Benchmarking and sustainability indicators for surface mining operations

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Benchmarking

- Benchmarking is a comparative analysis of a company against the leading companies of its sector, in order to determine how these companies achieve high performance levels, and to use this information as the basis for the improvement of its performance

Benchmarking

- Benchmarking breaks down the entire process into many activities and sets standards, goals and interim steps required to meet the goals for each particular activity
- In order to measure the progress achieved along the way benchmarking selects specific indicators

Benchmarking in surface mining sector

- Benchmarking in surface mining sector usually consists of a comparative analysis that covers the following components:
  - Production
  - Equipment repair and maintenance
  - Human resources management
  - Purchase of materials and services; Co-operation with third-parties
  - Investments

Benchmarking and sustainability

- Nowadays, benchmarking can be implemented on the basis of an integrated approach, which requires considering all **economical**, **environmental** and **social** aspects of surface mining as well as all involving parts as a system
- Also, requires definition of benchmarking indices based on sustainability indicators

Sustainability indicators (OECD)

- OECD uses a core set of environmental indicators, which are based on the Pressure-State-Response model:
  - human activities exert pressures on the environment and change its quality and the quantity of natural resources (the ‘state’ box).
  - Society responds to these changes through environmental, economic and sectorial policies (the ‘societal response’).

Sustainability indicators (UK-DETR)

- In 1999 the UK government published a strategy document that sets out the principles of SD
  - A core set of about 150 indicators should act as a benchmark against which future progress can be measured
  - Some of these indicators are connected with mineral extraction either directly (mine land covered by restoration and aftercare conditions) or indirectly (depletion of fossil fuels, soil losses to development, native species at risk, aggregate recycling)

Sustainability indicators (GRI)

- Global Reporting Initiative (GRI), a multi-stakeholder network of experts, has proposed a set of indicators, organized by economic, environmental, and social categories.
- Each category includes a Disclosure on Management Approach, which provides a brief overview of the organization’s management approach to the aspects defined under each indicator category in order to set the context for performance information.

Sustainability indicators (ICMM)

- In May 2003, the International Council on Mining & Metals committed themselves to implement and measure their performance against 10 sustainable development principles.
- The 10 principles were developed by benchmarking against other leading global standards including: the 1992 Rio Declaration, the Global Reporting Initiative, the OECD Guidelines for Multinational Enterprises, the World Bank Operational Policies, etc.

Sustainability indicators (SMR)

- Sustainable Mining Roundtable (sponsored by US Forest Services and US Geological Survey) has chosen a series of indicators that cover a broad range of attributes of energy and minerals systems.

- The indicators are organised based on four criteria and 38 sub-criteria:
  - Capacity to produce commodities (13 indicators)
  - Environmental quality (7 indicators)
  - Economic, cultural and social benefits (10 indicators)
  - Legal and institutional framework (8 indicators)

The mathematical approach of benchmarking

- Sustainable mineral exploitation models:
  - Systems theory and methodologies for structuring complex problems
  - Optimization and decision-making techniques to support policy formulation
  - Fuzzy sets and techniques for representing and analyzing a mixture of quantitative and qualitative, uncertain and imprecise data occurring in environmental, economic, and social problems

The holistic approach of mining optimisation proposed by SD initiatives classifies the benchmarking criteria in four major groups: economic, environmental, social and legal

Optimisation model for sustainable surface mine exploitation

Economic profitability

(Project economics, operations research, decision theory)

- Mineral reserves
- Exploration capacity
- Optimal extraction rates
- Cost optimization
- Productivity and efficiency

Environmental management

(Based on EIA studies)

- Land reclamation
- Control of releases
- Risk minimisation

Social benefits

- Employment
- Income
- Contribution to regional development
- Contribution to National income
- Support of cultural and social interests

Legal and institutional framework

- Property rights
- Land-use planning
- Public involvement
- Reporting

Benchmarking the mine productivity

Waste minimisation

&

Resource management

through the improvement of productivity

- Minimum energy and water consumption
- Optimum recovery of valuable materials
- Minimum production of solid and liquid waste

Benchmarking the mine productivity

Utilisation factor: **$UF = T_a \cdot L_f$**

where:

- T_a is the time factor, time available for production (i.e. after abstracting the time for repair and maintenance and other idles) divided by total time and
- L_f the loading factor of the installed equipment

