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Tourist flow and pure technical efficiency of critical infrastructure in Angola: a data envelopment approach using time series

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Abstract

This study analyzes the effect of tourism flow on the pure technical efficiency of critical health and energy infrastructure in Angola, from 2013 to 2023. The input-oriented DEA-VRS model (data envelopment analysis-variable returns of scale) and Spearman's coefficient were used as complementary analytical tools. Each year was treated as a distinct DMU (decision making unit) to ensure greater discretionary power in the resulting efficient frontier. The variables considered include: public hospitals and energy production (inputs), overnight stays by foreign tourists and jobs in the tourism sector (outputs), in addition to tourism flow as a control variable central to the entire analysis. The main finding of the study showed that, between 2013 and 2023, there was no significant correlation between international tourism flow and the pure technical efficiency of critical health and energy infrastructure in Angola, suggesting that technical performance was mainly determined by operational scale, not by the intensity of tourism demand. Thus, it was concluded that tourism was not a direct determinant of the technical efficiency of the analyzed infrastructures, suggesting the need to explore indirect mechanisms that affect their performance, such as complementary investments or economies of scale.

JEL classifications: C14, L25

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1. Introduction

Angola, a country with remarkable natural, cultural, and historical wealth, constitutes a competitive advantage. The Angolan coast, with approximately 1,650 km of Atlantic coastline, offers a diversity of landscapes including: tropical beaches like Mussulo and Ilha de Luanda. Areas ideal for surfing such as: Cabo Ledo and Sangano. And ecotourism areas like the Iona National Park in Namibe. Furthermore, coastal cities like Benguela and Namibe preserve a historical and cultural heritage that complements the tourism offerings in this part of the country. In particular, Angola holds treasures such as: Mbanza Kongo in the Zaire province, recognized by UNESCO as a World Heritage Site for being the political and spiritual center of the ancient Kingdom of Kongo. In Luanda, the São Miguel Fort and other colonial landmarks reveal the history of the capital, while also asserting itself as an urban center of nightlife, gastronomy, and cultural events. Other cities, such as Lubango and Huambo, offer traditional and religious festivals that reinforce the country's cultural identity and broaden the diversity of tourism offerings.

However, Angola's tourism potential extends far beyond the coast and encompasses the entire national territory. Inland highlights include the Kalandula Falls in Malanje, considered one of the largest waterfalls in Africa, and the Leba mountain range in Huíla, whose winding road leads to the Tundavala viewpoint, offering panoramic views of great visual impact. Moxico is home to Lake Dilolo, the largest lake in the country, while Huambo is distinguished by the Arco Lagoon, of singular beauty. In Cabinda, the Maiombe forest constitutes one of the most important tropical reserves in Central Africa, attracting visitors interested in biodiversity and ecotourism.

Thus, Angola offers a range of options, from paradisiacal beaches and national parks to historical heritage sites and vibrant cultural expressions, consolidating itself as a complete and multifaceted tourist destination. However, during the period studied (2020-2023), tourist flow in different regions of the country showed significant fluctuations, conditioned by internal factors such as: the quality of infrastructure, public policies, and institutional management; and external factors such as: exchange rate variations, the international situation, and health crises. This instability has compromised the consolidation of sustainable local development strategies and raises the need to evaluate not only the volume of tourists received but also the technical efficiency of the country in the use of available resources. The search for more efficient management of public resources stems not only from political goals but also from the financial limitations faced by local governments. Therefore, the option of reducing public spending or increasing the tax burden is presented, measures that tend to involve high political costs. Thus, one way to circumvent such restrictions, without incurring political costs, is to improve operational efficiency (Radulovic, Dragutinovic & Boskovic, 2023).

This raises the central problem of the present study: to what extent did the variation in the flow of tourists from abroad influence the levels of optimization of productive resources in basic infrastructure in Angola, in the period between 2013 and 2023?

Given this challenge, the objective of this study is to analyze the effect of tourist flow on the pure technical efficiency of critical health and energy infrastructure in Angola, using the data envelopment analysis-variable returns of scale (DEA-VRS) and Spearman's coefficient as a complementary analysis tool.

