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

Nicole M. Smith, Cansu Perdeli Demirkan, Sebnem Duzgun

Colorado School of Mines

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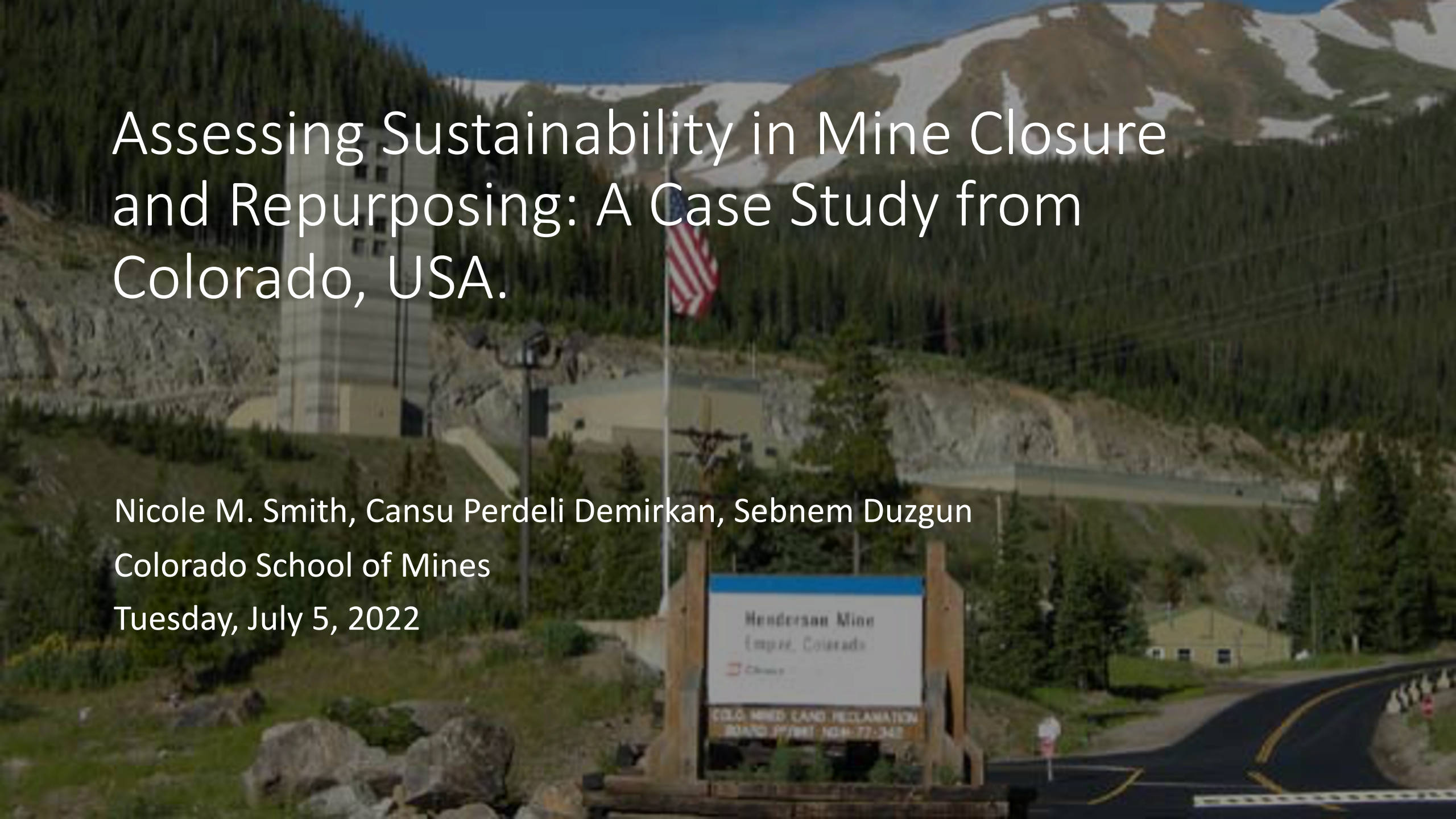
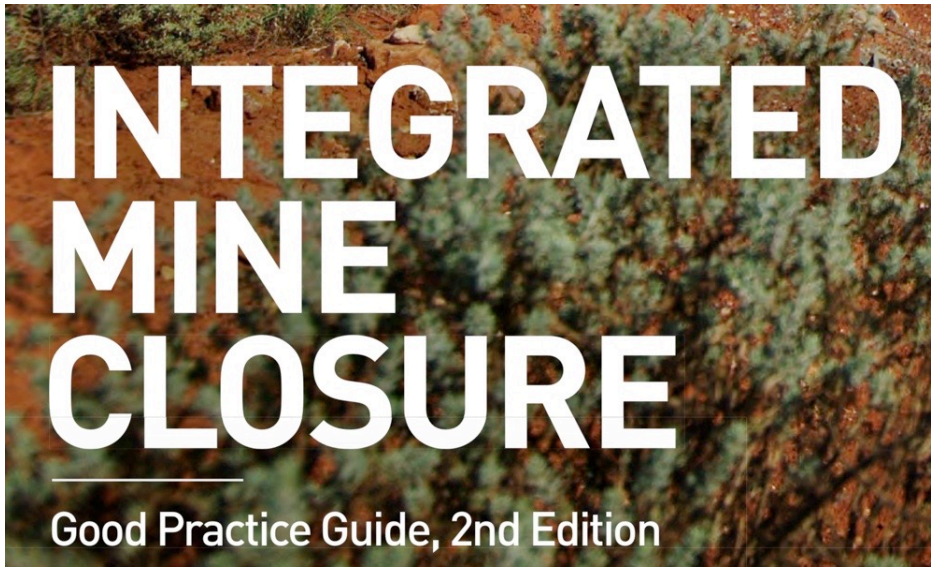


Why Focus on Mine Closure?

- 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).



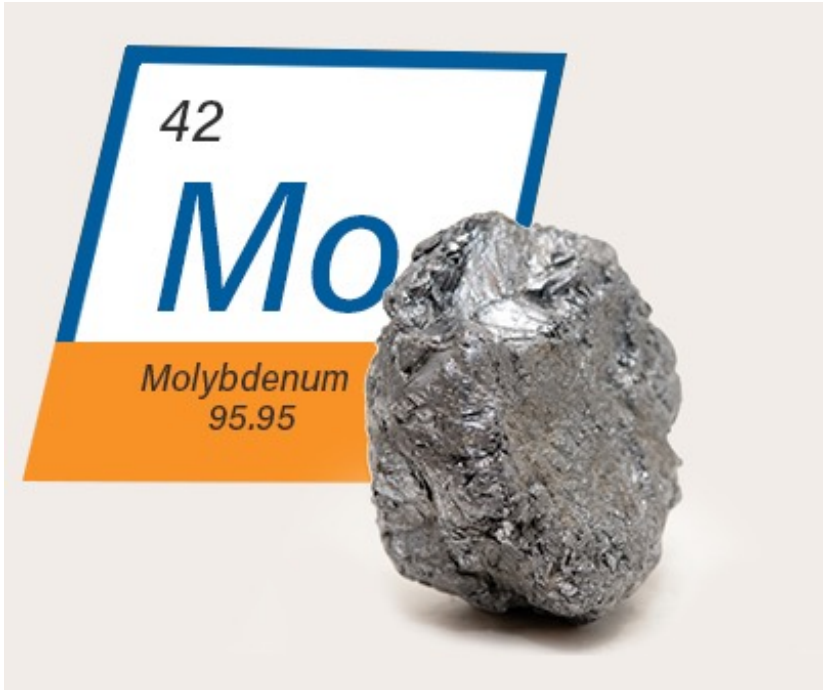
The *Integrated mine closure: good practice guide* provides ICMM members and other responsible mining companies with guidance intended to promote a disciplined approach to integrated closure planning and to increase the uniformity of good practices across the sector.

