Journal of Production, Operations and Systems Management

e-ISSN: 1984-2430

Open Access

SOCIAL EFFICIENCY BETWEEN MINING AND NON-MINING REGIONS IN MINAS GERAIS: AN ANALYSIS USING THE MALMQUIST INDEX

EFICIÊNCIA SOCIAL ENTRE REGIÕES MINERADORAS E NÃO MINERADORAS EM MINAS GERAIS: UMA ANÁLISE POR MEIO DO ÍNDICE DE MALMQUIST

Amanda Raphaela SILVA E SILVA[1]
e-mail: amanda.raphaela@aluno.ufop.edu.br

Alan BUENO[2]
e-mail: alan.bueno@unesp.br

Diogo FERRAZ[3]
e-mail: diogoferraz@usp.br

How to reference this paper:

Silva, A. R. S., Bueno, A., & Ferraz, D. (2025). Social efficiency between mining and non-mining regions in Minas Gerais: An analysis using the Malmquist index. *Revista GEPROS*, 20, e025003. DOI: 10.15675/gepros.3018.

| **Submitted**: 24/04/2024
| **Approved:** 18/08/2025
| **Published:** 23/09/2025

Editor: Prof. Dr. Paula de Camargo Fiorini

[1] BA in Economics, Departament of Economics-UFOP, Brazil.
[2] MA in Applied Economics, Post Graduate Program in Production Engineering (PPGEP/UNESP), Bauru, São Paulo, Brazil.
[3] Professor at the University of Sao Paulo (USP), Lorena School of Engineering, Department of Chemical and Production Engineering (DEQUI), Post Graduate Program in Production Engineering (PPGEP/UNESP) Lorena, São Paulo, Brazil.

ABSTRACT

Purpose: Compare the social efficiency indexes in the Minas Gerais state from 1990 to 2010. **Methodology/Approach:** This study uses a combination of parameters grouped by the method of data envelopment analysis (DEA) and by the Malmquist Index. **Findings:** We presented the top and bottom-ranked regions among the Minas Gerais municipalities. We analyzed these results by dividing them though regions with mining and no-mining regions. We found no relevant impacts, positive or negative, caused specifically by the mining activity on social efficiency. **Research, practical & social implications:** This article contributes to the formulation of public policies for human development in both mining and non-mining municipalities. Among the practical implications, the findings indicate the need for public policies aimed at improving the efficiency of financial resource allocation to promote human development. Regarding social implications, it is expected that the analysis of social efficiency will enhance the impact of other social programs (e.g., housing, health, and education) in the municipalities under study. **Originality/ Value:** There is a scarcity of studies analyzing social efficiency in mining and non-mining municipalities in developing countries, making this article a pioneer on the topic.

Keywords: Data Envelopment Analysis. Malmquist Index. Human Development. Mining. Brazil. Minas Gerais state

RESUMO

Objetivo: Comparar a eficiência social entre municípios mineradores e não mineradores do estado de Minas Gerais para os anos de 1990, 2000 e 2010. **Metodologia/Abordagem**: Utiliza-se uma combinação de parâmetros agrupados pelo método de Análise Envoltória de Dados (DEA) e pelo Índice de Malmquist. **Resultados**: São apresentadas as regiões com melhor e pior performance em eficiência social em Minas Gerais. Os resultados foram divididos entre regiões com atividade mineradora e sem atividade mineradora. Não foram encontrados impactos relevantes, positivos ou negativos, causados especificamente pela atividade de mineração sobre a eficiência social. **Contribuições, implicações práticas e sociais**: Este artigo contribui para a formulação de políticas públicas para o desenvolvimento humano em municípios mineradores e não mineradores. Dentre as implicações práticas, verificou-se que são necessárias políticas públicas para melhorar a eficiência na utilização dos recursos financeiros, a fim de promover o desenvolvimento humano. Dentre as implicações sociais, espera-se que a análise da eficiência social melhore o impacto de outros programas sociais (i.e., habitação, saúde e educação) nos municípios analisados. **Originalidade/Valor**: Há escassez de estudos que analisem a eficiência social em municípios mineradores e não mineradores em países em desenvolvimento, o que torna este artigo pioneiro no tema.

Palavras-chave: Análise Envoltória de Dados. Índice de Malmquist. Desenvolvimento Humano. Mineração. Brasil. Minas Gerais.

Introduction

Economic development has gradually proven insufficient to satisfactorily measure the progress of a municipality, state, or country. This limitation created room for novel approaches aimed at addressing complex questions, such as: what is the ultimate purpose of human beings? What do individuals value most in their lives? Is there a universal answer to this question, or does it depend on cultural factors? (Mariano, 2019). In the case of mining municipalities, identifying such outcomes would reveal the impact of economic activity on the region, thereby assisting local governments in making decisions that mitigate adverse effects while enhancing the positive consequences generated, particularly in developing areas.

Minas Gerais (MG) is one of the Brazilian states whose territory has been shaped by mining. According to the Minas Gerais Economic Development Company (CODEMIG, 2022), the state extracts more than 300 million tons of iron ore annually, accounting for 40% of the country's metallic mineral production and 50% of its total gold output. It is also noteworthy that within its nearly 587,000 km², Minas Gerais hosts the country's most significant production of zinc, phosphate, graphite, lithium, and limestone (CODEMIG, 2022).

Beyond this extractive perspective, the state is home to 20.87 million inhabitants and holds the third-largest GDP and the seventh-highest Human Development Index (HDI) in Brazil (IBGE, 2023). The HDI positions Minas Gerais favorably, as longevity, average years of formal education, and purchasing power are relatively well sustained at the state level. However, this favorable scenario does not extend uniformly across all municipalities, as local HDI values fluctuate upwards or downwards depending on the specific territorial boundaries analyzed.

The main challenge for public administration lies in mobilizing and managing resources in accordance with the services demanded by local society. One of the mechanisms established for tax collection is Financial Compensation for the Exploitation of Mineral Resources (CFEM). Created by the 1988 Federal Constitution, CFEM represents financial compensation paid by mining companies to the federal government, states, the Federal District, and municipalities for the extraction and use of mineral resources within their territories. The gross revenue used as the basis for CFEM calculation corresponds to gross sales revenue, with deductions allowed only for taxes levied on commercialization. Deductions for freight and insurance expenses are not permitted. For all export operations, the calculation basis is subject to verification through the Export Quotation Price (PECEX) or a reference value established by the National Mining Agency. The assessed amount serves as the minimum base for CFEM on exports, regardless of the value declared by the taxpayer. Furthermore, taxpayers benefit from a 50% reduction in CFEM obligations in cases of sales involving mining waste and tailings, provided that such materials are associated minerals and are utilized in other productive chains (AMIG, 2022).

The revenues collected through CFEM are assessed monthly and calculated individually for each mining company, according to their sales operations. Of the total amount collected, 65% must be allocated to the municipality, 23% to the state, and 12% to the federal government. This distribution highlights the crucial importance of monitoring how these resources are utilized, as the most significant share remains at the municipal level, where local governments often face the greatest limitations in terms of qualified human capital for effective fiscal management.

The funds are intended to finance projects that directly enhance the well-being of local communities, such as infrastructure improvements, environmental protection, healthcare, and education initiatives. In theory, this earmarking reflects a policy design aimed at transforming extractive activity into tangible social benefits for the regions most directly affected by mining operations. It is worth stressing, however, that the use of CFEM revenues to pay off debts or to cover the payroll of permanent public employees is expressly prohibited (Decree No. 01, December 11, 1991).

It is essential to acknowledge the substantial disparity in financial resources between mining and nonmining municipalities in Minas Gerais. Moreover, there are no guarantees that CFEM revenues effectively foster human development, as resources may be misallocated or wasted on projects that fail to generate meaningful improvements for the most vulnerable segments of the local population. In this context, there is an urgent need to develop an objective tool capable of measuring the extent to which CFEM revenues are converted into local human development, as well as empirically testing the discrepancy in human development outcomes between mining and nonmining municipalities. Against this background, the present article seeks to address the following research question: Does mining activity influence the human development of municipalities in Minas Gerais? To answer this question, the study aims to measure human development indicators across three periods (1991, 2000, and 2010). By doing so, this research seeks to contribute to the literature by providing evidence that can inform public authorities in designing more effective policies to convert the additional revenues from mining into tangible human development outcomes.

It is worth noting that no studies were found that directly address the issue of human development in municipalities of Minas Gerais, particularly those where mining constitutes the main economic activity. However, Magalhães et al. (2010) evaluated the efficiency of public expenditures in Minas Gerais, while Romero et al. (2009) examined social efficiency in the state's historic cities. This article advances the discussion by comparing human development across mining and nonmining municipalities, thereby contributing to the formulation of public policies in Minas Gerais and in other states with a significant mining presence.

