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RODRIGO SOARES LELIS GORI

EFFECTIVENESS OR EFFICIENCY IN THE EVALUATION OF PROFESSIONAL AND TECHNOLOGICAL EDUCATION? A PROPOSAL FOR AN INTEGRATED MODEL TO EVALUATE THE INSTITUTIONAL PERFORMANCE OF FEDERAL EDUCATION INSTITUTES

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Rated at 02/07/2025.

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I dedicate this thesis to my wife, Deine Danielle, my eternal angel, and to my children, Heitor and Benício, who are my greatest inspiration

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ABSTRACT

In recent decades, the assessment of technical efficiency has occupied a prominent position in performance evaluations of public educational institutions. Although relevant, this approach, when adopted in isolation, proves limited considering the operational complexity, regional diversity, and the multiple functions assigned to the Federal Institutes of Education, Science and Technology (IFs). This study argues that institutional assessment should incorporate different analytical levels and performance dimensions to support more accurate and contextualised decision-making. The research aims to propose an integrated model for evaluating institutional performance using the Directional Distance Function (DDF), an extension of traditional Data Envelopment Analysis (DEA), applied to panel data covering the period from 2017 to 2023. The first analytical strand, with an intra-institutional focus, assessed 11 teaching units of a Federal Institute. Quantitative data on human, financial, and physical resources were used, along with desirable and undesirable variables related to teaching, research, outreach, and management. The analysis adopted an input-oriented model with variable returns to scale (VRS), combining internal benchmarking, institutional segmentation, and metafrontier modelling. It revealed that unit efficiency was more closely associated with the organisation of resources than with budget volume, indicating opportunities for improvement. The institutional average efficiency during the period was 80.3%. In the second strand, an inter-institutional analysis was conducted involving all 38 Federal Institutes. A composite indicator was developed using a DDF-based model with constant returns to scale (CRS) and output orientation, eliminating resource-related heterogeneity to emphasise performance outcomes. In parallel, institutional effectiveness was assessed based on the achievement of strategic goals. Although the directional vector was fixed and unitary for all variables, its limitations in interpreting β as a proportional efficiency measure were acknowledged. The integration of efficiency and effectiveness dimensions enabled a comprehensive institutional assessment. Results indicated that 42% of the institutions performed above average in both dimensions, while 34% fell below. The proposed methodological framework enhances the diagnosis of institutional performance and offers strategic support for public education management. The main limitations relate to the absence of external benchmarking in the inter-institutional analysis and the reliance on standardised secondary data.

Keywords: Efficiency; Effectiveness; Meta-frontier; Composite Indicator; Benchmarking.

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LIST OF ABBREVIATIONS

OCDE	Organisation for Economic Co-operation and Development
HEIs	Higher Education Institutions
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DDF	Directional Distance Function
RSL	Systematic Literature Review
VRS	Variable Returns to Scale
CRS	Constant Returns to Scale
IC	Composite Indicator
UFs	Federal Universities
IF	Federal Institute
TU	Teaching Units
PNP	Nilo Peçanha Platform
SIAFI	Integrated Financial Administration System
SIAPENET	Integrated Federal Government Personnel Management System
SUAP	Unified Public Administration System
IFAC	Federal Institute of Acre
IFAM	Federal Institute of Amazonas
IFAP	Federal Institute of Amapá
IFPA	Federal Institute of Pará
IFRO	Federal Institute of Rondônia
IFRR	Federal Institute of Roraima
IFTO	Federal Institute of Tocantins
IF Baiano	Federal Institute of Baiano
IFBA	Federal Institute of Bahia
IF Sertão	Federal Institute of Sertão Pernambucano
IFPE	Federal Institute of Pernambuco
IFAL	Federal Institute of Alagoas
IFCE	Federal Institute of Ceará
IFMA	Federal Institute of Maranhão
IFPB	Federal Institute of Paraíba
IFPI	Federal Institute of Piauí
IFRN	Federal Institute of Rio Grande do Norte
IFS	Federal Institute of Sergipe
IF Goiano	Federal Institute of Goiano
IFG	Federal Institute of Goiás
IFB	Federal Institute of Brasília
IFMS	Federal Institute of Mato Grosso do Sul
IFMT	Federal Institute of Mato Grosso
IF Sudeste	Federal Institute of Southeast Minas Gerais
IFMG	Federal Institute of Minas Gerais
IFNMG	Federal Institute of North Minas Gerais
IFTM	Federal Institute of Triângulo Mineiro
IF Sul de Minas	Federal Institute of South Minas Gerais
IFSP	Federal Institute of São Paulo
IFES	Federal Institute of Espírito Santo
IFF	Federal Institute of Fluminense
IFRJ	Federal Institute of Rio de Janeiro
IF Farroupilha	Federal Institute of Farroupilha
IFRS	Federal Institute of Rio Grande do Sul
IF Sul	Federal Institute of Rio Grande do Sul
IFC	Federal Institute of Catarinense
IFSC	Federal Institute of Santa Catarina
IFPR	Federal Institute of Paraná

SUMMARY

1 INTRODUCTION

A nation's capacity to foster sustainable progress in areas such as health, public safety, and innovation largely depends on the robustness of its educational foundations. Educational investments generate multiplier effects, including enhanced productivity, improved employability, and stronger social cohesion, directly influencing economic development and collective well-being (Hanushek et al., 2021; OCDE, 2020). From this perspective, education not only drives economic growth but also constitutes a central pillar in the construction of more equitable, resilient, and innovative societies (Barrenechea et al., 2023; Soto, 2024).

Beyond direct economic benefits, recent studies underscore the role of education in promoting social justice, inclusion, and active citizenship, reinforcing its transformative nature and intergenerational impact (D'Inverno et al., 2025; Hanushek & Woessmann, 2020). The cross-cutting nature of education promotes long-term effects in reducing inequalities, increasing competitiveness and expanding individual and collective freedoms (Hanushek & Kimko, 2000; Hanushek & Woessmann, 2011; OCDE, 2023).

Consequently, education is widely recognised as one of the primary drivers of social development. Its contribution is evident in multiple dimensions: in the improvement of human capital, the promotion of equity, the strengthening of citizenship and the revitalisation of economic activities (Thomas, 2018; Turwelis et al., 2022). It is therefore a strategic investment, the effects of which extend throughout individuals' lives, generating significant social and economic benefits (Donald et al., 2018; Psacharopoulos & Patrinos, 2004, 2018). In this sense, expanding access to quality education in an equitable manner is essential. This entails not only achieving satisfactory academic outcomes but also ensuring that such outcomes are attained irrespective of students' socioeconomic conditions (Simon et al., 2007).

Empirical studies confirm the positive correlation between education and economic growth: each additional year of schooling is associated with an average increase of 0.6% in a country's Gross Domestic Product (GDP) (OCDE, 2020). Internationally, education represents an average of 10.6% of government expenditure, reaching up to 17% in certain countries (OECD, 2022). In Brazil, public investment in education accounts for approximately 14% of the national budget, with 1.05% of GDP allocated to higher education (OCDE, 2023b).

Within this context, Higher Education Institutions (HEIs) play a strategic role. In addition to offering high-quality training, they play a key role in generating applied knowledge, fostering technological development, and promoting innovation (Agasisti, Bolzoni, et al., 2024; Duan, 2019). The literature has highlighted the relevance of HEIs for economic and social development, especially in emerging countries such as those that make up the BRICS group (Brazil, Russia, India, China, South Africa, Saudi Arabia, Egypt, United Arab Emirates, Ethiopia, Indonesia and Iran), where quality, equity and efficiency are the main challenges for the sustainable expansion of the sector (Fan et al., 2022; Gyamfi et al., 2022; Wit & Altbach, 2021).

As publicly funded institutions, HEIs face increasing pressure to demonstrate transparency, accountability, and tangible outcomes. The efficient use of resources has become essential for ensuring both the sustainability of institutional management and the quality of services delivered to society (Egorov & Serebrennikov, 2023; Henriques & Marcenaro-Gutierrez, 2021). Such performance hinges on the institution's ability to allocate available resources effectively, maximise input potential, and achieve defined strategic objectives.

Nonetheless, assessing efficiency in the education sector poses significant challenges, due to the non-profit nature of HEIs, the diversity of their functions (teaching, research, and outreach), and the absence of market prices for many of their services. These challenges are further compounded by the need to consider regional specificities, institutional heterogeneity, and the effects of expanding education to rural areas.

Among the techniques available for this purpose, Data Envelopment Analysis (DEA) stands out as a non-parametric, data-driven approach widely used in higher education. DEA evaluates the relative performance of similar institutions—called decision-making units (DMUs)—that convert multiple inputs into various outputs. It does not require the specification of a production function and accommodates multiple variables on different scales, making it suitable for heterogeneous educational contexts (Naderi, 2022; Nepomuceno et al., 2024; Panwar et al., 2022; Salas-Velasco, 2024).

This analytical framework has evolved through the Directional Distance Function (DDF), an extension of DEA that allows for the simultaneous expansion of desirable outputs and reduction of undesirable ones. Unlike radial DEA models, DDF enables the specification of a directional vector, offering greater modelling flexibility and supporting proportional adjustments across variables. This formulation is especially useful in complex settings such as multicampus institutions, where diverse goals and trade-offs coexist (Camanho & D'Inverno, 2023; Egorov & Serebrennikov, 2023; Pereira et al., 2021).

The combined use of DEA and DDF has also supported benchmarking strategies, identification of improvement targets, and institutional comparisons using longitudinal data. Additionally, it allows for the integration of complementary methodologies—such as meta-frontier models and composite indicators—thereby broadening the analytical scope and enabling the definition of performance goals tailored to the specific context of each institution (Barra & Zotti, 2016; Brzezicki & Rusielik, 2020; Dyson et al., 2001; Halkos & Petrou, 2019; Y. Zhao & Gong, 2023).

The adoption of these approaches also highlights the need to understand institutional efficiency from a multidimensional perspective, simultaneously considering technical, operational, and strategic aspects in the evaluation process. Performance evaluation in HEIs should not be restricted to the analysis of inputs and outputs, nor to the budgetary dimension. It is essential to consider, in an integrated manner, academic performance, effectiveness in delivering social results, responsiveness to the regional context, and consistency between management instruments. Among these dimensions, the allocation of public resources is a relevant aspect, often explored in the literature for its impact on the equity and sustainability of the educational system (Johnes, 2015; Le, 2021; Munoz, 2016; Visbal-Cadavid et al., 2017). It is estimated that the allocation process accounts for, on average, 37% of overall efficiency in the use of public resources (Grosskopf et al., 2017; Haelermans & Ruggiero, 2013; Zhang et al., 2020). However, comprehensive evaluation models should consider multiple criteria, not only to rationalise resource use but also to strengthen institutional capacity and promote balanced development (Feng et al., 2023; Ghulam & Mousa, 2019; Salas-Velasco, 2020).

Although formal mechanisms for evaluation, planning, and budgeting do exist, these processes are often carried out in a fragmented manner within HEIs. This lack of coordination compromises not only the efficient use of resources but also the strategic coherence of institutional actions, which can lead to adverse effects such as uncoordinated decisions, opportunistic practices, and persistent structural inequalities (Fadda et al., 2022; Jeon & Kim, 2018). Strengthening the integration between these management tools — evaluation, planning, and budgeting — is therefore a fundamental measure to ensure the effectiveness of institutional policies and consolidate results-oriented educational management (Pedro et al., 2022).

Despite methodological advances, few studies have comprehensively addressed the multiple dimensions of institutional performance. Among these dimensions, cost, operational and academic efficiency stand out, as well as effectiveness in meeting goals. Added to this is the scarcity of research focused on analysing multi-campus structures and the implications of institutional heterogeneity on the performance of units. In this scenario, there is a growing need for approaches that articulate different methodological perspectives, simultaneously considering internal factors (such as management, resources, and results) and external factors (such as location, type, and regional context).

These variables are intertwined with the process of internalisation of education, the diversity of institutional profiles, and the complexity of the functions performed by the teaching units of institutions. Understanding these multiple dimensions is necessary to improve public management, promote greater equity among institutions, and inform the formulation of more consistent educational policies that are sensitive to regional particularities (Johnes & Virmani, 2020; Wanke et al., 2022; Zhang et al., 2020).

In this context, this thesis contributes to the debate on institutional efficiency in public education — both in general terms and within the Brazilian context — by focusing on the performance analysis of Federal Education Institutions across multiple dimensions, including resource allocation and utilization, as well as the fulfilment of institutional goals. Robust approaches to assessing institutional performance can contribute to strengthening educational management and promoting more efficient, equitable, and results-oriented education. The following section outlines the research problem and object that frame this investigation, based on the alignment between the analytical and methodological dimensions introduced above.

1.1 Research object and problem

In recent decades, the debate on efficiency in public management has gained prominence in the field of education, especially in institutions that operate under direct state funding (Kelchen et al., 2022; Ricciardelli, 2022; Sav, 2016). The expansion of access to higher education and the diversification of educational offerings have made it essential to understand how public resources are being used (Mizrahi, 2021). Furthermore, it is necessary to evaluate the results from a technical and institutional perspective, seeking consistency between the proposed objectives and the performance achieved (Liao et al., 2024; OCDE, 2020).

In this context, it is necessary to develop analytical models capable of capturing the complexity of educational institutions, respecting their structural, functional and regional diversity (Guzmán-Valenzuela et al., 2021). These models should support more accurate diagnoses, guide evidence-based decisions, and contribute to continuous improvements in resource allocation and institutional performance management (Chen, 2024; Gori et al., 2025).

Brazil has established a Federal Education Network comprising 122 educational institutions, including 69 Federal Universities (UFs), 38 Federal Institutes of Education, Science and Technology (IFs), 12 government schools, two Federal Centres for Technological Education (CEFETs), and the College Pedro II (MEC, 2024).

Although coordinated under the same federal structure, UFs and IFs differ significantly in terms of mission, structure, academic scope, and funding mechanisms. UFs focus primarily on higher education and scientific research, often operating from centralised units in major urban centres, with an emphasis on postgraduate programmes and disciplinary departments.

IFs, on the other hand, are multi-campus institutions offering vocational and technological education at the secondary level, undergraduate degrees, and postgraduate programmes. Their activities combine teaching, applied research and extension, with a strong regional focus. With units spread across small, medium and large municipalities, they are designed to promote local development, expand access to education and support productive inclusion (Brasil, 2008).

These differences extend to funding. Although both UFs and IFs receive federal funds, IFs follow a specific budget matrix that takes into account variables such as enrolment, infrastructure and educational verticalisation. However, this matrix does not always reflect institutional complexity or regional disparities, which can result in budget constraints and management challenges (Garozzi & Raupp, 2021; Oliveira et al., 2022).

Affirmative action policies, particularly Law 12.711/2012, have also changed the institutional context by expanding access through quotas based on racial and socioeconomic criteria. Although socially important, these measures require greater academic support, infrastructure, and inclusive practices (Borges & Bernardino-Costa, 2022). IFs also face operational challenges due to their structure and the need to align planning and decision-making across diverse realities (Furlan et al., 2021).

These elements reinforce the need for evaluation models that consider institutional heterogeneity and context. Beyond technical indicators, structural and financial dimensions must also be considered in performance evaluations. More comprehensive approaches can support a fairer allocation of resources, strengthen public policies, and improve institutional management (Silva et al., 2024; Silveira et al., 2023).

Recognising these differences is essential for developing evidence-based policies and ensuring the equitable and efficient allocation of public educational resources. The following table provides an overview of the 38 IFs, including their regional distribution, number of courses, enrolments, staff and total budget for the year 2023.

As illustrated in Table 1 and in line with the institutional specificities discussed above, the performance of IFs also deserves special attention, although the efficiency of UFs is more frequently addressed in the literature. This relevance is justified not only by the volume of public resources allocated to these institutions—which totalled approximately US$ 3.6 billion in 2023—but also by the high enrolment rate, with approximately 1.5 million students served in the same year (MEC/PNP, 2023).

The national relevance of Federal Institutes is also evident in their wide geographical distribution and reach. The 38 IFs are organised into rectorates and teaching units (campuses) present in the five regions of the country — North, Northeast, Central-West, Southeast and South — which reinforces their strategic role in bringing public education to the interior of the country and reducing regional disparities (Lima, 2021; Panosso et al., 2021). This territorial distribution reveals the diversity of operational contexts between units, which makes it essential to consider institutional heterogeneity in performance analyses.

Table 1 – Overview of Federal Institutes

Region	State	Institution	Courses	Enrolled Students	Staff	Total Budget (U$)
North	Acre	IFAC	89	6.727	750	27.913.742,67
	Amazonas	IFAM	292	22.716	1.931	82.767.572,17
	Amapá	IFAP	143	7.923	639	22.620.604,83
	Pará	IFPA	552	29.943	2.548	107.440.062,41
	Rondônia	IFRO	219	28.778	1.305	59.098.836,54
	Roraima	IFRR	80	6.817	656	30.092.028,61
	Tocantins	IFTO	172	18.410	1.339	41.589.508,45
Northeast	Bahia	IF Baiano	274	18.944	1.771	73.438.077,87
		IFBA	296	29.952	2.986	129.217.047,19
	Pernambuco	IF Sertão	208	11.604	1.053	42.057.618,7
		IFPE	354	27.448	2.344	118.245.504,55
	Alagoas	IFAL	231	23.491	1.917	94.578.416,99
	Ceara	IFCE	761	63.730	3.809	167.959.111,74
	Maranhão	IFMA	523	45.522	3.384	142.600.139,56
	Paraíba	IFPB	260	33.176	2.603	124.067.726,58
	Piauí	IFPI	395	31.670	2.538	103.882.093,35
	Rio Grande do Norte	IFRN	540	22.779	2.807	138.158.582,88
	Sergipe	IFS	123	11.543	1.275	57.999.954,53
Central-West	Goiás	IF Goiano	251	18.193	1.463	72.570.559,06
		IFG	245	20.067	2.179	100.691.415,86
	Brasília	IFB	244	24.273	1.425	58.509.741,01
	Mato Grosso do Sul	IFMS	336	66.320	1.267	49.222.465,20
	Mato Grosso	IFMT	305	27.076	2.175	104.090.565,02
Southeast	Minas Gerais	IF Sudeste	196	14.412	1.328	64.600.108,44
		IFMG	274	44.092	1.985	91.338.593,95
		IFNMG	272	21.917	1.449	59.892.291,34
		IFTM	182	11.992	1.159	53.008.340,74
		IF Sul de Minas	414	61.939	1.213	60.997.901,48
	São Paulo	IFSP	903	77.558	4.823	207.613.322,91
	Espírito Santo	IFES	342	62.843	2.975	156.997.119,79
	Rio de Janeiro	IFF	254	23.374	1.809	91.223.207,86
		IFRJ	169	43.483	2.040	91.890.733,42
South	Rio Grande do Sul	IF Farroupilha	233	18.371	1.511	68.447.713,61
		IFRS	434	383.029	2.290	100.028.023,81
		IFSul	450	138.925	1.920	96.897.823,44
	Santa Catarina	IFC	192	20.195	1.898	81.971.972,18
		IFSC	512	40.970	2.782	125.473.765,90
	Paraná	IFPR	436	30.924	2.610	99.107.832,63

Source: Prepared by the author based on the PNP (2023).