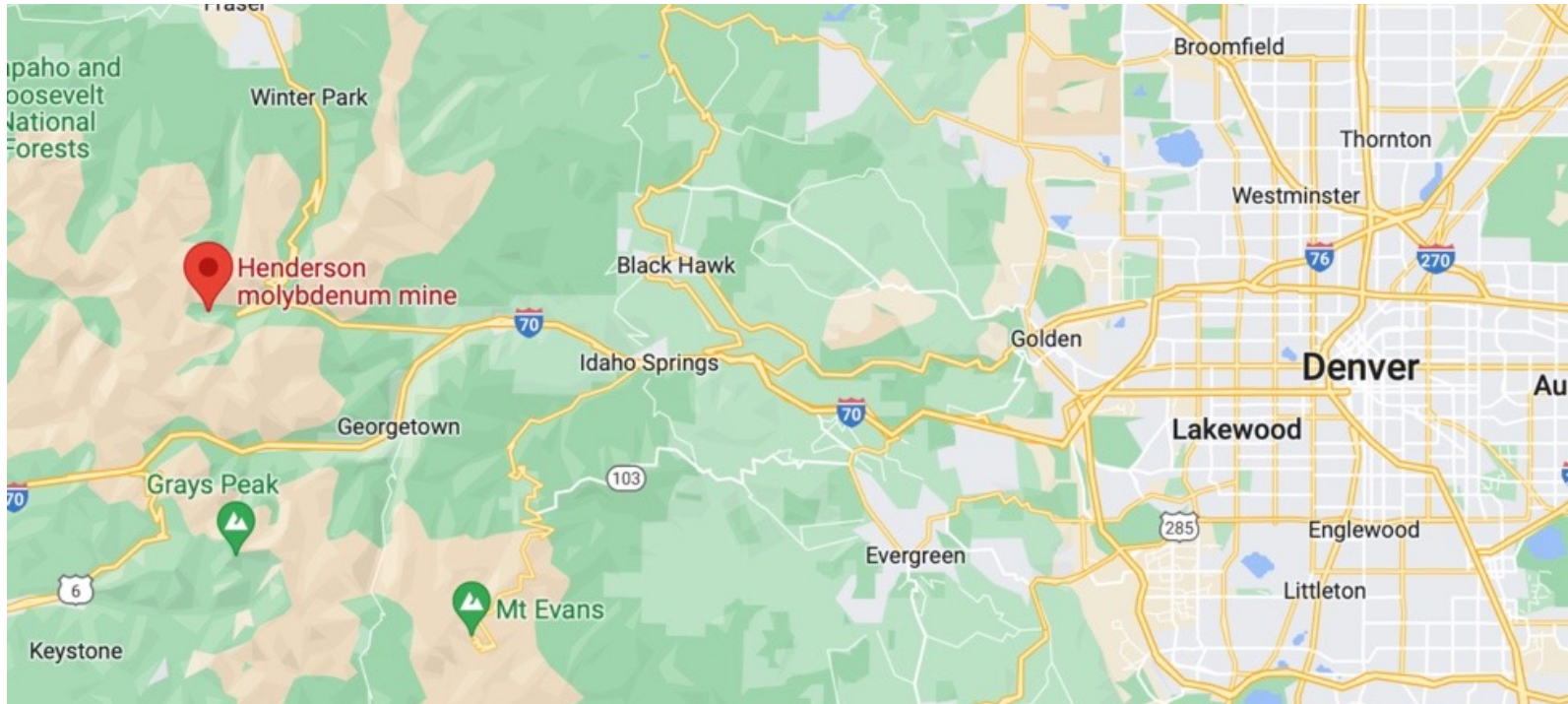
ICMM Closure Guidance (2019)

- 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**
  - (ICMM, 2019)

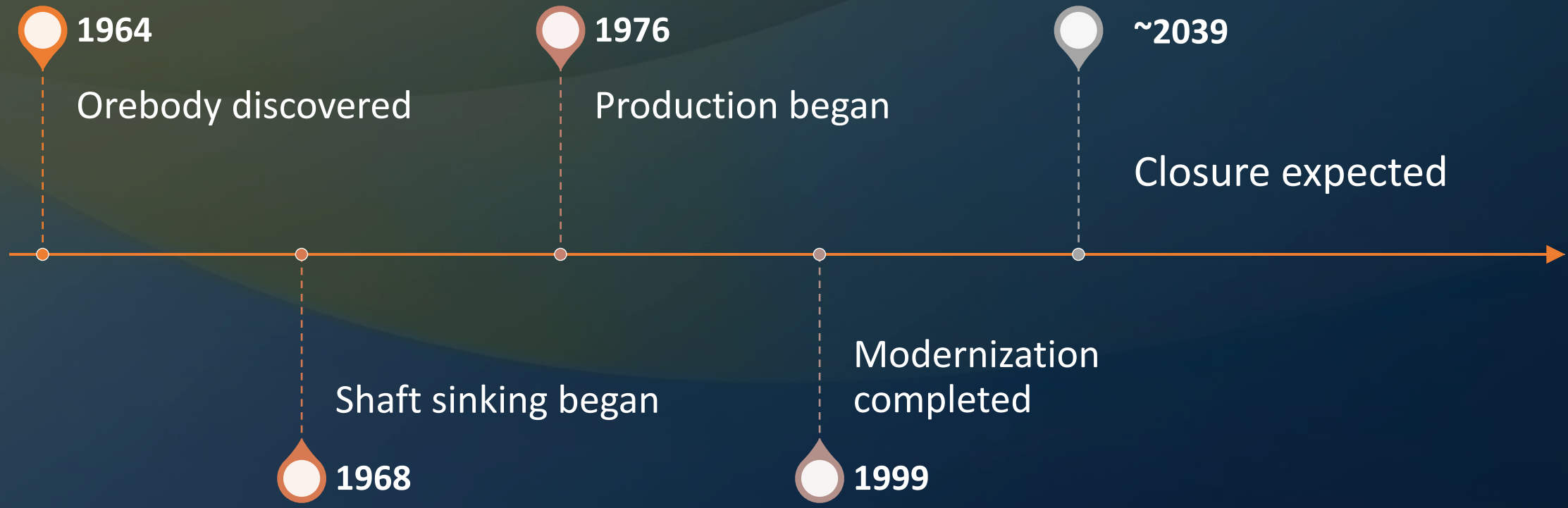
Henderson Mine

- 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

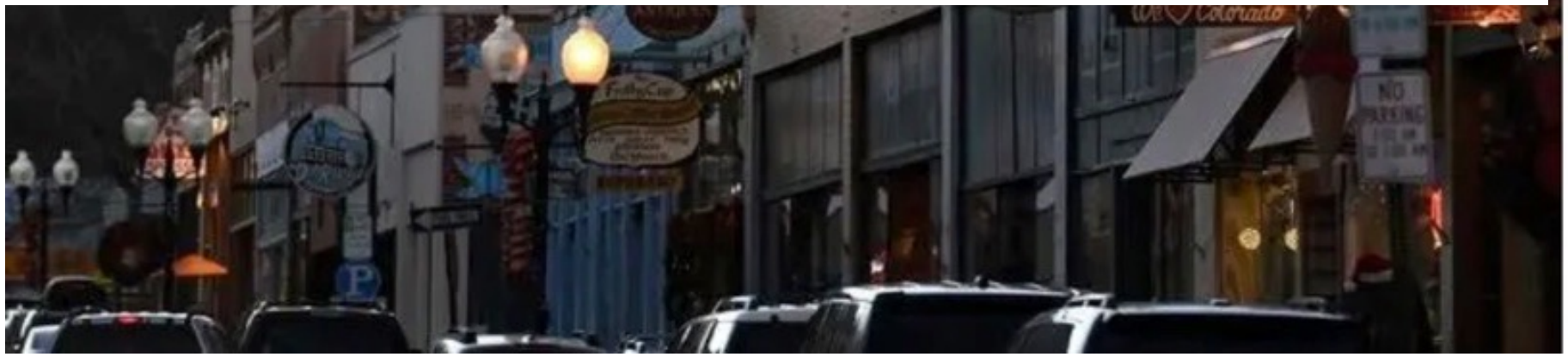
By **JESSE PAUL** | The Denver Post
PUBLISHED: December 10, 2015 at 2:30 p.m. | UPDATED: July 22, 2016 at 10:27 a.m.

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."

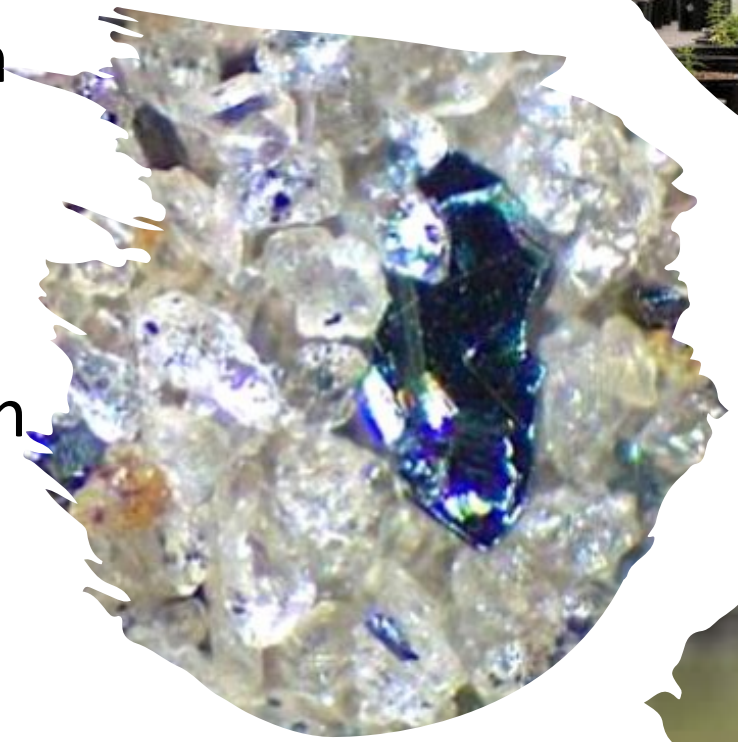
"I can't believe it's closing," the Idaho Springs resident said as she left her job at a diner in town. "We just bought a house."



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

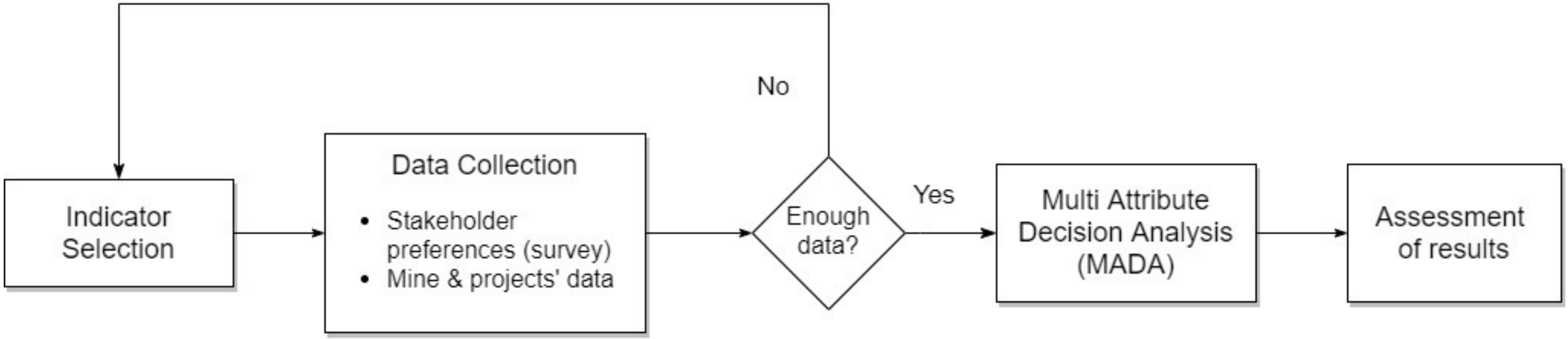
- Are these the right options in terms of sustainable development?
- How can we better understand different stakeholders' visions of post-mining repurposing?
- Is this quantifiable?

