Assessing Sustainability in Mine Closure and Repurposing: A Case Study from Colorado, USA.

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Why Focus on Mine Closure?

- Mine closure is rated among mining’s top operating risks (Vivoda et al. 2019).
- Mine closure regulations have mainly focused on the environmental and physical aspects of mine closure, specifically reclamation and rehabilitation and pay limited attention to the social aspects [Monosky and Keeling 2021].
- Only a few countries and individual provinces or states have enacted and executed specific mine closure laws or regulations (e.g., the United Kingdom, Chile, Peru, Manitoba and Ontario–Canada, and the state of Nevada, United States); most countries cover mine closure requirements either within the mining law or within broader environmental legislation that is applicable to mining (Vivoda et al. 2019).
- In recent years, international best-practice guidelines have encouraged mining companies to commit to principles of sustainable development in planning closure (Asr et al. 2019).
ICMM Closure Guidance (2019)

- Delayed closure planning
  - Reduces repurposing alternatives
  - Can rush the evaluation of the best alternatives / supporting SD is an issue!
- Effective and responsible mine closure and sustainable repurposing
  - Contributes to sustainable development (SD)
  - Environmental rehabilitation + Reduced socioeconomic risks
- Early definition of the closure vision:
  - Consistent and transparent stakeholder engagement
  - Community participation in planning
  - Better social transitions
  - Better closure management
  - More accurate cost estimates
  - Early identification of risks and mitigation strategies
  - Progressive reduction of liabilities

The Integrated mine closure: good practice guide provides ICMM members and other responsible mining companies with guidance intended to promote a disciplined approach to integrated closure planning and to increase the uniformity of good practices across the sector.
Henderson Mine
• 42 mi / 68 km west of Denver
BACKGROUND TO THE SITE

• 18 million pounds of molybdenum/year
• Land: 12,800 acres / > 5,000 hectares total
Mill Area of the Mine Site

- Mill: 15 mi / 24 km west of mine
- 1,400 acres / 566 hectares of tailings
Economic impacts of closure

• Jobs: 350+
• Local tax contributions:
  • 2017: ~ $22.5 M
  • 2018: ~ $18.3 M
  • $3 - $8 M over next 7 years

Looming Henderson Mine closure stokes big fears in Clear Creek County

“They have been a great place for my husband to work,” Dhyne said. “We raised our four kids with him working up in the mine. They provided for us.”

Andi Anderson’s husband has worked as an electrician at Henderson for five years, and while they are hoping he will make it through the January layoffs, she called it “a longshot.”

“I can’t believe it’s closing,” the Idaho Springs resident said as she left her job at a diner in town. “We just bought a house.”
MOTIVATION

Student Challenge: Post-closure (repurposing) alternatives

• Winners
  • 1: Glass manufacturing from tailings (Tailings)
  • 2: Organic shrimp farming (Shrimp)
  • 3: CBD and hemp production (Hemp)
Driving Questions

• Are these the right options in terms of sustainable development?
• How can we better understand different stakeholders’ visions of post-mining repurposing?
• Is this quantifiable?
STUDY OBJECTIVES

• Evaluate each scenario’s contributions to sustainable development
• Identify strengths and weaknesses,
• Investigate the most important aspects of “sustainability” to various stakeholders
• Determine which better reflects stakeholder preferences and results in the most economically, environmentally, and socially sustainable outcomes.

Source: Mining Company
METHODOLOGY

Indicator Selection → Data Collection
- Stakeholder preferences (survey)
- Mine & projects' data

Enough data?