These institutions stand out for their multi-campus structure, regional focus, and wide range of courses, which cover everything from technical training to postgraduate studies. Their institutional activities involve multiple dimensions — teaching, research, extension, innovation, and management (Brasil, 2008). This diversity requires evaluation approaches that integrate different variables and consider the complexity of operations, the particularities of each unit, and the varied educational, social, and economic objectives that make up their institutional mission (Pozzer & Neuhold, 2024).

The diversity of institutional profiles and their units, combined with the internalisation of structures and their insertion in regions with different levels of socioeconomic development, poses additional challenges for performance evaluation. These challenges manifest themselves both at the intra-institutional level — between units of the same institution — and at the inter-institutional level — between different IFs. Given this, methodologies are needed that recognise and incorporate these differences in the definition of benchmarks that are appropriate to each institutional reality (Silveira et al., 2023).

Over the years, different regulatory and operational efforts have been implemented to strengthen the mechanisms for monitoring and evaluating the performance of IFs, such as the creation of standardised indicators, the systematisation of data via the Nilo Peçanha Platform (PNP) and the incorporation of allocation parameters through budget matrices. However, the gap between the production of indicators and their effective use for decision-making remains a critical issue (Parente, 2023). Data fragmentation, the absence of integrated evaluation models, and limited coordination between planning, budgeting, and institutional evaluation hinder the full use of available information (Figueiró et al., 2022; Supriharyanti & Sukoco, 2023).

Furthermore, traditional evaluation models — based on rankings, isolated indicators or descriptive analyses — tend not to capture the complexity of multi-campus institutions (Colclough et al., 2024). Several of these approaches ignore the existence of undesirable variables, such as dropout rates and enrolment costs, and disregard structural differences between units, treating all institutions as homogeneous. Such methodological limitations compromise the quality of diagnoses and can affect both the effectiveness of management actions and the formulation of public policies (Tang, 2024).

In this scenario, approaches such as Data Envelopment Analysis (DEA) and its extension, the Directional Distance Function (DDF), stand out because they allow the measurement of the relative efficiency of units with multiple inputs and outputs, without the need for predefined production functions (Chambers et al., 1996; Chung et al., 1997). The DDF, in particular, allows the incorporation of undesirable variables into the model, in addition to working with directional vectors defined by the researcher and offering flexibility for longitudinal analyses (Halkos & Petrou, 2019). When integrated with other techniques, such as meta-frontier analysis and composite indicator construction, this approach significantly expands the explanatory and comparative power of analyses (Tsionas, 2023).

However, there are still few studies that articulate these methodologies, especially in public and multi-campus educational contexts, such as those of the IFs. The literature lacks research that comprehensively evaluates technical efficiency, cost aspects, and institutional effectiveness, considering the heterogeneity between units and using consistent time series to identify performance patterns over time. This lack of comprehensive analysis compromises both theoretical advancement and institutional management improvement, hindering the identification of best practices and the development of evidence-based policies.

The evidence presented indicates the existence of problems that need to be addressed to advance evaluation practices focused on the performance of IFs. In summary, these problems are:

i. The predominance of traditional models in the literature on DEA applied to educational institutions, with an emphasis on cross-sectional analyses, disregarding undesirable variables and with little representation of emerging countries such as Brazil, especially in the context of IFs;
ii. The absence of studies focused on intra-institutional analysis that incorporate internal benchmarking, consider the heterogeneity between units of the same institution, and use panel data in efficiency assessments;
iii. The limitation of approaches that integrate efficiency and effectiveness into a single model, making it difficult to identify consistent performance patterns and formulate evidence-based public policies;
iv. The lack of studies exploring the use of composite indicators based on DEA-DDF models, capable of synthesising multiple dimensions of institutional performance in an integrated and measurable manner;
v. The need for longitudinal and inter-institutional analyses that enable the monitoring of performance evolution over time and across different institutions, a fundamental aspect for the planning and strategic management of IFs.

Considering this context, this thesis studies the institutional performance of Federal Institutes of Education, Science and Technology, focusing on the integrated assessment of efficiency and effectiveness, considering both intra-institutional differences — between units of the same IF — and structural variations at the interinstitutional level — between different IFs —, in addition to the challenges inherent in multi-campus management and the operational specificities of public educational institutions in Brazil.

Based on this, the following research question is formulated: ***How can the efficiency of Federal Institutes be evaluated, considering intra and inter-institutional variations over time?***

1.2 Objectives

This section presents the general objective and specific objectives that guide this work.

1.2.1 General objective

The overall objective of this study is to propose a model for evaluating the efficiency of Federal Institutes of Education, Science and Technology through Data Envelopment Analysis (DEA), at the intra and inter-institutional levels.

1.2.2 Specific objectives

The specific objectives of this research include:

1) Critically evaluate empirical studies that apply DEA in assessing efficiency in higher education institutions, with an emphasis on the methodological approaches adopted, the trends observed, and guidelines for future research;

2) Compute the efficiency of a Federal Institute through internal benchmarking, considering the performance of its units and their structural and operational specificities;

3) Explore the feasibility of expanding benchmarking to the inter-institutional level, focusing on assessing efficiency and effectiveness among different Federal Institutes.

1.3 Justification

The central thesis of this research consists of proposing an integrated approach to assessing the efficiency of IFs. It starts from the understanding that a comprehensive analysis of the performance of these institutions requires the simultaneous consideration of different dimensions — technical, structural, financial and contextual. This perspective involves the use of panel data, consideration of differences between units (with different sizes, locations and operational profiles) and the incorporation of varied variables into analytical models.

This understanding reinforces that technical efficiency, although fundamental, is not sufficient to guide management decisions. It is also necessary to incorporate cost analysis and the capacity of institutions to fulfil their objectives, respecting their operating conditions and the regional contexts in which they operate. Based on these fundamentals, this research seeks to improve institutional assessment tools and strengthen more efficient public management. Although the focus is on IFs, the proposed approach is adaptable to other HEI.

The first contribution refers to a systematic review of the literature on the application of DEA in HEIs. The review proposed in this thesis responds to specific problems observed in the literature: the predominance of traditional DEA models, the scarcity of models that incorporate undesirable variables directly, without the need for manipulation, and the limited representation of institutions from emerging countries. Since its formulation by Charnes et al. (1978), the technique has been widely adopted, with a growing volume of publications. According to Emrouznejad and Yang (2018), between 1978 and 2016, approximately 10,300 articles on DEA were published, with more than 1,000 publications per year between 2014 and 2016. Recently, Camanho et al. (2024) identified more than 5,100 articles with the expression 'Data Envelopment Analysis' in the title between 2017 and 2022 alone, which highlights the consolidation of the technique. This volume has prompted several literature reviews aimed at systematising practices, mapping the state of the art, and defining future research agendas.

Among these revisions, those with a general scope stand out (Cook & Seiford, 2009; Emrouznejad & Yang, 2018; Panwar et al., 2022; Seiford, 1996), others focused on specific topics, such as weight restrictions (Berger & Humphrey, 1997), Networked DEA (Cao et al., 2022; J. Lee et al., 2015) and comparisons with the stochastic frontier (SFA) (Lampe & Hilgers, 2015). Also, noteworthy are reviews focused on specific sectors, such as sustainability (Song et al., 2012; Zhou et al., 2008); human development (Mariano et al., 2015); health (Paradi & Zhu, 2013); finances (Berger & Humphrey, 1997); transport (Cavaignac & Petiot, 2017) and insurance industry (Kaffash et al., 2020). These reviews contribute to deepening understanding of the evolution of DEA, guiding new researchers, and expanding the application of the technique in different theoretical and practical contexts.

In the field of education, some reviews have focused on consolidating the use of DEA in institutional performance evaluation. The study by De Witte and López-Torres (2017) focused specifically on educational literature, offering a comprehensive summary of efficiency measurement techniques, with an emphasis on DEA, up to the year 2015. Johnes, Portela and Thanassoulis (2017) discuss the role of efficiency in education in light of the impacts of the global financial crisis and public financing challenges. Johnes (2015) also presents an overview of the main difficulties faced by managers and policymakers, in addition to highlighting the contributions of Operational Research techniques — including DEA — in the search for solutions. Mergoni and De Witte (2022) address the effect of public interventions on performance, highlighting that the combination of efficiency and effectiveness is essential for evaluating policies, especially in the education, health, and environment sectors. Alkhars et al. (2022), in turn, conducted a review and classification of 109 articles applying DEA in different areas, identifying education as an emerging frontier for the development of evaluation models. Finally, Casado (2007) provides a historical overview of the evolution of productivity and efficiency analysis until the consolidation of DEA as a tool for evaluating higher education.

The second contribution relates to the intra-institutional assessment of the technical efficiency of units belonging to the same IF, through internal benchmarking. This approach offers significant advantages for institutional management, such as: (i) monitoring the effects of long-term interventions; (ii) identifying variations in performance over time; and (iii) evaluating implemented policies (Piran et al., 2021, 2023). By focusing the analysis on units subject to the same governance structure, budgetary rules and operational guidelines, more equitable and consistent comparisons can be made, overcoming common limitations in inter-institutional studies.

The application of internal benchmarking made it possible to monitor the performance trajectory of the units, identify efficiency patterns, and suggest goals adapted to the reality of each campus. In multi-campus systems, this strategy is especially useful for informing evidence-based management decisions. The literature review (Chapter 3) indicates that studies using internal benchmarking with panel data in public HEIs are still rare, which reinforces the methodological originality of the research applied to the context of IFs.

The third contribution consists of the joint application of the segmentation of teaching units, based on normative criteria, and meta-frontier analysis, with a view to deepening the assessment of intra-institutional efficiency. This segmentation considered the staff structure and the type of each unit. This made it possible to form more homogeneous groups and make more equitable comparisons (Dyson et al., 2001; Z. Ma et al., 2021).

The application of the meta-frontier made it possible to assess the relative efficiency between different groups of units and their distance from a common technological frontier, constructed based on best practices observed within the institution itself (Walheer, 2024). This approach reinforces the diagnostic capacity of intra-institutional assessment by revealing performance disparities among the segments formed, providing more accurate inputs for strategic planning and the formulation of differentiated interventions according to the profile of each group (O'Donnell et al., 2008).

The fourth contribution refers to the construction of a composite indicator (CI) based on the integration of multiple variables — desirable and undesirable — into a single aggregate measure. This type of indicator allows complex dimensions to be captured through the synthesis of individual variables that do not share common units (D'Inverno et al., 2025; Szuwarzyński, 2022). ICs consist of the mathematical aggregation of individual variables that represent complex and heterogeneous concepts, providing an integrated view of performance (Camanho et al., 2023b).

The application of the CI to the 38 IFs enabled a comparative inter-institutional analysis, revealing performance asymmetries and facilitating the identification of benchmarks between institutions. This approach represents a relevant methodological alternative to support systemic planning, guide resource allocation, and inform public policy decisions that are more sensitive to regional inequalities in the Federal Network.

The fifth contribution concerns the integration between the dimensions of efficiency and effectiveness in institutional evaluation. Efficiency is associated with the rational use of resources to generate results, while effectiveness refers to the achievement of defined goals and objectives (González & Alvarez, 2021; Mergoni & De Witte, 2022). The combined analysis of these dimensions broadens the understanding of organisational performance, going beyond assessments focused exclusively on technical productivity.

In the context of IFs, this integration made it possible to identify different institutional profiles, such as technically efficient units with low target achievement, and institutions that are effective in terms of results but inefficient in the use of resources. The joint analysis of these dimensions generated more consistent inputs for institutional diagnosis, revealing complementary strengths and weaknesses. This integrated approach strengthens results-oriented management and provides a more solid basis for the design of public policies aimed at equity, quality, and sustainability in public higher education in Brazil.

Finally, the sixth contribution of this thesis consists of proposing an integrated approach to institutional performance evaluation. The combination of different approaches — systematic review, internal benchmarking, segmentation of teaching units based on normative criteria, meta-frontier analysis, composite indicator construction, and joint efficiency and effectiveness analysis — allows us to deal with the complexity of multi-campus institutions. Furthermore, by integrating intra-institutional analyses — between units of the same institute — and inter-institutional analyses — between different IFs —, this thesis contributes to overcoming one of the main challenges in the literature, which is reconciling internal specificities with external comparisons. This methodological proposal provides a consistent basis for improving institutional evaluation models in the context of Brazilian public education.

Thus, this research stands out for organising and systematising the contributions of the literature on the application of DEA in the institutional evaluation of HEIs, offering a theoretical and methodological foundation that supports the proposed model and its application to IFs, as described in Chapter 2. Next, the study's scope is presented, specifying the institutional, temporal, and methodological parameters adopted to clarify the limits and analytical possibilities of this research.

1.4 Delimitations

This research presents some important limitations for defining its institutional, methodological, and temporal scope. The first limitation concerns the nature of the studies included in the systematic review: the research focuses on empirical applications of DEA aimed at evaluating efficiency in HEIs, excluding theoretical propositions or developments of mathematical models.

The second delimitation involves the thematic areas considered in the review, restricted to the fields of administration, economics, engineering, and multidisciplinary areas, as they concentrate the largest number of studies applied to the educational context. The third delimitation concerns the type of institution analysed: while the review covers HEIs in general terms, the empirical analyses in this thesis focus on IFs.

The fourth delimitation refers to the use of secondary data from official and public sources — such as the Nilo Peçanha Platform (PNP), the Integrated Financial Administration System (SIAFI), the Integrated Personnel Administration System of the Federal Government (SIAPENET), the IFTO Unified Public Administration System (SUAP) and regulations from the Ministry of Education — which enabled the construction of an integrated database of academic, operational and budgetary information.

The fifth limitation relates to the time frame of the empirical analysis, which is restricted to the period from 2017 to 2023, due to data availability and standardisation. The sixth limitation concerns the combined use of internal and external benchmarking, allowing comparisons between units within the same IF and between different IFs, enabling intra and inter-institutional analyses.

Finally, the seventh limitation considers that the institutional evaluation proposed here covers not only efficiency but also effectiveness in meeting goals, integrating multiple dimensions of public performance.

These delimitations help to clarify the analytical contours of the investigation, ensuring consistency between the research objectives, the methodological procedures adopted, and the expected results. The structure of the thesis is presented below.

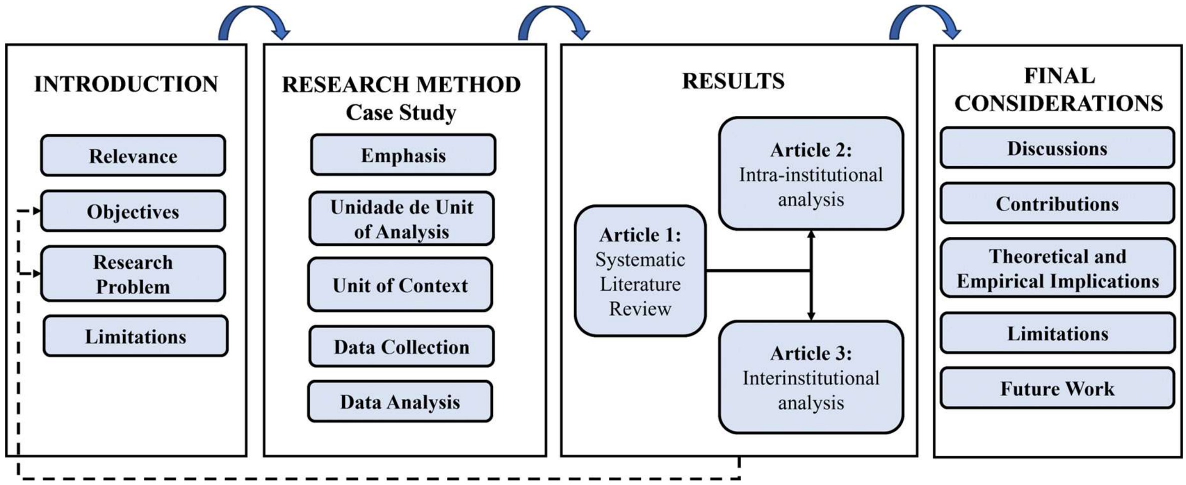
1.5 Structure of the thesis

This research is structured in the format of an article-based thesis, consisting of six chapters. The articles were organised coherently and aligned with the research problem, contributing to an integrated investigation, as proposed by Kubota et al. (2021).

The structure presented in Figure 1 represents the central reasoning that guides this thesis: it starts from an initial level of understanding of the object of study, based on evidence and pre-existing discussions, aiming to achieve a broader and more contextualised understanding of the phenomenon. To this end, the thesis follows a progressive trajectory, based on a robust methodological approach, structured in interconnected chapters. The evidence, analyses and interpretations are integrated to ensure consistency between the articles, objectives and results.

Following this introduction, Section 2 describes the methodological design of the research. Sections 3 to 5 comprise the three articles that make up the thesis, each linked to specific objectives (see Table 2). Finally, Section 6 presents the final considerations.

Figure 1 – Structure of the thesis



Source: Prepared by the author

The first article, corresponding to Chapter 3, presents a systematic literature review (RSL) on the use of Data Envelopment Analysis (DEA) in evaluating efficiency in HEI. The objective is to map the predominant methodological approaches, identify trends, and point out gaps that may guide future investigations.