- In large-scale open-pit mines equipped with continuous excavation, transportation and stacking systems UF takes often values less than 20%

Benchmarking the mine productivity

Total Factor Productivity : $$TFP = \frac{Q_{output}}{Q_{input}}$$

where Q_{output} is the quantity of outputs, and Q_{input} is the quantity of inputs

Through index number theory TFP index provides an ideal method of benchmarking an organization's productivity by developing a model that includes:

– Production economics: production function (revenue functions, cost functions, profit functions)

– Scale economies

– Technical efficiency parameters

Benchmarking the mine productivity

- The effect of improving mining equipment productivity (from E to E_1) on the cost per production unit:
  - Investment cost: I
  - Operating expenses: Cop
  - Total annual cost per m^3 of excavations: C_t and $C_{t,1}$
  - Mine life: N years
  - Discount rate: r

$$C_t = \frac{I \cdot f(N,r) + C_{op}}{E}$$

$$C_{t,1} = \frac{I \cdot f(N,r) + C_{op}}{E_1}$$

$$f(N,r) = \frac{(1+r)^N \cdot r}{(1+r)^N - 1}$$

$$\frac{C_{t,1}}{C_t} = \frac{E}{E_1}$$

Assessing the feasibility of investments

- The investments required at different phases of the development of a surface mine include:
  - Land expropriation / purchase
  - Equipment purchase (new or replacement)
  - Maintenance/repair
  - Compliance with legal obligations
  - Exploitation
  - Development of infrastructures
  - Studies / exploration

Assessing the feasibility of investments

Investments for the purchase of new equipment

- alternatives regarding the theoretical capacity of equipment
- both the investment and operating cost will be changed according to the installed equipment capacity:

$$\frac{I_1}{I} = \left(\frac{C_1}{C}\right)^a$$

where a is ~0.6 for surface mining equipment

Assessing the feasibility of investments

- The relationship of the operating cost C_{op} and $C_{op,1}$ for theoretical capacity C and C_1 respectively can be expressed by the following equation:

$$C_{op,1} = 0.4 \cdot C_{op} \cdot \left(\frac{C_1}{C}\right)^a + 0.6 \cdot C_{op}$$

- The corresponding costs are represented by the following equations:

$$C_t = \frac{I \cdot f(N,r) + C_{op}}{E} \qquad C_{t,1} = \frac{I \cdot f(N,r) + C_{op}}{E_1}$$

Assessing the feasibility of investments

- It can be assumed that: $$\frac{C_1}{C}=\frac{E_1}{E}=k$$
- and defining: $$\frac{I_1}{I}=(\frac{E_1}{E})^a=(\frac{C_1}{C})^a$$
- it is derived that: $$\frac{C_{t,1}}{C_t}=\frac{I\cdot k^a\cdot f(N,r)+C_{op}(0.4\cdot k^a+0.6)}{I\cdot f(N,r)+C_{op}}\cdot\frac{1}{k}$$
- The above equations can be incorporated into the profit objective function in order to find the optimal theoretical capacity of the equipment that will be installed in the mine.

Management of human resources

- Because of its significant share of total mining cost, labour inputs obtain a high weighting in the calculation of Total Factor Productivity.

- *Personnel utilisation*: $U_p = A_p P$

- A_p (Availability) is the ratio of the time that the personnel are present at the workplace (i.e. excluding the period of vacations, etc) and the total working time.

- P (Productivity) is the ratio of productive time and the time that the personnel are present at their workplace.