No → Multi Attribute Decision Analysis (MADA)

Yes → Assessment of results
• Selection of indicators out of a comprehensive set of 230 indicators
  • 3 subsets: environmental, social, economic
• Refined to 17 indicators
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Verbiage used in Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECONOMIC INDICATORS</strong></td>
<td></td>
</tr>
<tr>
<td>Corporate income taxes and royalties paid at full capacity</td>
<td>The new facility’s income tax payments</td>
</tr>
<tr>
<td>Extent of community and infrastructure investments</td>
<td>New facility’s investments in public services for the community (road maintenance, housing assistance)</td>
</tr>
<tr>
<td>Number of years it will take to reach the full capacity from the day production begins</td>
<td>The time it will take for the new facility to reach its maximum production amount</td>
</tr>
<tr>
<td>Annual production capacity at full capacity</td>
<td>The maximum number of products that the new facility can produce</td>
</tr>
<tr>
<td>Annual revenue at full capacity</td>
<td>The amount of money the new facility makes from the sale of their goods and services</td>
</tr>
<tr>
<td><strong>SOCIAL INDICATORS</strong></td>
<td></td>
</tr>
<tr>
<td>Potential nuisance and more significant risks that may affect local communities</td>
<td>Nuisances or hazards that may arise form the new facility and could impact the nearby communities</td>
</tr>
<tr>
<td>Road use and traffic lead compared to the baseline</td>
<td>The potential traffic volume around the project site</td>
</tr>
<tr>
<td>Average annual salary of full-time workers</td>
<td>Annual salary offered for employees by the new facility</td>
</tr>
<tr>
<td>Number of full-time and hourly-based employees at full capacity</td>
<td>Number of employees that can work in the new facility</td>
</tr>
<tr>
<td>Number of different job types offered on site</td>
<td>Number of different job types offered by the new facility</td>
</tr>
<tr>
<td>Indicator</td>
<td>Verbiage used in Survey</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ENVIRONMENTAL INDICATORS</td>
<td></td>
</tr>
<tr>
<td>Expense of anticipated energy consumption</td>
<td>The new facility’s energy use</td>
</tr>
<tr>
<td>Proportion of heating energy that the new facility can potentially supply by renewables on-site</td>
<td>The amount of energy that the new facility gets from renewable energy resources such as solar roof panels</td>
</tr>
<tr>
<td>Potential percentage of recycled input materials</td>
<td>The amount of recycled materials used by the new facility to produce their products</td>
</tr>
<tr>
<td>Total amount of untreated tailings in 15 years</td>
<td>The amount of unremoved mine waste remaining in the new project area after 15 years</td>
</tr>
<tr>
<td>Waste production potential</td>
<td>The amount of waste to be produced by the new facility</td>
</tr>
<tr>
<td>Estimated total air emissions</td>
<td>Air pollution</td>
</tr>
<tr>
<td>Area used for production</td>
<td>Total land area used by the new facility</td>
</tr>
</tbody>
</table>
DATA COLLECTION

1. Data from the mine and student projects
   - location, operations, community
   - Proposed scenarios / student reports

2. Stakeholder survey
   - Online (covid)
   - 7 stakeholder groups
   - 45 total respondents; 41 complete responses
   - Analytical Hierarchy Process (AHP) to determine the weights
MULTI-ATTRIBUTE DECISION ANALYSIS (MADA)
Step 1: Goals Hierarchy -- attributes defined
MADA – Step 2: Formulate Utility Functions

• Single-measure utility functions (SUF) for each attribute
• Mathematically transformed monetary or other values into «standardized» utility values (0 to 1)
• Logical Decisions Software
• Assumed linear SUFs

Source: Hahn, 2012
MADA – Step 3: Weighting Preferences

✓ Establish preferences *between* the attributes
  - weights in multi-attribute utility function

✓ Survey results revealed the weights:
  - relative importance of each attribute (L4), category (L3), and sub-goal (L2)

✓ Results obtained for:
  - each individual stakeholder group
    - Aggregation of individual judgments (AIJ)
  - all stakeholder groups combined
    - Aggregation of individual priorities (AIP)
Weights Assigned by Stakeholder Group at Level 3: Economic Criteria

- Faculty members
- Industry advisors
- Government Agencies
- Mining Company
- Local Non-profits
- Community Members
- Local governments
- Combined Decision