STUDY OBJECTIVES

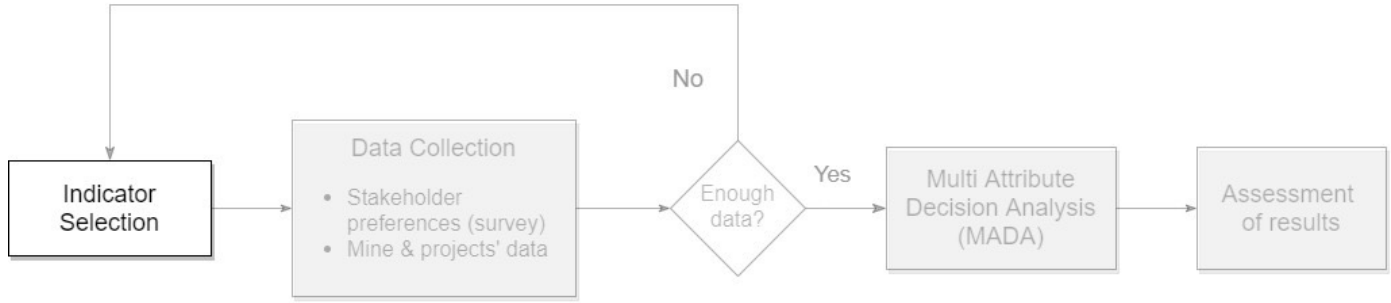
- Evaluate each scenario's contributions to sustainable development
- Identify strengths and weaknesses,
- Investigate the most important aspects of "sustainability" to various stakeholders
- Determine which better reflects stakeholder preferences and results in the most economically, environmentally,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

Source: Mining Company

METHODOLOGY



INDICATOR SELECTION



- Selection of indicators out of a comprehensive set of 230 indicators
  - 3 subsets: environmental, social, economic
- Refined to 17 indicators

iied International Institute for Environment and Development

ICMM International Council on Mining & Metals

GRI Empowering Sustainable Decisions

OECD

UNITED NATIONS

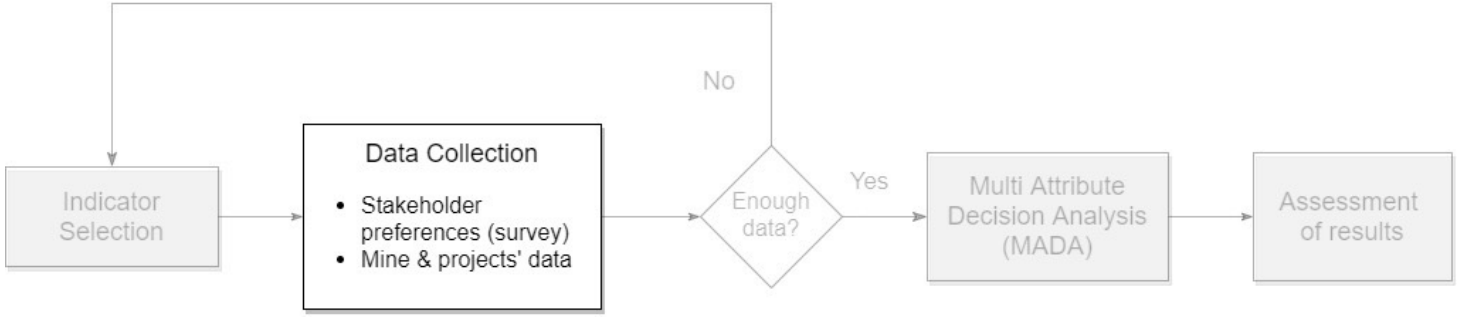
Scientific journals

THE WORLD BANK

Indicator	Verbiage used in Survey
ECONOMIC INDICATORS	
Corporate income taxes and royalties paid at full capacity	The new facility's income tax payments
Extent of community and infrastructure investments	New facility's investments in public services for the community (road maintenance, housing assistance)
Number of years it will take to reach the full capacity form the day production begins	The time it will take for the new facility to reach its maximum production amount
Annual production capacity at full capacity	The maximum number of products that the new facility can produce
Annual revenue at full capacity	The amount of money the new facility makes from the sale of their goods and services
SOCIAL INDICATORS	
Potential nuisance and more significant risks that may affect local communities	Nuisances or hazards that may arise form the new facility and could impact the nearby communities
Road use and traffic lead compared to the baseline	The potential traffic volume around the project site
Average annual salary of full-time workers	Annual salary offered for employees by the new facility
Number of full-time and hourly-based employees at full capacity	Number of employees that can work in the new facility
Number of different job types offered on site	Number of different job types offered by the new facility

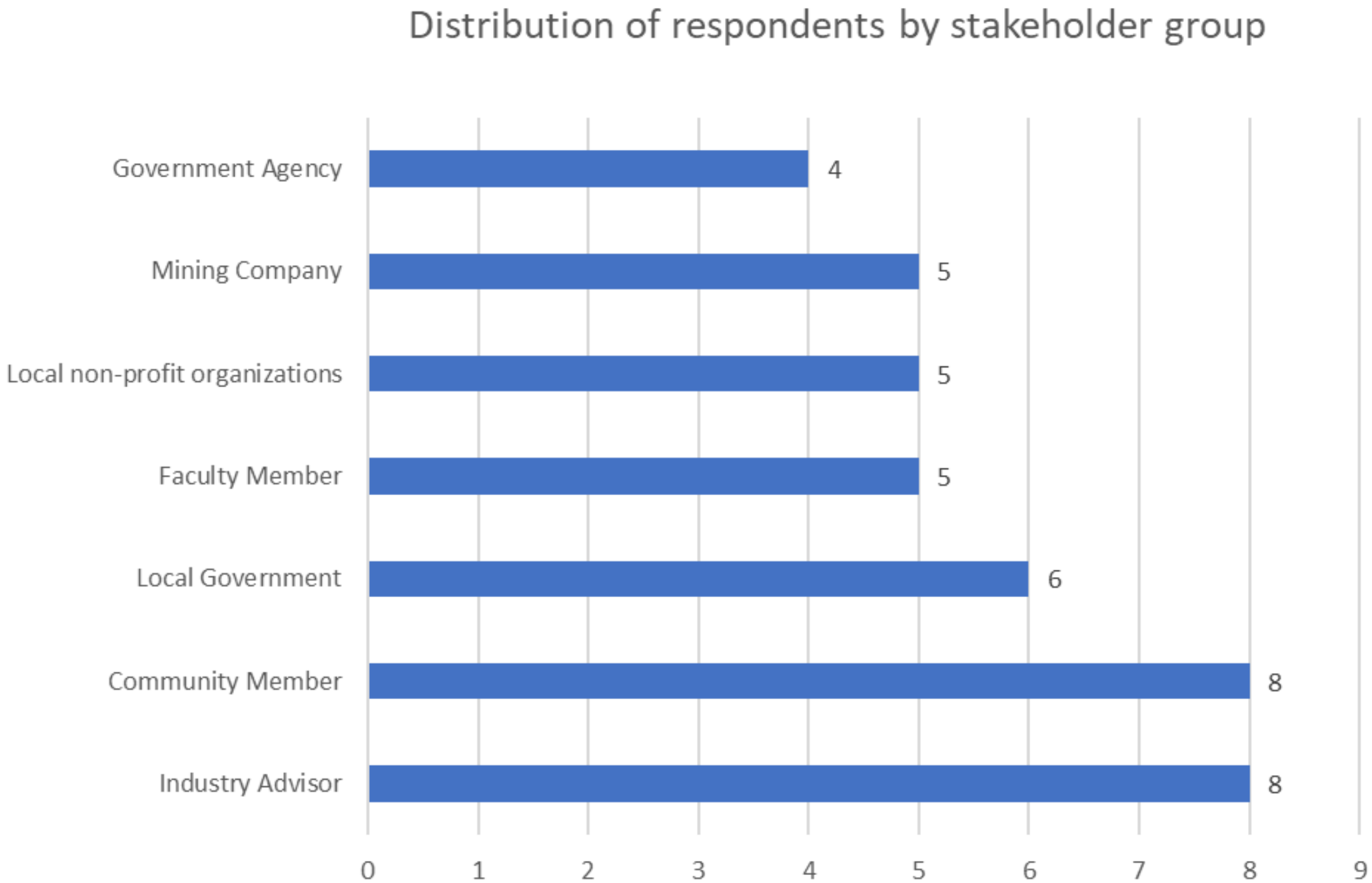
Indicator	Verbiage used in Survey
ENVIRONMENTAL INDICATORS	
Expense of anticipated energy consumption	The new facility's energy use
Proportion of heating energy that the new facility can potentially supply by renewables on-site	The amount of energy that the new facility gets from renewable energy resources such as solar roof panels
Potential percentage of recycled input materials	The amount of recycled materials used by the new facility to produce their products
Total amount of untreated tailings in 15 years	The amount of unremoved mine waste remaining in the new project area after 15 years
Waste production potential	The amount of waste to be produced by the new facility
Estimated total air emissions	Air pollution
Area used for production	Total land area used by the new facility