This study complements others, such as that of Sanches-António (2025), which, when analyzing the concentration of regional tourism activity in Angola, do not consider the economic dimension of the result of tourism activity, namely, the volume of employment created in the sector. It also finds justification in the need to document the relationship between tourist flow and the technical efficiency of sanitary and energy infrastructure.

Angola, due to its strategic location and natural wealth, constitutes a potential hub for the growth of regional tourism. However, the way in which its critical infrastructure supporting the reception of tourists is optimized still lacks systematic analyses that would allow for the guidance of effective public policies at the sector level. The application of DEA-VRS offers an objective evaluation, providing subsidies for managers, investors, and policymakers, in addition to contributing to academic literature by integrating the analysis of fluctuations in tourist flow with metrics of productive efficiency. In this way, the study broadens the debate on sustainability and competitiveness in the sector, reinforcing the importance of tourism as an engine of local and national development.

2. Theoretical background

2.1. Relationship between technical efficiency and tourism intensity

Analyzing technical efficiency in strategic sectors requires considering external variables that condition the performance of the evaluated units. In the case of the tourism industry, the intensity of visitor flow is a determining factor, capable of altering the pressure on critical infrastructure and consequently, influencing the results of their technical efficiency. This evidence can be attested to by studies by Yan et al. (2025), González-Tejero, Escobar and González-Herrera (2025) and Jitmaneeroj (2026). In this sense, several authors employ the DEA methodology combined with Spearman's correlation analysis to capture the non-linear relationship between technical efficiency and tourism intensity, allowing us to understand how the increase or decrease in the number of tourists affects the optimal use of public resources intended to support tourism activity.

Studies demonstrate that tourist flow has a positive relationship with energy demand, health expenditures, per capita income, foreign direct investment flows, trade, and carbon dioxide emissions (Qureshi et al., 2017), emphasizing the transversality of this relationship that generates economic and social benefits, but brings environmental costs and pressures on existing infrastructure. In this sense, according to Franco et al. (2025), the relationship between the infrastructure supporting tourism activity and the flow of tourists in high-demand areas justifies the implementation of solutions that optimize the operational performance of infrastructures, reduce environmental impacts, and strengthen adaptation to climate change.

In academic discussion, several studies analyze the relationship between the technical performance of basic infrastructure and tourism intensity in a given region and during a certain period of time. However, according to El Houcine and Alla (2026), a considerably larger portion of the literature analyzes how infrastructure drives the performance of tourism as a sector of activity, but the inverse influence, the role of tourism in the performance of infrastructure, remains little explored. Therefore, this study is directed towards exploring this relationship in the Angolan context. This gap is also identified in the present study, and is even greater when the field of research is Angola.

In summary, studies that apply the DEA methodology to the tourism sector focus on three main areas: hotels (Barros & Dieke, 2008), where it is used to measure operational efficiency considering energy costs; airports (Lozano & Gutiérrez, 2014), to assess the performance of installed capacity in relation to passenger flow; and to assess the technical efficiency of regional destinations (Assaf & Josiassen, 2012), incorporating public infrastructure variables, approaching the relationship with energy and health. Although studies such as Qureshi et al. (2017) directly discuss the link between tourism, energy, and health, there are still few studies that use DEA to explicitly address this relationship. Thus, the literature shows that there is a consolidated methodological basis, but open space for new applications that integrate energy efficiency ↔ hospital capacity ↔ tourist flow, especially in emerging contexts such as Angola, where the literature review carried out did not yield similar studies.

In order to assess whether the results of technical efficiency, without the effect of tourism intensity are consistent or strongly context-dependent, this study analyzes the correlation between the number of visitors provided by the volume of tourist arrivals from abroad (tourism

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intensity) and pure technical efficiency (measured by the DEA-VRS model). In this regard, the studies by Assaf and Josiassen (2012); Assaf and Josiassen (2016); Li et al. (2020), can be cited, where the correlation between environmental variables (such as tourism intensity) and efficiency scores is analyzed, demonstrating how external factors, including tourist flow, affect technical efficiency.