Literature Review

This section presents the theoretical framework of the study. First, it discusses the definition of human development. Second, it examines the concept of social efficiency. Finally, it provides data on the economic development of Minas Gerais.

Human Development

Amartya Sen is a key scholarly reference in the international literature on human development. Sen (2010) argues that human development should be understood as the expansion of individual freedoms. He considers individuals to be truly free when they have the real conditions to pursue their own goals. Viewing citizens as agents allows individuals to become more complete "social beings," with enriched lives that enable them to put aspirations into practice and to influence the world around them (Mariano, 2019). In this regard, Sen's Capability Approach (Sen, 2010) offers an alternative perspective on well-being and economic development, shifting the focus away from physical resources and material outcomes toward the actual capabilities individuals possess to pursue the kind of life they value. Accordingly, well-being should be assessed based on the concrete opportunities available to individuals to achieve essential functionings—such as living a healthy life, accessing education, and actively participating in society. These capabilities are shaped by factors such as social conditions, public policies, and cultural contexts. The theory emphasizes freedom as the central element of development, understanding that expanding people's choices is both a means and an end to improving the quality of life and reducing inequalities.

In this context, the concept of Human Development emerged, which until the 1950s was assessed almost exclusively through Gross Domestic Product (GDP). In 1993, it began to be measured by the Human Development Index (HDI) and has been published annually by the United Nations Development Programme (UNDP) in its Human Development Report (HDR) since then. The HDI is composed of three key indicators: life expectancy at birth, average years of formal education, and income measured in terms of purchasing power. The advantages of the HDI include: (a) its foundation on the idea that development is linked to the expansion of human choices; (b) reliance on a small set of variables; (c) aggregation of multiple dimensions into a single index; (d) inclusion of both economic and social aspects; and (e) flexibility and gradual improvement over time (Haq, 1995). Its adoption was a landmark, representing a significant advance over the previous model, although the HDI continues to face methodological criticism.

One of the main strengths of the HDI is its simplicity. However, this very feature may obscure the complexity of human development by reducing multiple dimensions into a single composite metric of health, education, and income. Such reductionism overlooks essential aspects, including within-country inequalities, environmental issues, security, and political participation (Ferraz et al., 2021). Moreover, the equal weighting assigned to the three dimensions has been considered arbitrary and may not reflect the priorities of specific contexts (Mariano et al., 2021). Critics also point out that reliance on national averages conceals regional and social disparities, particularly in highly unequal countries. The use of limited indicators, such as life expectancy, years of schooling, and GDP per capita, may fail to capture the essential nuances of human well-being. Furthermore, scholars such as Mahlberg and Obersteiner (2001) argue that the problem lies in the weighting scheme assigned to each of these dimensions.

The criticism regarding the weighting scheme of the HDI can be addressed through alternative indices calculated using Data Envelopment Analysis (DEA). This technique has been widely applied and explained in past decades (Despotis, 2005b; Mariano et al., 2015; Tofallis, 2013; Zhou et al., 2010; Ferrari & Mariano, 2016). Two alternative approaches for measuring human development—DEA and the Malmquist Index (MI)—take into account the conversion of wealth into other dimensions (Chen & Iqbal Ali, 2004; Zofio, 2007; Zrelli et al., 2020). The MI has been used to measure efficiency in various contexts, including the plastics industry in Jordan (Al-Refaie et al., 2015) and the energy sector in China (Walheer, 2022). Tohidi and Razavyan (2013) combined DEA with the MI by creating the Global Profit Malmquist Productivity Index (GPMPI). The proposed GPMPI is applicable when input costs and output prices are known and when decision-making units (DMUs) seek to maximize total profit, thereby linking productivity changes over time. This flexibility and change in perspective are necessary to keep pace with the accumulation of knowledge over the years, while also acknowledging that human beings are complex and cannot be fully captured—at least not to the extent initially suggested by the HDI. The proposition of broader and more innovative indices must therefore be a continuous process, driven by the evolving needs of human existence.

Social Efficiency

The concept of Social Efficiency was introduced by Mariano and Rebelatto (2014) and further developed by Mariano (2019) in response to the earlier approach proposed by Despotis (2005a, 2005b). Social efficiency measures how effectively regions convert financial resources (i.e., Gross Domestic Product) into human development outcomes (such as education, health, and other social variables) (Mariano & Rebelatto, 2014). The idea of analyzing the conversion of wealth into social outcomes stems from the premise that the economy cannot be grounded solely in the maximization of utility and income. Instead, quality of life becomes the central focus, bringing considerations of justice and social efficiency into the discussion. In this sense, social efficiency builds on the broader notion of efficiency, understood as achieving the best possible performance of the analyzed units by minimizing the use of resources while generating the most favorable outcomes.

Despotis (2005a) conducted the first analysis on the performance of countries in converting wealth into human development. The author employed GDP per capita as the input, while the outputs were represented by education and life expectancy variables. Despotis (2005b) advanced this line of research by analyzing the social efficiency of Asia-Pacific countries in the year 2000. Morais and Camanho (2011) broadened the concept of measuring social efficiency by examining civic, educational, and environmental dimensions in 284 European cities. Mariano and Rebelatto (2014) analyzed 101 countries to assess the capacity of nation-states to convert wealth into quality of life. Their results showed that: (1) developed countries, despite high social indicators, did not stand out in terms of efficiency; (2) Southern African countries exhibited the worst social conditions and inefficiency; and (3) former Soviet republics and countries with a socialist background achieved the best performance. Gimenes et al. (2018) examined the leading global freedom indices and their relationship with the HDI. Their findings highlighted the need to explore the relationship between overall freedom and human development more robustly, taking into account a broader range of indices and dimensions. Ferraz et al. (2020) proposed the Capability Index Adjusted by Social Efficiency (CIASE) to measure social efficiency in Brazil using DEA. Their results indicated that poorer regions perform relatively better in terms of social efficiency than in absolute human development. In contrast, several wealthier regions perform relatively worse in terms of social efficiency compared to their absolute values.

In the Brazilian context, Ferraz et al. (2021a) developed the Deprivation and Financial Responsibility Based Prioritization Index (DFRP) for the state of Pará. The objective of the study was to identify which microregions should be prioritized in the allocation of public resources for education, health, housing, and employment. Castanhal was identified as the city with the greatest need for prioritization in resource distribution to promote human development. Conversely, the mining municipality of Parauapebas ranked lowest, suggesting that it has not effectively utilized available resources to foster local human development. The study also sparked a debate on the lack of a robust tool to support policymakers in their decision-making processes. In a related study, Ferraz et al. (2021b) measured the social efficiency of the Amazon region, assessing the social performance of its microregions while also considering local development strengths through DEA. The results revealed that 63.22% of Amazonian microregions were in the lowest quartile of the social efficiency ranking, highlighting a pressing need for government attention.

Campoli et al. (2017) examined the social efficiency of municipalities in the state of São Paulo with populations above 100,000. According to the authors, municipalities such as Americana, Araçatuba, Araraquara, Assis, Birigui, Campinas, Jaú, Jundiaí, Marília, Ourinhos, Presidente Prudente, Ribeirão Preto, and São José do Rio Preto were classified as socially efficient. The study highlights that many municipalities with high GDP levels are not considered efficient, as they fail to translate wealth into improvements in social indicators. It is also worth noting that Ferraz et al. (2017) evaluated the relationship between proxies of productive structure sophistication and human development variables using adjusted Cobb-Douglas multiple linear regressions, based on data from 49 countries between 2010 and 2013. Their results provided statistically significant evidence of a positive correlation between economic sophistication and human development.

Magalhães et al. (2010) examined government initiatives aimed at promoting environmentally and socially sustainable practices while maximizing well-being. As a result, seventeen municipalities were identified as achieving maximum efficiency, with variables such as population density, the proportion of urban population, and the existence of a municipal environmental council proving relevant in explaining efficiency scores. Soares et al. (2019) analyzed the spatial relationship of social efficiency across 853 municipalities in Minas Gerais in 2010. Their results revealed problems in the allocation of resources and relatively high levels of public expenditure, particularly in smaller municipalities. Romero et al. (2009) investigated the HDI of 23 historic cities in Minas Gerais using the DEA method. Their findings showed that: (1) in 69% of the cities, schooling levels were explained by variations in GDP; (2) two cities presented an HDI lower than 0.7 (Conceição do Mato Dentro and Serro); and (3) São João Del Rey emerged as the most promising in terms of human development.