DATA COLLECTION

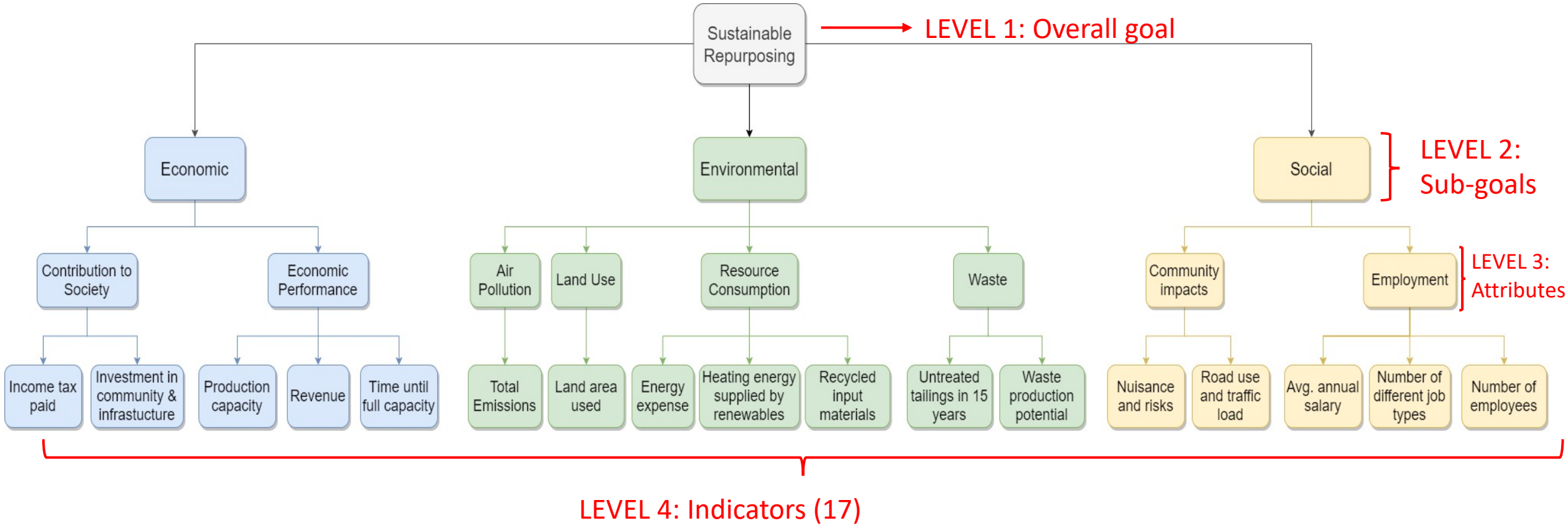


1. Data from the mine and student projects
- location, operations, community
- Proposed scenarios / student reports

2. Stakeholder survey
- Online (covid)
- 7 stakeholder groups
- 45 total respondents; 41 complete responses
- Analytical Hierarchy Process (AHP) to determine the weights

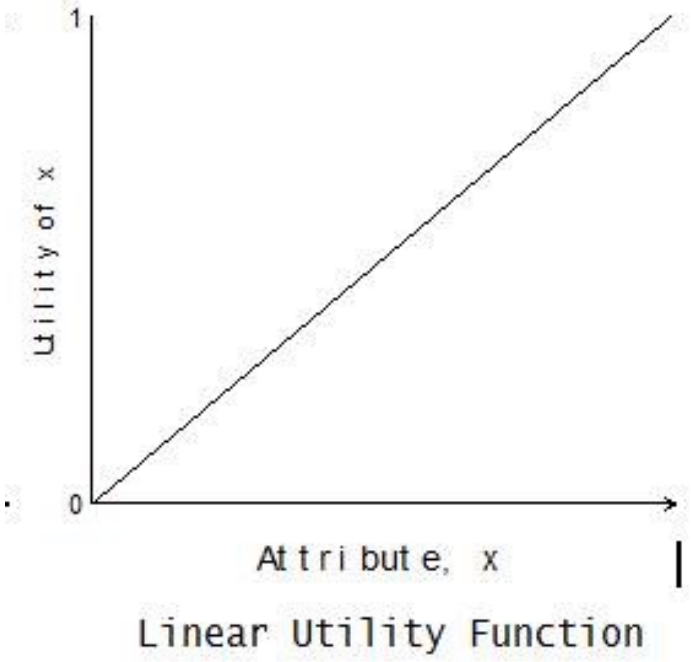

Distribution of respondents by stakeholder group
Government Agency
Mining Company
Local non-profit organizations
Faculty Member
Local Government
Community Member
Industry Advisor
4
5
5
5
6
8
8
0
1
2
3
4
5
6
7
8
9