Starting from the premise that tourist flow may be monotonically associated with the technical performance of DMUs (decision making units), without assuming linearity between variables, studies by Barros (2005); Assaf and Dwyer (2013). The following can be mentioned as theoretical support for these premises, where DEA is used to measure technical efficiency and Spearman correlation to relate the results obtained with tourism demand variables. Thus, Spearman coefficient (ρ), which according to Espírito-Santo and Daniel (2017), measures the strength and direction of the monotonic association between two variables using ranks as an alternative to values collected directly from unprocessed records, is ideal for data that are not presented on an ordinal scale, i.e., do not follow a normal distribution. In its formulation presented in (1), (d_i) provides the difference between the ranks of each pair and (N) the number of observations:

$$\rho = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{N^3 - N} \quad (1)$$

The Spearman correlation coefficient thus allows us to indicate whether there is a linear association between technical efficiency (DEA) and tourism intensity (measuring only monotonic association between variables and not causality). Therefore, according to Zar (2010); Dancey and Reidy (2013) and considering the variables analyzed in this study, we find that: $\rho > 0 \rightarrow$ higher tourist flow is associated with greater efficiency and $\rho < 0 \rightarrow$ higher tourist flow is associated with lower efficiency.

Concerning more recent studies that employed Spearman's coefficient as a robust tool to validate the monophonic relationship between tourism intensity and pure technical efficiency, the following can be cited: (Singh, Pratap & Laud, 2025; Avilés-Sacoto et al., 2025; Zhou & Bao, 2026)

2.2. Fundamentals of the DEA-VRS model

The DEA-VRS model is one of the most relevant extensions of DEA, as it allows technical efficiency to be evaluated in contexts where proportionality between inputs and outputs is not assumed. Unlike the DEA-CRS version, which assumes constant returns to scale, the DEA-VRS model assumes that DMUs can operate under conditions of constant, increasing, or decreasing returns, reflecting realities closer to economic practice. This methodological flexibility makes the model especially useful for comparative studies, where the aim is to understand how management factors, technology, or scale of operation influence the relative performance of DMUs over time and in different sectors of activity.

Its formalization, with an input-oriented approach, is presented below:

Objective function: the model seeks to maximize efficiency DMU_k, considering that performance can vary according to the size of the operations (scale), with the term being u_k the scalar that captures this effect, and which represents the difference, for the DEA-CRS model;

$$\theta_k = \sum_{r=1}^{m} u_r y_{rk} - u_k \quad (2)$$

θ_k: Relative technical efficiency of DMU_k adjusted for variable returns

y_{rk}: Quantity of output r produced by DMU_k

u_r: Weight assigned to the output r $\rightarrow$ decision variable

u_k: Scalar (intercept) that allows measuring the effect of variable returns to scale.

Constraints: the model presents adjustments to the efficiency frontier, which ensure: that no weight DMU_j exceeds the frontier defined by the weights (u_r and v_i) and by the intercept u_k and that the DEA frontier is non-proportional (non-linear);

$$\sum_{i=1}^{m} u_r y_{rj} - \sum_{i=1}^{n} v_i x_{ij} - u_k \leq 0 \quad (3)$$

Normality of DMUs: the inputs are DMU_k normalized so that the efficiency scores are comparable;

$$\sum_{i=1}^{n} v_i x_{ik} = 1 \quad (4)$$

In accordance with the assumptions of production theory, the weights assigned to both inputs and outputs must have non-negative values;

$$u_r, v_i \geq 0 \quad (5)$$

3. Empirical approach

3.1. Analytical model

In this study, the analysis is conducted with an input-oriented approach, seeking to identify the extent to which resources can be reduced without compromising results. Under the assumption of variable returns to scale, the model captures records of constant, increasing, or decreasing technical efficiency, reflecting conditions closer to the reality under analysis. The evaluated efficiency corresponds to pure technical efficiency, isolating scale effects and focusing on input optimization. The efficiency frontier is piecewise constructed linearly, comparing each DMU with observed efficient combinations and its estimation is performed using linear programming.