Economic development in Minas Gerais

The region currently occupied by Minas Gerais was first explored in the sixteenth century, when *bandeirantes* sought gold and precious stones. Initially part of São Paulo, it became a single captaincy in 1709 but was separated a decade later to form its own jurisdiction. By the eighteenth century, Minas Gerais had become an important economic center for Portugal after its settlement, although it was subjected to rigid forms of taxation. This fiscal rigidity triggered the *Inconfidência Mineira*, a political movement led by Joaquim José da Silva Xavier (Tiradentes).

Mining in the state constrained the development of other activities, such as coffee cultivation, which, when introduced in the nineteenth century, quickly assumed economic prominence and ushered in a period of prosperity. However, reliance on a single economic activity proved ineffective in the long term, as regional productive specializations reshaped the economic structure, influenced local dynamics, altered social relations of production, and impacted territorial appropriation (Eskinazi & Souza, 2013). While specialization can generate certain advantages, such as fostering more balanced negotiations between public and private interests and reducing time spent on production processes, the challenges are more significant. A lack of labor force diversification, for instance, makes it difficult to reallocate workers during periods of job scarcity, whether due to aging, market shifts, or career changes. Moreover, regional specialization tends to homogenize productive spaces while simultaneously exacerbating inequalities between them (Joly & Arroyo, 2007).

In education, the stock of human capital, measured by average years of schooling, tends to increase the population's demands regarding the quality of public services and the allocation of resources (Daniel & Gomes, 2015). This dynamic also improves health outcomes, as rising income and education levels provide better access to healthcare resources (Soares et al., 2019). In the healthcare sector, smaller regions, on average, are less efficient in managing public expenditure. Municipalities with smaller populations generally lack timely and comprehensive access to essential healthcare services. To meet part of this demand, resources are allocated to small health facilities, which typically operate with high average fixed costs. For this reason, among others, small municipalities tend to be less efficient, as they lack the scale necessary to provide a broad range of health services. Consequently, public investments result in higher per capita expenditures compared to those of larger municipalities. For instance, the northern region of the state records vaccination coverage rates above 90% (averaging 95%). Yet, it exhibits low life expectancy indicators within the HDHL, reflecting a critical bottleneck in healthcare provision. In inefficient cities, one out of every four households lacks access to waste collection services (Soares et al., 2019).

Method

The data used in this study were drawn from the Brazilian Demographic Census, corresponding to the three most recent census years available (IBGE, 1991, 2000, and 2010). These years were selected based on the availability of data for the municipalities under analysis. The variables were chosen in line with the social efficiency literature to assess the conversion of GDP (input) into variables relevant to human development (i.e., health and education) (outputs) (Despotis, 2005a, 2005b; Ferraz et al., 2020; Morais & Camanho, 2011). This study differs from Ferraz et al. (2020) in that it focuses specifically on the municipalities of Minas Gerais. Table 1 summarizes the variables across five dimensions, represented by a total of 14 social indicators.

Table 1

Variables.

	Variable	Dimension	Literature Review
Input	Gross Domestic Product (GDP)	Wealth	(Despotis, 2005a, 2005b)
Outputs	Literate population	Education	(Despotis, 2005a, 2005b; Raab et al., 2000)
	Children are enrolled in daycare.	Education	(Morais & Camanho, 2011)
	Households with electricity	Housing	(Morais & Camanho, 2011)
	Households with piped water	Housing	(Morais & Camanho, 2011)
	Number of vaccinated people	Health	(Morais & Camanho, 2011)
	Life expectancy	Health	(Despotis, 2005a, 2005b)
	Formal employment	Economy	(Morais & Camanho, 2011)

A drawback of analyzing at the municipal level is that many municipalities lack autonomy in certain areas of service provision, such as healthcare. Small municipalities often rely on medium-sized cities or the state capital to provide essential support to their surrounding populations. On the other hand, a compensating advantage of DEA lies in its ability to aggregate relevant information directly and straightforwardly, thereby providing policymakers with valuable insights (Ferraz et al., 2020).

Data envelopment analysis (DEA)

The DEA technique is widely applied to evaluate social efficiency, incorporating variables that influence municipal- and state-level development. This section draws on Mariano's book *Progress and Human Development* (Mariano, 2019), which presents relevant concepts concerning DEA and human development. Initially proposed by Charnes et al. (1978), DEA is a non-parametric mathematical method based on linear programming. Its application enables the measurement of performance among Decision Making Units (DMUs) through the construction of a segmented linear frontier.

According to Mariano (2019), DEA results indicate the maximum amount of social outputs that can be generated from a given set of inputs. The technique ranks each region based on performance, assigning scores that range from 1 (maximum performance) to 0 (minimum performance). To define this efficiency frontier, the method focuses on the strengths of each unit analyzed, assigning optimal weights to maximize relative efficiency (Mariano et al., 2015). In the formulation of DEA, Thanassoulis (2001) structures the model by considering the relationship between inputs (resources employed), outputs (results achieved), and linear programming problems. Furthermore, he establishes the connection between primal and dual models, resulting in eight distinct representations of the CCR and BCC models, as illustrated in Table 2.

Table 2

Breakdown of DEA mathematical models according to type and orientation.

DEA	**CCR**	Input	Primal
			Dual
		Output	Primal
			Dual
	BCC	Input	Primal
			Dual
		Output	Primal
			Dual

Note. Adapted from Almeida et al. (2006).

The concept of the efficiency frontier refers to the set of points that define the maximum limits of productivity, representing an ideal productive unit operating with full technical efficiency (Mariano, 2019). This frontier establishes a benchmark for evaluating the performance of other productive units within the same context. The term DMU is used to designate firms, organizations, or productive entities analyzed in efficiency studies. DMUs must satisfy three fundamental criteria: (a) they must be comparable to one another, (b) they must operate under equivalent conditions, and (c) they must use the same types of inputs and outputs, differing only in production scale (Mariano, 2019). Based on this methodological structure, DMUs are classified as efficient or inefficient, depending on their relative performance against the established frontier.

To address social efficiency, two primary indicators and one composite indicator are constructed. First, the Standard Social Efficiency (ESP) indicator identifies the regions that achieve the best results in converting public expenditure into human development. Second, the Inverted Social Efficiency (ESI) indicator highlights the regions with the worst outcomes. The ESI is necessary to reduce ties among the municipalities analyzed (Leta et al., 2005; Yamada et al., 1994). This approach is known as the Inverted Frontier, as it measures efficiency by reversing the roles of inputs and outputs. In this way, it produces an indicator that captures regional weaknesses and establishes a frontier of worst practices—the opposite of the traditional frontier, which is based on strengths.

The primary indicators are then aggregated into the Social Efficiency Indicator (IES), as recommended by Leta et al. (2005). The IES results in a composite index calculated as the average of the value obtained from the standard frontier (ESP) and one minus the value obtained from the inverted frontier (ESI), as shown in Equation 1.

$$IES = \beta \cdot ESP + (1 - \beta) \cdot (1 - ESI) \quad (1)$$

Where:
IES – Social Efficiency Indicator;
ESP – Standard Social Efficiency;
ESI – Inverted Social Efficiency;
$\beta = 0.5$

Malmquist Index

The MI is designed to provide a comparative performance analysis of a set of DMUs, with their respective inputs and outputs, within a given base period (Caves et al., 1982; Malmquist, 1953). According to Färe et al. (2004), changes in total factor productivity are obtained through shifts in efficiency frontiers, as described in Equation 2:

$$AFTP = AT \cdot AE \quad (2)$$

Where:
AFTP – Change in total factor productivity;
AE – Efficiency change (measured by shifts in DMU performance)
AT – Technological change (measured by shifts in the frontier over time).

According to Färe et al. (2004), it is also possible to integrate the MI with DEA. This integration is calculated through Equation 3:

$$IM = \sqrt{\frac{D^0(x^tv,y^tv)}{D^t(x^tv,y^tv)}\frac{D^0(x^0v,y^0v)}{D^t(x^0v,y^0v)}} \cdot \frac{D^t(x^tv,y^tv)}{D^0(x^0v,y^0v)} = AT \cdot AE \quad (3)$$

Where:

IM – Malmquist Index;

D0 – Relative distance of period 0 with respect to the frontier;

Dt – Relative distance of period t with respect to the frontier;

y0v – Quantity of DMU outputs in period 0;

x0v – Quantity of DMU inputs in period 0;

ytv – Quantity of DMU outputs in period t;

xtv – Quantity of DMU inputs in period t;

AT – Technological change;

AE – Efficiency change.

The advantage of using the MI lies in its ability to compare similarities and differences across reference periods, thereby contributing to a deeper understanding of human development.