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



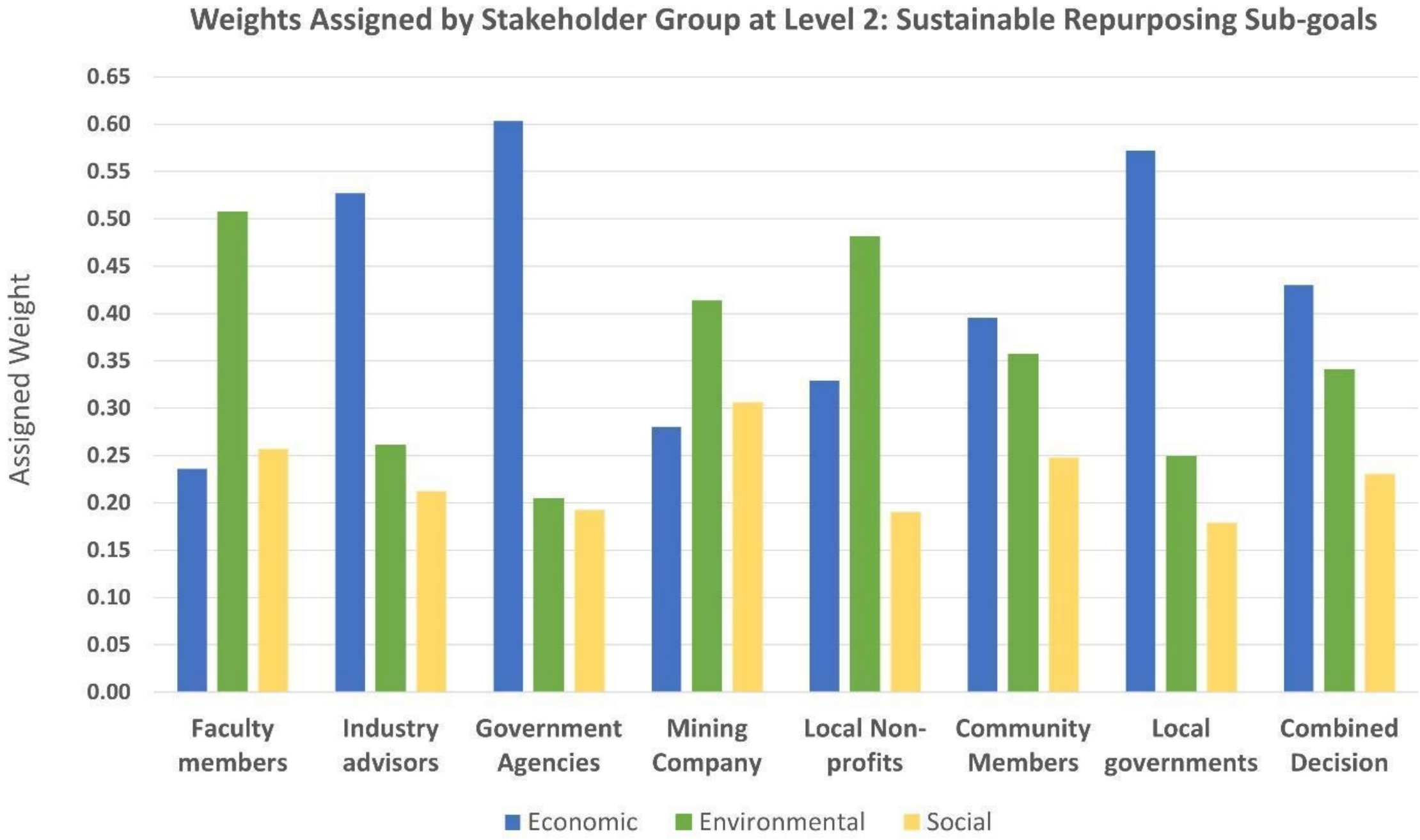
Linear Utility Function

Source: Hahn, 2012

LOGICAL DECISIONS

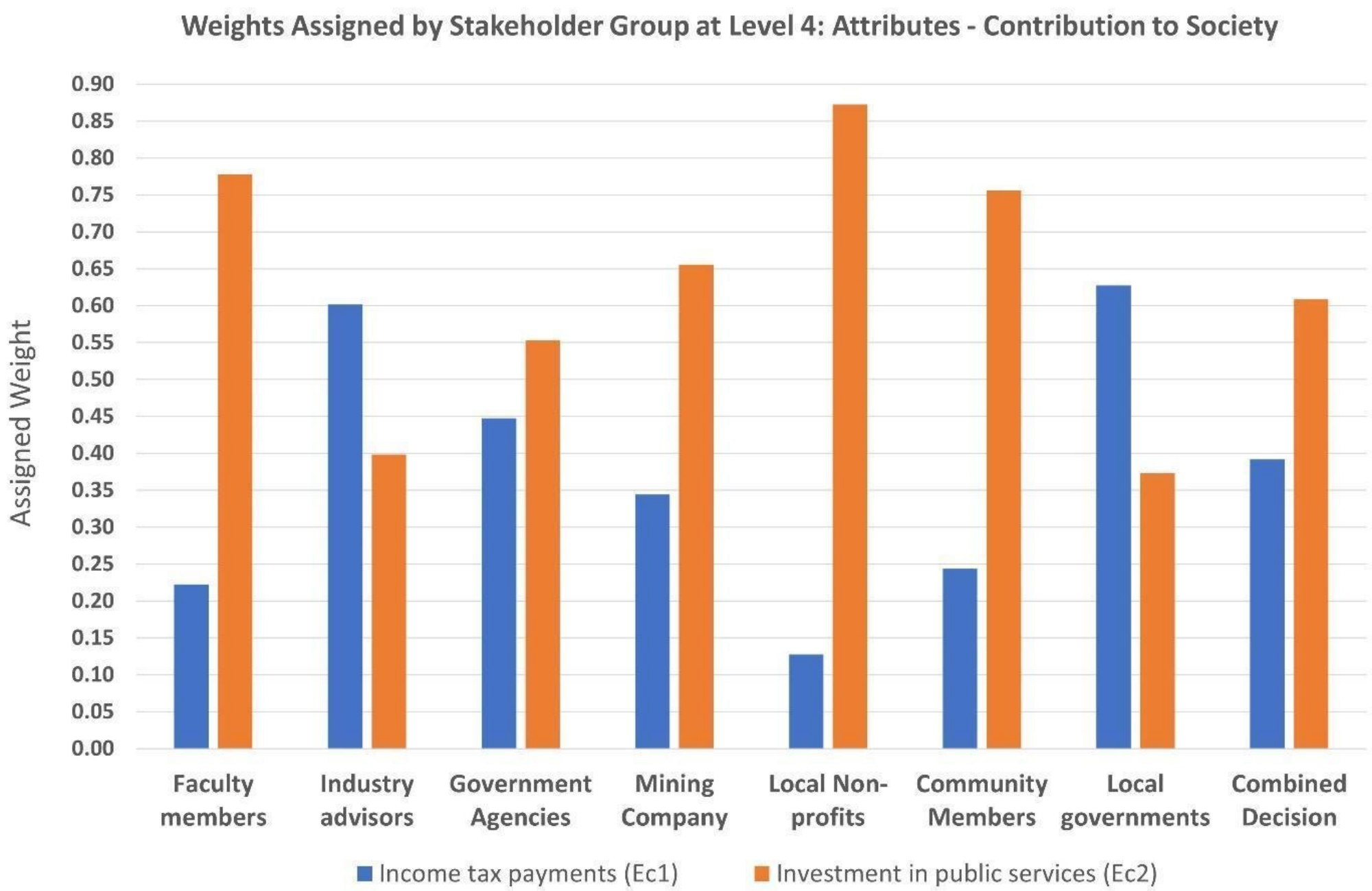
MADA – Step 3: Weighting Preferences

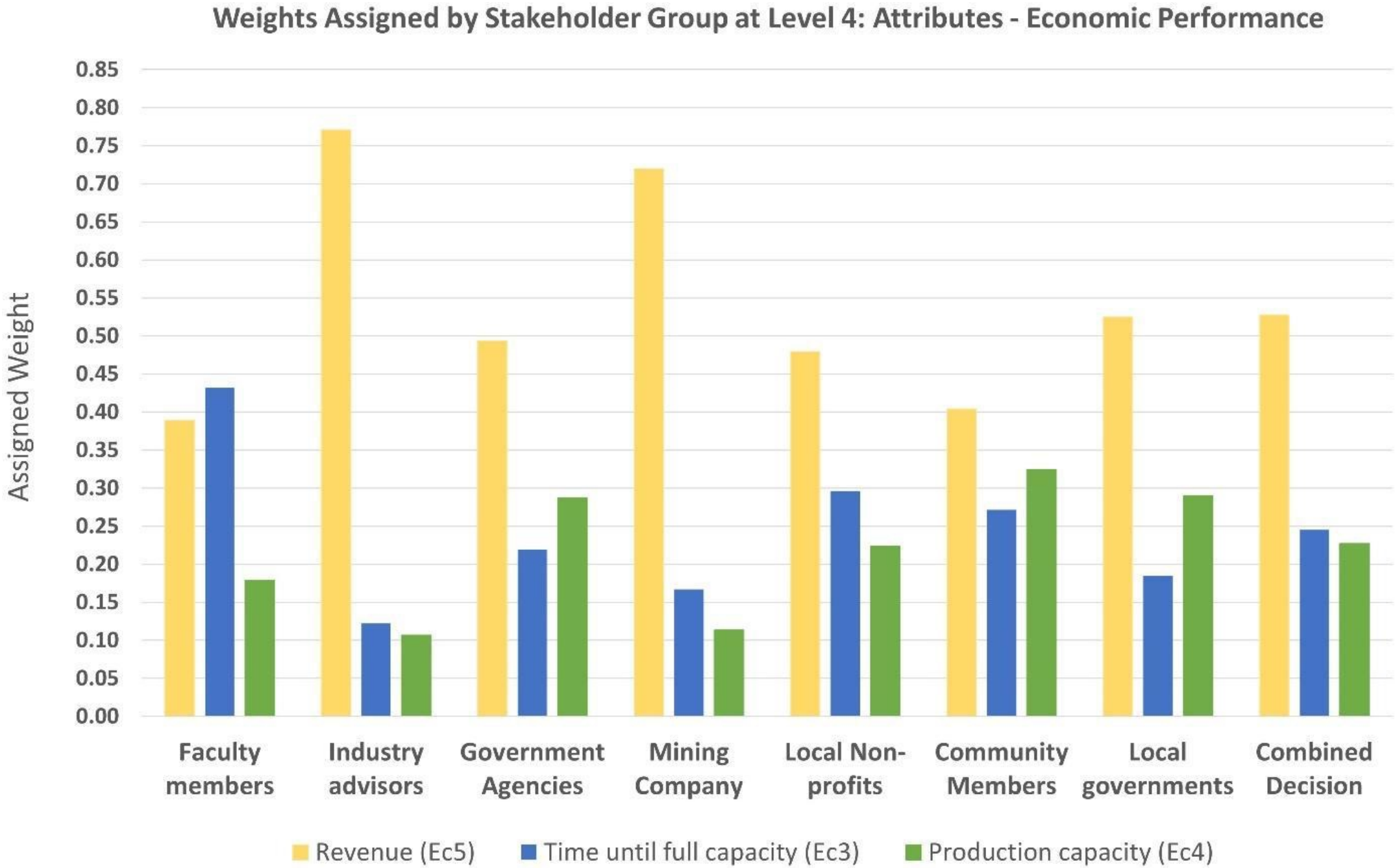
- ✓ Establish preferences *between* the attributes
  - weights in **multi-attribute utility function**
- ✓ **Survey results** revealed the **weights**:
  - relative importance of each attribute (L4), category (L3), and sub-goal (L2)
- ✓ Results obtained for:
  - each individual stakeholder group
    - *Aggregation of individual judgments (AIJ)*
  - all stakeholder groups combined
    - *Aggregation of individual priorities (AIP)*