In the case under analysis, the evaluated periods (years) are considered as DMUs, with three inputs and two outputs, also incorporating a control variable (tourist flow), which adjusts the analysis to fluctuations in external tourist demand, ensuring that technical efficiency is measured in relation to the real context of visitors received therefore, the summary of the adopted model is presented in Table 1.

Table 1. Model synthesis: analytical components and application parameters

Component	Description
Model	Radial DEA
Guidance	Input (minimizing resources to maintain outputs)
Returns to scale	Variables (constant, increasing or decreasing, depending on the size of the DMU in each year)
Type of efficiency	Pure technique (isolating scale effects, focusing on resource management)
Border shape	Piecewise linear (envelope built from efficient DMUs)
Estimation	Linear programming (solving systems for calculating scores)
DMUs	11 (corresponding to the number of periods analyzed)
Number of inputs	2 inputs variables (resources)
Number of outputs	2 outputs variables (results)
Control variable	1 contextual variable (tourist flow, adjusting the analysis to actual tourist demand)

3.2. Variables and indicators of pure technical efficiency

According to Narbón-Perpiñá and De Witte (2018), depending on the context (regulatory, specific accounting practices and research objectives), the type of variables selected to assess the efficiency of local governments can be quite distinct. In the study by D'Inverno, Carosi and Ravagli (2018), local technical efficiency was measured by the ratio between the mean annual number of tourists and the total population. Furthermore, the authors considered the growth of the resident population, associated with the mean annual number of visitors, as an indicator of the increased demand for local public services.

In this study, the selection of inputs and outputs reflects the logic that public spending on basic infrastructure forms the basis for tourism development in the coastal provinces of Angola, particularly in nature and adventure tourism. Therefore, based on the study by Assaf and Josiassen (2016), the socio-economic criteria were considered for selecting the variables included in the model, as described below.

Inputs: number of public hospitals and energy production. These represent the essential structural resources that support both the residents and visitors. Hospitals guarantee sanitary security, and the energy produced is an indispensable condition for the operation of hotels, transportation and other tourist services, thus reflecting the public effort to create conditions that support tourism activity.

Outputs: the number of overnight stays by foreign tourists in hotels and the number of jobs created in the tourism sector. These variables capture the concrete results of public policies on the tourism sector. Overnight stays by foreign tourists in hotels reflect the attractiveness and use of tourism infrastructure, while jobs reflect the direct socio-economic impact of tourism activity, indicating how public investments translate into tangible benefits for the local economy.

Control variable (tourist flow): introduces the dimension of external demand, allowing the analysis of technical efficiency to be adjusted to fluctuations in the number of visitors. This procedure prevents periods with higher or lower tourist influx from being evaluated in a biased way, ensuring that technical efficiency is measured in relation to the real context of demand, that is, it allows the technical efficiency of the local basic infrastructure to be evaluated, conditioned by the level of tourists received locally.

3.3. Method, sampling, data collection and processing procedures

This study adopts a quantitative method, as it is based on measurable variables and the application of data envelopment analysis (DEA), which allows for the calculation of pure technical efficiency scores. The sampling adopted in this study is intentional, selecting temporal units (DMUs) that presented relevant tourism activity and complete statistical data for the period between 2013 and 2020. This methodological choice was based on socioeconomic criteria, according to Assaf & Josiassen (2016), prioritizing the comparability between inputs and outputs in different periods with differences in the composition of the variables used (both input and output). This procedure ensured that the analysis of technical efficiency focuses on relevant cases with reliable information, even if not representative of the entire population.

To obtain descriptive statistics for the variables and pure technical efficiency scores for each year, and to perform Spearman correlation analysis, first between the variables included in the DEA model and subsequently between the DEA scores and the tourism intensity records, the Microsoft Excel (2019) application and the Efficiency platforms were used, respectively, EMS (2000) and SPSS 26.0 (2019). To obtain descriptive statistics of the variables, pure technical efficiency scores in each year, and to perform Spearman correlation analysis (first between the variables included in the DEA model and subsequently between the DEA scores and the tourism intensity records, the Microsoft Excel application (2019) and the Efficiency platforms were used, respectively. Measurement System (2000) and SPSS 26.0 (2019).