The second article, which comprises Chapter 4, analyses units of an IF using an input-oriented DEA-DDF model, incorporating desirable and undesirable variables. The analysis, which is longitudinal in nature (2017–2023), uses internal benchmarking to assess efficiency at the intra-institutional level. Structural and operational differences between teaching units are addressed by segmenting units based on normative criteria (Ordinance No. 713/2021) and applying the meta-frontier, thereby expanding the explanatory power of the model.

The third article, presented in Chapter 5, proposes the construction of a composite indicator based on DEA-DDF to measure the performance of the 38 IFs. The model integrates desirable and undesirable variables, allowing for the joint assessment of technical efficiency and the fulfilment of institutional goals. With a longitudinal approach, the analysis identifies inter-institutional performance patterns over time, offering insights for enhancing public management and informing educational policies attuned to regional disparities.

Table 2 - Relationships between the objectives of the thesis and main contributions

General Objective	Specific Objectives	Chapter and Scope	Article	Main Contributions
Propose a model to assess the efficiency of Federal Institutes of Education, Science and Technology through Data Envelopment Analysis (DEA) at intra and inter-institutional levels.	•Critically evaluate empirical studies that apply DEA in assessing efficiency in higher education institutions, with an emphasis on the methodological approaches adopted, the trends observed, and guidelines for future research.	**Chapter 3:** Systematic Review of Literature on Efficiency Assessment in HEIs Using DEA.	**Article 1:** Efficiency in higher education institutions: An analysis of data envelopment analysis applications **Status:** Published on International Journal of Management in Education (IJMIE) https://doi.org/10.1504/IJMIE.2025.142875	It systematises and deepens the theoretical and methodological understanding of the literature on the application of Data Envelopment Analysis (DEA) in higher education, highlighting gaps that have been little explored and suggesting directions for future research. This contribution provides the conceptual basis for the other articles in the thesis.
	•Compute the efficiency of a Federal Institute through internal benchmarking, considering the performance of its units and their structural and operational specificities.	**Chapter 4:** Evaluation of efficiency in teaching units of a federal educational institution through internal benchmarking, with integrated use of DEA, institutional segmentation and meta-frontier analysis.	**Article 2:** Efficiency in Federal Educational Institutions: An intra-institutional analysis with Directional Distance Function and Meta-frontier. **Status:** Submitted on Evaluation and Program Planning	It brings the methodological debate closer to the reality of multi-campus institutions by proposing an original application of internal benchmarking combined with meta-frontier analysis. It deepens the analysis of efficiency at the intra-institutional level by considering variations between teaching units within the same institution and suggests operational guidelines for evidence-based management. The findings and the methodological approach developed support the construction of the composite indicator used in Article 3.
	•Explore the feasibility of expanding benchmarking to the inter-institutional level, focusing on assessing efficiency and effectiveness among different Federal Institutes.	**Chapter 5:** Assessment of efficiency and effectiveness among Federal Institutes through inter-institutional benchmarking and the construction of a composite indicator based on DEA, integrating multiple dimensions of institutional performance.	**Article 3:** The use of composite indicators to assess the performance of Federal Institutes of Education, Science and Technology **Status:** Submitted on Socio-Economic Planning Science	It adopts an inter-institutional approach by integrating the DEA-DDF model, with desirable and undesirable variables, into the construction of a composite indicator that combines technical efficiency and institutional goal achievement. The results obtained provide relevant inputs for strategic planning and the design of public policies that are more sensitive to regional inequalities.

Source: Prepared by the author

2 METHODOLOGICAL PROCEDURES

This chapter presents an overview of the methodological procedures that guided the development of this thesis. Given that the study adopts an article-based structure, the methodological specificities of each analytical stage are addressed in detail in Chapters 3, 4, and 5. Here, we summarise the general research design and working method to provide a unified understanding of the approach adopted.

2.1 Research design

The research design guides the study's planning and supports decisions regarding data collection, variable control, and data interpretation (Yin, 2001). This step helps to understand the context in which the data is obtained and ensures consistency between the objectives, development and conclusions of the research (Bertrand et al., 2023). Table 3 summarises the methodological framework adopted in this thesis.

Table 3 – Methodological framework

Dimension	Background
Nature	Applied
Objective	Exploratory
Scientific method	Inductive
Approach	Quantitative
Research method	Case-based modelling

Source: Prepared by the author based on Hazari (2023).

Scientific inquiry is typically driven by either theoretical or practical motivations. When guided by the construction of knowledge, without direct links to immediate applications, it is classified as basic or pure, focusing on scientific advancement (Dresch et al., 2015). Applied research focuses on solving concrete organisational or societal problems by generating results that inform decisions or improve existing practices (Ermel et al., 2021). Thus, this thesis is characterised as applied research.

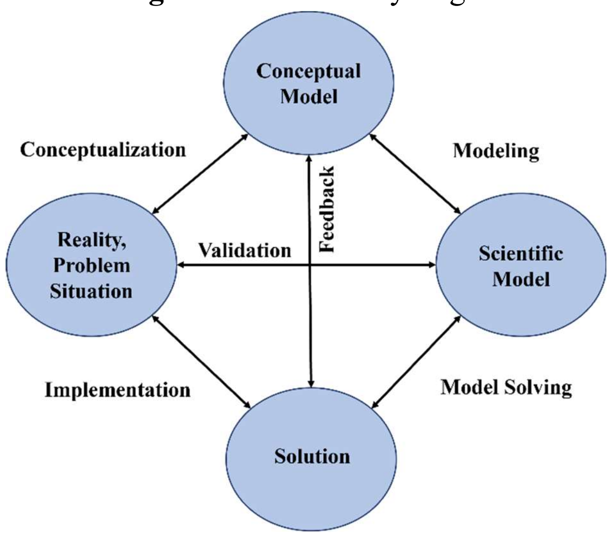
The researcher must clearly define the objective to be achieved with the development of the research, determining whether its purpose is to explore, describe, explain or predict the behaviour of the phenomenon under study. The present research is classified as exploratory, since this type of investigation seeks to formulate hypotheses, provide clarification or both, with the purpose of deepening the understanding of a particular problem (Dresch et al., 2015).

The scientific method adopted is inductive, which starts from the observation of phenomena and the identification of patterns to formulate generalisations (Hazari, 2023). This method is common in empirical studies on institutional performance based on observational data (Bertrand et al., 2023).

In terms of approach, research can be classified as qualitative, quantitative or mixed (Barratt et al., 2011; Dresch et al., 2015). The qualitative approach focuses on understanding phenomena without the use of numerical data, while the quantitative approach uses mathematical language to analyse structured data and identify relationships between variables (Bertrand et al., 2023). This thesis adopts a quantitative approach, applying mathematical techniques to assess institutional efficiency through DEA modelling.

This research adopts case-based modelling, which enables the development of models that reflect real-world processes encountered by institutional managers. These models can be validated through practical application and, in some cases, their results can be tested (Bertrand et al., 2023). This model served as a reference for structuring the working method adopted in this thesis, see Figure 2. In this representation, the arrows represent the processes that transform inputs into outputs, while the geometric shapes (ellipses) denote the inputs, outputs and results involved in each process. This interpretation aligns with the conceptual structure of the case-based model adopted in this thesis and is clarified here to prevent potential misreadings of the visual representation.

Figure 2 – Case study stages



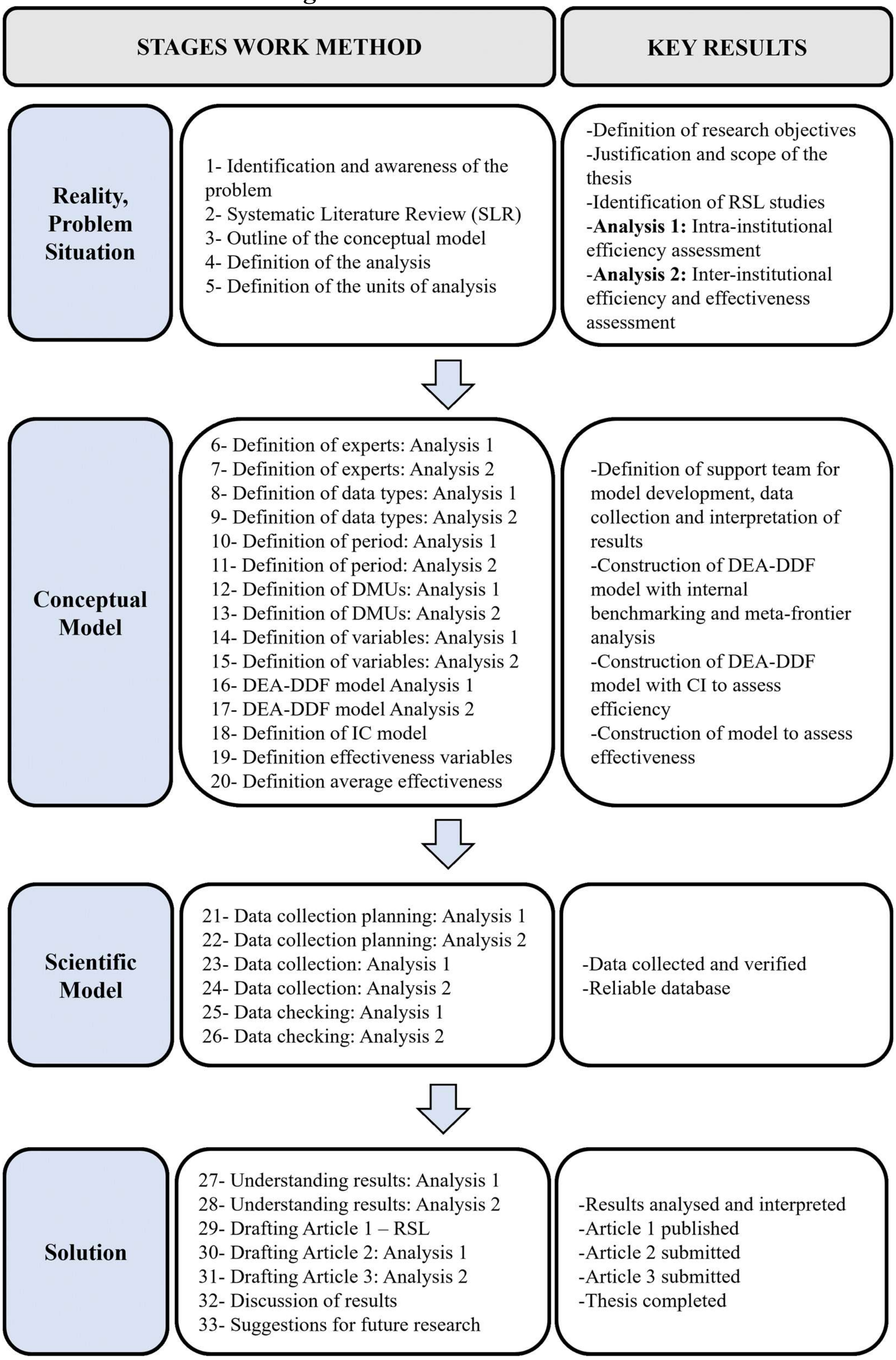
Source: Prepared by the author based on Mitroff et al. (1974).

The conceptualisation stage involves developing a conceptual model of the problem and gaining a deeper understanding of the system under study. At this stage, the scope of the research, the model to be developed and the variables that make up the analysis are defined. Next, in the modelling stage, the quantitative model is constructed and the causal relationships between the variables are established. The model resolution stage corresponds to the application of mathematical techniques and the calculation of results. Finally, in the implementation stage, the results obtained are applied to the reality of the problem, which may initiate a new cycle of investigation (Bertrand et al., 2023). The next section presents the steps of the working method adopted in this thesis.

2.2 Working method

The working method adopted in this study includes 33 procedures, as shown in Figure 3.

Figure 3 - Work method thesis



Source: Prepared by the author based on Mitroff et al. (1974) and Bertrand et al. (2023).

These procedures are structured into four main stages and corresponding sub-stages. The stages represent the overarching phases of the research, while the substages correspond to specific routines selected for their methodological relevance. For each stage, the key outcomes are summarised below.

The first stage involves the conceptual development of the study, encompassing the definition of the research context and the underlying problem. This involved an in-depth analysis of the functioning of Higher Education Institutions (HEIs), with emphasis on management, resource allocation, and institutional performance. The diagnosis was supported by a review of scientific literature on performance evaluation in public educational institutions, focusing on methodological approaches such as DEA. This review provided the theoretical and empirical grounding for formulating the research objectives and propositions. The findings and methodological contributions are presented in Chapter 3.

Drawing on this conceptual framework, two complementary lines of analysis were established. Analysis 1 focuses on an intra-institutional perspective, assessing the performance of teaching units within a single Federal Institute. Analysis 2 adopts an inter-institutional approach, evaluating all 38 Federal Institutes across Brazil.

The selection of the Federal Institute for Analysis 1 (Article 2) was guided by three criteria: (i) broad territorial coverage in the state of Tocantins, allowing for efficiency assessment in diverse socioeconomic contexts; (ii) the availability of reliable academic, budgetary, and operational data across all teaching units from 2017 to 2023; and (iii) internal heterogeneity in terms of institutional size, staffing, and typology.

Analysis 2 (Article 3) investigates efficiency and effectiveness across all 38 Federal Institutes. These institutions form part of the Federal Network for Professional and Technological Education, which in 2023 served around 1.6 million students with a combined budget of approximately US$ 3.5 billion (MEC/PNP, 2023). Figure 4 presents the evolution of federal investment in this network.

Figure 4 - Budget evolution of Federal Institutes

Source: Prepared by the author based on the PNP (2023).

The inclusion of all 38 Federal Institutes was justified by four main criteria: (i) broad regional coverage; (ii) standardised, publicly available data from the PNP; (iii) comparable institutional frameworks and missions as defined by the Ministry of Education; and (iv) availability of time series data for longitudinal analysis.

The second stage involved the development of the conceptual models for both analyses. In Analysis 1, the DEA-DDF model was designed with expert support (see Table 4) and applied to 11 teaching units, generating 77 panel observations over seven years. The model adopted an input-oriented approach with variable returns to scale (VRS), appropriate for cost-based inputs such as personnel and operational expenses. The model's capacity to incorporate both desirable and undesirable outputs allowed for a more refined assessment of institutional performance and facilitated the application of internal benchmarking and meta-frontier analysis.

Table 4 – Experts consulted in Analysis 1

Area of Expertise	Project Support
Administration – Budget and Accounting	Support in defining the model and collecting data
People Management – Registration and Payment	Support in collecting data
Extension – Extension Projects	Support in collecting data
Research – Research Projects	Support in defining the model and collecting data
Teaching – Institutional Registration	Support in collecting data
Efficiency Management and Analysis	Support in defining the model
Efficiency Management and Analysis	Support in defining the model

Source: Prepared by the author.

In Analysis 2, the DEA-DDF model was also developed with expert input (Table 5), this time addressing institutional-level data. The experts contributed to model coherence, indicator selection, and data validation. This phase resulted in a composite indicator integrating academic and financial dimensions. Effectiveness was assessed separately, based on institutional goal attainment.

Table 5 – Experts consulted in Analysis 2

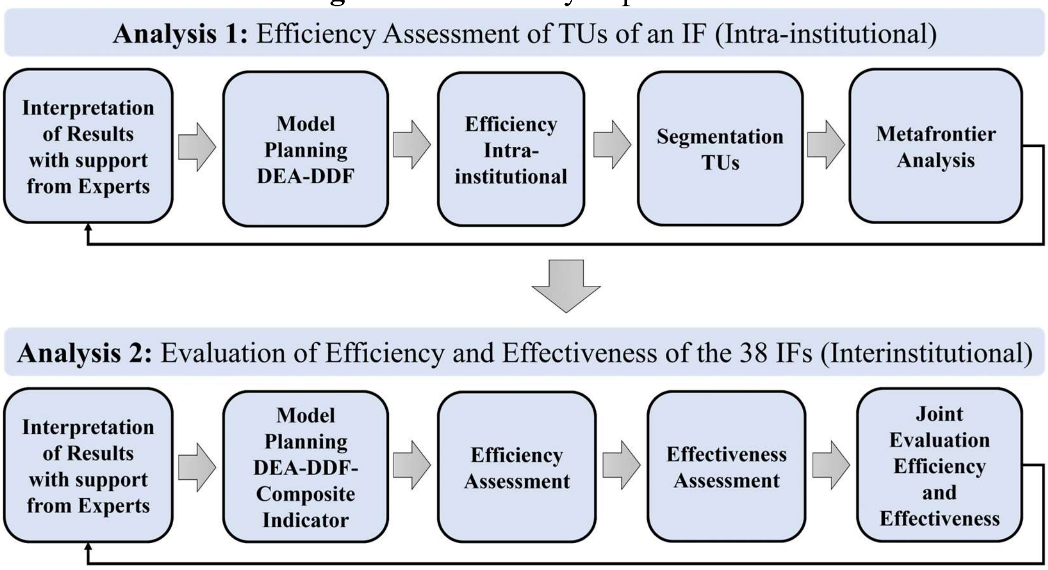
Area of Expertise	Project Support
Administration - Budget, Accounting and Costs	Support in defining the model and collecting data
Teaching - Institutional Registration	Support in defining the model and collecting data
Institutional Management	Support in defining variables
(General Management)	Support in defining variables
Institutional Management	Support in defining variables
(General Management)	Support in defining the model
Institutional Management	Support in defining the model
(Former Rector)	Support in defining variables

Source: Prepared by the author.

The third stage refers to planning and data collection. In Analysis 1, data from the period 2017–2023 were collected from platforms such as PNP, SIAFI, SIAPENET, and SUAP, and subsequently validated with institutional support. In Analysis 2, academic and cost data were compiled using a similar process, in collaboration with specialists, ensuring the consistency and feasibility of the information used for DEA-DDF application and composite indicator construction.

The fourth and final step involves interpreting the results, writing the articles, and formulating recommendations. Chapter 3 presents the Systematic Literature Review. Figure 5 illustrates the analytical procedures used in Analysis 1 (Chapter 4) and Analysis 2 (Chapter 5).

Figure 5 - Data analysis procedure



Source: Prepared by the author.

Results from both analyses were discussed with DEA experts and institutional practitioners to refine interpretations and enhance alignment with practical realities. The analyses also incorporated iterative refinements based on feedback and emerging findings.