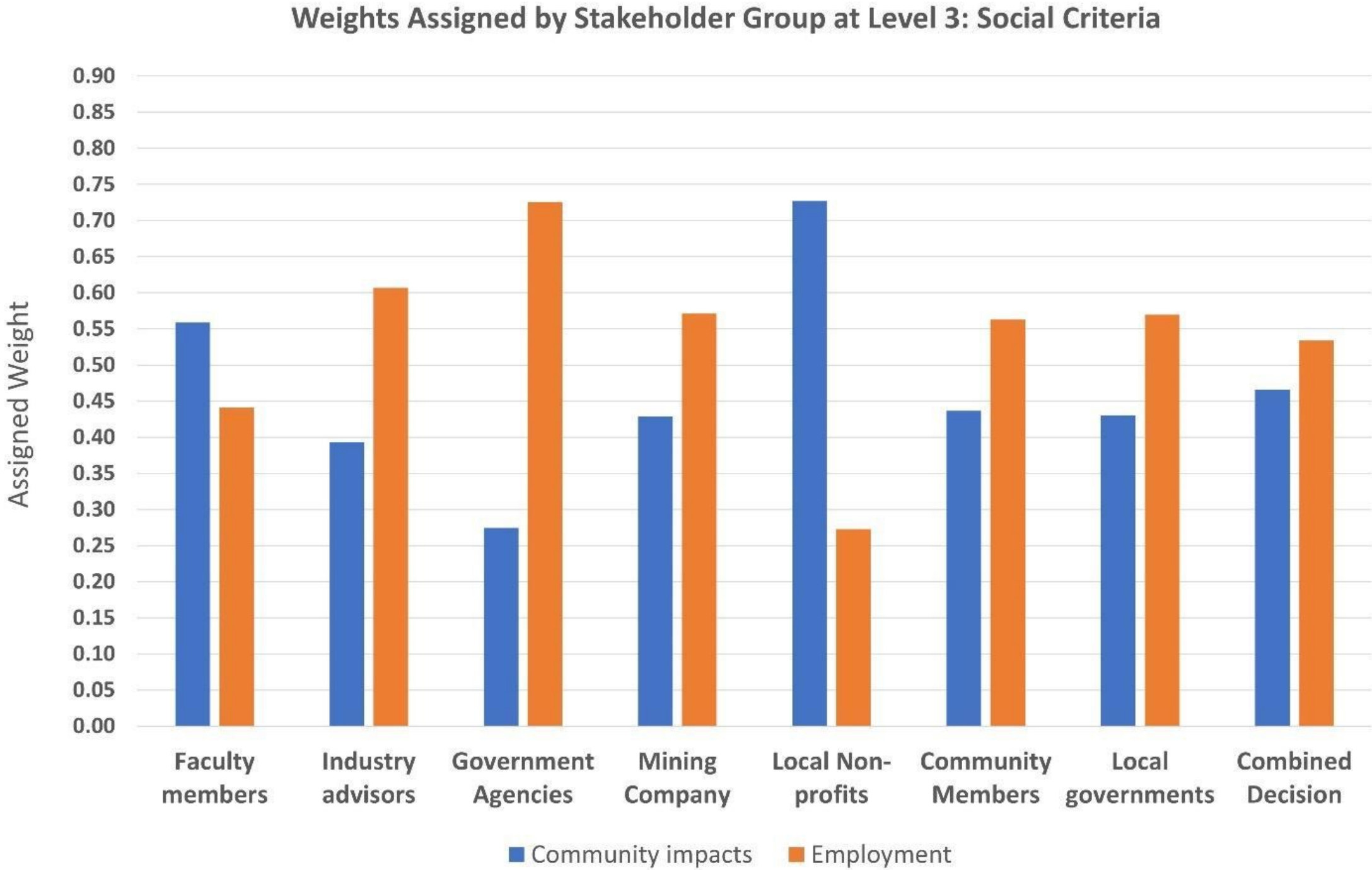

Weights Assigned by Stakeholder Group at Level 2: Sustainable Repurposing Sub-goals
Assigned Weight
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Economic
Environmental
Social

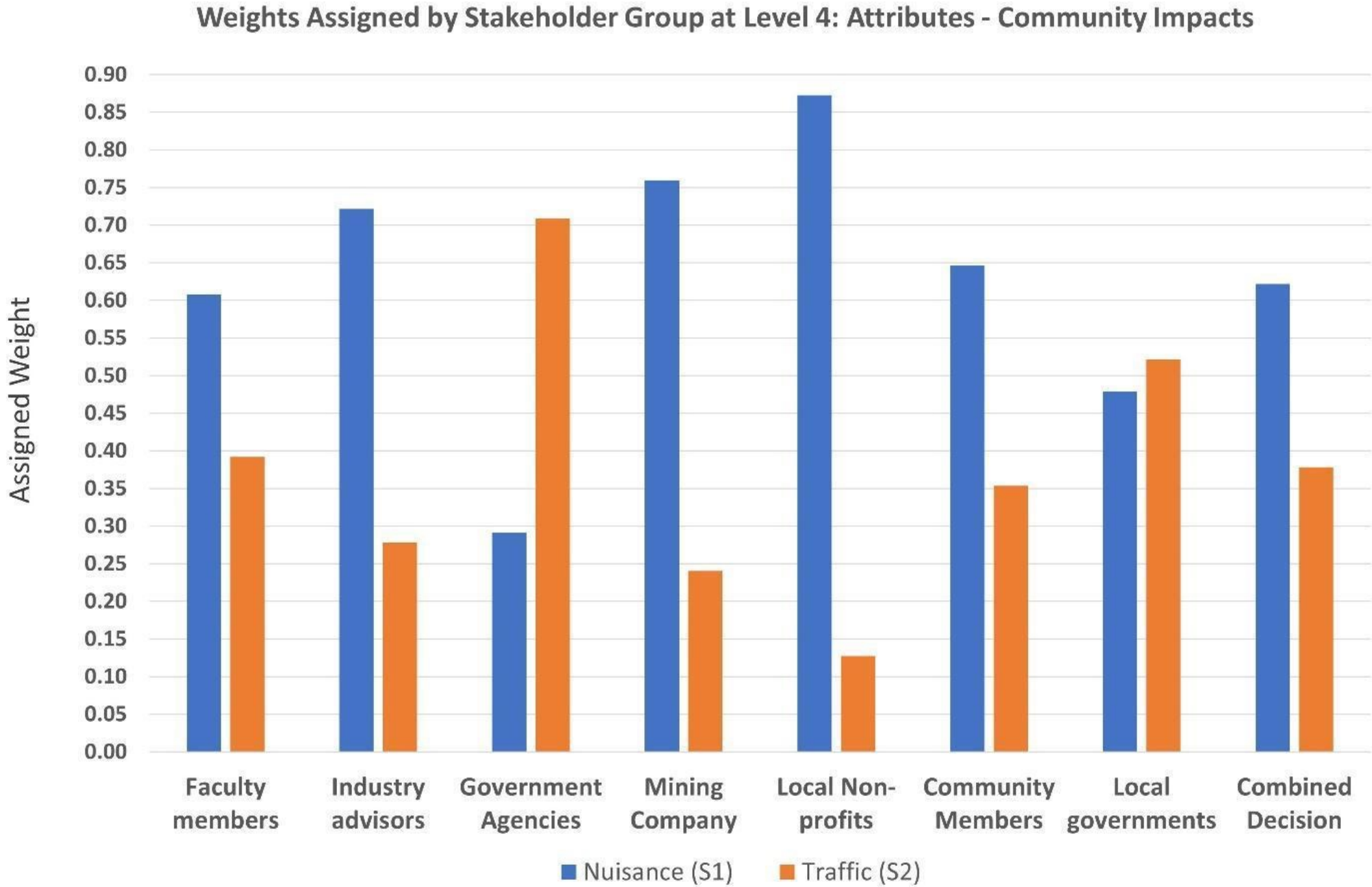
investments in infrastructure and public services and income tax

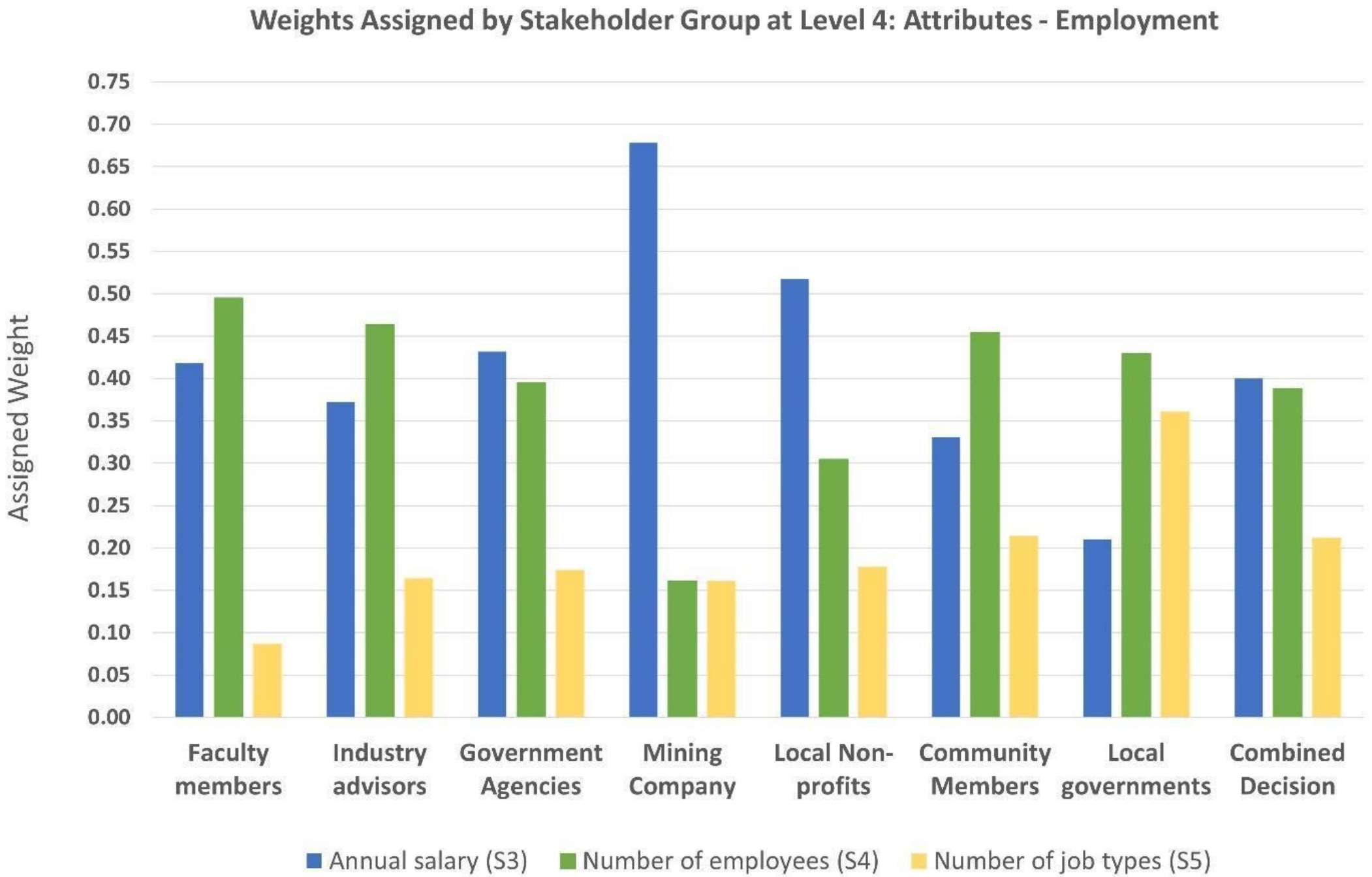
production capacity, revenue, time until full production