Assigned Weight

- Contribution to society
- Economic performance
  - Investments in infrastructure and public services and income tax
  - Production capacity, revenue, time until full production
Weights Assigned by Stakeholder Group at Level 3: Social Criteria

- Faculty members
- Industry advisors
- Government Agencies
- Mining Company
- Local Non-profits
- Community Members
- Local governments
- Combined Decision

Assigned Weight:

- Community impacts
- Employment
Weights Assigned by Stakeholder Group at Level 4: Attributes - Employment

- Faculty members
- Industry advisors
- Government Agencies
- Mining Company
- Local Non-profits
- Community Members
- Local governments
- Combined Decision

Assigned Weight

- Annual salary (S3)
- Number of employees (S4)
- Number of job types (S5)
Weights Assigned by Stakeholder Group at Level 3: Environmental Criteria

- Faculty members: Air pollution, Waste, Resource consumption, Land use
- Industry advisors: Air pollution, Waste, Resource consumption, Land use
- Government Agencies: Air pollution, Waste, Resource consumption, Land use
- Mining Company: Air pollution, Waste, Resource consumption, Land use
- Local Non-profits: Air pollution, Waste, Resource consumption, Land use
- Community Members: Air pollution, Waste, Resource consumption, Land use
- Local governments: Air pollution, Waste, Resource consumption, Land use
- Combined Decision: Air pollution, Waste, Resource consumption, Land use
Judge’s Picks
1: Glass manufacturing from tailings (Tailings)
2: Organic shrimp farming (Shrimp)
3: CBD and hemp production (Hemp)
# RESULTS

## Overall Ranking

### Combined Decision

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Utility (0-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrimp</td>
<td>0.598</td>
</tr>
<tr>
<td>Hemp</td>
<td>0.538</td>
</tr>
<tr>
<td>Tailings</td>
<td>0.492</td>
</tr>
</tbody>
</table>