In Analysis 1, performance among teaching units was evaluated using DEA-DDF, with benchmarking and efficiency targets established. Units were later segmented, and meta-frontier analysis applied to compare performance against both group-specific and common frontiers.

In Analysis 2, the DEA-DDF model was used to assess efficiency, and a composite indicator was developed. Effectiveness was measured separately, and the joint analysis enabled identification of institutions with balanced or unbalanced performance across both dimensions.

All models were implemented using MAXDEA 12.2 software (MaxDEA, 2025), which supports directional vectors and the modelling of undesirable variables. Upon conclusion of all stages, the research articles were finalised, thereby consolidating the thesis and fulfilling its stated research objectives.

3 EFFICIENCY IN HIGHER EDUCATION INSTITUTIONS: AN ANALYSIS OF DATA ENVELOPMENT ANALYSIS APPLICATIONS

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Abstract: Estimating efficiency in higher education has been a challenge due to the complexity and heterogeneity of institutions. Data Envelopment Analysis (DEA) has emerged as the main technique used to evaluate efficiency in the educational field. This study aims to analyse the applications of DEA in evaluating efficiency in Higher Education Institutions (HEIs). This article contributes to the literature by discussing efficiency in higher education and by providing methodological and practical advances. Firstly, we carried out a Content Analysis considering 113 relevant studies in the fields of efficiency evaluation using DEA in HEIs. We identified motivators, results and main methodological approaches. In addition, we identified the need to expand studies focussing on the process of evaluating efficiency in resource allocation using DEA.

Keywords: Higher Education Institutions; DEA; Efficiency Evaluation; Content Analysis; Motivators; Results; Resource Allocation; Methodological Approaches; Methodological Advances; Practical Advances.

3.1 Introduction

Education is one of the most important factors in measuring a society's level of development (Turwelis *et al.*, 2022). Studies show that education is positively related to the economic development of a region (e.g. Hanushek & Kimko, 2000; Hanushek & Woessmann, 2008, 2012), indicating that each additional year of schooling leads to an average growth of 0.6% in the country's Gross Domestic Product (GDP) (OECD, 2020).

The benefits of education accrue to both society and individuals and, as such, the provision of education in many countries is public and subsidised, at least in part, by the government (Johnes, 2006; Johnes, Portela and Thanassoulis, 2017). A study conducted by the Organisation for Economic Co-operation and Development (OECD) analysed the financial resources invested in education. The results show that total public resources invested in education represent an average of 10.6% of total government spending, with a range of 7% to 17% (OECD, 2022).

Given this scenario, evaluating efficiency in education becomes crucial. The education sector is characterised by its non-profit nature, the use of multiple inputs generating multiple outputs and the absence of input and output prices, which makes it difficult to assess efficiency (Johnes, 2006; Witte and López-Torres, 2017). Despite the complexity involved, evaluating the efficiency of the use of resources earmarked for education, especially higher education, is essential to understanding the real situation of the administration and setting objectives in line with the country's reality in terms of educational productivity (Smith and Street, 2005; Witte and López-Torres, 2017).

It should be noted that although efficiency and productivity are sometimes considered synonymous, the concept of productivity differs from that of efficiency (Macedo, Moutinho & Madaleno, 2023). Efficiency assesses performance by reflecting the relationship between the product obtained and the resources used, considering their limited availability (Di Maio et al., 2017). On the other hand, productivity is defined as output divided by input (or resource), representing a static or level concept that can be measured to compare a company's performance at a given time, allowing differences in productivity levels between companies to be analysed (Meireles, 2023). As such, this article will focus on the study of efficiency evaluation, exploring in detail the methodologies and approaches for evaluating and improving organizational efficiency.

Among the techniques for assessing efficiency in education, Data Envelopment Analysis (DEA) stands out as the most widely used (Emrouznejad & Yang, 2018; Johnes & Johnes, 2009; Thanassoulis et al., 2016; Wolszczak-Derlacz, 2017). For this reason, several literature reviews have been developed analysing the application of DEA in the field of education. For example, De Witte and López-Torres (2017) reviewed efficiency evaluation techniques, including DEA, highlighting its application in the educational context until 2015. Johnes, Portela and Thanassoulis (2017) provide an overview of the topic of efficiency in education. Johnes (2015) provides an overview of the various problems faced by government, managers and consumers of education, addressing Operations Research (OR) techniques, including DEA. Recently, Mergoni and De Witte (2022) provided a state-of-the-art review of studies that using non-parametric techniques, including DEA, to investigate the combination of efficiency and effectiveness to evaluate public interventions and detect inefficiencies at the policy level, especially in key sectors such as education, health and the environment.

However, to date, no review has focused specifically on the use of DEA to evaluate efficiency in Higher Education Institutions (HEIs). Therefore, this study aims to analyse the applications of DEA in evaluating efficiency in HEIs. We sought to identify the methodological approaches of the list of articles, including publications by year, authors identified, country by volume of publications, input and output category, DEA models, type/orientation of each model, data analysis techniques, types of efficiencies and types of benchmarking, as well as their main relationships.

In this way, this analysis can contribute to comparative studies, increase the potential for application in other regions of the world and raise the quality of the research carried out. Initially, the research identified the motivators and results of the applicability of DEA in evaluating efficiency in HEIs, as well as the main methodological approaches of the DEA technique. As a second contribution, the research identified the need to expand studies focusing on efficiency evaluation in HEIs using DEA in the resource allocation process, especially in emerging countries such as the BRICS group (Brazil, Russia, India, China and South Africa), using internal benchmarking as a central concept.

This study is structured in five sections. The first presents the introduction. The second section describes the methodological procedures. The third presents the results of the study. The fourth discusses and analyses the results identified. Finally, the last section presents the final considerations and suggestions for future research.

3.2 Methodology

The methodology employed in this study was based on a Systematic Literature Review (SLR), using the Literature Grounded Theory (LGT) method (Ermel et al., 2021). LGT is made up of four stages, all of which are duly addressed throughout this work: (i) Literature Review, (ii) Literature Analysis, (iii) Literature Synthesis, and (iv) Research Results (Ermel et al., 2021).

The CIMO tool - Context, Intervention, Mechanisms and Outcomes - was used to guide the definition of the research questions (Table 6). CIMO is an important tool used to specify the four essential parts in the development of systematic review questions (Denyer, Tranfield and Van Aken, 2008).

Table 6 - CIMO

Context	Higher Education Institutions
Intervention	Efficiency evaluation
Mechanisms	Data Envelopment Analysis (DEA)
Outcomes	Identifying how efficiency is evaluated in HEIs

Source: Adapted from Denyer, Tranfield and Van Aken (2008).

A research protocol was then developed (Appendices Chapter 3 – A3.1). The protocol was validated by four experts, who were selected based on the following requirements: (i) publication of systematic reviews or knowledge on the subject, and (ii) researchers with a minimum qualification of a doctorate in their area of research. Table 7 shows the list of experts.

Table 7 - Identification of experts

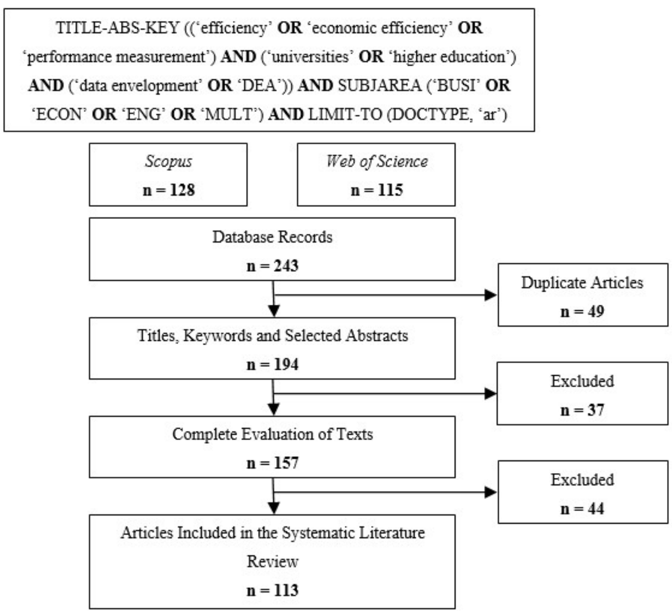
Specialist	Training	Program and Institution to which it is linked
1	Doctor in Production and Systems Engineering - UNISINOS	School of Management and Business and Polytechnic School - UNISINOS - BR
2	Doctor in Industrial Management and Engineering - University Polytechnic di Milano	Department of Management, Economics and Industrial Engineering - University Polytechnic di Milano School of Management - Milano, IT
3	Doctor in Business Administration - University of South Wale	Business School - Swansea University - Wales, UK
4	Doctor in Management and Operational Research - University of Aston	Business School - Portuguese Catholic University - Porto, PT

Source: Prepared by the author.

The search strategy was then outlined and carried out in the Scopus and Web of Science databases, using the terms in Figure 6. The choice of these databases was based on their ability to provide agile access to the main global citation repositories, as well as demobilising advanced tools for tracking, analysing and visualising research (Gauss et al., 2021). About the period and subject area, articles published up to 2022 were consulted, covering research in the areas of business, economics and engineering.

After searching the databases, the textual corpus identified was refined and duplicate articles were excluded, followed by an inspection of the titles, keywords and abstracts (Brunton, Stansfield and Thomas, 2012). Seeking to include only articles that were related to the aim of the study, two reviewers carried out the inspection. The results of this stage were compared and, if any discrepancies in the choice were identified, they were resolved through discussion between the reviewers to ensure agreement. The selected articles were then analysed in depth. Figure 6 illustrates the process of selecting the studies that make up the research, considering the 113 articles analysed.

Figure 6 - Search Flow, Filters and Results - RSL



Source: Prepared by the author.

Next, Table 8 presents the exclusionary statistics. Potentially relevant studies were analysed in depth, and those that were within the scope of the research were selected for review (Appendices Chapter 3 – A3.2).

Table 8 - Exclusion statistics

Exclusion Criteria	Number of exclusions	Percentage (%)
Duplicate studies	49	37,7
Articles not related to the research objective	44	33,8
No approach to the DEA technique or no approach to efficiency in HEIs	37	28,5
Total	**130**	**100**

Source: Prepared by the author.

The second stage involved analysing the data. A scientific mapping was carried out based on the aggregative review strategy (Ermel et al., 2021; Zimmer, 2006). Vosviewer software was used as a computer resource to manipulate the data.

The next step was to carry out a content analysis, defining a coding system to analyse the studies included in the RSL (Mayring, 2014). After reading and coding the studies, a categorisation was carried out based on Ma and Li (2021), considering: (i) Efficiency in the Functioning of the Institution; (ii) Efficiency in the Allocation of Resources; (iii) Efficiency in Research/Technological Innovation; and (iv) Investment Efficiency.

Additionally, after categorising the articles, the input and output variables were identified. Based on the study by Witte and López-Torres (2017), categories were created to facilitate the analysis of the list of articles. The inputs were: (i) Research/Innovation; (ii) Server/Collaborator; (iii) Student; (iv) Budget; (v) Infrastructure; and (vi) Other. As for the outputs: (i) Student; (ii) Research/Innovation; (iii) Infrastructure; (iv) Evaluation of the Institution; and (v) Other.

Next, the occurrence, co-occurrence and frequency relationships of the methodological variables were analysed. The variables identified include: (i) efficiency; (ii) benchmarking; (iii) DEA model; (iv) orientation and type of each DEA model; and (iv) whether the approach used was a single-stage or two-stage DEA analysis.

After the data coding process, a matrix was generated between the Motivators and Results. The aim was to seek an understanding of the Motivators that led HEIs to implement DEA for efficiency evaluation and what Results were achieved as a result. Atlas.ti® data analysis software was used to assist this entire process. The results of this process are presented in the next section.

3.3 Results

This section begins by analysing the scientific output of the textual corpus surveyed. Between 2016 and 2022, the average number of scientific publications was 12 articles/per year. By considering the output of authors who have contributed to the field and considering the bibliographic portfolio analysed, the research listed the total number of publications and citations per author, as can be seen in Table 9. Among the main authors, Jill Jones stands out, followed by Tommaso Agasisti.

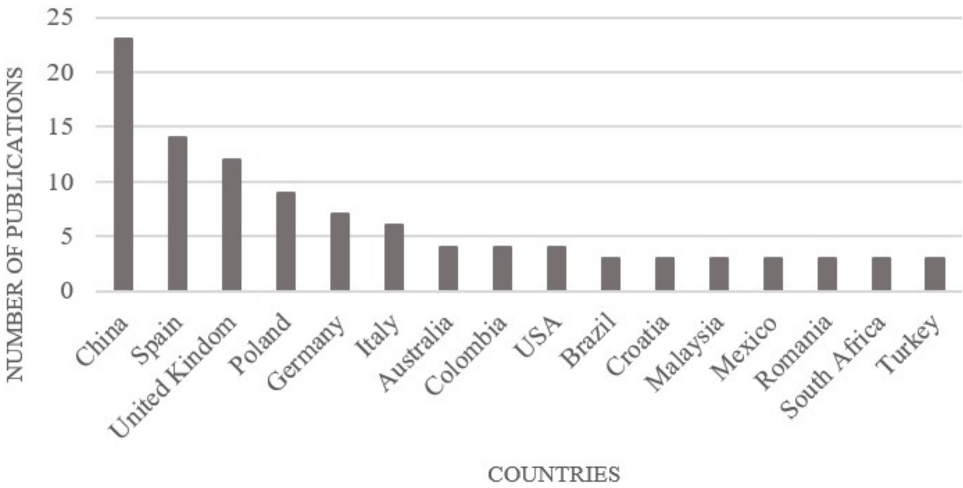
Table 9 - Main Authors

Author	Articles	Citations
Jhones, J.	5	728
Agasisti, T.	5	326
Jhones, G.	3	244
Brzezicki, Ł.	3	1
Iee, B. L.	2	132
Bornmann, L.	2	43
Wohlrabe, K.	2	43
Chen, X.	2	24
Kosor, M. M.	2	13

Source: Prepared by the author.

When considering the main countries with scientific production on the subject, 47 were identified. China leads the way with 23 publications, followed by Spain with 14 publications and the United Kingdom with 12 publications. The distribution of the countries' scientific output can be seen in Figure 7.

Figure 7 - Main Countries with Scientific Productions



Source: Prepared by the author.

Table 10 shows the articles grouped according to the research objective, grouping them into four categories, according to Ma and Li (2021). In the Efficiency in the Functioning of the Institution category, the studies aimed to assess, analyse, measure or compare general aspects related to the institutional efficiency of HEIs (Ding et al., 2021; Hoz et al., 2021). The category

Efficiency in Resource Allocation addresses the development of more efficient mechanisms, seeking to assist decision-makers in measuring the results of their institutional strategies and policies (Lita, 2018; Madaleno & Moutinho, 2023). The studies in the Research/Innovation Efficiency category have as one of their main objectives to analyse the productivity of HEIs about scientific production and innovation (Du & Seo, 2022; 2023; Luo, 2021). Finally, the Investment Efficiency category encompasses studies that address measures to foster investment in higher education (Dumitrescu et al., 2020).

Table 10 - Research textual corpus categorization

Category	Articles	Occurrence (articles)
Efficiency in the Functioning of the Institution	I7, I9, I10, I11, I14, I15, I16, I17, I19, I20, I21, I26, I27, I28, I29, I30, I34, I35, I36, I38, I39, I40, I41, I43, I44, I46, I48, I51, I52, I54, I56, I57, I58, I59, I60, I61, I66, I67, I69, I70, I71, I72, I73, I74, I75, I77, I78, I79, I80, I82, I85, I86, I87, I88, I89, I90, I92, I93, I96, I97, I98, I99, I100, I101, I102, I103, I104, I105, I107, I108, I110, I112, I113	73
Efficiency in Research/Innovation	I1, I5, I6, I8, I13, I18, I22, I24, I25, I31, I32, I33, I42, I45, I47, I49, I50, I55, I64, I65, I68, I76, I81, I83, I84, I94, I95, I109, I111	29
Efficient Resource Allocation	I2, I3, I4, I12, I23, I53, I62, I63, I91, I106	10
Investment Efficiency	I37	1

Source: Prepared by the author.

The relationship between the input/output variables, their categories and the occurrence identified in the studies can be seen in Table 11. The main input category was Server/Collaborator, present in 63 articles. When analysing outputs, the main category was Student, identified in 75 articles.

Another point considered was the identification of the methodological variables of the DEA models (Table 12). Initially, the types of efficiency were identified. Based on the work of Johnes and Johnes (2004), the types of efficiency observed in this research were technical and allocative. In addition, the orientation and type of each DEA model were identified. The types of benchmarking were also observed, according to the classification by Elmuti, Kathawala and Lloyed (1997), which divides the types into: (i) internal; (ii) external; (iii) functional or industrial and (iv) process or generic. Within the scope of this study, the types of benchmarking observed were internal and external.