In general, the sources of data relating to infrastructure and tourism information were the statistical yearbooks published by the National Institute of Statistics of Angola (INE), namely (INE, 2022; INE, 2023; INE, 2024a; INE, 2024b; INE, 2025). Regarding the data on energy production, this was obtained from the International Energy Agency website (IEA, 2026).

Regarding the data on the number of existing public hospitals, the 2015 figures were taken from the National Health Development Plan 2012-2025 of the Angolan Ministry of Health (MINSA, 2015), with the values for the years (2013, 2014 and 2016) obtained by imputing the mean of the years found. The same procedure was applied to the data on the variable number of overnight stays by foreign tourists in the years (2013 and 2019).

Due to the adoption of non-standardized interval metrics by the INE (regarding the time units of the reports consulted), for the variable number of overnight stays by foreign tourists, which between 2016 and 2019 were presented biannually, these values were obtained from the World Tourism Organization report (WTO, 2024). Similarly, due to a lack of granular data on the variables included in the analysis and relating to the different provinces that make up Angola, global data composed of time series were used. This data refers to the country as a whole and served to ensure that each year a different DMU was considered in the analysis, as mentioned in section 3.1.

4. Results and discussion

In order to provide an overview of the data, enabling comparisons, initial analyses, and preparation for more detailed statistical methods, Table 2 presents the descriptive statistics of the data relating to the variables included in the model. It can be observed that the data do not follow a normal distribution; that is, given the tendency towards extreme values in the sample, a non-parametric Spearman correlation analysis was performed, which appears at the bottom of the table. Therefore, Table 2 was included in the analysis as it provides a synthetic view of the statistical characteristics of the variables and the structural relationships between them. The descriptive statistics allow us to understand the range and dispersion of the data, highlighting relevant differences between periods in terms of energy production, overnight stays by foreign tourists in local hotels, and the resulting volume of employment. The Spearman correlation matrix complements this analysis by identifying patterns of association between the indicators, highlighting the significant negative correlation between public hospitals and overnight stays by foreign tourists. This relationship suggests a possible dissociation between hospital infrastructure and tourism dynamics, which reinforces the relevance of exploring sectoral interdependencies, based on the adopted DEA model. Thus, the table contributes to validating the consistency of the data and supporting the interpretation of the results obtained in the subsequent stages of the analysis.

Table 2. Descriptive statistics and correlation between variables

Variables	Public hospitals	Energy production	Overnight stays	Number of jobs
Maximum	263	16554	985117	223965
Minimum	208	8142	242018	173478
Mean	228	12695	580851	200660
Standard deviation	20	2973	242097	18869
Spearman correlation matrix input/output				
Public hospitals	1.000	0.171	-0.692*	-0.106
Energy production	0.171	1.000	-0.287	-0.264
overnight stays	-0.692*	-0.287	1.000	0.141
Number of jobs	-0.106	-0.264	0.141	1.000

* The correlation is significant at the 0.05 level (2 extremes)

Table 3 presents the results of pure technical efficiency, resulting from the combination of inputs and outputs, within the framework of the input-oriented DEA-VRS model. Between 2013 and 2023, the infrastructure supporting tourism activity in Angola showed a mean technical efficiency of 94%, with moderate variations (standard deviation = 8%). Overall stability and occasional records of full efficiency were observed (2013, 2015, 2017, 2022 and 2023), interspersed with declines in (2018-2019), possibly associated with cyclical constraints. The recovery in the final years demonstrates operational resilience and adjustment capacity in the health and energy sectors, suggesting that tourism, although not a direct determinant of technical efficiency, may exert an indirect influence.

Initially, the mean DEA scores were calculated and in a second phase, the correlation between the efficiency results obtained in the DEA and the records of the contextual variable was calculated.

