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# ОЦЕНКА ЭФФЕКТИВНОСТИ ДОБЫЧИ НИКЕЛЯ НА КУБЕ

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***Аннотация:*** Целью исследования является определение технических, экономических и экологических показателей, которые служат возможными переменными для оценки эффективности добычи никеля на Кубе. Интегрируя эти переменные, можно определить элементы, которые следует учитывать при разработке мер по улучшению производства с целью получения продуктов с более высокой добавленной стоимостью. На Кубе, по сравнению с другими странами мира, применение математических методов, не требующих спецификации функциональной формы, ограничено не только числом применений, но и областями исследований. Метод анализа охвата данных представлен в качестве эффективного инструмента сравнительного анализа для проведения данного исследования. Вышеуказанные элементы определяют постановку целей и способствуют разработке планов действий, которые помогают компаниям быть эффективными и повышать свою производительность экологически ответственным образом, применяя экономию за счет масштаба в соответствии с целями устойчивого развития.

***Ключевые слова:*** добыча никеля, показатели, анализ эффективности, анализ охвата данных, устойчивое развитие.

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## Evaluation of efficiency in the nickel mining in Cuba

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***Abstract:*** The purpose of the study is to identify technical, economic and environmental indicators that serve as possible variables for evaluating the efficiency of nickel mining in Cuba. By integrating these variables, it is possible to identify the elements to be considered in the development of measures to improve production in order to obtain products of higher-value-added products. In Cuba, compared to the rest of the world, there has been limited not only in the number of applications, but also the fields of study, the application of mathematical methods that do not require the specification of a functional form. The data envelopment analysis method it's presented as an effective tool of benchmarking to carry out this study. The above identified elements that condition goal setting and contribute to the elaboration of action plans that help companies to be efficient and improve their productivity in an environmentally responsible way, leveraging economies of scale in line with the goals of the sustainable development.

***Key words:*** nickel mining, indicators, efficiency analysis, data envelopment analysis, sustainable development.

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**1. Purpose of the study**

Performance measurement based on technical, economic and environmental assessment in nickel mining operations can bring new elements to the traditional business performance evaluation scheme. Business practice has traditionally approached performance measurement and control through the use of partial productivity, index numbers, and total factor productivity. One of the main difficulties in the application of these methods is the need to address the homogenization of resources and/or products through price systems, which limits the practical validity of the results obtained since they are affected by the dynamism and variability of international price quotations, which has motivated greater interest of researchers in finding, beyond the theoretical contributions, analytical tools that allow the evaluation of efficiency without of the need for prices and markets that are so volatile [1].

In Cuba, the nickel mining sector has been a determining weight in the reproductive dynamics of the economy for more than 10 lustrums. The production and export of Nickel+Cobalt occupy an important place in the country's production values, concentrating such production in the Pedro Soto Alba plants, with a capacity of 37 thousand tons per year of nickel sulfide plus cobalt and the Che Guevara plant, with a capacity of about 18 thousand tons, both located in the northeast of Holguín, in the municipality of Moa [2]. According to data published in the Economic and Commercial Report prepared by the Economic and Commercial Office of Spain in Havana, at the end of April 2021, nickel stocks in Cuba ranked fifth in world reserves and third-largest in cobalt [3].

Cuban nickel reserves are estimated at 37.3% of the world's reserves of this mineral. Experts agree that Cuba's currently exploited deposits guarantee the availability of the mineral for the next 18 to 20 years. The mining sector accounted only for 0.4% of the Cuban GDP at the end of 2019, according to the National Bureau of Statistics and Information of Cuba and ECLAS's 2020 Economic Survey of Latin America and the Caribbean, indicating a negative trend in recent years [4]. The above confirms the thesis that significant investments are necessary to mitigate technological obsolescence in the sector, since more importance is currently given to the registration of economic indicators than technical ones, and instruments designed to determine productivity and production plans have not demonstrated their effectiveness, given that the tons produced are far from the capacities installed in the plants.

Martin (2019) states that the mining cluster is not implementing an R+D+I strategy, integrating the efforts of all technical and professional production staff, as well as academic and research centers, to develop software for mining geologists, promote technological change, produce a higher value-added product and less environmentally polluting production [5].

Despite the dynamics of global nickel prices, the economic outlook for nickel is good. According to Nickel Magazine (2018), concerns about climate change, the pursuit of energy efficiency, and the adoption of carbon reduction targets by governments are driving interest in renewable energy technologies involving batteries and energy storage, where, although nickel is not always mentioned, its presence in lithium-ion batteries is relevant and expected to grow over the years [6].

Forecasts provided by CRU International Limited to the Chilean Mining and Energy Planning Department at the end of 2018 foresee that the demand for nickel will reach 3.2 million tons by 2035, with prices above 19 thousand dollars per ton projected as of 2025 [7]. The above points to a prosperous scenario for the nickel mining industry, hence the importance of focusing efforts and resources, both human, financial and scientific and technological, and towards environmental protection, to improve productivity and efficiency in all its aspects within this economic and production activity.