Table 11 - Input/Output ratio

Variables	Categories	Main Variables	Articles	Occurrence
Input	Research Innovation	-Research/Innovation Team; -Investment in research/innovation activities; -Number of academic papers published; -Number of patents granted; -Number of research grants; -Number of scientific projects	I1, I2, I5, I6, I8, I13, I17, I18, I20, I22, I24, I31, I33, I35, I36, I42, I47, I49, I50, I51, I64, I65, I68, I92, I93, I94, I95, I102, I107, I109, I111	31
	Server Employee	-Number of teaching staff; -Quantity of administrative staff	I2, I7, I10, I14, I15, I16, I18, I20, I21, I22, I23, I25, I26, I28, I29, I30, I33, I35, I36, I39, I40, I41, I42, I43, I44, I46, I47, I51, I53, I54, I56, I57, I58, I59, I61, I63, I64, I66, I67, I68, I71, I72, I73, I74, I76, I77, I79, I81, I82, I83, I84, I85, I87, I89, I90, I91, I102, I103, I105, I107, I111, I112, I113	63
	Student	-Number of undergraduate students -Number of postgraduate students; -Number of master's/doctoral theses; -Number of courses; -Socio-economic and cultural level	I2, I3, I7, I15, I17, I18, I25, I28, I30, I33, I38, I39, I48, I53, I54, I56, I58, I61, I62, I63, I66, I67, I71, I74, I75, I77, I85, I86, I87, I89, I92, I96, I104, I105, I107, I108, I110, I112	38
	Budget	-Public funds received; -Personnel costs; -Administrative expenses, -Allocation of budgetary resources; -Financial resources obtained; -Maintenance and Investment Budget; -Government spending on higher education as a percentage of GDP; -Expenditure per student	I3, I6, I8, I12, I14, I16, I18, I20, I23, I26, I32, I35, I36, I37, I38, I40, I41, I43, I46, I48, I52, I54, I55, I58, I60, I62, I66, I67, I68, I70, I71, I74, I79, I80, I81, I82, I83, I84, I85, I88, I89, I94, I97, I98, I99, I100, I101, I103, I105, I106, I108, I110, I111, I113	54
	Infrastructure	-Physical space; -Number of educational institutions; -Number of laboratories -Number of libraries; -Number of books; -Technological resources; -Number of classrooms	I4, I10, I12, I15, I16, I17, I23, I25, I32, I33, I45, I46, I59, I78, I100, I103, I107, I109, I111, I113	20
	Others	-Number of posts in the forum topic; -Number of replies in the forum; -Time spent browsing videos; -Results in national standardized exams	I9, I11, I27, I34, I69	5
Output	Student	-Quantity of undergraduate graduates; -Number of students completing postgraduate studies -Average undergraduate student grades; -Number of scientific monographs; -Student employability; -Social/economic benefits; -Services to the community; -Academic results	I3, I4, I7, I10, I12, I14, I15, I16, I17, I19, I21, I23, I26, I28, I29, I30, I32, I35, I36, I37, I39, I40, I41, I43, I44, I46, I48, I51, I52, I53, I54, I55, I56, I58, I59, I60, I62, I63, I64, I66, I67, I70, I71, I72, I75, I77, I78, I79, I80, I81, I82, I83, I84, I85, I86, I87, I88, I89, I92, I93, I94, I96, I97, I98, I99, I100, I101, I102, I103, I104, I105, I106, I108, I110, I112, I113	75
	Server Employee	-Quantity of work by the teaching staff; -Human resources	I17, I65	2
	Research Innovation	-Technology transfer agreements (revenue from the sale of patents); -Number of articles published; -Number of patents authorized; -Number of approved research projects; -Citation count; -Number of research grants; -Volume of scientific production; -Software application developed; -Volume of scientific production; -International scientific index	I1, I3, I5, I6, I7, I8, I12, I13, I14, I15, I17, I18, I19, I20, I22, I23, I24, I25, I28, I30, I31, I33, I35, I36, I39, I40, I41, I42, I45, I47, I49, I50, I51, I53, I54, I55, I57, I58, I59, I60, I61, I63, I64, I65, I66, I67, I68, I70, I71, I72, I73, I76, I77, I81, I82, I83, I84, I90, I93, I94, I95, I100, I101, I102, I103, I105, I106, I107, I108, I109, I110, I111, I112, I113	74
	Infrastructure	-Quantity of books; -Infrastructure	I7, I15, I72, I98	4
	Evaluation of the Institution	-National exam score/concept; -Institutional peer evaluation score	I2, I9, I11, I26, I27, I69, I91, I94, I96, I98	10
	Others	-Number of times the ad was shown on the screen; -Financial income collected by the HEI	I34, I38, I74, I78, I111	5

Source: Prepared by the author.

Table 12 - Co-occurrence analysis methodological variables

Occurrence		Type of Efficiency		Type of Benchmarking		DEA Model Orientation			DEA Model Type		
		Allocative	Technical	Internal	External	Input	Output	Input/Output	CRS	VRS	CRS/VRS
Allocative	9			3	6	2	7		2	6	1
Technical	104			15	89	16	86	2	31	57	16
Internal	18	3	15			4	13	1	7	8	3
External	95	6	89			14	80	1	26	55	14
Input	18	2	16	4	14				4	9	5
Output	93	7	86	13	80				28	54	11
Input/Output	2		2	1	1				1		1
CRS	33	2	31	7	26	4	28	1			
VRS	63	6	57	8	55	9	54				
CRS/VRS	17	1	16	3	14	5	11	1			

Source: Prepared by the author.

Table 13 shows the DEA models used, with the classic model predominating in empirical applications. However, other models were applied, such as Super-efficiency DEA, Network DEA - NDEA and Slack-Based Models - SBM, among others.

Table 13 - DEA models

Models	Occurrence
Classic	89
Super-efficiency	10
Network DEA (NDEA)	8
Slack Based Models (SBM)	2
Inverse DEA (InvDEA)	1
Directional Distance Function (DDF)	1
Centralised DEA (CDEA)	1
Multi-objective DEA (MODEA)	1

Source: Prepared by the author.

About the number of studies carried out using two-stage DEA approaches, Table 14 shows the complementary techniques used. Most of the articles (57%) conducted a second-stage analysis to relate the efficiency calculated by DEA to exogenous variables. Among the main techniques used to carry out two-stage DEA analyses, Bootstrap Regression, Tobit Regression and the Malmquist Index predominate.

Table 14 - Two-step DEA approaches

	Approach	Occurrence
Regression	Bootstrap Regression	8
	Tobit Regression	6
	Truncated Regression	5
	Linear Regression	4
	Least Squares Regression (OLS)	2
	Dynamic Panel Regression	1
	Meta Regression	1
	Second Stage Regression	1
Correlation	Spearman Correlation	3
	Pearson Correlation	1
Hypothesis Testing/Other Techniques	Malmquist Index	14
	SFA	5
	Analysis of Variance (ANOVA)	2
	Sensitivity Analysis	2
	K-means Analysis	2
	Cluster Analysis	2
	Markov Chain	1
	AHP	1
	FHD	1
	Theil Index	1
	Hotelling Test	1

Source: Prepared by the author.

Another point of this analysis was to identify the main Motivators and the main Results of the implementation of the DEA technique for evaluating efficiency in HEIs by continent. Table 15 shows these figures.

Table 15 - Co-occurrence analysis Motivators x Results

		Motivators (M)		Results (R)	
		Academic Performance	Research/Innovation Productivity	Decision -making	Institutional Performance
Continent	America	7	5	14	4
	Africa	1	1	3	
	Asia	12	17	30	6
	Europe	29	8	29	16
	Oceania	1	1	3	-
R	Decision Making	30	25	-	-
	Institutional Performance	17	3	-	-

Source: Prepared by the author.

Among the Motivators, Academic Performance and Research/Innovation Productivity stood out. About Results, Decision Making and Institutional Performance were identified. The Academic Performance motivator is related to improving the performance of multiple departments within an institution (Ding et al., 2021; Nkohla et al., 2021). While the Decision-Making outcome provides ways to solve/anise problems in the transformation between knowledge production and results in scientific activities, leading to improvements in the governance structure of HEIs (Lehmann et al., 2018; Zhao et al., 2022). The results are discussed below.

3.4 Discussions

The results show that China leads the scientific production with 23 studies, as it is an emerging economy country belonging to the BRICS group of countries (Amin and Haq, 2022). However, when analysing the scientific output of the other members of the group, it can be seen that South Africa and Brazil have only 3 studies each, while Russia has 2 and India 1. This scarcity of studies in the BRICS countries stands out as a promising research niche in the field of education, given that their university systems have existed since 1995 and have undergone a transformation over the years, redefining the public/private nature of their educational systems, as well as together representing around 41% of the world's population and generating 25% of the global gross domestic product (Neto et al., 2022; WorldData, 2023).

About inputs and outputs, there was significant convergence between the studies when it came to defining outputs. This agreement is justified by the fact that these are outputs that can drive the evaluation of efficiency in HEIs (Li, 2022). Overall, the results obtained in the studies are highly dependent on the selection of the variables to be included in the evaluation, as well as how they are measured.

The main DEA models, such as classic and super-efficiency, were predominant in studies categorised into efficiency in the functioning of the institution and efficiency in research/innovation. Some models were little applied, for example, the NDEA. Although NDEA is a growing field of research in the general literature on efficiency (Camanho et al., 2023a).

We note that most two-stage applications employ regression techniques (Bootstrap Regression, Tobit Regression and Truncated Regression). This preference occurs regardless of the existing discussion around these methods, with Banker & Natarajan (2008) arguing that Ordinary Least Squares (OLS) methods can be applied as second-stage tools, even showing that Tobit regression is not significantly better than simple OLS.

Regarding the orientation and type of DEA models, the output-oriented VRS configuration stands out as the most used. This preference is in line with the studies identified in this research Gebru, Khan, Raza (2022); Herberholz and Wigger (2021); Nkohla et al. (2021) and Brzezicki, Pietrzak, Cieciora (2022), where the aim is to maintain resource consumption and maximise results.

When analysing benchmarking, it was found that external benchmarking was the most widely used. This finding is in line with the study by Macedo, Coutinho and Madaleno (2023), where the authors state that efficiency evaluations based on DEA are often associated with external benchmarking. However, only 18 studies (16%) used internal benchmarking. This percentage indicates that the literature has not explored the use of internal benchmarking very much.

As for the type of efficiency, there was a concentration of studies analysing technical efficiency models (104 articles), while 9 articles analysed allocative efficiency. According to the co-occurrence assessment, there was a concentration of studies - 89 in total - which analysed external benchmarking from the point of view of technical efficiency. Among the studies we highlight: Pedro, Leitão and Alves (2022); Chen et al. (2021); Kosor, Perovic and Golem (2019) and Moreno-Gómez, Calleja-Blanco and Moreno-Gómez (2020). These studies tended to define Decision-Making Units (DMUs) in annual periods, i.e. the DMU is the institution or country itself, where data is collected in annual periods over time.

Most of the articles focus on the categories of efficiency in the functioning of the institution and efficiency in research/innovation. Despite the relevance of these categories, we identified that the category of efficiency in resource allocation is something that the literature has not explored much, which corroborates the studies by Nazli et al. (2019) and Zhang et al. (2020).

One of the possible causes of this scarcity may be the fact that most of the studies in this review focus on the allocation of budgetary resources only (Abdullah et al., 2018; Alam et al., 2023; Fu & Heenko, 2022; Olariu & Brad, 2022). Studies focusing on the allocation of intangible resources, such as human resources (teaching and administrative staff), physical resources (buildings, classrooms, laboratories and libraries), academic resources (curriculum and books), research resources (laboratories and funding for research projects) and student support resources (psychological support, student housing and financial assistance) can expand research into the allocation of resources in institutions, providing more efficient management in HEIs.

Another point to note was that most of the HEIs in this study have established processes for institutional evaluation, strategic planning and resource allocation. However, these processes are often disconnected, which results in an inefficient allocation of resources. To alleviate inequalities and provide equity between HEIs, or between units that make up a given HEI, the process of allocating resources, for example, budget resources, can be based on a matrix that considers factors such as the number of enrolments, faculty titles, academic efficiency index, dropout rate, among others.

When identifying scientific production by continent, considering the Motivators and Results (Table 15), it was found that most studies from countries on the European and American continents focus on the Academic Performance Motivator (Herberholz & Wigger, 2021; Kosor et al., 2019; Papadimitriou & Johnes, 2019; Perović & Kosor, 2020). While most countries on the Asian continent focus on the Research/Innovation Productivity Driver (Du & Seo, 2022; Khurizan et al., 2018; Luo, 2021; Sing & Imen, 2022). About Results, Decision Making was a common point between Asia, America and Europe. As such, DEA is an important tool for evaluating multiple options in decision-making processes. It offers a structured approach to analysing perspectives and predictabilities to make compensatory or non-compensatory decisions based on explicitly defined criteria (Nepomuceno et al., 2024). This corroborates the studies by Shariatmadari Serkani et al. (2022); Ranjan and Singh (2021); Mousa and Ghulam (2019); Abdullah et al. (2018), where applying DEA models allowed managers to identify weaknesses and improve the overall efficiency of the institution by focusing on deficiencies.

Finally, the analysis of the matrix presented in Table 15 revealed a concern on the part of the HEI with the pursuit of strategic initiatives in Decision Making associated with Academic Performance and Research/Innovation Productivity. This finding is in line with the authors Rodionov and Velichenkova (2020); Shariatmadari Serkani et al. (2022) and Vilela et al. (2021). In these studies, the results suggest the need for actions with managerial implications to optimise and improve academic performance and productivity in research/innovation. The conclusions of this study are presented below.

3.5 Conclusions

This study provides a comprehensive analysis of the applications of the DEA technique in evaluating efficiency in HEIs. In reviewing the 113 articles, the literature examined reveals a significant global interest in this topic, highlighting the strategic importance attributed to efficiency in HEIs around the world. The results obtained suggest that strengthening the connections between institutional evaluation, strategic planning and the budgeting process of a HEI are essential for a satisfactory allocation of resources.

The main contributions of this study were: (i) identification of the main methodological approaches, providing a comprehensive overview of current practices in the application of DEA in HEIs; (ii) identification of the main Motivators and the main Outcomes, highlighting the need to align institutional objectives with efficiency strategies, as evidenced by the emphasis on Academic Performance and Research/Innovation Productivity; (iii) the importance of improving the process of allocating budgetary resources, based, for example, on a matrix that takes into account factors such as the number of enrolments, the qualifications of teaching staff, the academic efficiency index and the drop-out rate, in order to optimise and ensure equity between institutions; and (iv) the need to expand studies involving the BRICS countries, focusing on the applicability of DEA in evaluating efficiency in HEIs, using internal benchmarking as a central concept, which will provide a more comprehensive and personalised understanding of educational dynamics in different contexts.

As a limitation, although we used appropriate keywords for this study and searched the most relevant scientific databases, the use of other keywords in other databases may produce different results. We, therefore, suggest that future research explore new methodological variables and emerging challenges in evaluating efficiency using the DEA technique in HEIs.

4 EFFICIENCY IN FEDERAL EDUCATIONAL INSTITUTIONS: AN INTRA-INSTITUTIONAL ANALYSIS WITH DIRECTIONAL DISTANCE FUNCTION AND META-FRONTIER

Status: Submitted on Evaluation and Program Planning

Abstract: The search for efficiency in educational institutions has become a global priority. Despite advances in the literature on Data Envelopment Analysis, there are still few studies that integrate undesirable variables and intra-institutional analyses. This study proposes an innovative approach by combining the Directional Distance Function and meta-frontier analysis to measure the efficiency of teaching units (TUs) at a Federal Institute. Using a panel data structure, we analysed 11 TUs with 77 observations over seven years (2017–2023), incorporating desirable and undesirable variables. The results indicate that 31% of Decision-Making Units were classified as efficient, with an institutional average efficiency of 80.3%. The methodological combination allowed us to identify internal benchmarks and show that the scale and organisation of resources significantly impact efficiency, regardless of the available budget.

Keywords: Efficiency; Data Envelopment Analysis; Directional Distance Function; Benchmarks; Meta-frontier.

4.1 Introduction

Education plays an important role in the economic and social progress of a nation and is recognised as one of the pillars of sustainable development. In this context, Higher Education Institutions (HEIs) stand out for their dissemination of knowledge and training of a skilled workforce (Alam et al., 2020; Chankseliani et al., 2021; Sun et al., 2023). By integrating teaching, research and outreach, these institutions consolidate their role as agents of social progress (Godonoga & Sporn, 2023; Machado & Davim, 2023; Nepomuceno et al., 2024).

Given this relevance, there is a growing need to assess how public resources allocated to education are used by HEIs, especially in relation to the results obtained. Although financial contributions are significant, investment alone does not guarantee improved institutional performance. For example, data from the Organisation for Economic Co-operation and Development (OCDE) reveal that between 2018 and 2020, Luxembourg allocated only 0.42% of its GDP to higher education, while Norway led the way with 1.80%. Brazil, in turn, ranked 15th, with 1.05% of GDP allocated to the sector (OCDE, 2023b). However, this difference in investment does not necessarily translate into proportional performance, as according to PISA 2022, Luxembourg ranked higher than Brazil in reading, science and mathematics, despite investing less. Norway, with the highest percentage of investment, performed well in reading and science, but lower in mathematics when compared to other OECD countries (OCDE, 2023a). These contrasts show that factors such as management, efficient resource allocation, and institutional context strongly influence educational outcomes. This scenario reinforces the importance of studies that assess the efficiency of IEs, even in contexts with similar—or even higher—levels of public investment (Johnes & Virmani, 2020).

Given this strategic role, Brazil has structured a federal education network comprising 122 Educational Institutions (IEs), including 69 Federal Universities (UFs), 38 Federal Institutes (IFs), 12 Government Schools, 2 Federal Education Centres and the Dom Pedro II College (MEC, 2024). Although the efficiency of the UFs is widely debated, the performance of the IFs also deserves attention. This is justified not only by the volume of public resources allocated to these institutions, which totalled approximately US$ 3.6 billion in 2023, but also by the high number of enrolments, around 1.5 million students in the same year (MEC/PNP, 2023). In this scenario, it is essential to deepen our understanding of the performance of IFs, especially considering the specific operational challenges faced by these institutions.

This study will analyse a Federal Institute located in the state of Tocantins, Brazil's youngest federal unit, whose socioeconomic reality highlights important structural challenges. With an average HDI of 0.699, lower than the national average of 0.76, the state faces structural challenges that affect access to and quality of education. These inequalities are also evident in the cities where the institution has units, whose development indices range from 0.627 in Lagoa da Confusão to 0.788 in Palmas (IPEA, 2025). In this way, the multi-campus structure of the IFs becomes an important tool for promoting inclusion and regional development (T. H. O. Silva et al., 2022; Wanke et al., 2022).

The adoption of a multi-campus approach to institutional efficiency analysis allows for a more detailed assessment of each unit's performance. This analysis makes it possible to identify variations in performance between units operating under different socioeconomic and structural conditions, providing more accurate diagnoses and strategic recommendations for institutional management (Colclough et al., 2024; Tang, 2024). However, this assessment represents a challenge, even after the publication of Judgment No. 2,267/2005 (TCU, 2005) and, more recently, Ordinance No. 1, of 3 January 2018 (MEC/SETEC, 2018), which established the Nilo Peçanha Platform (PNP) as a virtual environment for the collection, validation, and dissemination of official statistics from the Federal Network for Professional, Scientific, and Technological Education (RFEPCT).