Results and Discussion

This study analyzed 614 municipalities in the state of Minas Gerais, using data from the Brazilian Institute of Geography and Statistics (IBGE, 2023) Demographic Census for the years 1991, 2000, and 2010. Table 3 presents the municipalities with the lowest MI values between 1991 and 2000. It is worth noting that the municipality of Lagoa dos Patos registered an MI of 0.64. This result indicates a 36% reduction in the conversion of income into human development over the period from 1991 to 2000. Other municipalities follow a similar pattern, namely São José da Safira (0.69), Maravilhas (0.70), Santa Maria do Suaçuí (0.70), Materlândia (0.74), Botumirim (0.75), Francisco Dumont (0.76), Campo Florido (0.78), Ubaí (0.79), and Datas (0.79).

Table 3

Municipalities of Minas Gerais with the lowest MI, 1991–2000.

Ranking	Municipality	Microregion	Macroregion	Malmquist	AE	AT
614°	Lagoa dos Patos	Norte de Minas	Pirapora	0.64	0.43	1.51
613°	São José da Safira	Vale do Rio Doce	Governador Valadares	0.69	0.44	1.56
612°	Maravilhas	Metropolitana de Belo Horizonte	Sete Lagoas	0.70	0.44	1.59
611°	Santa Maria do Suaçuí	Vale do Rio Doce	Peçanha	0.70	0.45	1.54
610°	Materlândia	Vale do Rio Doce	Guanhães	0.74	0.50	1.48

It is worth noting that the municipalities ranked with the lowest MI values do not have mining as their main economic activity. This finding suggests that mining is not a significant factor in explaining the poor performance of the MI during the period analyzed. Furthermore, it is noteworthy that four of the ten lowest-ranked municipalities are located in the North of Minas Gerais, while three are situated in the Rio Doce Valley region. Table 3 also shows that, despite an increase in AT, all municipalities experienced setbacks in human development, which can be explained by a decline in AE.

To complement these findings, Table 4 maps additional data on the distance of each municipality to its macroregional hub and to the state capital, as well as the percentage of population growth and the number of inhabitants recorded in 2000. This analysis shows that the average distance to Belo Horizonte is 394.0 kilometers, with Botumirim being the farthest municipality from the capital (609 km) and Maravilhas the closest (129 km).

In addition, the average distance to the municipality with the most extensive support infrastructure within each macroregion is 74.94 kilometers, with Ubaí being the most distant (153 km) and Datas the closest (34.4 km). Regarding population size, the average was 6,642 inhabitants per municipality. Santa Maria do Suaçuí was the most populous in 2000 (14,337 inhabitants), whereas São José da Safira was the least populous (3,906 inhabitants). It is also worth noting that the average population growth across these municipalities was 4.04% over the ten years. Francisco Dumont recorded the highest growth (0.24%), while Ubaí registered the steepest population decline, with a 0.22% reduction.

Table 4

The lowest MI between 1991 and 2000, and the relation to distance from larger cities and population.

Ranking Malmquist	Municipality	Distance to Macroregion (km)	Distance to Capital (km)	Population Growth (%)	Population in 2000
614°	Lagoa dos Patos	67.1	423.0	0.1	4476
613°	São José da Safira	90.1	398.0	0.06	3906
612°	Maravilhas	65.4	129.0	0.17	6285
611°	Santa Maria do Suaçuí	69.4	357.0	-0.21	14337
610°	Materlândia	52.6	300.0	0.05	4860

It is not possible to establish a clear relationship between the results of Table 3 and Table 4 with respect to the distance to the macroregion and to the state capital, given the wide variation in the data analyzed. Regarding population, it is noteworthy that both the variation and the absolute number of inhabitants are relatively low, indicating that these municipalities are not attractive destinations for migration. However, this observation alone does not clarify whether it is a cause or a consequence of poor performance in the MI.

Table 5 presents the municipalities with the highest MI values between 1991 and 2000. Notably, the municipality of Viçosa recorded an MI of 6.05, representing a 600% increase in the conversion of income into human development over the ten years. Other municipalities follow a similar pattern, namely Prata (5.03), Ouro Branco (3.10), Santa Luzia (2.73), Vieiras (2.65), Campestre (2.62), São José do Divino (2.57), Casa Grande (2.52), Santa (2.42), and Serra da Saudade (2.38).

Table 5

Highest MI between 1991 and 2000.

Ranking	Municipality	Microregion	Macroregion	Malmquist	AE	AT
1°	Viçosa	Zona da Mata	Viçosa	6.05	3.74	1.62
2°	Prata	Triângulo Mineiro/Alto Paranaíba	Uberlândia	5.03	2.86	1.76
3°	Ouro Branco	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	3.10	1.99	1.56
4°	Santa Luzia	Metropolitana de Belo Horizonte	Belo Horizonte	2.73	2.02	1.35
5°	Vieiras	Zona da Mata	Muriaé	2.65	1.66	1.60

It is worth noting that among the municipalities ranked with the highest MI values, only Santa Bárbara (ranked 9th) has mining as its primary economic activity. This suggests that mining alone is insufficient to explain the strong performance in the MI for the analyzed period. Furthermore, it is noteworthy that four of the top 10 municipalities are located in the Metropolitan Region of Belo Horizonte. Table 5 also shows that all municipalities experienced increases in both AT and AE.

To complement the information on the MI, Table 6 maps the distances of each municipality to its macroregional hub and to the state capital, as well as the percentage of population growth and the number of inhabitants recorded in 2000. The analysis shows that the average distance to Belo Horizonte is 266.7 kilometers, with Prata being the farthest municipality from the capital (622 km) and Santa Luzia the closest (18.2 km).

In addition, the average distance to the municipality with the most extensive support infrastructure within each macroregion is 56.52 kilometers, with São José do Divino being the farthest (135 km). At the same time, Viçosa itself serves as the macroregional hub. The results also show that the municipalities had an average of 36,375 inhabitants, with Santa Luzia being the most populous in 2000 (187,948 inhabitants) and Serra da Saudade the least populous (874 inhabitants). It is worth noting that the average population growth rate during the analyzed decade was 10.20%. Santa Luzia recorded the highest increase (0.38%), while São José do Divino experienced the most significant population decline, with a reduction of 0.09%.

Table 6

The highest MI between 1991 and 2000, and the relation to distance from larger cities and population.

Ranking Malmquist	Municipality	Distance to Macroregion (km)	Distance to Capital (km)	Population Growth (%)	Population in 2000
1°	Viçosa	-	225.0	0.29	65708
2°	Prata	87.5	622.0	0.01	23507
3°	Ouro Branco	21.6	100.0	0.13	30574
4°	Santa Luzia	18.2	18.2	0.38	187948
5°	Vieiras	45.8	355.0	0.05	3962

It is not possible to establish a clear relationship between the results in Table 5 and Table 6 regarding the distance to the macroregion and the state capital, given the wide variation in the data. Regarding population size, it is notable that there is relatively small variation, suggesting that although these municipalities are attractive for migration, they tend to maintain stable average population levels.

Table 7 presents the municipalities with the lowest MI values between 2000 and 2010. Notably, the municipality of Nova Serrana recorded an MI of 0.80, indicating a 20% reduction in the conversion of income into human development over the ten years. Other municipalities follow a similar trend, namely Luminárias (0.83), Munhoz (0.85), Monjolos (0.89), Papagaios (0.89), Jacutinga (0.90), Monte Sião (0.90), Novo Cruzeiro (0.90), Serra da Saudade (0.91), and Divino das Laranjeiras (0.91).

Table 7

Lowest MI between 2000 and 2010.

Ranking	Municipality	Microregion	Macroregion	Malmquist	AE	AT
614°	Nova Serrana	Oeste de Minas	Divinópolis	0.80	0.67	1.18
613°	Luminárias	Campo das Vertentes	Lavras	0.83	0.69	1.19
612°	Munhoz	Sul/Sudoeste de Minas	Pouso Alegre	0.85	0.70	1.20
611°	Monjolos	Central Mineira	Curvelo	0.89	0.71	1.25
610°	Papagaios	Metropolitana de Belo Horizonte	Sete Lagoas	0.89	0.75	1.19

It is worth noting that none of the municipalities ranked among the lowest positions in the MI for the period 2000–2010 had mining as an economic activity. This suggests that the presence of mining as a productive sector is insufficient to explain the poor performance observed in the MI during the analyzed period. Furthermore, it is noteworthy that three of the ten lowest-ranked municipalities are in the South/Southwest region of Minas Gerais. Table 7 further shows that, despite an increase in AT, all municipalities experienced setbacks in development, driven by a decline in AE.