There is a clear need to develop alternative procedures to complement the technical and economic analysis of the production of Ni+Co, starting with a comparative analysis to set goals with greater objectivity and possibilities of improvement, based on knowledge and real potential, in terms of raw materials, funds and labor in accordance with the Guidelines approved for the economic and social policies of the Cuban Party and Revolution [8]; the Porter hypothesis[9] and in line with the goals of the sustainable development program and its 2030 goals [10].

The overall goal of the study is to propose variables to be considered in assessing the efficiency of nickel production in Cuba.

**2. Conducting the research**

Data Envelopment Analysis (DEA) provides a measurement of relative efficiency, i.e. how well a unit is performing compared to the benchmark set. DEA does not provide a measure of absolute efficiency, i.e., it does not compare a unit to a theoretical maximum. When assessing the relative efficiency of a specific unit, DEA considers the most favorable conditions [11].

It is this technique of mathematical programming that, by identifying efficient units, identifies the elements to be considered in the development of improvement actions, in order to obtain products with higher added value and less polluting for the environment, based on a system of technical, economic, and environmental indicators, starting from the maxim that «a company can be technically efficient and still be able to improve its productivity by exploiting economies of scale» [12].

Experience with the application of the DEA technique has not received the same recognition in Cuba compared to the rest of the world, being limited not only in of the number of applications, but also in relation to the areas of study [13], as shown in the table 1.

The above presents the Cuban mining scenario as a suitable case study to apply as an effective benchmarking tool, Data Envelopment Analysis, given its wide applicability and significant potentialities. The measurement of the efficiency of a production unit using data envelopment analysis (DEA) follows a logical structure in which two basic steps must be completed [25]:

1. Delimitation of a set of production possibilities on the basis of observable data and formulated technological assumptions

*Table 1*
***Applications of Data Envelopment Analysis in Cuba***

| Sector | Institution | Province | Author |
|---|---|---|---|
| Agricultural | Agricultural companies | Villa Clara | Cancio y Barrios (2010) [14] |
| | Sugarcane UBPC | Villa Clara | Romeu, Rodríguez (2008) |
| | Sugarcane UBPC | Villa Clara | Barrios (com. impr. 2009) |
| Public Health | Polyclinics | Matanzas | Chaviano y otros (2007) [15] |
| | Polyclinics | Cienfuegos | García y otros (2008) [16] |
| | International Neurological Restoration Center Clinics | La Habana | Rodríguez, García y García (2016) [17] |
| Tourism | Four star hotels | Varias | Montes de Oca (2009) [18] |
| | Points of sale within a hotel facility | La Habana | Acosta Cabrera (2011) [19] |
| Corporate | Group of companies (4) | La Habana | Marrero, Fernández y Ortiz (2012) [20] |
| | | | Marrero y Ramírez (2012) [21] |
| | Individual negotiators | La Habana | Marrero, Pérez y Ortiz (2013) [22] |
| | | | Marrero y Mederos (2013) [23] |
| | | | Marrero, González y Ortiz (2013) [24] |

2. Estimation of the measure of relative efficiency that provides the maximum feasible expansion of output or the maximum contraction of unit factors within the set of production possibilities.

To complete the first stage and identify feasible production processes, the following assumptions must be considered:

- Free availability of products and factors
- Technology with constant or variable returns to scale
- Convexity of the set of product/resource combinations.

After determining a set of processes that are considered feasible, the second stage is developed which determines the efficiency index to be estimated.

The above is based on the following formula:

$$E_j = \frac{u_1 y_1 + u_2 y_{2j} + \ldots + u_i y_{ij} + \ldots + u_r y_{rj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots + v_i x_{ij} + \ldots + v_m y_{mj}}, \quad (1)$$

where: $E_j$ is the relative efficiency of the $j$-th production unit;

$u_i$ is the weight associated with the r-th generic product;

$v_i$ is the weight associated to the i-th generic factor;

$y_{ij}$ is the quantity of the i-th generic product in the j-th production unit;

$x_{ij}$ is the quantity of the i-th generic resource in the j-th production unit.

The expression corresponds to the total factor productivity index, where it is transformed from the situation of many factors and products into the situation of a single factor and a virtual product by weighting the variables, so we have a method that includes the estimation of the total factor productivity index without the need to establish a priori weights or weighting factors (or prices). Determining the efficiency index implies establishing the direction in which the comparison process is sought at the frontier where the reference productive units are located.

According to Guerrero (2005), the System of Sustainability Indicators (SIS) generates indicators that are directly interrelated with the economic and environmental phenomena of the mining scenario in question, providing an integral perspective of the elements at different scales [26].

As indicators, the aforementioned author names the following:

1. Geological Potential (GP). The components that constitute this potential are: geomorphology, mineral resources, natural phenomena and geodynamic risks.

