EBGN 645: Homework 1, Part B

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Q1: Model Description:

"Energy Recovery Optimization Across Mine Sites"

Goal

Which system type (energy-recovery scenario) should be installed at each mine site to maximize total recovered energy, taking into account efficiency, environmental, and operational considerations?

Indices

- Mine sites [**i**] (site1, site2, site3)
- Scenarios or system types [**s**] (s1, s2)
- Time periods [**t**] (t1–t20)

Logic:

I decouple mine sites, system configurations, and time periods for indexing them. This gives the model the flexibility to take into consideration several operating sites, analyze alternative system designs, and operate over time (hours, days, and months).

Parameters

Symbol	Description
H(i,s)	Tailings heat potential at site i under scenario(s)
E(s)	Energy conversion efficiency for scenario(s)
Price(t)	Electricity price at time(t)
WaterUse(i,s)	Water is used if scenario(s) are selected at site (i)
WaterLimit(i)	Maximum allowable water use at each site (i)

Logic:

- $H(i,s)$captures the available thermal heat generated..
- $E(s)$converts heat into energy.
- $Price(t)$gives revenue context if later choose to maximize profit.
- $WaterUse(i,s)$and$WaterLimit(i)$enforce an **environmental constraint**, ensuring sustainable operation.

Decision Variables

Variable
$X(i,s)$
$P(i,s,t)$
$Rev(i,s,t)$
$Energy\_total$
$Revenue\_total$

- Binary variable indicating whether scenario(s) are selected for site(i)
- Power output at site (i), scenario (s), time (t)
- Revenue from power generation at (i,s,t) ($)
- Total energy recovered (MWh)
- And finally, Total revenue ($)

Logic:

- The binary variable X(i,s) is the core decision to select one system per site.
- P(i,s,t) and R(i,s,t) are dependent (they're calculated from X).
- Energy_total and Revenue_total summarize system-wide performance.

Objective Function

Maximize Total Energy Recovered

$$\textbf{Maximize } \boldsymbol{Energy\_total} = \sum_{\boldsymbol{i,s,t}} \boldsymbol{P(i,s,t)}$$

Logic:

The objective is to extract the highest available energy from waste at mine sites.

This is a strategic optimization criterion when the aim of the company is to maximize the internal energy recovery or reduce purchased electricity.

Constraints

(a) Power Output Definition

$$\mathrm{P(i,s,t) = H(i,s) \times E(s) \times X(i,s)}$$

Logic:

Power generation at each site depends on the higher temperature of the available heat and the heat engine efficiency; it will be generated only if you have deployed.

(b) Scenario Selection Limit

$$\sum_{s} X(i,s) \leq 1 \forall i$$

Logic:
Each site can only install **one** energy-recovery system.

(c) Environmental Water Constraint

$$\sum_{s} WaterUse(i,s) \times X(i,s) \leq WaterLimit(i) \forall i$$

Logic:
Prevents the total water consumption from exceeding the site's environmental permit.

(d) Revenue Calculation

$$Rev(i,s,t) = P(i,s,t) \times Price(t)$$

Logic:
Revenue is derived directly from energy sold at market prices.

(e) Aggregate Revenue

$$Revenue\_total = \sum_{i,s,t} Rev(i,s,t)$$

Logic:
Summarizes total site revenue for reporting and alternative objective optimization.

Model Logic Explanation

This optimization model compares different energy-recovery systems at several mines aimed to maximise the total amount recoverable. Each site has a unique characteristics about tailings heating and water supply, however, each scenario is also different due their performance of efficiency and resource consumption. The objective function adds up the total power generated over all the sites and times with an expectation the model will choose those configurations that produce as much recoverable energy as possible.

As described, the scenario-selection constraint ensures that each mine implements at most one technology which is consistent with real capital budgeting constraints. The power output (product of tailings heat potential and 2.3 system efficiency) is activated if only that case is checked. Ultimately, local water-use restrictions limit the total consumption of each site to comply with environmental permits.Profit equations connect energy generation with market prices, and optimizes either the energy or the finances.

