediation technology **should be addressed through scenario planning.**

Closing comments

Identification, quantification and inclusion of ESG-S criteria, at an **appropriate estimate level,** in **life of mine planning and optimization** is necessary to address closure and relinquishment risk.

This can be achieved through **ESG-S impact attribute inclusion in block models and strategic life of mine planning processes**.

Spatial and temporal impacts and associated likely business operating envelopes can be addressed through **scenario based planning** approaches.

Thank you