To complement this information, Table 8 also maps the distance of each municipality to its respective macroregion and to the state capital, in addition to reporting the percentage of population growth and the total number of inhabitants recorded for the last year of the period (2010). This investigation allows the following observations: (1) the average distance to Belo Horizonte is 339.7 kilometers, with Monte Sião being the farthest municipality from the capital (478 km) and Nova Serrana the closest (124 km); (2) the average distance to the municipality with the most extensive support infrastructure is 82.18 kilometers, with Monte Sião being the farthest from its macroregion (120 km) and Luminárias the closest (42.6 km); (3) the average population per municipality is 18,237 inhabitants, with Nova Serrana being the most populous in 2010 (73,699 inhabitants) and Serra da Saudade the least populous (815 inhabitants); (4) the average population growth rate over the decade was 11.76%. Nova Serrana recorded the most significant increase, at 0.9%, while Monjolos experienced the most significant population decline, with a reduction of 0.08%.

Table 8
Lowest MI between 2000 and 2010, and the relationship with distance to larger cities and population.

Ranking Malmquist	Municipality	Distance to Macroregion (km)	Distance to Capital (km)	Population Growth (%)	Population in 2010
614°	Nova Serrana	44.6	124.0	0.9	73699
613°	Luminárias	42.6	278.0	-0.01	5422
612°	Munhoz	97.6	472.0	-0.07	6257
611°	Monjolos	90.9	230.0	-0.08	2360
610°	Papagaios	76.0	143.0	0.12	14175

It is not possible to establish a relationship between the results of Table 7 and Table 8 regarding the distance to the macroregion and the state capital, given the wide variation observed. Concerning population, it is worth noting both the low variation and the small number of inhabitants, which suggests that these municipalities are not attractive for migration. However, this descriptive evidence alone does not indicate whether this fact is a cause or a consequence of poor performance.

Table 9 presents the municipalities with the best MI scores between 2000 and 2010. Notably, the municipality of Jequitibá obtained an MI of 2.94. This indicates a 290.4% increase in the conversion of income into human development over the ten years analyzed. Other municipalities follow the same dynamic, namely Juruaia (2.35), Pouso Alto (2.24), Chiador (2.22), Itaverava (2.17), Senador Cortes (2.16), Coronel Xavier Chaves (2.12), Itacambira (2.12), Conceição da Barra de Minas (2.12), and Salinas (2.11). Table 9 presents the municipalities with the best MI scores between 2000 and 2010. Notably, the municipality of Jequitibá obtained an MI of 2.94. This indicates a 290.4% increase in the conversion of income into human development over the ten years analyzed. Other municipalities follow the same dynamic, namely Juruaia (2.35), Pouso Alto (2.24), Chiador (2.22), Itaverava (2.17), Senador Cortes (2.16), Coronel Xavier Chaves (2.12), Itacambira (2.12), Conceição da Barra de Minas (2.12), and Salinas (2.11).

Table 9

Highest MI between 2000 and 2010.

Ranking	Municipality	Microregion	Macroregion	Malmquist	AE	AT
1°	Jequitibá	Metropolitana de Belo Horizonte	Sete Lagoas	2.94	2.37	1.24
2°	Juruaia	Sul/Sudoeste de Minas	São Sebastião do Paraíso	2.35	1.86	1.26
3°	Pouso Alto	Sul/Sudoeste de Minas	São Lourenço	2.24	1.85	1.21
4°	Chiador	Zona da Mata	Juiz de Fora	2.22	1.85	1.20
5°	Itaverava	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	2.17	1.77	1.23

It is worth noting that none of the municipalities ranked among the top positions in the MI had mining as a primary economic activity. This suggests that the presence of mining as an economic sector is insufficient to explain the good performance observed in the MI during the period analyzed. Furthermore, it is noteworthy that the microregions are evenly distributed, with two municipalities of distinction in each of the following areas: the North of Minas, Zona da Mata, the Metropolitan Region of Belo Horizonte, Campos das Vertentes, and the South/Southeast. Table 9 also shows that there was an increase in both AT and AE across all municipalities.

To complement this information, Table 10 also maps the distance of each municipality to its respective macroregion and to the state capital, in addition to reporting the percentage of population growth and the number of inhabitants recorded for the last year of the period (2010). This investigation allows the following observations: (1) the average distance to Belo Horizonte is 324.4 kilometers, with Salinas being the farthest municipality from the capital (651 km) and Jequitibá the closest (114 km); (2) the average distance to the municipality with the most extensive support infrastructure is 38 kilometers, with Itacambira being the farthest from its macroregion (108 km), while Salinas itself serves as its own support center; (3) the average population per municipality is 8,260 inhabitants, with Salinas being the most populous in 2010 (39,178 inhabitants) and Senador Cortes the least populous (1,988 inhabitants); (4) the average population growth rate over the decade was 1.56%. Juruaia recorded the highest population increase (0.19%), while Itaverava experienced the most significant decline (−0.09%).

Table 10

The highest MI between 2000 and 2010, and the relationship with distance to larger cities and population.

Ranking Malmquist	Municipality	Distance to Macroregion (km)	Distance to Capital (km)	Population Growth (%)	Population in 2010
1°	Jequitibá	39.2	114.0	0	5156
2°	Juruaia	96.1	407.0	0.19	9238
3°	Pouso Alto	22.0	409.0	-0.08	6213
4°	Chiador	78.0	336.0	-0.06	2785
5°	Itaverava	24.9	123.0	-0.09	5799

It is not possible to establish a relationship between the results of Table 9 and Table 10 regarding the distance to the macroregion and the state capital, given the wide variation observed. With respect to population, it is interesting to note both the low variation and the relatively small number of inhabitants, which indicates that, although these municipalities may be attractive for migration, they tend to maintain a stable average population.

Table 11 presents the MI values for mining municipalities between 1991 and 2000. Notably, the municipality of Santa Bárbara obtained an MI of 2.42. This indicates a 142% increase in the conversion of income into human development over the ten years analyzed. Other municipalities follow a similar dynamic, namely Entre Rios de Minas (1.72), Caeté (1.64), Nova Lima (1.64), Desterro de Entre Rios (1.52), Belo Vale (1.52), Piracema (1.47), Jeceaba (1.44), Brumadinho (1.39), Itaúna (1.38), São Tiago (1.36), Dom Joaquim (1.35), Prados (1.33), Itabirito (1.30), Ouro Preto (1.30), Diamantina (1.29), Morro do Pilar (1.26), Guanhães (1.21), Coronel Fabriciano (1.20), Pains (1.18), Governador Valadares (1.16), Mariana (1.15), Paracatu (1.15), Itabira (1.14), Conceição do Mato Dentro (1.14), Barão de Cocais (1.14), Congonhas (1.11), and Porteirinha (1.06).

Table 11

MI of mining municipalities between 1991 and 2000.

Ranking	Municipality	Microregion	Macroregion	Malmquist	AE	AT
9°	Santa Bárbara	Metropolitana de Belo Horizonte	Itabira	2.42	1.56	1.55
56°	Entre Rios de Minas	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	1.72	1.08	1.59
79°	Caeté	Metropolitana de Belo Horizonte	Belo Horizonte	1.64	1.04	1.58
81°	Nova Lima	Metropolitana de Belo Horizonte	Belo Horizonte	1.64	1.04	1.58
116°	Desterro de Entre Rios	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	1.52	0.96	1.58
117°	Belo Vale	Metropolitana de Belo Horizonte	Itaguara	1.52	0.94	1.61
143°	Piracema	Oeste de Minas	Oliveira	1.47	0.92	1.60
160°	Jeceaba	Metropolitana de Belo Horizonte	Itaguara	1.44	0.89	1.62
200°	Brumadinho	Metropolitana de Belo Horizonte	Belo Horizonte	1.39	0.89	1.57
214°	Itaúna	Oeste de Minas	Divinópolis	1.38	0.88	1.57
231°	São Tiago	Campo das Vertentes	São João Del Rei	1.36	0.84	1.62
236°	Dom Joaquim	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.35	0.91	1.48
254°	Prados	Campo das Vertentes	São João Del Rei	1.33	0.82	1.61