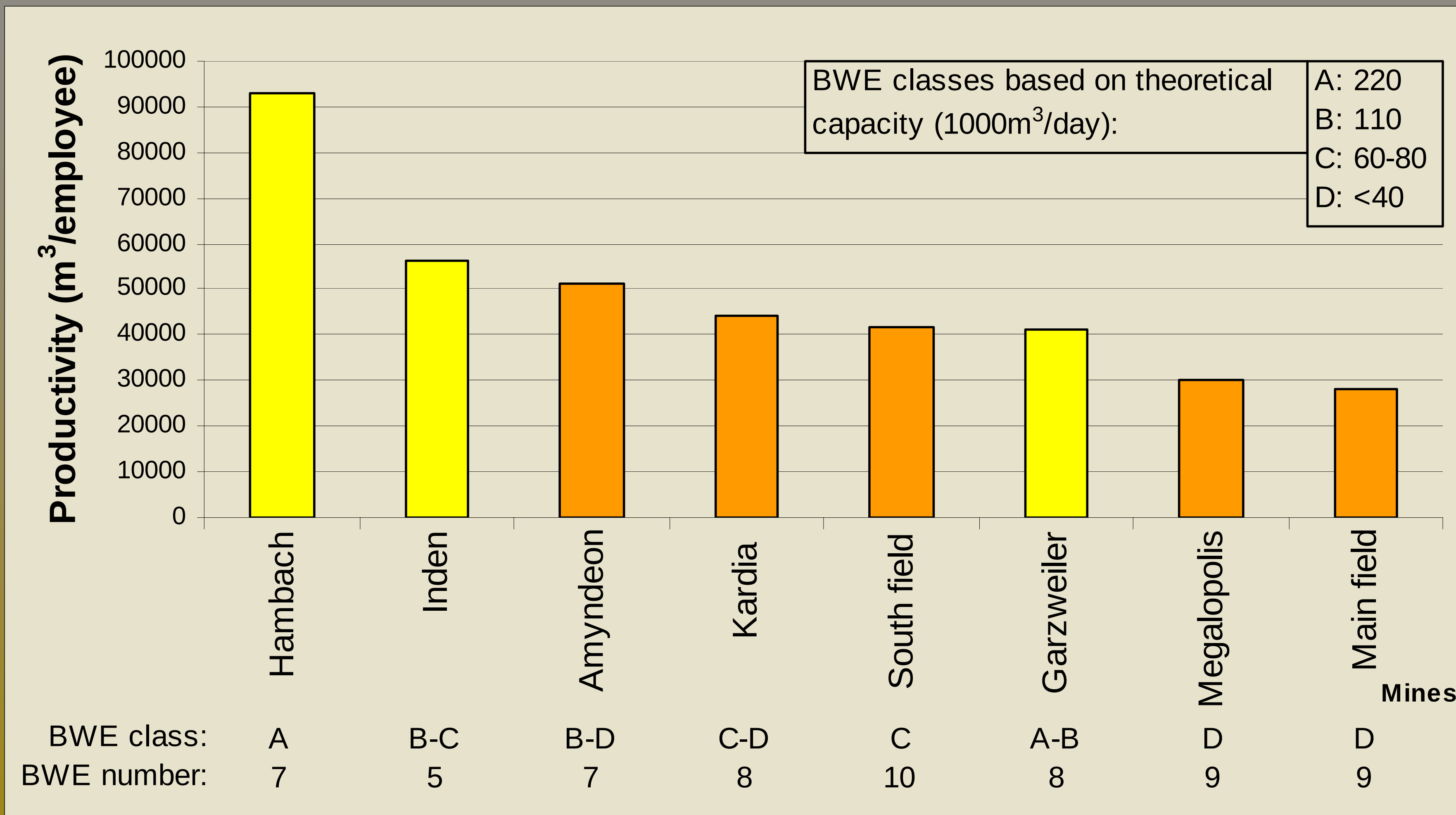
Management of human resources

- In Greek lignite mines the average non-productive time in an 8-hours-shift is estimated to be 1.5 hr. This figure gives a productivity of 79%. Assuming an availability of 84%, the personnel utilisation index takes a value of 66%.

Management of human resources

- The term *productivity* is also used for expressing the quantity of excavated material per employee. This factor is indicative of an efficient selection of the equipment type, number and size. Also, it is closely related to the number of personnel and its skills.

Relation of Bucket Wheel Excavators (BWE) capacity and productivity in Greek and German mines



Conclusions

- Benchmarking, as a process that compares the overall performance of a company with the leading companies of its sector, is a tool that promotes the implementation of best practices and creates a culture of continuous improvement.
- In this process, sustainability indicators are useful as analytical, explanatory, communication, planning, and performance assessment tools that turn vast amounts of analyzed data into meaningful and relevant information.

Conclusions

- These indicators allow a holistic comparative analysis, which takes into account numerous economic, environmental, social and political aspects of surface mines development, operation and closure.

- The proposed methodology provides a tool for determining the rate of agreement between sustainability criteria and mine exploitation efficiency, expressed in terms of equipment and personnel productivity and feasibility assessment of investments in equipment purchase