Despite regulatory advances, there are difficulties in applying guidelines aimed at improving institutional performance, and little use is made of structured guidelines to ensure efficient and results-oriented management (Corral et al., 2025; Nunes et al., 2021). It should be noted that efficiency, established as a constitutional principle by Amendment No. 19 of 4 June 1998, guides public management in the pursuit of the best use of resources and imposes on managers the duty to adopt the best available alternatives to serve the public interest (Brasil, 1988). Thus, the absence of a standardised model for assessing the efficiency of IFs reinforces the need for methods, techniques and tools that enable a more consistent analysis of the relationship between the resources employed, and the results achieved (Rodrigues et al., 2018). This scenario is consistent with international literature, which highlights efficiency analysis as an essential strategy for improving the quality of public services and informing evidence-based policies (Kristof Witte et al., 2025).

The statistical indicators presented in the RFEPCT structure, made available through the PNP, help identify data on teaching, student and technical-administrative staff, as well as information related to the financial expenditure of institutions (MEC/PNP, 2023). These indicators enable the analysis of possible inequalities and challenges faced by institutions, providing input for the formulation of more effective educational policies, as well as constituting an important database for research focused on the evaluation and performance of the Federal Network (Prado et al., 2022). The effectiveness of any efficiency assessment model depends on the availability of data and the choice of an appropriate analysis method, factors that require transparency and good management practices (Gomes et al., 2023). In this sense, techniques that enable the identification of internal references and comparisons between different IF units are fundamental to inform strategic decisions and promote continuous improvements in educational management.

Among the techniques used for this purpose, Data Envelopment Analysis (DEA) has stood out as an effective approach for evaluating the efficiency of IEs (Camanho et al., 2024; Emrouznejad & Yang, 2018; Johnes & Johnes, 2009; Emmanuel Thanassoulis et al., 2016; Wolszczak-Derlacz, 2017). DEA allows comparison between units based on the relationship between inputs used and products generated, identifying those that operate efficiently and those that have opportunities for improvement (Agasisti, Egorov, et al., 2024; Salas-Velasco, 2024). In the context of IEs, efficiency stands out as a fundamental criterion for distinguishing units that make better use of available resources, considering the inputs employed (inputs) and the results obtained (outputs). Thus, the application of DEA in IEs contributes to management improvement by indicating paths for resource optimisation and supporting more informed decision-making (Camanho & D’Inverno, 2023; Labijak-Kowalska & Kadziński, 2021; Pereira et al., 2021).

This study proposes an innovative approach to intra-institutional analysis by measuring efficiency among Teaching Units (TUs) within the same Federal Institute. Using a data panel structure, we analysed 11 units of an IE with 77 observations over seven years (2017–2023), incorporating desirable and undesirable variables. The logic adopted is that of internal benchmarking, in which different units of the same institution are compared with each other, considering their operational specificities. For this, we use the DEA-DDF (Directional Distance Function) model, with an input orientation, which allows the incorporation of undesirable variables without the need for prior data transformation (Halkos & Petrou, 2019).

The main methodological contribution of the study consists of applying internal benchmarking based on panel data, combining multiple units and multiple periods of analysis. This configuration enables the identification of consistent performance patterns, the definition of achievable targets for inefficient units, and the strengthening of institutional management based on empirical evidence.

To enhance the robustness of the analysis, the study incorporates two complementary methodological steps. The first consists of segmenting educational units based on similar institutional characteristics, according to the typology defined by Ordinance No. 713/2021. This organisation allows for a more balanced and comparable assessment of performance patterns between different institutional profiles. The second involves the application of meta-frontier analysis, which makes it possible to compare the groups formed among themselves and in relation to a common technological frontier (Dyson et al., 2001; Ma et al., 2021). This methodological framework contributes to a comprehensive assessment of institutional efficiency by considering different operational contexts within the same organisation. This combination of methodologies strengthens the reliability of the results and allows for the identification of structural constraints influencing performance.

The article is structured into five sections. The next section presents the main aspects of the literature that contextualise this work. Section 3 describes the methodological procedures used in the study. Section 4 presents and analyses the results based on a real application. Finally, the discussions, conclusions and prospects for future research are presented in Section 5.

4.2 Theoretical framework

4.2.1 Efficiency in Educational Institutions

Efficiency is a central concept in the management of IEs, as it allows for the evaluation of the relationship between resources employed and results generated. The evaluation of efficiency enables an accurate analysis of institutional performance and guides strategies for the continuous improvement of management (Egorov & Serebrennikov, 2023). Thus, the pursuit of efficiency becomes a priority, especially in publicly funded institutions, where there is a growing need for transparency and optimisation of resources (Agasisti et al., 2023).

Measuring efficiency in IEs, however, presents methodological challenges. Unlike traditional productive sectors, these institutions operate with multiple inputs and outputs, many of which do not have market values, making it difficult to apply conventional financial metrics (Johnes, 2006). Furthermore, due to its multidimensional nature, which involves teaching, research and extension, it increases the complexity of defining appropriate performance indicators.

Given these particularities, the literature has resorted to different methodological approaches to assess institutional performance, with emphasis on frontier methods. Among them, Data Envelopment Analysis (DEA) stands out, widely used in measuring efficiency in educational institutions (Camanho et al., 2024). The following is a detailed overview of its application and relevance in the context of evaluating public educational institutions.

4.2.2 DEA models for evaluating efficiency in IEs

The assessment of efficiency in educational institutions has received increasing attention in the DEA literature. Studies offering an overview of the strengths and limitations of DEA in this type of assessment have grown steadily, reflecting academic interest in improving efficiency metrics in the education sector (Gori et al., 2025; Johnes et al., 2017; Rella & Vitolla, 2024; Witte & López-Torres, 2017).

The literature also presents different approaches to the types of results analysed. Some studies evaluate the joint performance of teaching and research activities, while others focus exclusively on one of these domains. One of the first studies to apply DEA in an IE was conducted by Beasley (1990). Since then, the work has diversified: some authors have focused solely on measuring the efficiency of teaching in HEIs, such as Brzezicki (2020); others turned exclusively to scientific production, such as Zhang & Wang (2022). There are also studies that integrate both domains — teaching and research — into a single model, as proposed by Herberholz & Wigger (2021). Although less common, some analyses still explore the efficiency of institutional resource allocation, as in Alam et al. (2023).

In Brazil, studies on the performance of IEs, especially public ones, are relatively scarce. In the case of UFs, some research is dedicated to analysing the efficiency of resource allocation (Aparecida & Silva, 2022; K. M. F. Barbosa et al., 2021; Filho et al., 2023; Hammes et al., 2020). Others evaluated the efficiency of postgraduate activities for research and innovation systems (De Almeida Vilela et al., 2021; Torres & Ramos, 2024; Zoghbi et al., 2013). When it comes to IFs, the literature is even more limited. Most research has focused on assessing technical efficiency among institutes (Krieser et al., 2018; Parente, 2023; T. H. O. Silva et al., 2022). Only one study adopted a multi-campus approach to an IF, analysing efficiency between its campuses and identifying benchmarking units based on 2019 data (Silveira et al., 2023). However, this analysis did not use panel data, which limits its ability to capture more accurately the specifics of institutional performance.

Benchmarking emerges as a strategic approach to identify best practices and drive improvements in academic and administrative management. It can be classified as external or internal (Piran et al., 2021). External benchmarking, also called functional benchmarking, compares an organisation with others in the same industry, but its application may be limited by the unavailability of reliable data. Internal benchmarking focuses on comparing units within the same organisation, allowing for the identification of opportunities for operational improvement (Piran et al., 2023). When applied to panel data analysis, this approach can offer additional benefits to management, such as (i) monitoring the impacts of long-term interventions, (ii) capturing variations in performance over time, and (iii) evaluating the effectiveness of institutional policies.

The literature presents two mathematical approaches to dealing with undesirable variables in DEA: indirect and direct (Ramli et al., 2013). The widely used indirect approach consists of transforming the data from undesirable outputs so that they can be included in the standard model. However, this manipulation requires careful interpretation of the results before they can be used for management purposes, preventing the assessment from being reduced to mere mathematical modelling (Dyson et al., 2001).

In contrast, the direct approach does not require data transformation, allowing for greater transparency by incorporating undesirable outputs into the model. One of the most widely used methods in this approach is the Directional Distance Function (DDF) (Chambers et al., 1996; Chung et al., 1997).

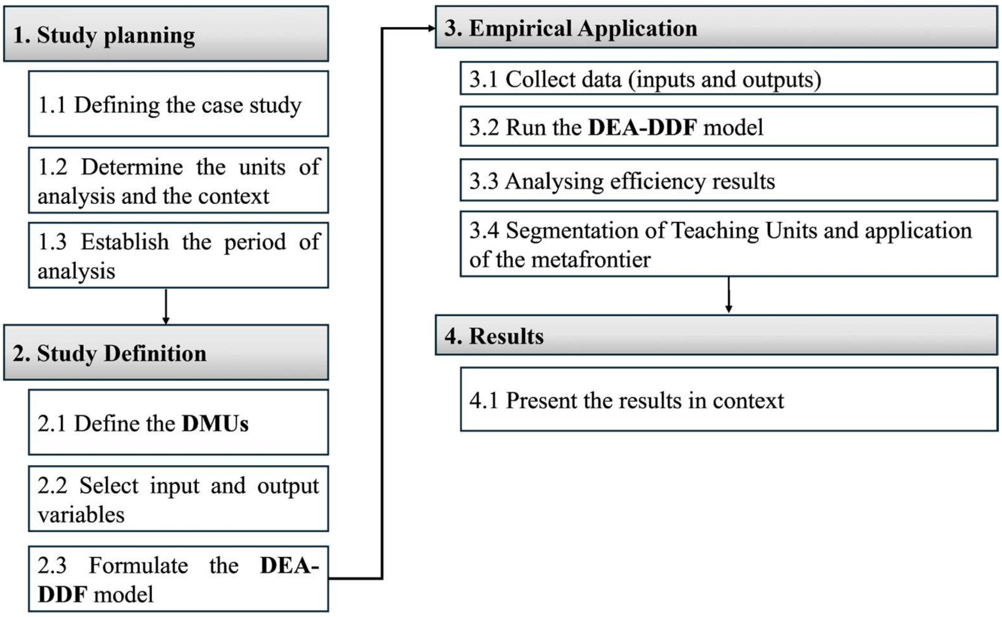
The DDF model allows for the inclusion of undesirable variables, both between inputs and outputs, which makes it particularly suitable for educational evaluations. This feature allows for the simultaneous consideration of desirable outcomes, such as the number of graduates, and undesirable outcomes, such as the number of dropouts (Barra & Zotti, 2016; Brzezicki & Rusielik, 2020). In addition to these applications, the DDF approach has been employed in studies on technical and technological changes (Barros et al., 2011; Essid et al., 2014) and in the evaluation of research productivity (Li et al., 2024; Weber & Xia, 2011).

4.3 Methodological Procedures

To develop this study, we adopted a case study-based research methodology. This type of research is particularly appropriate when seeking to understand complex phenomena in contexts where the boundaries between the object of study and the context are not clearly defined, and when there is a need for theoretical and empirical depth (Dubé & Paré, 2003). Specifically, we conducted a single, embedded case study using panel data and an intra-institutional approach, focusing on a multi-campus institution in the Federal Network. This configuration—a single case with multiple units of analysis—allows us to examine internal variations over time, which contributes to strengthening the internal validity of the research through triangulation between units and time frames (Barratt et al., 2011; Voss et al., 2002).

Furthermore, the use of panel data is essential for internal benchmarking, as it allows for the identification of performance patterns and systematic comparison between campuses over time (Bondan et al., 2024; Piran et al., 2021). Figure 8 presents the working method adopted, structured in four stages.

Figure 8 - Work method of analysis 1 - Article 2



Source: Prepared by the author.

4.3.1 Context and selection of analysis units

The study is being conducted at the Federal Institute of Education, Science and Technology of Tocantins (IFTO), located in northern Brazil. Despite its recent creation, the state of Tocantins recorded a 6% growth in Gross Domestic Product (GDP) in 2022, above the national average of 3% in the same period, ranking 13th among Brazilian states (IBGE, 2023).

Established by Law No. 11,892 of 29 December 2008, IFTO plays a strategic role in promoting the internalisation of education, contributing to regional development. The institution has 12 units, including 11 teaching units (TUs) and one administrative unit (rector's office). In this study, the 11 TUs will be analysed.

The institution serves approximately 15,400 students, distributed across 166 courses at the following levels: technical (T), initial and continuing education (FIC), undergraduate (G) and postgraduate (PG). It has 1,200 employees, including permanent and temporary teaching staff, as well as administrative technicians in education (TAE). In 2023, the institution's total budget was approximately US$ 41.5 million (MEC/PNP, 2023). Table 16 presents an overview of the 11 TUs.

Table 16 – Overview of the TUs

Teaching Unit (TUs)	Courses					Students	Teaching	TAE	Budget (US$)
	T	FIC	G	PG	Total				
Palmas	16	7	17	4	44	4.625	266	104	12.711.652,85
Araguatins	3	1	5	3	12	1.644	84	103	5.878.900,17
Paraíso do Tocantins	3	2	8	1	14	2.151	69	39	3.629.827,63
Araguaína	5	3	2	2	12	1.098	62	52	3.538.541,28
Porto Nacional	9	3	8	1	21	1.878	62	39	3.310.755,44
Gurupi	6	3	6	2	17	1.026	58	41	3.250.656,82
Dianópolis	3	6	3	1	13	837	43	39	2.634.152,16
Colinas do Tocantins	3	2	3	3	11	916	42	32	2.432.622,80
Pedro Afonso	2	6	1	-	9	691	17	13	1.331.413,82
Formoso do Araguaia	7	-	-	1	8	250	22	10	1.070.098,96
Lagoa da Confusão	3	1	1	-	5	349	15	12	919.744,56

Source: Prepared by the author.

4.3.2 Variable selection and data collection

After characterising the institution and defining the conceptual framework of the study, we began the process of selecting variables. To this end, we consulted professionals from the institution itself, selected based on their experience and area of expertise. These collaborators contributed relevant information, supporting both the definition of variables and the organisation of the database used in the analysis.

The study required the definition of an observation period. After consulting the IFTO and Federal Network for Professional, Scientific and Technological Education (RFEPT) databases of the Ministry of Education (MEC), especially the Nilo Peçanha Platform (PNP), data availability was verified from 2017 onwards. Thus, the period from 2017 to 2023 was adopted as the basis for the analysis.

Thus, this study used panel data covering 11 Teaching Units (TUs) of a Federal Institute over seven consecutive years. This structure resulted in panel data with a total of 77 observations (DMUs), allowing for longitudinal analysis of institutional performance. The panel configuration makes it possible to capture both variations over time and differences between units, giving greater robustness to the results obtained.

Data related to academic and cost indicators were considered. Table 17 presents the variables used in this study, along with their type and definition. To ensure an adequate level of discrimination, the number of inputs and outputs is consistent with the approach proposed by Dyson et al. (2001). The selection of variables was based on previous studies (Johnes, 2014, 2015; Rella & Vitolla, 2024; Kristof Witte & López-Torres, 2017). The final stage of variable validation was conducted by the team responsible for preparing the article.

Table 17 – Input and output variables

Type	Variable	Name	Description	Unit
Input	x_1	Number of Courses	Set of formal educational activities offered by the teaching unit.	Courses
	x_2	Total Budget Cost	Operating expenses of teaching units, including personnel expenses (permanent and temporary teaching staff and administrative and support staff) and other operating costs.	R$
	x_3	PNAE Budget	Costs related to the implementation of the National Student Food and Assistance Programme (PNAE).	R$
	x_4	Number of Enrolments	Students with active enrolment for at least one day in the reference year.	Enrolments
Desirable Output	y_{g1}	Number of Graduates	Number of students who graduated.	Graduates
	y_{g2}	Number of Institutional Projects	Number of research and extension projects developed during the period.	Projects
Undesirable Output	y_{b1}	Number of Dropouts	Number of students who lost their connection with the institution before completing the course.	Dropouts

Source: Prepared by the author.

The data from the inputs x_1 and x_4, as well as the outputs y_{g1} and y_{b1}, were extracted from the Nilo Peçanha Platform (PNP), which is fed by information from the National Professional and Technological Education Information System (SISTEC) and other official databases (MEC/PNP, 2023).

The data from the inputs x_2 and x_3 were extracted from the Federal Government's Integrated Financial Administration System (SIAFI), a system used to record, monitor and control the budgetary, financial and asset management of federal public administration bodies (Brasil, 2025). For the purposes of this research, the Total Operating Budget (x_2) was constructed by aggregating the operating and personnel budget items.

Finally, the data for the output variable y_{g2} were obtained from the IFTO Unified Public Administration System (SUAP), the IFTO's institutional platform used for administrative and academic management. For analysis purposes, information on research and extension projects was consolidated into a single variable. The complete data set for each EU for the period 2017 to 2023 can be found in Appendices Chapter 4 – A4.1.

4.3.3 Model configuration

We adopted the Directional Distance Function (DDF), a linear programming-based model widely used to measure efficiency in contexts with multiple inputs and outputs, including undesirable variables (Arabmaldar et al., 2023; Fukuyama & Weber, 2010). The model allows estimating, for each decision-making unit (DMU), the degree of distance from the efficient frontier, simultaneously considering the possibility of reducing inputs and undesirable outputs, as well as expanding desirable outputs.

The DDF is particularly suited to evaluating multi-campus educational institutions, where the processes involved in producing results involve different types of costs and multiple dimensions of performance. By applying this model, it is possible to identify which units operate most efficiently in terms of resource use and which have the greatest room for improvement, thereby contributing to the strengthening of budgetary and institutional management. For further methodological details, see Chambers et al. (1996) and Chung et al. (1997).

The DDF model uses direction vectors 'g', which define how variables should be adjusted so that an inefficient unit reaches the efficiency frontier. In this study, a predefined directional vector was adopted, assigning negative values to undesirable outputs and positive values to desirable inputs and outputs. This configuration was defined based on the observed variation of the variables over the analysed period, which allows the projected adjustments to be proportional to the actual magnitudes of the data. The definition of the directional vector followed the methodological recommendations of Chambers et al. (1996), ensuring that the directions adopted were compatible with the scale of the variables, as well as promoting greater clarity in the interpretation of the results.