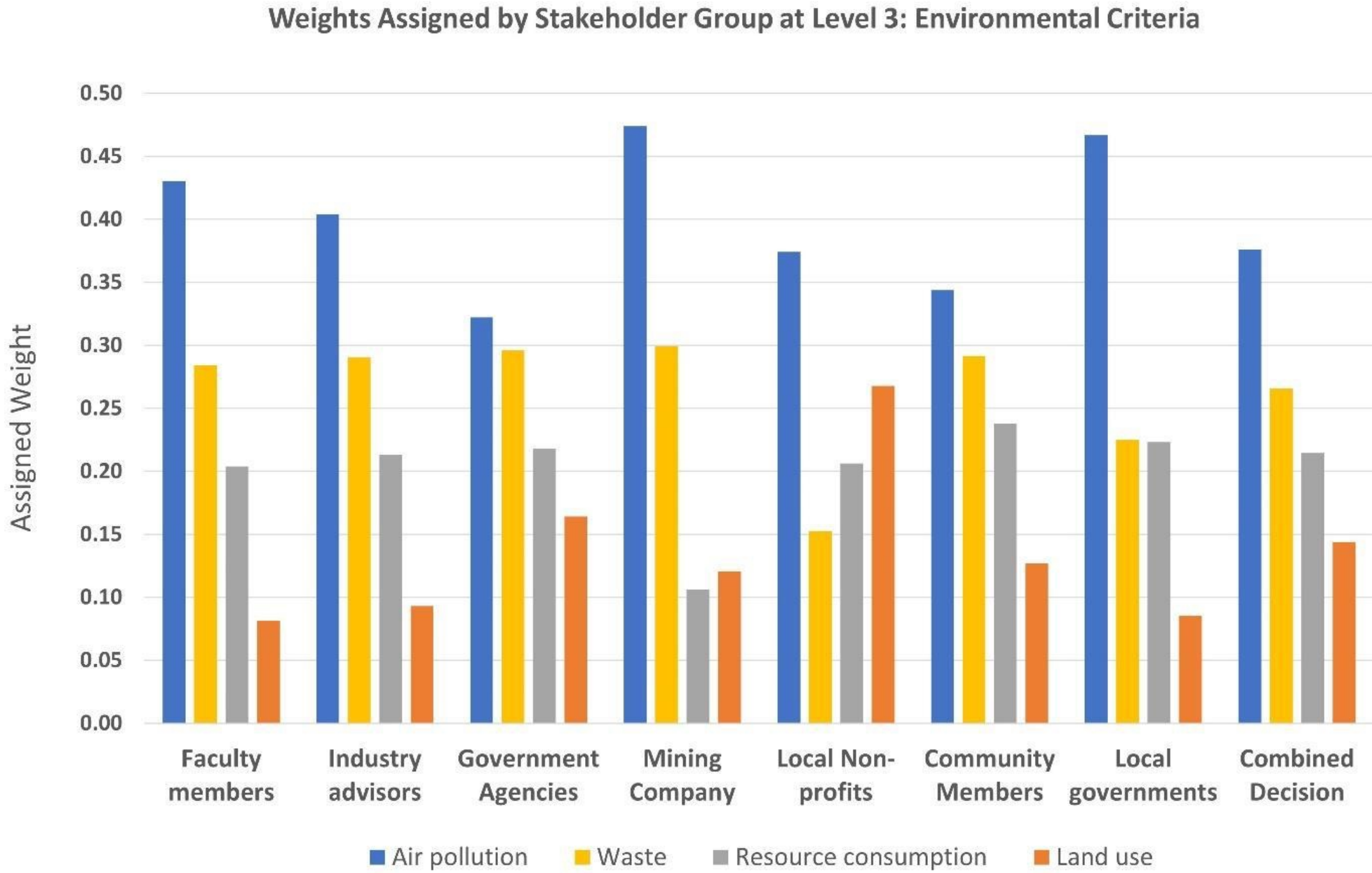

Weights Assigned by Stakeholder Group at Level 4: Attributes - Contribution to Society
Assigned Weight
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Income tax payments (Ec1)
Investment in public services (Ec2)

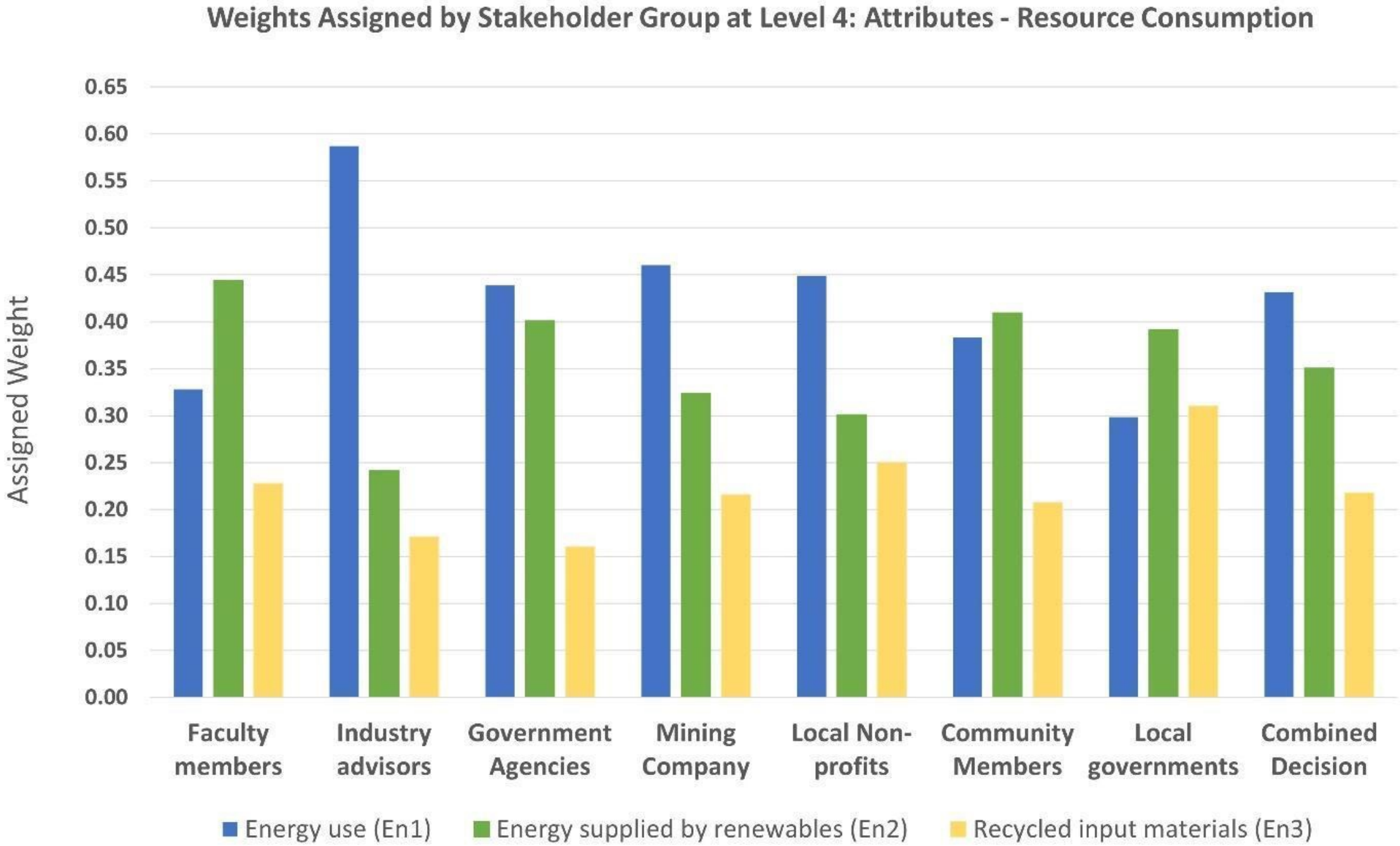

Weights Assigned by Stakeholder Group at Level 4: Attributes - Economic Performance
Assigned Weight
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Revenue (Ec5)
Time until full capacity (Ec3)
Production capacity (Ec4)