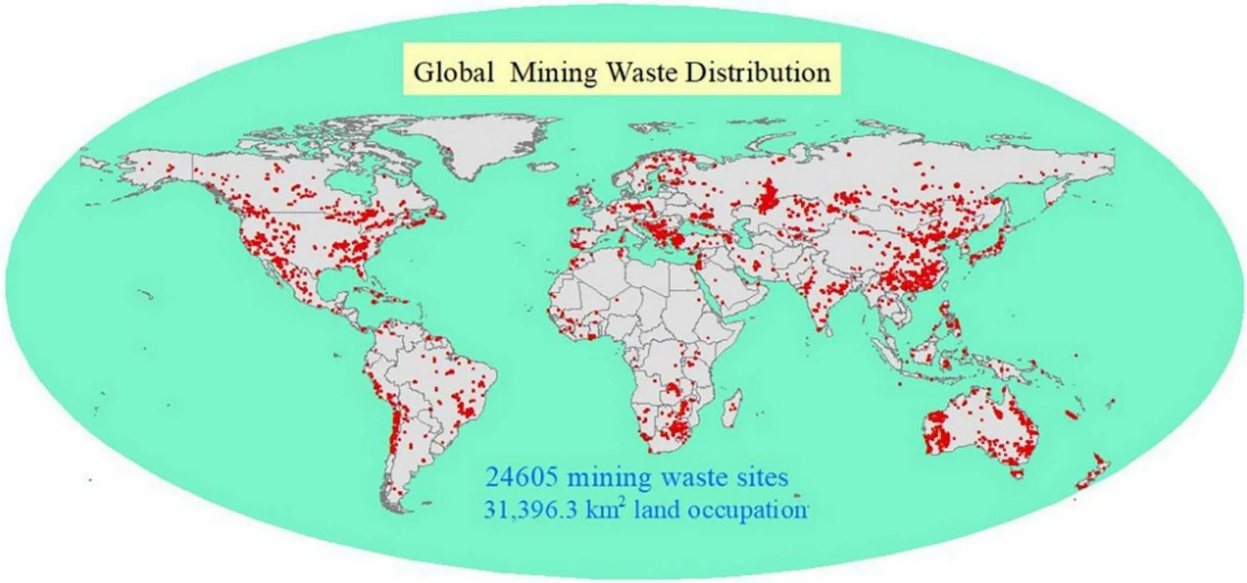
Overall, the model achieves a trade-off between technical feasibility and sustainability by identifying system combinations that maximize energy output without exceeding resource limits, depicting a planning tool fit for initial investment screening of mine-site energy recovery projects

Q2: Data Sources and Assumptions

Data Source 1: A Review on the Recovery of Critical Metals from Mine and Mineral Processing Tailings: Recent Advances

(A Review on the Recovery of Critical Metals from Mine and Mineral Processing Tailings: Recent Advances | Journal of Sustainable Metallurgy)

In this paper, global datasets on tailings storage facilities, residual metal content, and mineralogical and thermal properties of mine wastes are combined. From this review, I will pull data on the temperature of tailings, its specific heat capacity, and volumetric distribution from this review in order to parameterize site-specific energy potential into the model (parameter H(i,s)). These physical features determine the heat content available and thus the potential power that can be generated within each technology scenario. The database also allows for information on recovery technologies and process efficiencies, which determine the estimated values of E(s).



Data Source 2: USGS Mineral Resources Data System (MRDS) or NREL Geothermal Resource Database

(https://www.usgs.gov/centers/gggsc/science/usmin-mineral-deposit-database)

The USMIN database combines geologic and spatial properties from more than 100,000 mineral points across the United States, including deposit type, commodity, and location coordinates. I will apply this dataset to identify potential mine areas in the Western United States that I can map against thermal gradient and surface heat-flow data on related USGS layers. These data underpin the assumptions made in estimating baseline subsurface temperatures and regional geothermal potential at the site, used to validate or bound modeled tailings temperature profiles. Together with Source 1, this makes it possible to verify the physical feasibility of the thermal recovery at individual locations.

Table 1. Summary of Model Input Data

Site (Example)	Tailings Temp (°C)	Efficiency (%)	Water Use (m^3)	Water Limit (m^3)	Power Price ($/MWh)	Data Source
Site 1	80	85	100	110	30	Review (2025)
Site 2	85	80	90	100	30	USMIN + Review
Site 3	90	80	95	100	30	USMIN + Review

Model Assumptions

- **Fixed Electricity Price:** Electricity price is fixed at $30/MWh, following the average 2024 Western-U.S. wholesale market values (EIA 2024).
- **Single Scenario at a Site:** At each mine only one technology configuration because of capital cost and phasing restrictions.
- **Thermal Steady-State Profile:** The tailings temperature and volume remain constant between time steps as an average daily operation.
- **Water-Use Limit:** Each site must remain below its water-use permit threshold (100–110 m^3), based on typical US EPA mine-site limits.
- **Technology Efficiency:** Conversion efficiency factors (0.80–0.85) are taken from the ORC and low-enthalpy geothermal system averages mentioned in the Review paper.
- **Homogeneous Heat Distribution:** The whole tailings deposit is considered as thermally homogeneous, toting vertical heat loss gradients for convenience reasons.