We opted to use the DDF model with variable returns to scale (VRS) and input orientation. This configuration was chosen due to the nature of the input variables, which are mostly composed of costs, such as personnel expenses, investment, and overhead**.** Thus, the model allows us to estimate how much each input can be proportionally reduced while maintaining constant production levels, so that the DMU achieves full efficiency.

The directional vector adopted in this study was defined as unitary and constant across all DMUs, with a value of 1 assigned to each input and output. While this simplification facilitates implementation and enables consistent evaluation across units, it does not consider the scale of observed values. As a result, the β values represent non-proportional directional distances from the meta-frontier, and their interpretation as efficiency measures requires caution.

Although the conversion formula Efficiency $= 1/1 + \beta$ is commonly used in the literature, it assumes proportionality between the directional vector and the values observed for each

DMU. In this study, this formula is applied solely to facilitate comparative analysis, and the implications of using a fixed directional vector are acknowledged as a methodological limitation.

The analysis was carried out using data from 2017 to 2023, using a single efficiency frontier for the entire period, characterised as a meta-frontier. This approach allows for the assessment of the relative efficiency of units over time based on a common reference point, which ensures consistency and comparability of results between different years (Panwar et al., 2022). The results were obtained using MAXDEA software version 12.2 (MaxDEA, 2025).

To deepen the analysis and make comparisons fairer, teaching units (TUs) were segmented based on the institutional typology established by Ordinance No. 713 (MEC, 2021), which classifies IF units according to their size and operational characteristics. This categorisation avoids comparisons between units with very different profiles, such as small units compared to others with vastly superior resources. By grouping TUs into more similar profiles, the conditions for more accurate diagnoses and more balanced comparisons are expanded.

Finally, the meta-frontier approach was applied, which allows the efficiency of each EU to be assessed both within its group and in relation to a common technological frontier. This methodology is particularly useful when comparing distinct groups that are subject to different structural conditions. Efficiency was broken down into two components: (i) relative efficiency within the group and (ii) the Metatechnology Ratio (MTR), which represents the distance between the group frontier and the global meta-frontier (O'Donnell et al., 2008).

4.4 Analysis of Results

This section presents the results of the performance evaluation of the teaching units of an IF. The analysis considers multiple institutional dimensions and allows for the observation of efficiency patterns, variations over time, and differences between them.

4.4.1 Efficiency indices

The inefficiency score β, obtained using the DEA-DDF model, represents the potential adjustment required for a DMU to reach the efficient frontier. This value indicates how much the input variables could be proportionally reduced. Thus, a DMU is considered efficient when $\beta = 0$, which indicates that their results are fully aligned with the model's efficiency frontier. Table 18 shows the efficiency scores of the 11 TUs analysed over the period, totalling 77 observations (DMUs).

Table 18 – Efficiency scores

Teaching Units (TUs)	DMUs							Average	Median
	2017	2018	2019	2020	2021	2022	2023		
Palmas	0,440	0,442	0,453	0,769	1	0,788	1	0,699	0,769
Araguatins	0,702	0,817	1	0,528	0,655	0,787	0,754	0,749	0,754
Paraíso do Tocantins	0,556	0,638	0,664	1	0,530	0,613	1	0,714	0,638
Araguaína	0,853	0,734	0,883	0,917	0,582	1	0,652	0,803	0,853
Porto Nacional	0,719	0,798	1	0,732	0,544	0,388	0,505	0,670	0,719
Gurupi	0,554	0,561	0,549	0,450	0,632	1	0,828	0,653	0,561
Dianópolis	0,879	0,908	1	1	0,996	1	1	0,969	1
Colinas do Tocantins	0,652	0,760	0,659	1	0,818	0,705	0,444	0,720	0,705
Pedro Afonso	0,892	1	1	0,905	0,832	0,853	0,947	0,919	0,905
Formoso do Araguaia	1	1	0,825	0,923	0,949	1	1	0,957	1
Lagoa da Confusão	1	1	1	0,915	1	0,923	1	0,977	1
Average	0,750	0,787	0,821	0,831	0,776	0,823	0,830	**0,803**	-
Median	0,719	0,798	0,883	0,915	0,818	0,853	0,947	-	-
Standard Deviation	0,179	0,182	0,208	0,199	0,187	0,204	0,216	-	-

Source: Prepared by the author.

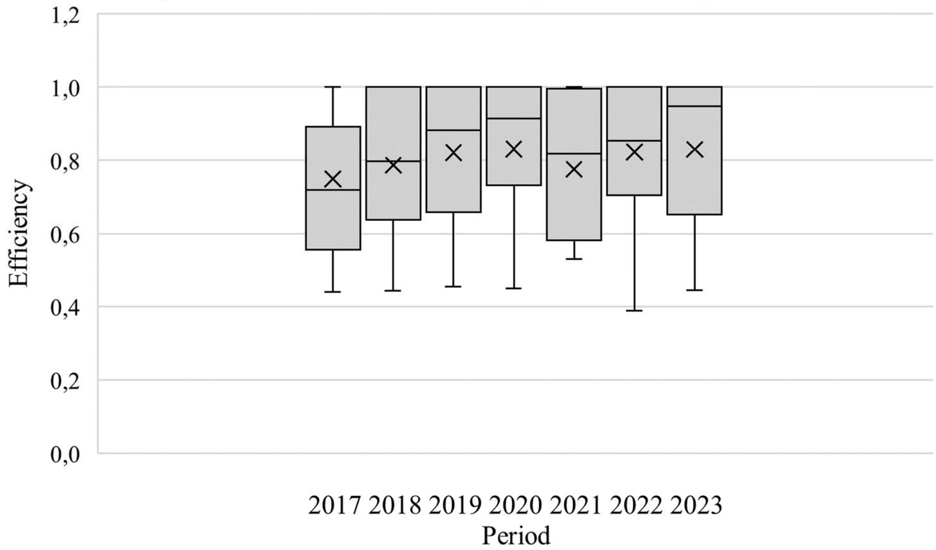
The annual averages and medians of efficiency for the set are also indicated. It can be seen that no teaching unit maintained full efficiency throughout the period analysed. The Lagoa da Confusão unit performed particularly well, with an average efficiency of 0.977, serving as a benchmark for the other units in the sample. Although it did not achieve full efficiency in all cycles, this unit operated consistently close to the efficiency frontier over time. This pattern suggests stability in the use of resources, although opportunities for adjustment remain at specific times.

The institution presented an average efficiency of 80.3% over the period analysed. This result reflects the performance of some of the units evaluated, with 24 of the 77 DMUs (31%) operating at the efficiency frontier. According to the input-oriented DDF model, a DMU located on this frontier is one that achieves the maximum feasible reduction in inputs while maintaining constant outputs, as defined by the directional vector. Under these conditions, there is no possibility of simultaneous improvement in any variable without compromising another dimension of performance, which qualifies this unit as a benchmark for the others in the sample.

The boxplot in Figure 9 shows the annual distribution of efficiency scores. The median was higher between 2019 and 2023, suggesting that units were closer to the efficient frontier during those years. In 2017, the median was the lowest of the period, revealing lower performance in most units that year. Although there are variations in the quartiles over time, the graph does not show significant outliers, which reinforces the consistency of the results observed.

After continuous growth in average institutional efficiency between 2017 and 2020, a decline was observed in 2021, coinciding with the second year of the COVID-19 pandemic. In this cycle, operational constraints caused by the adoption of remote learning and the suspension of face-to-face activities may have negatively influenced the results. This behaviour is in line with the OECD's analyses (2021), which identified difficulties faced by educational institutions in maintaining their performance levels, especially during the return to face-to-face activities.

Figure 9 - Patterns of variability in efficiency scores



Source: Prepared by the author.

From 2022 onwards, the indices rose again, with 2023 returning to the performance levels observed before the decline. This progress may be associated with the administrative reorganisation of educational institutions, the resumption of face-to-face activities and the incorporation of practices developed during the adaptation period, such as the expanded use of digital tools and the improvement of internal processes.

In analysing the results, it is possible to identify common characteristics among the DMUs with the best performance throughout the series. The units classified as efficient operated, on average, with a lower volume of resources. As the model adopted is input-oriented, efficiency was determined by the ability to reduce inputs while maintaining output levels. This shows that institutional efficiency is more associated with the strategic allocation of resources than with their absolute availability.

A comparison between the ten most efficient DMUs and the ten least efficient reinforces this trend. For this analysis, monetary values were converted from Brazilian reais (R$) to US dollars (US$), although the original data remains expressed in the national currency (R$). The units operating on the border had average total costs (operating and staff) of approximately US$ 1.4 million and spent US$ 56,000 on student assistance (PNAE). In contrast, the least efficient units recorded, on average, US$ 4.5 million in total operating expenses and US$ 165,000 directed to PNAE — values approximately three times higher than those found in units operating at the efficiency frontier.

These results reinforce that institutional efficiency depends less on the volume of available resources and more on strategic management and the ability to allocate these inputs effectively to achieve better results. The individual data supporting this analysis are available in the Appendices Chapter 4 – A4.2.

4.4.2 Inefficiency indices and pair identification

In contrast to efficient DMUs, inefficient units are those in which the model identified opportunities for improvement. The DEA-DDF model allows individualised targets to be set for each input variable, indicating how much each input can be proportionally reduced for the unit to reach the efficiency frontier. This feature is especially useful for supporting evidence-based management actions, as it allows not only the level of performance to be identified, but also the adjustments needed to improve it (see Appendices Chapter 4 – A4.2).

The data obtained from identifying pairs (reference units) and associated targets enable more accurate operational diagnoses. In particular, it is possible to detect inputs with the greatest potential for adjustment and, as a result, propose specific strategies for their rationalisation. This approach is in line with efforts to improve public management by enabling interventions focused on the real needs of each unit.

Tables 19 and 20 illustrate this process using two selected DMUs: DMU 7 (Araguaína – 2023) and DMU 77 (Porto Nacional – 2023), respectively. The λ (lambda) values obtained in the optimal solution of the model indicate the relative contribution of each efficient unit to the definition of the targets of the analysed unit. As all reference units are efficient, they represent, by definition, examples of good institutional practices. For emphasis, the pairs with the highest weight (λ) in the composition of the targets are indicated in bold, as they are those that most influenced the definition of the efficiency frontier of the evaluated unit.

Table 19 – DMU 7 assessment – Araguaína 2023

	Variables	Unit Evaluated		Pairs		
		DMU 7 - β =0,348		**DMU 6**	DMU 22	**DMU 28**
		Observed	Goal	**λ=0,359**	λ=0,248	**λ=0,350**
x_1	Number of Courses	12	8	11	7	5
x_2	Total Budget (R$)	19.966.666	8.713.898	17.295.504	2.495.729	5.032.534
x_3	PNAE Budget (R$)	471.905	278.401	527.242	129.616	148.216
x_4	Number of Enrolments	1098	715	1322	438	349

Source: Prepared by the author.

Table 20 – DMU 77 assessment – Porto Nacional 2023

Variables		Unit Evaluated		Pairs		
		DMU 77 - β= 0,505		**DMU 28**	**DMU 30**	DMU 70
		Observed	Goal	**λ=0,495**	**λ=0,341**	λ=0,163
x_1	Number of Courses	21	9	5	12	14
x_2	Total Budget (R$)	18.704.715	7.274.170	5.032.534	4.268.362	20.371.946
x_3	PNAE Budget (R$)	456.220	230.473	148.216	179.905	586.207
x_4	Number of Enrolments	1878	694	349	499	2151

Source: Prepared by the author.

An analysis of the projected targets for the two units highlights the potential for proportional reductions in inputs while maintaining current performance levels. These estimated adjustments, calculated based on weighted combinations of efficient units, illustrate how the model can support management decisions, promote more strategic resource allocation and encouraging internal benchmarking.

4.4.3 Segmentation of Teaching Units (TUs)

To enable more balanced comparisons between units with similar operational profiles, this study segmented the WUs based on the official typology defined by Ordinance No. 713, dated 8 September 2021 (MEC, 2021). This regulation establishes objective institutional criteria for classifying TUs, considering the number of teaching and technical-administrative positions provided, the type of unit (such as regular, advanced or agricultural campus) and its organisational and territorial profile. It is important to note that the segmentation adopted was entirely normative, without the application of statistical grouping methods, which ensures greater alignment with the official guidelines of the Federal Network.

Table 21 presents the distribution of IFTO TUs according to these types. Each group represents a distinct institutional profile, allowing for a fairer analysis of relative efficiency between units that share similar structures. In practice, the types reflect different levels of complexity and institutional size.

Table 21 – Distribution of TUs

Group	Type Ordinance	TUs
1	IF Campus - 70/60 Agricultural	Colinas do Tocantins, Dianópolis e Paraiso do Tocantins
2	IF Campus - 70/45	Araguaína, Porto Nacional e Gurupi
3	IF Campus Advanced 20/13	Formoso do Araguaia, Pedro Afonso e Lagoa da Confusão
4	IF Campus - 90/70 Agricultural	Araguatins
5	IF Campus - 150/100	Palmas

Source: Prepared by the author.

By way of illustration, the code ‘70/60’ indicates, respectively, a forecast of up to 70 teaching staff and 60 technical-administrative staff for a given unit. Classifications such as “Agricultural” or ‘Advanced’ indicate specific vocations or a differentiated structure. This segmentation allows for the creation of normative groups with greater homogeneity in terms of institutional capacity, which strengthens the robustness of comparative analyses.

This organisation by group, based on institutional typology, underpins the application of the meta-frontier model (described in the following section) by providing a framework for comparing units operating under similar conditions.

4.4.4 Meta-frontier analysis

The relative efficiency of the units was also assessed using the meta-frontier model, which enables the comparison of distinct groups subject to different operating conditions but belonging to the same institutional system. This model considers two dimensions: efficiency in relation to the group-specific frontier (Within Group Efficiency) and efficiency in relation to the common frontier of the entire sample (Meta-efficiency).

Based on the ratio between these two measures, it is possible to calculate the Metatechnology Ratio (MTR), which reflects the relative technological distance of each group from the global frontier. The closer this value is to 1, the smaller the distance, indicating greater alignment between the group’s practices and those observed at the technological frontier.

The results, presented in Table 22, indicate that Group 3, composed of smaller institutional units, achieved the highest MTR (0.973), suggesting that these units operate with practices closely aligned with maximum efficiency. Group 2 follows (MTR = 0.882), displaying intermediate performance, while Group 1 (MTR = 0.826) showed a greater distance from the global frontier.

Table 22 – Results of the Meta-frontier Model

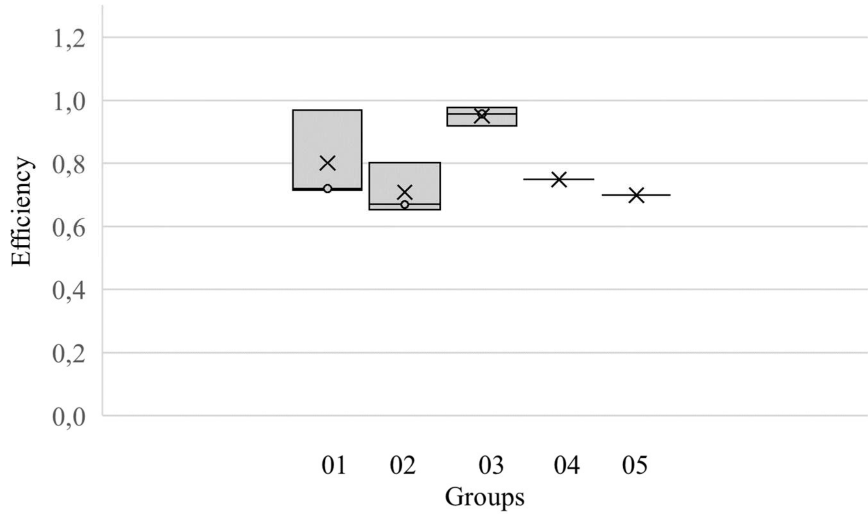
	Group	Meta-efficiency	Within Group Efficiency	MTR
	Global meta-frontier	0,803	-	-
1	Colinas do Tocantins, Dianópolis e Paraiso do Tocantins	0,801	0,969	0,826
2	Araguaína, Porto Nacional e Gurupi	0,709	0,803	0,882
3	Formoso do Araguaia, Pedro Afonso e Lagoa da Confusão	0,951	0,977	0,973
4	Araguatins	0,749	0,749	1
5	Palmas	0,699	0,699	1

Source: Prepared by the author.

Groups 4 (Araguatins) and 5 (Palmas), each consisting of a single teaching unit, were evaluated over a seven-year period using panel data, resulting in seven efficiency observations per unit. In both cases, the group-specific frontier was constructed exclusively from the historical performance of the unit itself. Thus, the within-group efficiency scores reflect the unit's average performance over time — 0.749 for Araguatins and 0.699 for Palmas. As the meta-efficiency scores are identical to these values (that is, one instance of these units belongs to the meta-frontier in at least one of the years), the resulting MTR for both groups is 1. Therefore, the observed value of 1 for the MTR is not an indication of full efficiency in each year, but a consequence of the model configuration for single-unit groups.

To complement the results in Table 22, Figure 10 shows the distribution of average efficiencies within each group. The graph indicates that Group 1 has the highest internal variability, with considerable dispersion among its units and the presence of a low-performing outlier. Group 2 also shows dispersion, albeit with a narrower interquartile range. In contrast, Group 3 demonstrates homogeneity, with values close to the frontier. Groups 4 and 5, each comprising a single unit, are represented in the graph by isolated points, with no variation.

Figure 10 - Distribution of average efficiencies within each group



Source: Prepared by the author.

The results indicate that teaching units operate under different structural and operational conditions, which impacts their performance. Analysis by group showed that smaller units (group 3) were more aligned with the meta-frontier, suggesting a more efficient capacity to convert resources into results.

Medium-sized units (groups 1 and 2) face more limitations in achieving equivalent performance, even with broader institutional structures. Groups 4 and 5, each consisting of a single unit, were kept as separate segments due to their specific operational characteristics.

These findings reinforce that greater institutional size does not necessarily lead to better results and highlight the importance of considering the size and complexity of units when planning the Federal Network. The analysis by groups reveals possible limits to economies of scale and can inform decisions on resource allocation, expansion, and institutional restructuring.