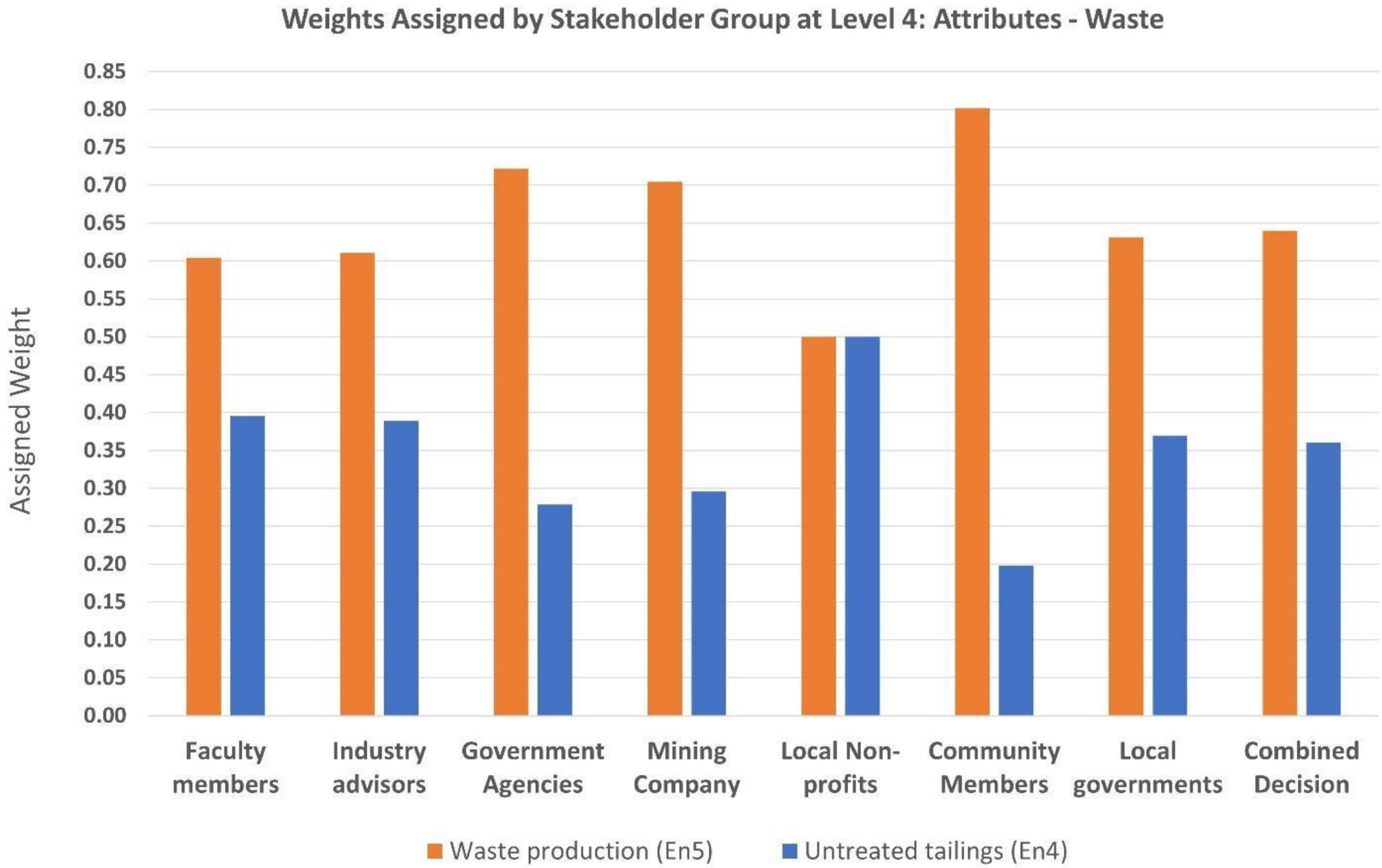

Weights Assigned by Stakeholder Group at Level 3: Social Criteria
Assigned Weight
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Community impacts
Employment


Weights Assigned by Stakeholder Group at Level 4: Attributes - Community Impacts
Assigned Weight
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Nuisance (S1)
Traffic (S2)


Weights Assigned by Stakeholder Group at Level 4: Attributes - Employment
Assigned Weight
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Annual salary (S3)
Number of employees (S4)
Number of job types (S5)


Weights Assigned by Stakeholder Group at Level 3: Environmental Criteria
Assigned Weight
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Air pollution
Waste
Resource consumption
Land use

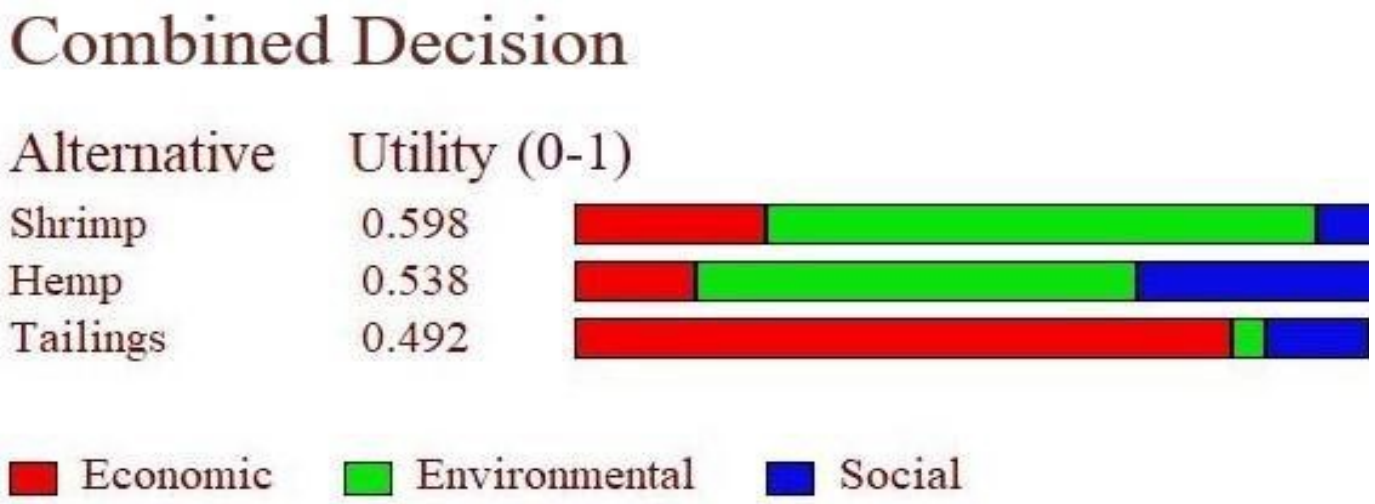

Weights Assigned by Stakeholder Group at Level 4: Attributes - Resource Consumption
Assigned Weight
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Energy use (En1)
Energy supplied by renewables (En2)
Recycled input materials (En3)

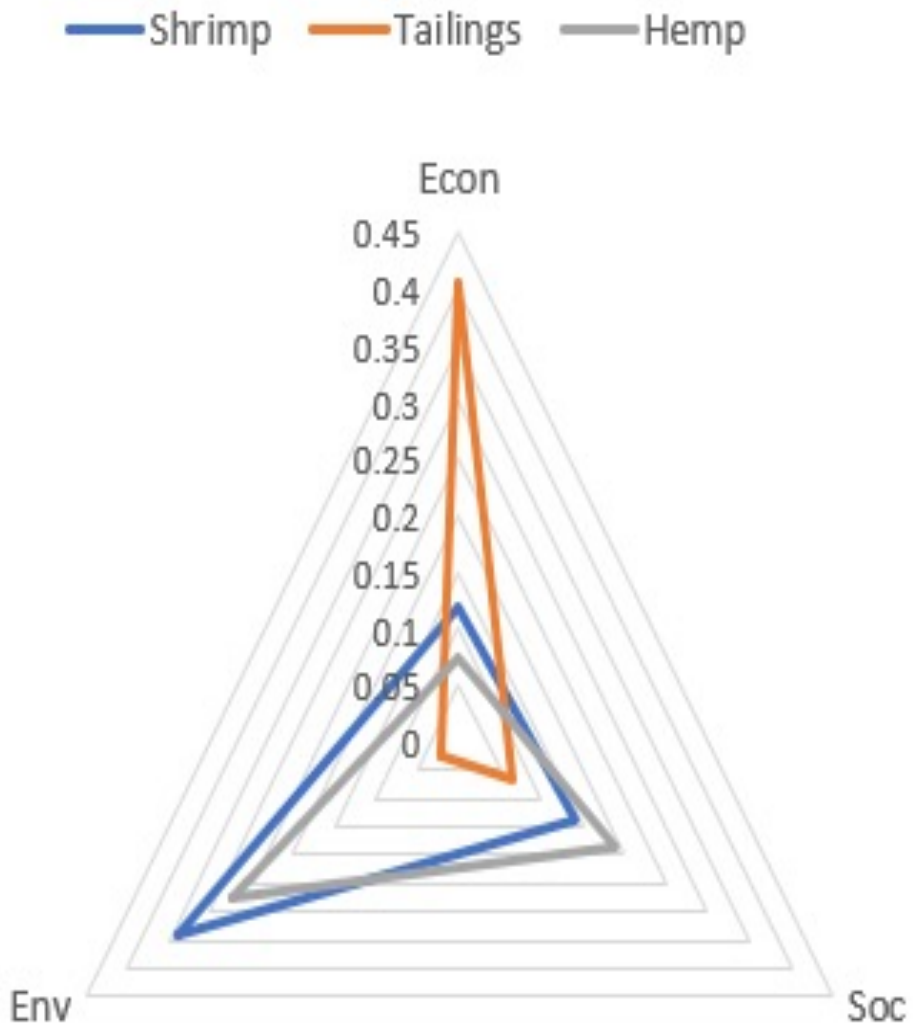

Weights Assigned by Stakeholder Group at Level 4: Attributes - Waste
Assigned Weight
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Faculty members
Industry advisors
Government Agencies
Mining Company
Local Non-profits
Community Members
Local governments
Combined Decision
Waste production (En5)
Untreated tailings (En4)

Judge's Picks
1: Glass manufacturing from tailings (Tailings)
2: Organic shrimp farming (Shrimp)
3: CBD and hemp production (Hemp)

RESULTS

Overall Ranking





Level (L)	Aspect	Parameter	Range in Assigned Weights Within Stakeholder Groups							
			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	0.400	0.666	0.775
L4	Env	Waste production (En5)	0.583	0.775	0.775	0.775	0.500	0.400	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 combin group decision (reflects heterogeneity)
- Local non-profits and the mining company had the closest view 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

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THANK YOU!

nmsmith@mines.edu