The results of the Spearman correlation coefficient, obtained from Table 3, reveal a practically null association between technical efficiency scores and foreign tourist arrivals. That is, the correlation coefficient ($\rho = 0.048$), despite indicating a positive association between the variables (greater tourist flow associated with greater technical efficiency), indicates a practically null association between both and the number of foreign tourists. The statistical significance ($p = 0.889$) is much higher than the 0.05 level, indicating that there is no statistically significant correlation between the variables. These results are consistent with those found by Radovanov et al. (2020), Banerjee (2025) and Singh, Pratap and Laud (2025).

Radovanov et al. (2020), applying two-stage DEA with Tobit regression, they show that tmourist arrivals have a limited effect on efficiency, conditioned by external variables such as sustainability and visa policies. Banerjee (2025), when evaluating 22 European countries, concludes that the number of arrivals does not robustly explain efficiency scores, indicating a weak association between variables; Singh, Pratap and Laud (2025) present results showing that, even in countries with high international tourist flows (France, Spain, USA, Italy, Turkey), efficiency gains are not strongly correlated with tourist arrivals, suggesting that internal factors (management and infrastructure) are more relevant.

Table 3. Technical efficiency of infrastructure supporting tourism activity (%)

DMU	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean	Standard deviation
$\hat{\theta}$	100	96	100	94	100	80	79	90	91	100	100	94	8

In contrast to the results found in this study, the findings of D'Inverno, Carosi, and Ravagli (2018) can be mentioned, where an inverse relationship was observed between tourism activity and the efficiency of the local government analyzed.

5. Conclusions

Based on both the results and their discussion, the conclusions of this study, in a comparative manner, indicate a practically negligible association between technical efficiency scores and tourist arrivals from abroad in the period between 2013 and 2023. This allows us to satisfactorily answer the research problem raised and, on the other hand, fulfill the objective proposed for the study. This lack of statistical significance indicates that the pure technical efficiency of critical health and energy infrastructure in Angola is not related to the volume of international tourists arriving in Angola during the period in question, suggesting that technical performance was predominantly determined by the size of operations, rather than by the intensity of tourist demand.

Similarly, it was concluded that the lack of a significant correlation between the pure technical efficiency of critical health and energy infrastructure in Angola and tourist flow may reflect the distinct nature of the indicators, while the DEA score captures the relative efficiency in resource utilization, tourist arrivals represent an exogenous variable, influenced by promotional policies, air connectivity, and macroeconomic conditions. Thus, the result reinforces the finding that the technical efficiency of critical infrastructure supporting tourism activity does not directly depend on the dynamics of the tourism sector but can be enhanced by sectoral integration strategies and coordination policies between tourism and public services.

In summary, the main findings of this study confirm that international tourism, while relevant to regional development, is not a direct determinant of the observed pure technical efficiency, which opens space for future research on indirect mechanisms that may influence the technical performance of infrastructure supporting tourism, such as complementary investments or economies of scale.

The main limitations of this study include: the unavailability of granular tourism statistics data by province, which restricted the possibility of conducting a more in-depth intertemporal analysis of technical efficiency based on tourism intensity. This limitation, stemming from data access, restricted the temporal scope of the analysis to the national aggregate, masking local heterogeneities that could alter results and consequently conclusions about technical efficiency; the adoption of non-standardized interval metrics by the INE (with respect to units of the time units of the different statistical yearbooks used as data sources, for the variable number of overnight stays by foreign tourists, and the naming of health units). This lack of standardization generated a certain level of inconsistency in the variable number of overnight stays by foreign tourists and in the classification of health units. Thus, the comparison between periods or categories was compromised by the lack of methodological uniformity, reflected in the temporal misalignment between inputs and outputs, resulting in a certain level of distortion of the measures of technical efficiency.

Although the results indicate a lack of significant correlation between technical efficiency and tourist arrivals, it is important to recognize that Spearman's coefficient only measures monotonic associations, without implying causality. Therefore, it is recommended that future studies control relevant external variables, such as public investment, infrastructure quality, and tourism promotion policies, which can simultaneously influence efficiency and demand. Furthermore, the literature suggests that the robustness of the analysis can be enhanced by combining Spearman's coefficient with Tobit regression models or with the conditional DEA approach, allowing for the capture of censored effects and the incorporation of environmental variables more consistently.

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