283°	Itabirito	Metropolitana de Belo Horizonte	Ouro Preto	1.30	0.80	1.62
286°	Ouro Preto	Metropolitana de Belo Horizonte	Ouro Preto	1.30	0.83	1.56
297°	Diamantina	Jequitinhonha	Diamantina	1.29	0.82	1.58
320°	Morro do Pilar	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.26	0.82	1.55
372°	Guanhães	Vale do Rio Doce	Guanhães	1.21	0.78	1.56
381°	Coronel Fabriciano	Vale do Rio Doce	Ipatinga	1.20	0.80	1.51
402°	Pains	Oeste de Minas	Formiga	1.18	0.74	1.59
418°	Governador Valadares	Vale do Rio Doce	Governador Valadares	1.16	0.97	1.20
425°	Mariana	Metropolitana de Belo Horizonte	Ouro Preto	1.15	0.74	1.56
436°	Paracatu	Noroeste de Minas	Paracatu	1.15	0.75	1.54
445°	Itabira	Metropolitana de Belo Horizonte	Itabira	1.14	0.75	1.51
446°	Conceição do Mato Dentro	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.14	0.72	1.58
448°	Barão de Cocais	Metropolitana de Belo Horizonte	Itabira	1.14	0.73	1.56
455°	Congonhas	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	1.11	0.70	1.58
494°	Porteirinha	Norte de Minas	Janaúba	1.06	0.67	1.59
536°	Serro	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.00	0.64	1.56
561°	Taquaraçu de Minas	Metropolitana de Belo Horizonte	Itabira	0.94	0.58	1.63
562°	Itambé do Mato Dentro	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	0.94	0.62	1.51
593°	São Gonçalo do Rio Abaixo	Metropolitana de Belo Horizonte	Itabira	0.85	0.55	1.56

It is worth noting that all the municipalities listed engage in mining activity, ranking between 9th and 593rd place in the MI for the period 1991–2000. This suggests that the presence of mining as an economic activity is insufficient to explain either good or poor performance in the MI during the analyzed period.

Furthermore, the distribution of the microregions is as follows: 21 municipalities in the Metropolitan Region of Belo Horizonte, 3 in the West of Minas, 3 in the Rio Doce Valley, 2 in Campos das Vertentes, 1 in Jequitinhonha, 1 in the Northwest of Minas, and 1 in the North of Minas. Table 11 also shows that, among the 32 mining municipalities, 3 experienced a decline in human development (Taquaraçu de Minas, Itambé do Mato Dentro, and São Gonçalo do Rio

Abaixo), while 28 recorded an increase in human development over the analyzed period. One municipality showed no change (Serro). Moreover, of the 28 mining municipalities that experienced an increase in human development, only 4 (Santa Bárbara, Entre Rios de Minas, Caeté, and Nova Lima) also registered an increase in AE. All 32 mining municipalities recorded an increase in AT.

To complement this information, Table 12 also maps the distance of each municipality to its respective macroregion and to the state capital, in addition to reporting the percentage of population growth and the total number of inhabitants recorded for the last year of the period (2000). This analysis allows the following observations: (1) the average distance to Belo Horizonte is 166.50 kilometers, with Governador Valadares being the farthest municipality from the capital (315 km) and Nova Lima the closest (22.9 km); (2) the average distance to the municipality with the most extensive support infrastructure is 39.6 kilometers, with Jeceaba being the farthest from its macroregion (135 km), while Ouro Preto, Diamantina, Guanhães, Paracatu, Governador Valadares, and Itabira each serve as their own support centers; (3) the average population per municipality is 37,752 inhabitants, with Governador Valadares being the most populous in 2000 (248,205 inhabitants) and Itambé do Mato Dentro the least populous (2,571 inhabitants); (4) the average population growth rate over the decade was 7.61%. Brumadinho recorded the highest population increase (0.41%), while Porteirinha experienced the most significant decline (−0.29%).

Table 12
MI of mining municipalities between 1991 and 2000, and the relationship with distance to larger cities and population.

Ranking Malmquist	Municipality	Distance to Macroregion (km)	Distance to Capital (km)	Population Growth (%)	Population in 2000
9°	Santa Bárbara	75.4	109.0	-0.06	24314
56°	Entre Rios de Minas	51.0	124.0	0.08	13170
79°	Caeté	48.3	48.3	0.11	36496
81°	Nova Lima	22.9	22.9	0.26	65162
116°	Desterro de Entre Rios	84.0	156.0	0	6806
117°	Belo Vale	65.4	73.4	0.06	7454
143°	Piracema	72.5	124.0	0.08	6538
160°	Jeceaba	135.0	113.0	-0.09	6054

200°	Brumadinho	54.8	54.8	0.41	27087
214°	Itaúna	41.1	79.6	0.17	77539
231°	São Tiago	48.8	196.0	0.07	10284
236°	Dom Joaquim	33.4	198.0	-0.05	4681
254°	Prados	29.1	185.0	0.05	7724
283°	Itabirito	47.1	58.7	0.2	38277
286°	Ouro Preto	-	102.0	0.08	66520
297°	Diamantina	-	291.0	0.01	44256
320°	Morro do Pilar	27.5	151.0	-0.03	3726
372°	Guanhães	-	248.0	0.12	28000
381°	Coronel Fabriciano	17.8	215.0	0.13	98099
402°	Pains	35.4	217.0	-0.03	7781
418°	Governador Valadares	-	315.0	0.08	248205
425°	Mariana	14.4	116.0	0.24	47262
436°	Paracatu	-	502.0	0.22	76021
445°	Itabira	-	107.0	0.16	99145
446°	Conceição do Mato Dentro	-	163.0	0	18632
448°	Barão de Cocais	63.8	96.5	0.17	23592
455°	Congonhas	23.1	80.3	0.19	41637
494°	Porteirinha	38.5	600.0	-0.29	37949
536°	Serro	63.5	229.0	0.1	21120
561°	Taquaraçu de Minas	74.2	55.1	0.04	3498
562°	Itambé do Mato Dentro	62.6	117.0	-0.05	2571
593°	São Gonçalo do Rio Abaixo	34.8	88.2	0.02	8471

It is not possible to establish a relationship between the results of Table 11 and Table 12 regarding distance to the macroregion, distance to the state capital, population size, and population growth, given the wide variation observed.

Table 13 presents the MI values for mining municipalities between 2000 and 2010. Notably, the municipality of Nova Lima obtained an MI of 1.99. This indicates an increase of 0.99 in the conversion of income into human development over the ten years analyzed. Other municipalities follow a similar dynamic, namely Belo Vale (1.79), Serro (1.75), São Gonçalo do Rio Abaixo (1.75), Brumadinho (1.74), Prados (1.70), Congonhas (1.69), Itabirito (1.56), Barão de Cocais (1.55), São Tiago (1.52), Itambé do Mato Dentro (1.52), Piracema (1.52), Guanhães (1.52), Pains (1.52), Desterro de Entre Rios (1.51), Conceição do Mato Dentro (1.48), Taquaraçu de Minas (1.47), Mariana (1.42), Entre Rios de Minas (1.40), Ouro Preto (1.39), Itabira (1.36), Porteirinha (1.35), Jeceaba (1.34), Dom Joaquim (1.33), Itaúna (1.32), Diamantina (1.29), Coronel Fabriciano (1.27), Paracatu (1.22), Santa Bárbara (1.18), Caeté (1.09), Governador Valadares (1.08), and Morro do Pilar (1.08).

Table 13

MI of mining municipalities between 2000 and 2010.

Ranking	Municipality	Microregion	Macroregion	Malmquist	AE	AT
15°	Nova Lima	Metropolitana de Belo Horizonte	Belo Horizonte	1.99	1.67	1.19
34°	Belo Vale	Metropolitana de Belo Horizonte	Itaguara	1.79	1.39	1.29
43°	Serro	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.75	1.33	1.31
44°	São Gonçalo do Rio Abaixo	Metropolitana de Belo Horizonte	Itabira	1.75	1.46	1.20
47°	Brumadinho	Metropolitana de Belo Horizonte	Belo Horizonte	1.74	1.43	1.22
59°	Prados	Campo das Vertentes	São João Del Rei	1.70	1.42	1.19
62°	Congonhas	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	1.69	1.39	1.22
123°	Itabirito	Metropolitana de Belo Horizonte	Ouro Preto	1.56	1.30	1.20
126°	Barão de Cocais	Metropolitana de Belo Horizonte	Itabira	1.55	1.29	1.21
147°	São Tiago	Campo das Vertentes	São João Del Rei	1.52	1.27	1.20
148°	Itambé do Mato Dentro	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.52	1.13	1.35
150°	Piracema	Oeste de Minas	Oliveira	1.52	1.25	1.21
153°	Guanhães	Vale do Rio Doce	Guanhães	1.52	1.23	1.23
155°	Pains	Oeste de Minas	Formiga	1.52	1.27	1.20
160°	Desterro de Entre Rios	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	1.51	1.22	1.24
190°	Conceição do Mato Dentro	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.48	1.14	1.30