2. Environmental potential (PA) is related to the natural value present in the territory and the impact of mining activity on the environment. The components that constitute the potential are: vegetation and fauna, atmosphere, water, soils and landscape.

3. Mining potential (MP) is identified with the exploitation of mineral resources. Its objective is to assess mining exploitation and its impact on communities and the environment. For its determination, the technological processes of exploration, development, exploitation, loading and transportation, treatment and benefit of minerals are considered. It is related to technology and closure of mining activities.

4. Socio-economic potential (SEP) is identified with the capacity of the mining entity to relate to the natural system and neighboring communities, and to transform its resources into goods and services in order to reproduce better living conditions, but without forcing the natural and anthropogenic environment beyond its actual availability.

The Sustainability Indicator System (SIS) is part of the company's decision-making cycle to establish priorities in obtaining data and working towards sustainable mining development. The indicators serve to show existing knowledge gaps; help guide available resources in the most appropriate direction and make assessments of existing capacities and potentialities in each mining scenario.

Reynaldo (2013), states that «The technical indicators of environmental management make it possible to analyze and regulate the physical interactions of nickel mining activity with the environment from two mutually dependent perspectives: first, mining as a consumer of natural resources and generator of waste; second, the relationship between the consumption of natural resources and the units produced» [27].

The relationship between the use or consumption of environmental factors and the units of nickel produced, expressed in ratios or indices, makes it possible to design technical indicators of environmental management as shown in Table 2.

The increase in consumption of environmental factors with unchanged behavior of produced units reflects the inefficiency of the nickel mining activity. Systematicity in the calculation of technical indicators of natural resource use makes it possible to regulate the consumption, use, and pollution of labor in this sector. The quantitative expression of these indicators enables their incorporation in the technical, productive and economic efficiency analyses. Given that the accounting process of mining companies does not consider management of environmental costs, economic and environmental indicators are developed based on the criteria of measures collected in Table 3.

Nickel mining is an economic activity with a high level of corporate responsibility, where management plays a fundamental role in environmental management. The efficiency of this task lies not in measuring the economic consequences of environmental impacts, but in the preventive work that enables the development of environmentally responsible and profitable mining.

*Table 2*
***Technical environmental indicators***

| Environmental Factors | Impacts | Technical indicators of environmental management |
|---|---|---|
| Soil | Erosion | ER |
| Natural resources | Water consumption | RWC |
| | Water pollution | RWP |
| Energy resources | Energy consumption | CER |
| Social agents | Deterioration of hygienic conditions | RWG |

ER: erosion ratio
RWC: water consumption ratio
RWP: ratio of water pollution
CER: consumption of energy ratio
RWG: ratio of waste generated.

*Table 3*
***Economic and environmental indicators***

| Measurement criteria | Economic and environmental indicators | UM |
|---|---|---|
| Environmental responsibility | CP: cost of prevention<br>EC: environmental costs<br>LTT: loss due to transportation technology | USD<br>USD<br>USD |
| Environmental feasibility | ICT: investment in clean technology | USD |
| Residual management | DL: loss due to debris<br>RSC: residual storage cost<br>RTC: residual transportation cost | USD<br>USD<br>USD |
| Energy efficiency | CE: cost of energy consumption | USD |
| Environmental formality | EO: environmental obligations<br>ML: loss of mineral<br>PCR: provision for contingencies and environmental risks | USD<br>USD<br>USD |
| Environmental profitability | VPR: value of proven reserves | USD |

It is designed to be used in efficiency analysis, as the PRODUCT VARIABLES: tons of Nickel+Cobalt produced and as the INPUT OR RESOURCE VARIABLES: technical, economic and environmental indicators that have greater weight in the units selected to identify and diagnose the conditioning factors that affect efficiency in the nickel industry; with the ultimate goal of having a procedure that provides timely and scientifically based information for making coherent decisions in the Cuban mining industry for the desired sustainable development of the mining industry.

The use of technical, economic and environmental indicators as variables for the development of a procedure that evaluates the efficiency of nickel mining in Cuba will create a basis for improving productivity, as well as direct actions to mitigate the negative externalities of mining, and thus contribute to the sustainable development of the municipality of Moa, as the Che Guevara Company is subject to the Territorial Contribution, a tax that provides for a contribution of 1% of the gross income from sales or services to ensure economic, social and sustainable territorial development [28].

## 3. Conclusions

The systematic study of technical, economic and environmental indicators allows introducing elements, data and relevant information to be incorporated in a continuous way into efficiency analysis. In this sense, Data Envelopment Analysis is presented as a complementary and effective tool for determining efficiency indexes. The determining variables in nickel mining and their relationship to the results achieved serve as a basis for the design of a procedure to evaluate efficiency, as well for identifying elements to be considered in the development of improvement measures to produce higher value-added and less polluting products.

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