Legend:
- **Red**: Economic
- **Green**: Environmental
- **Blue**: Social

[Diagram showing utility distribution for Shrimp, Hemp, and Tailings]
| Level (L) | Aspect | Parameter                                      | Faculty Members | Industry Advisors | Government Agencies | Mining Company | Local Non-profits | Community Members | Local Governments | All Respondents |
|----------|--------|-----------------------------------------------|----------------|-------------------|---------------------|----------------|-------------------|-------------------|------------------|----------------|----------------|
| L2       | Econ   | Economic Aspects                              | 0.496          | 0.369             | 0.443               | 0.284          | 0.597             | 0.634             | 0.720            | 0.731           |                 |
| L2       | Soc    | Social Aspects                                 | 0.347          | 0.349             | 0.141               | 0.108          | 0.262             | 0.376             | 0.406            | 0.431           |                 |
| L2       | Env    | Environmental Aspects                         | 0.372          | 0.353             | 0.361               | 0.205          | 0.481             | 0.681             | 0.459            | 0.681           |                 |
| L3       | Econ   | Contribution to Society                       | 0.375          | 0.800             | 0.333               | 0.625          | 0.400             | 0.775             | 0.708            | 0.800           |                 |
| L3       | Econ   | Economic Performance                          | 0.375          | 0.800             | 0.333               | 0.625          | 0.400             | 0.775             | 0.708            | 0.800           |                 |
| L3       | Soc    | Community Impacts                              | 0.708          | 0.750             | 0.375               | 0.708          | 0.400             | 0.775             | 0.775            | 0.800           |                 |
| L3       | Soc    | Employment                                    | 0.708          | 0.750             | 0.375               | 0.708          | 0.400             | 0.775             | 0.775            | 0.800           |                 |
| L3       | Env    | Air pollution                                  | 0.349          | 0.419             | 0.456               | 0.067          | 0.198             | 0.337             | 0.377            | 0.575           |                 |
| L3       | Env    | Land use                                       | 0.099          | 0.302             | 0.443               | 0.225          | 0.488             | 0.310             | 0.104            | 0.513           |                 |
| L3       | Env    | Resource Consumption                          | 0.186          | 0.477             | 0.238               | 0.170          | 0.220             | 0.386             | 0.435            | 0.513           |                 |
| L3       | Env    | Waste                                         | 0.344          | 0.296             | 0.063               | 0.160          | 0.255             | 0.332             | 0.329            | 0.423           |                 |
| L4       | Econ   | Income tax payments (Ec1)                     | 0.375          | 0.708             | 0.625               | 0.333          | 0.067             | 0.625             | 0.733            | 0.800           |                 |
| L4       | Econ   | Investment in public services (Ec2)            | 0.375          | 0.708             | 0.625               | 0.333          | 0.067             | 0.625             | 0.733            | 0.800           |                 |
| L4       | Econ   | Time until full capacity (Ec3)                 | 0.554          | 0.198             | 0.215               | 0.376          | 0.593             | 0.321             | 0.252            | 0.638           |                 |
| L4       | Econ   | Production capacity (Ec4)                      | 0.261          | 0.200             | 0.625               | 0.195          | 0.205             | 0.564             | 0.548            | 0.659           |                 |
| L4       | Econ   | Revenue (Ec5)                                  | 0.483          | 0.122             | 0.515               | 0.291          | 0.662             | 0.658             | 0.406            | 0.710           |                 |
| L4       | Soc    | Nuisance (S1)                                  | 0.775          | 0.400             | 0.625               | 0.375          | 0.067             | 0.750             | 0.583            | 0.775           |                 |
| L4       | Soc    | Traffic (S2)                                   | 0.775          | 0.400             | 0.625               | 0.375          | 0.067             | 0.750             | 0.583            | 0.775           |                 |
| L4       | Soc    | Annual salary (S3)                             | 0.375          | 0.625             | 0.241               | 0.337          | 0.705             | 0.561             | 0.593            | 0.729           |                 |
| L4       | Soc    | Number of employees (S4)                       | 0.394          | 0.580             | 0.423               | 0.214          | 0.599             | 0.346             | 0.534            | 0.664           |                 |
| L4       | Soc    | Number of job types (S5)                       | 0.049          | 0.435             | 0.215               | 0.364          | 0.273             | 0.389             | 0.628            | 0.665           |                 |
| L4       | Env    | Energy Use (En1)                               | 0.556          | 0.717             | 0.689               | 0.511          | 0.712             | 0.691             | 0.684            | 0.743           |                 |
| L4       | Env    | Energy supplied by renewables (En2)            | 0.434          | 0.598             | 0.563               | 0.685          | 0.512             | 0.640             | 0.604            | 0.685           |                 |
| L4       | Env    | Recycled input materials (En3)                 | 0.400          | 0.278             | 0.376               | 0.380          | 0.363             | 0.262             | 0.549            | 0.632           |                 |
| L4       | Env    | Untreated tailings (En4)                       | 0.583          | 0.775             | 0.775               | 0.775          | 0.500             | 0.404             | 0.666            | 0.775           |                 |
| L4       | Env    | Waste production (En5)                         | 0.583          | 0.775             | 0.775               | 0.775          | 0.500             | 0.404             | 0.666            | 0.775           |                 |
FINDINGS

- The judges’ assessments did not reflect the stakeholders’ preferences
- Ranking of alternatives changed based on the decision maker's preferences and values
- Stakeholder groups share similar and different priorities both within and across groups
- Each alternative has its own strengths and weaknesses
- Overall, the combined group prioritized economic, then environment, then social
- Community members’ views generally in line with the combined group decision (reflects heterogeneity)
- Local non-profits and the mining company had the closest views among their members while local governments and community members had the greatest diversity among their groups
- Only a small set of indicators could be selected for this study out of a large sustainability indicator set, therefore, the next student challenge should include a wider range of indicators
References


THANK YOU!
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