192°	Taquaraçu de Minas	Metropolitana de Belo Horizonte	Itabira	1.47	1.16	1.27
234°	Mariana	Metropolitana de Belo Horizonte	Ouro Preto	1.42	1.17	1.22
252°	Entre Rios de Minas	Metropolitana de Belo Horizonte	Conselheiro Lafaiete	1.40	1.17	1.20
269°	Ouro Preto	Metropolitana de Belo Horizonte	Ouro Preto	1.39	1.14	1.21
297°	Itabira	Metropolitana de Belo Horizonte	Itabira	1.36	1.11	1.22
309°	Porteirinha	Norte de Minas	Janaúba	1.35	0.96	1.40
324°	Jeceaba	Metropolitana de Belo Horizonte	Itaguara	1.34	1.09	1.23
338°	Dom Joaquim	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.33	1.06	1.25
346°	Itaúna	Oeste de Minas	Divinópolis	1.32	1.10	1.21
376°	Diamantina	Jequitinhonha	Diamantina	1.29	1.05	1.23
401°	Coronel Fabriciano	Vale do Rio Doce	Ipatinga	1.27	1.02	1.25
457°	Paracatu	Noroeste de Minas	Paracatu	1.22	0.98	1.24
492°	Santa Bárbara	Metropolitana de Belo Horizonte	Itabira	1.18	0.78	1.51
550°	Caeté	Metropolitana de Belo Horizonte	Belo Horizonte	1.09	0.89	1.22
554°	Governador Valadares	Vale do Rio Doce	Governador Valadares	1.08	0.84	1.29
560°	Morro do Pilar	Metropolitana de Belo Horizonte	Conceição do Mato Dentro	1.08	0.88	1.22

It is worth noting that all the municipalities listed engage in mining activity, ranking between 15th and 593rd place in the MI for the period 2000–2010. This suggests that the presence of mining as an economic activity is insufficient to explain either good or poor performance in the MI during the analyzed period. Furthermore, the distribution of the microregions is as follows: 21 municipalities in the Metropolitan Region of Belo Horizonte, 3 in the West of Minas, 3 in the Rio Doce Valley, 2 in Campos das Vertentes, 1 in Jequitinhonha, 1 in the Northwest of Minas, and 1 in the North of Minas. Table 13 also shows that all 32 mining municipalities experienced an increase in human development during the analyzed period, with only 5 registering a reduction in AE. All 32 municipalities recorded an increase in AT.

To complement this information, Table 14 also maps the distance of each municipality to its respective macroregion and to the state capital, in addition to reporting the percentage of population growth and the number of inhabitants recorded for the last year of the period (2010).

This analysis allows the following observations: (1) the average distance to Belo Horizonte is 166.50 kilometers, with Governador Valadares being the farthest municipality from the capital (315 km) and Nova Lima the closest (22.9 km); (2) the average distance to the municipality with the most extensive support infrastructure is 39.6 kilometers, with Jeceaba being the farthest from its macroregion (135 km), while Ouro Preto, Diamantina, Guanhães, Paracatu, Governador Valadares, and Itabira each serve as their own support centers; (3) the average population per municipality is 41,334 inhabitants, with Governador Valadares being the most populous in 2010 (263,689 inhabitants) and Itambé do Mato Dentro the least populous (2,283 inhabitants); (4) the average population growth rate over the decade was 6.84%. Brumadinho recorded the highest population increase (0.25%), while Itambé do Mato Dentro and Jeceaba both registered the most significant population decline (−0.11%).

Table 14
MI of mining municipalities between 2000 and 2010, and the relationship with distance to larger cities and population.

Ranking Malmquist	Municipality	Distance to Macroregion (km)	Distance to Capital (km)	Population Growth (%)	Population in 2010
15°	Nova Lima	22.9	22.9	0.24	80998
34°	Belo Vale	65.4	73.4	0.01%	7536
43°	Serro	63.5	229.0	-0.01	20835
44°	São Gonçalo do Rio Abaixo	34.8	88.2	0.15	9777
47°	Brumadinho	54.8	54.8	0.25	33973
59°	Prados	29.1	185.0	0.09	8391
62°	Congonhas	23.1	80.3	0.17	48519
123°	Itabirito	47.1	58.7	0.19	45449
126°	Barão de Cocais	63.8	96.5	0.21	28442
147°	São Tiago	48.8	196.0	0.03	10561
148°	Itambé do Mato Dentro	62.6	117.0	-0.11	2283
150°	Piracema	72.5	124.0	-0.02	6406
153°	Guanhães	-	248.0	0.12	31262
155°	Pains	35.4	217.0	0.03	8014
160°	Desterro de Entre Rios	84.0	156.0	0.03	7002

190°	Conceição do Mato Dentro	-	163.0	-0.04	17908
192°	Taquaraçu de Minas	74.2	55.1	0.08	3794
234°	Mariana	14.4	116.0	0.15	54219
252°	Entre Rios de Minas	51.0	124.0	0.08	14242
269°	Ouro Preto	-	102.0	0.06	70281
297°	Itabira	-	107.0	0.11	109783
309°	Porteirinha	38.5	600.0	-0.01	37627
324°	Jeceaba	135.0	113.0	-0.11	5395
338°	Dom Joaquim	33.4	198.0	-0.03	4535
346°	Itaúna	41.1	79.6	0.1	85463
376°	Diamantina	-	291.0	0.04	45880
401°	Coronel Fabriciano	17.8	215.0	0.06	103694
457°	Paracatu	-	502.0	0.11	84718
492°	Santa Bárbara	75.4	109.0	0.15	27876
550°	Caeté	48.3	48.3	0.12	40750
554°	Governador Valadares	-	315.0	0.06	263689
560°	Morro do Pilar	27.5	151.0	-0.09	3399

It is not possible to establish a relationship between the results of Table 13 and Table 14 regarding distance to the macroregion, distance to the state capital, population size, and population growth, given the wide variation observed.

Conclusion

In summary, this article has demonstrated that among the 614 municipalities analyzed between 1991 and 2000, 79 municipalities experienced a decline in human development, accounting for 12.87% of the total analyzed. The remaining 535 municipalities recorded an increase in human development. Between 2000 and 2010, 29 of the 614 analyzed municipalities experienced a reduction in human development, accounting for 4.72% of the total. The remaining 585 municipalities registered an increase in human development. Between 1991 and 2000, the municipality of Belo Horizonte faced a decline in its capacity to convert income into human development. During this period, AE showed no variation, while AT was responsible for the decline. Between 2000 and 2010, the state capital's capacity to convert income into human development increased. In this case, AE again remained unchanged, while AT was responsible for the improvement.

It is worth noting that most mining municipalities were positioned in lower ranks of the MI during both decades analyzed. However, it was not possible to establish either a positive or negative relationship between mining activity and human development in the municipalities of Minas Gerais through the MI for human development. Between 1991 and 2000, some municipalities experienced deterioration or no change in the capacity to transform income into human development (5 out of the 32 mining municipalities). Between 2000 and 2010, all mining municipalities recorded an increase in their MI. It is also important to highlight that when comparing the results between 1991–2000 and 2000–2010, the best ranking of a mining municipality declined from 9th (1991–2000) to 15th (2000–2010), while the worst ranking improved from 593rd (1991–2000) to 560th (2000–2010).

In summary, mining revenues neither improved nor worsened the efficiency of returns in terms of human development. This is particularly evident when analyzing the best MI scores: despite having greater financial resources, mining municipalities were not among the top performers. The wide dispersion in the social efficiency rankings shows that mining revenues were converted into human development in very different ways across municipalities. In this sense, public policies are necessary to enhance the effectiveness of mining resources in promoting human development. For instance, policymakers should examine housing, health, and education programs in high-performing non-mining municipalities in the social efficiency ranking. These can serve as benchmarks for inefficient municipalities to develop similar programs aimed at improving local human development. Furthermore, public authorities should develop legislation establishing more effective metrics for evaluating the use of mining revenues, thereby ensuring a more efficient allocation of available resources.

Finally, although this article has presented some advances in the analysis of human development in Minas Gerais, several limitations were encountered. First, the data analyzed refers to the information available for 2010, which does not allow an assessment of the state’s reality in the following decade. Second, there are limitations in comparing data between 1991 and 2010 due to methodological changes in the Demographic Censuses. Third, it is suggested that future studies employ additional indicators, such as the quality of education. Despite these limitations, the main objective of this article—to demonstrate the evolution of human development in Minas Gerais—was achieved, particularly through the analysis of patterns in MI rankings for both mining and non-mining municipalities.

REFERENCES

Almeida, M., Mariano, E., & Rebelato, D. (2006). Análise por envoltória de dados: Evolução e possibilidade de aplicação. *Anais do IX Simpósio de Administração de Produção, Logística e Operações Internacionais*.

AMIG, A. dos M. M. de M. G. e do B. (2022). *AMIG – Associação dos Municípios Mineradores de Minas Gerais e do Brasil*. www.amig.org.br

Campoli, J., Ferraz, D., Milani Zambianco, W., Melo, I., & Rebelatto, D. (2017). A eficiência do bem-estar social dos municípios paulistas: Uma análise envoltória de dados (DEA). *Anais do XXIV SIMPEP – Simpósio de Engenharia de Produção*. XXIV SIMPEP – Simpósio de Engenharia de Produção.

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometrica*, *50*(6), 1393–1414. https://doi.org/10.2307/1913388

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Chen, Y., & Iqbal Ali, A. (2004). DEA Malmquist productivity measure: New insights with an application to computer industry. *European Journal of Operational Research*, *159*(1), 239–249. https://doi.org/10.1016/S0377-2217(03)00406-5

CODEMIG, – Companhia de Desenvolvimento Econômico de Minas Gerais. (2022). *CODEMIG – Companhia de Desenvolvimento Econômico de Minas Gerais*. www.codemig.com.br

Daniel, L. P., & Gomes, A. P. (2015). Eficiência na oferta de serviços públicos de saúde nos municípios do estado de Mato Grosso. *Reflexões Econômicas*, *1*(1), Artigo 1.

Despotis, D. K. (2005a). A reassessment of the human development index via data envelopment analysis. *Journal of the Operational Research Society*, *56*(8), 969–980. https://doi.org/10.1057/palgrave.jors.2601927

Despotis, D. K. (2005b). Measuring human development via data envelopment analysis: The case of Asia and the Pacific. *Omega*, *33*(5), 385–390. https://doi.org/10.1016/j.omega.2004.07.002

Eskinazi, B., & Souza, J. (2013). Especialização produtiva e homogeneização territorial: A monocultura de eucalipto no Vale do Paraíba Paulista e as transformações nas dinâmicas de produção. *PEGADA – A Revista da Geografia do Trabalho*.

Färe, R., Grosskopf, S., & Hernandez-Sancho, F. (2004). Environmental performance: An index number approach. *Resource and Energy Economics*, *26*(4), 343–352. https://doi.org/10.1016/j.reseneeco.2003.10.003

Ferrari, V., & Mariano, E. (2016). Índice de desenvolvimento humano com contribuições relativas iguais: Uma proposta com a análise envoltória de dados. *XXIII SIMPEP – Simpósio de Engenharia de Produção*.

Ferraz, D., Alves, R., Correa, J., & Santiago, B. (2021, novembro). Eficiência Social na Amazônia Brasileira. *Anais do XXVIII SIMPEP – Simpósio de Engenharia de Produção*. XXVIII SIMPEP – Simpósio de Engenharia de Produção.

Ferraz, D., Alves, R., Vaz, D., & Santos, V. (2021). Privação social e responsabilidade financeira no estado do Pára/Brasil. *Anais do XXVIII SIMPEP – Simpósio de Engenharia de Produção*. XXVIII SIMPEP – Simpósio de Engenharia de Produção.

Ferraz, D., Mariano, E. B., Rebelatto, D., & Hartmann, D. (2020). Linking Human Development and the Financial Responsibility of Regions: Combined Index Proposals Using Methods from Data Envelopment Analysis. *Social Indicators Research*, *150*(2), 439–478. https://doi.org/10.1007/s11205-020-02338-3

Ferraz, D., Moralles, H., Oliveira, F., & Rebelatto, D. (2017). Complexidade econômica e desenvolvimento humano: Uma análise econométrica. *Anais do XXIV SIMPEP – Simpósio de Engenharia de Produção*. XXIV SIMPEP – Simpósio de Engenharia de Produção.

Gimenes, F. P., Angelo, M., & Mariano, E. (2018). A mensuração da liberdade e sua relação com o desenvolvimento humano. *XXV SIMPEP – Simpósio de Engenharia de Produção*.

Haq, M. (1995). *Reflections on Human Development*. Oxford University Press.

IBGE. (2023). *Sistema IBGE de Recuperação Automática—SIDRA* [Dataset]. SIDRA - IBGE. www.ibge.gov.br

Joly, C. (2007). Especialização produtiva do território e o circuito espacial produtivo de celulose em Eunápolis – BA. *GEOUSP – Espaço e Tempo*.

Leta, F. R., Soares de Mello, J., Gomes, E. G., & Angulo Meza, L. (2005). Métodos de melhora de ordenação em DEA aplicados à avaliação estática de tornos mecânicos. *Investigação Operacional*, *25*(2), 229–242.

Magalhães, E., Wakim, V., & Gomes, A. (2010). Análise de eficiência dos municípios de Minas Gerais: Uma abordagem sobre o IMRS no ano de 2010. *Anais do XIV Seminário sobre Economia Mineira*. 14º Seminário sobre Economia Mineira, Diamantina, MG, Brasil.

Malmquist, S. (1953). Index numbers and indifference curves. *Trabajos de Estatistica*, *4*(1), 209–242.

Mahlberg, B., & Obersteiner, M. (2001). Remeasuring the HDI by data envelopement analysis. Available at SSRN 1999372.

Mariano, E. (2019). *Progresso e desenvolvimento humano: Teorias e indicadores de riqueza, qualidade de vida, felicidade e desigualdade* (1ª Edição). Alta Books.

Mariano, E. B., & Rebelatto, D. A. D. N. (2014). Transformation of wealth produced into quality of life: Analysis of the social efficiency of nation-states with the DEA's triple index approach. *Journal of the Operational Research Society*, *65*(11), 1664–1681. https://doi.org/10.1057/jors.2013.132

Mariano, E. B., Sobreiro, V. A., & Rebelatto, D. A. do N. (2015). Human development and data envelopment analysis: A structured literature review. *Omega*, *54*, 33–49. https://doi.org/10.1016/j.omega.2015.01.002

Mariano, E. B., Ferraz, D., & de Oliveira Gobbo, S. C. (2021). The human development index with multiple data envelopment analysis approaches: A comparative evaluation using social network analysis. Social Indicators Research, 157, 443-500.

Morais, P., & Camanho, A. S. (2011). Evaluation of performance of European cities with the aim to promote quality of life improvements. *Omega*, *39*(4), 398–409. https://doi.org/10.1016/j.omega.2010.09.003

Raab, R., Kotamraju, P., & Haag, S. (2000). Efficient provision of child quality of life in less developed countries: Conventional development indexes versus a programming approach to development indexes. *Socio-Economic Planning Sciences*, *34*(1), 51–67. https://doi.org/10.1016/S0038-0121(99)00013-0

Romero, W., Fortes, M., & Martins, E. (2009). Uma análise do desenvolvimento humano das cidades históricas mineiras por meio da técnica DEA. *Reúna. Revista de Economia da UNA*.

Sen, A. (2010). *Desenvolvimento como liberdade*. Companhia das Letras.

Soares, T. C., Costa, J. B. da, & Lopes, L. S. (2019). Análise espacial da eficiência dos gastos públicos em saúde em Minas Gerais. *Análise Econômica*, *37*(72), Artigo 72. https://doi.org/10.22456/2176-5456.70816

Thanassoulis, E. (2001). *Introduction to the Theory and Application of Data Envelopment Analysis*. Springer US. https://doi.org/10.1007/978-1-4615-1407-7

Tofallis, C. (2013). An automatic-democratic approach to weight setting for the new human development index. *Journal of Population Economics*, *26*(4), 1325–1345. https://doi.org/10.1007/s00148-012-0432-x

Yamada, Y., Matui, T., & Sugiyama, M. (1994). New analysis of efficiency based on DEA. *Journal of the Operations Research Society of Japan*, *37*(2), 158–167.

Zhou, P., Ang, B. W., & Zhou, D. Q. (2010). Weighting and Aggregation in Composite Indicator Construction: A Multiplicative Optimization Approach. *Social Indicators Research*, *96*(1), 169–181. https://doi.org/10.1007/s11205-009-9472-3

Zofio, J. L. (2007). Malmquist productivity index decompositions: A unifying framework. *Applied Economics*, *39*(18), 2371–2387. https://doi.org/10.1080/00036840600606260

Zrelli, H., Alsharif, A. H., & Tlili, I. (2020). Malmquist Indexes of Productivity Change in Tunisian Manufacturing Industries. *Sustainability*, *12*(4), Artigo 4.

https://doi.org/10.3390/su12041367