4.5 Discussion and Conclusions

This study proposed and applied a DEA-DDF model with input orientation and variable returns to scale to measure the efficiency of the Teaching Units (TUs) of a Federal Institute, adopting an intra-institutional approach. The analysis used data from 77 DMUs over seven years (2017 to 2023), extracted from public databases such as PNP, SIAFI, and SIAPENET. The model allowed not only to estimate the efficiency levels of the units but also to identify internal performance benchmarks, contributing to more contextualised institutional benchmarking practices.

The analysis of the results indicated that the most efficient units operated with lower volumes of inputs, maintaining satisfactory levels of performance. In contrast, units with higher volumes of resources but lower conversion into results showed higher levels of inefficiency. It was observed that, on average, the least efficient units operated with input values up to three times higher than those recorded in the most efficient group, especially in relation to the total cost budget and the PNAE budget. The identification of factors limiting the performance of each unit provided a detailed view of the main operational weaknesses, reinforcing the importance of strategic resource management.

By segmenting units based on institutional type and applying the meta-frontier model, it was possible to further analyse relative efficiency between different groups. The results reinforce the trend already observed in the individual analysis of units: smaller units performed better on average, while larger units faced additional difficulties related to administrative complexity and resource management. This finding was corroborated by the Metatechnology Ratio (MTR) values, which indicated a smaller technological gap between smaller units and the global efficiency frontier, suggesting greater alignment with the best practices observed in the sample.

Compared to previous approaches, this study presents relevant methodological advances in the field of efficiency assessment in educational institutions. While most studies have focused on the isolated analysis of a single dimension — teaching, research or extension — this research advances by simultaneously incorporating different institutional outcomes, including variables associated with school dropout rates.

Another distinguishing feature is the direct incorporation of undesirable variables through the application of the Directional Distance Function (DDF). In most of the literature, these variables are treated indirectly or even disregarded, which limits the ability of traditional models to reflect the complexity of the educational environment more accurately.

In addition, while many studies focus on inter-institutional analyses or static snapshots of a single period, this study goes further by conducting an internal assessment using panel data. This approach made it possible to track institutional performance over time, identify variations between the periods analysed, and establish more realistic internal benchmarks tailored to the specific characteristics of each unit.

The use of internal benchmarking, combined with meta-frontier analysis, broadened the practical applicability of the results by providing performance benchmarks tailored to the specific conditions of each unit. These findings can support Federal Network managers and regulatory agencies in formulating policies that are more aligned with the operational specificities of multi-campus units.

The model adopted in this study can be replicated in other multi-campus institutions or educational networks that operate under a similar organisational logic. Future studies should apply the model at the inter-institutional level, constructing composite indicators that integrate different dimensions of educational performance, thereby contributing to the strengthening of evidence-based public policies.

5 THE USE OF COMPOSITE INDICATORS TO ASSESS THE PERFORMANCE OF FEDERAL INSTITUTES OF EDUCATION, SCIENCE AND TECHNOLOGY

Status: Socio-Economic Planning Sciences

Abstract: Education plays a strategic role in the development and training of human capital, directly impacting the progress of nations. Simultaneously assessing the efficiency and effectiveness of educational systems is essential to ensure sustainable results that are aligned with institutional goals. This study proposes an integrated assessment approach based on Data Envelopment Analysis with Directional Distance Function, associated with the construction of a Composite Indicator that incorporates desirable and undesirable variables. The methodology was applied to 38 educational institutions, with panel data from 2017 to 2023. The analysis combined operational efficiency with institutional effectiveness verification, identifying different performance patterns. Sixteen IFs (42%) exceeded the average in both dimensions, while thirteen (34%) fell below. In addition, the most efficient units had enrolment costs approximately half those of the least efficient. The findings contribute to benchmarking practices and the improvement of public education policies.

Keywords: Data Envelopment Analysis; Composite Indicator; Directional Distance Function; Efficiency; Effectiveness.

5.1 Introduction

Quality education develops critical thinking, problem-solving and communication, skills that are essential for social progress. As a promoter of human capital, it plays a central role in inclusive development, making countries' growth trajectories dependent on the efficiency and effectiveness of their education systems (Barrenechea et al., 2023; Soto, 2024). The evaluation of this performance, therefore, becomes a priority for government authorities and educational organisations (Gulati et al., 2024).

Assessing institutional performance is a complex process, as it involves multiple indicators that reflect different dimensions of educational performance (Stumbriene et al., 2020). To deal with this complexity, composite indicators (CIs) have been widely used to integrate these variables into a single, comparable measure. This is a mathematical aggregation of individual indicators that measure multidimensional concepts and, in general, do not share the same unit of measurement (Camanho et al., 2023b).

Although several studies on the construction of ICs have been developed in recent years, many still use traditional methods with fixed weights or weights defined by subjective criteria, such as expert judgements, statistical analyses or arbitrary rules (Pereira et al., 2021). These approaches have limitations in providing management information that is aligned with the institutional context. In addition, the prior definition of weights is criticised for introducing subjectivities that compromise the comparability of results (Babaee et al., 2021). In view of this, Data Envelopment Analysis (DEA) has emerged as a methodological alternative, allowing the weighting and aggregation of variables through an optimisation process based on linear programming. This procedure eliminates the need for exogenous weights and reduces the likelihood of controversy in the results (Stumbrienė et al., 2025).

The use of DEA to construct ICs was popularised by Cherchye et al. (2007), through the approach known as 'Benefit of Doubt' (BoD). The BoD model is formally equivalent to the original CRS DEA model, with all indicators considered as outputs and a constant as input for all DMUs (Cherchye et al., 2007). The units evaluated can choose a set of weights that maximises their performance, provided that this same set does not assign a higher value to any other unit (Karagiannis & Karagiannis, 2018). Thus, DEA-based ICs constitute a consolidated methodological approach to assessing educational efficiency.

Different measures have been used in the literature to assess institutional performance, with emphasis on the concepts of effectiveness and efficiency (Duncombe & Yinger, 1997; Grosskopf & Moutray, 2001; Stukalina, 2010). Although ICs and DEA are widely used in the evaluation of Higher Education Institutions (HEIs), important limitations remain. Several studies perform static analyses, without the use of panel data that allow monitoring performance evolution over time (El Gibari et al., 2022; Szuwarzyński, 2019). Furthermore, most studies treat efficiency and effectiveness separately, without articulating these dimensions (El Gibari et al., 2018; González-Garay et al., 2019).

Another limitation observed concerns the use of composite indicators, which, although useful for comparison between institutions, tend to simplify organisational performance (Manikas et al., 2023; Stefana et al., 2021). The aggregation of multiple dimensions into a single measure can mask relevant structural differences, making it difficult to identify specific areas of excellence or need for improvement (Mariani & Ciommi, 2022).

Although recent advances have sought to overcome some of these limitations through dynamic and integrated approaches (Alqararah, 2023; Andonova & Trenovski, 2023; Jain & Gulati, 2024; Karagiannis & Ravanos, 2023), studies that systematically combine efficiency, effectiveness, and temporal evolution are still needed. This integration between different dimensions of performance is not unique to the education sector and has been explored in other organisational areas.

This joint analysis approach has already been applied in sectors such as occupational safety (Gomes et al., 2023), provision of public services (Shi et al., 2023) and power generation

(Jung & Schindler, 2023). However, in the field of education, this practice is still in its infancy, which reinforces the need for methodological advances capable of integrating multiple dimensions of institutional performance and guiding public policies with greater consistency.

In Brazil, the evaluation of the efficiency of Educational Institutions (IEs), especially the Federal Professional Education Network, is governed by standards that seek to improve public management and institutional performance. Judgment No. 2,267/2005 (2005b) was an important milestone in this process, followed by the creation of the Nilo Peçanha Platform (PNP) through Ordinance No. 1 of 2018 (MEC/SETEC, 2018), which enabled the collection and dissemination of data from institutions. More recently, Ordinance No. 646/2022 established the Budget Distribution Matrix, based on PNP indicators, to improve the allocation of resources to Federal Institutes and other institutions in the Federal Network.

Despite regulatory advances, the implementation of indicators still faces challenges. Low adherence to structured guidelines and practical difficulties in applying the guidelines prevent these instruments from supporting more efficient and results-oriented management (Nunes et al., 2021; Parente, 2023). Thus, even with relevant regulatory frameworks, institutional performance assessment remains limited in its ability to support decisions aligned with the institutions' objectives.

This study proposes an integrated assessment of the efficiency and effectiveness of Federal Institutes, based on a longitudinal analysis using panel data from 2017 to 2023. The empirical contribution lies in the identification of benchmarks and opportunities for continuous improvement. From a theoretical perspective, the study proposes an approach based on the construction of composite indicators with Directional Distance Functions (DDF), which allows for the simultaneous incorporation of desirable and undesirable variables. By applying this approach to institutional management, the results provide insights for both the improvement of management practices and methodological advances in the evaluation of educational performance.

The article is structured into five sections. The next section presents the main aspects of the literature that contextualise the study. Section 3 describes the methodological procedures. Section 4 presents the results. Discussions and conclusions are addressed in Section 5.

5.2 Theoretical framework

5.2.1 Performance evaluation in IEs

Performance evaluation in educational institutions is a widely adopted practice in several countries, requiring the collection of indicators that measure educational outcomes at different levels of education, as well as the availability and adequate allocation of resources (Griebeler et al., 2022). This practice allows comparisons between institutions and provides input for improving academic management (Camanho et al., 2023b).

Education systems are analysed at different levels, ranging from primary education to higher education. In primary education, studies generally assess schools' ability to promote good academic results for their students, considering factors such as initial knowledge levels and socioeconomic context. In this sense, some approaches broaden this perspective by integrating variables related to school flow, teacher training, infrastructure, and standardised test results into the efficiency analysis (Cardoso et al., 2021).

In higher education, the focus is predominantly on efficiency in the use of resources, investigating the capacity of institutions to optimise costs and inputs to generate results, such as student training, scientific production and outreach activities (Kristof Witte & López-Torres, 2017). The research uses data at different levels of aggregation, ranging from individual analyses — considering students, classrooms and schools — to regional studies involving cities, districts or countries (Johnes et al., 2017). In the context of HEIs, the approach varies between evaluations at the departmental level or between different institutions (Hernandez-Diaz et al., 2021).

In this scenario, the concepts of efficiency and effectiveness gain prominence because they represent complementary dimensions in institutional performance evaluation. Efficiency refers to the ability of IEs to maximise their results with the available resources (Kristof Witte & López-Torres, 2017). In turn, effectiveness is related to the degree to which previously established goals are achieved, such as completion rates, planned scientific output, or targets agreed upon in institutional plans (OCDE, 2008; Stukalina, 2010). Thus, an institution may be efficient but not effective if it uses its resources appropriately without achieving the expected objectives. The reverse is also possible: achieving goals at the expense of excessive use of resources, which constitutes effectiveness without efficiency.

From a methodological point of view, two techniques are widely used to assess performance and the factors that impact it: frontier methods and multilevel regression (Naderi, 2022). Frontier methods enable comparisons between institutions, identifying best practices and guiding continuous improvement processes (Rostamzadeh et al., 2021), while multilevel regression aims to assess the impact of different factors organised according to distinct hierarchical levels (Ferreira et al., 2021).

Although the literature presents important advances in the evaluation of educational performance, it is observed that, for the most part, studies address different dimensions of institutional performance in a fragmented manner, such as budget management, organisational structure, academic results, and internal processes (Figueiró et al., 2022;

Supriharyanti & Sukoco, 2023). Given this scenario, it is necessary to use integrated approaches, simultaneously incorporating multiple aspects related to the efficiency and effectiveness of institutions.

Among these approaches, frontier methods stand out as appropriate tools for measuring efficiency. These models allow for the evaluation of how units operate in relation to best practices observed in the sector (Nepomuceno et al., 2024). Among the most widely used techniques in this context is Data Envelopment Analysis (DEA), recognised as a robust methodology for evaluating efficiency in educational institutions (Camanho et al., 2024)

5.2.2 Composite indicators based on DEA models

Institutional performance evaluation often focuses on the results achieved, regardless of the amount of resources available (Pereira et al., 2024). To this end, the approach known as 'Benefit of Doubt' (BoD), developed based on Data Envelopment Analysis (DEA) by Cherchye et al. (2007), presents itself as an effective methodological solution. This technique combines multiple variables into a single synthetic measure, facilitating monitoring, communication of results, and decision-making (Pereira et al., 2021).

The composite indicators constructed based on DEA stand out for their flexibility in the endogenous definition of weights, determined by linear programming (Cherchye et al., 2008). This gives objectivity to the evaluation and avoids subjective weighting of the criteria analysed. The BoD model has been applied in several investigations in the field of education. The first studies using the BoD model focused on evaluating teacher performance in Belgium, integrating teaching and research variables (Rogge, 2011). Subsequently, it was found that specialisation in these areas contributes to better academic results (De Witte et al., 2013).

Methodological comparisons were also conducted, indicating that the variation in scores is more influenced by the internal configuration of the weights than by the choice between different models (Karagiannis & Paschalidou, 2017). Furthermore, De Witte e Schiltz (2018) proposed a robust version of the BoD, incorporating conditional variables to reduce the impact of outliers and external factors.

Recent studies reinforce the applicability of the BoD model in the education sector. Bas e Carot (2022) used the model to measure the multidimensional performance of teachers and group them into clusters. Szuwarzyński (2022), in turn, he applied the technique in Australian universities, highlighting greater efficiency in research-oriented institutions and better performance among foreign students.

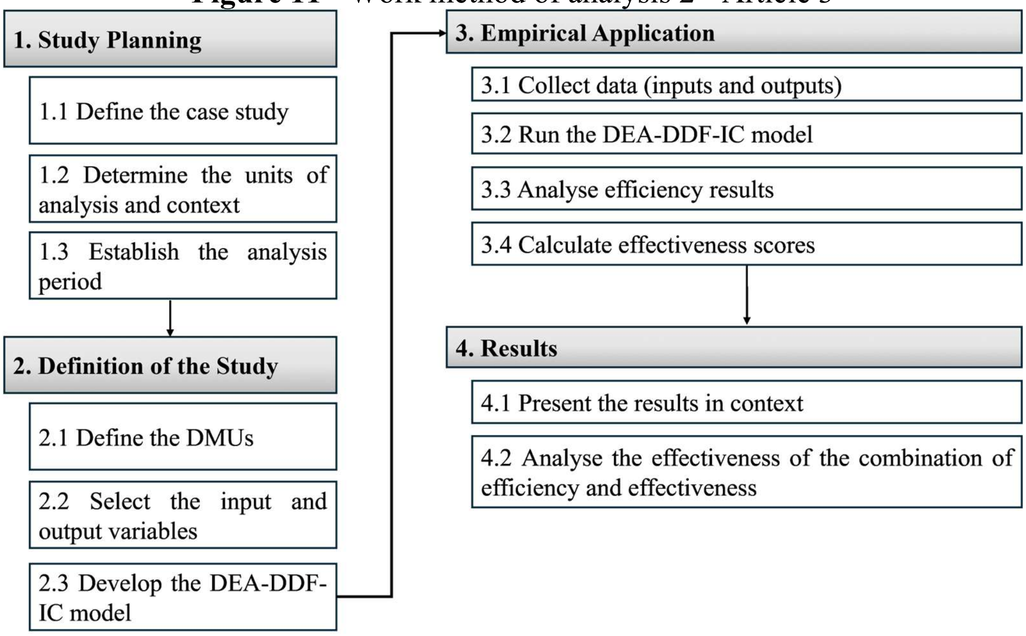
In Brazil, the use of BoD-based ICs is still in its infancy. One of the few studies identified evaluated the quality of undergraduate courses in public institutions, demonstrating the potential of the methodology to support improvement strategies (Torres et al., 2023). Thus, the use of ICs based on DEA models constitutes a consolidated methodological approach for assessing educational efficiency. Although widely used in international studies, its application in Brazil is still limited, especially with regard to the joint analysis of multiple institutional dimensions with longitudinal data. This study contributes to this advancement by proposing a model capable of simultaneously integrating aspects related to institutional efficiency and effectiveness.

5.3 Methodological Procedures

To develop this study, we adopted case-based research as our methodological approach. Case studies are appropriate when in-depth knowledge of research areas that have not been fully explored is required (Dubé & Paré, 2003). Specifically, we conducted a longitudinal case study covering a period of 7 years. This approach is suitable for unique cases because it has the potential to increase the internal validity of the result (Piran et al., 2016, 2020).

Furthermore, the use of panel data is a necessary condition for applying the benchmarking proposed in this study, as well as enabling the assessment of the impacts of external factors and managerial decisions on institutional performance over time. Figure 11 presents the four methodological steps adopted in the study.

Figure 11 - Work method of analysis 2 - Article 3



Source: Prepared by the author.

5.3.1 Context and selection of analysis units

With a presence in all regions of the country, Federal Institutes (IFs) play a strategic role in providing quality public education. Created by Law No. 11,892 (Brasil, 2008), they are part of the Federal Network for Professional, Scientific and Technological Education (RFEPCT), coordinated by the Brazilian Ministry of Education (MEC). Table 23 presents an overview of the institutions included in the sample, considering data for the year 2023.

Table 23 – Overview of IFs

Region	State	Institution	Number of Courses	Number of Enrolled Students	Number of Staff	Total Budget (U$)
North	Acre	IFAC	89	6.727	750	28.185.425,98
	Amazonas	IFAM	292	22.716	1.931	83.573.145,52
	Amapá	IFAP	143	7.923	639	22.840.770,24
	Pará	IFPA	552	29.943	2.548	108.485.772,09
	Rondônia	IFRO	219	28.778	1.305	59.674.043,07
	Roraima	IFRR	80	6.817	656	30.384.913,08
	Tocantins	IFTO	172	18.410	1.339	54.111.092,92
	Total by Region		1.547	121.314	9.168	387.255.162,90
Northeast	Bahia	IF Baiano	274	18.944	1.771	74.152.847,65
		IFBA	296	29.952	2.986	130.474.711,35
	Pernambuco	IF Sertão	208	11.604	1.053	42.466.963,78
		IFPE	354	27.448	2.344	119.396.383,15
	Alagoas	IFAL	231	23.491	1.917	95.498.944,80
	Ceara	IFCE	761	63.730	3.809	169.593.850,81
	Maranhão	IFMA	523	45.522	3.384	143.988.060,81
	Paraíba	IFPB	260	33.176	2.603	125.275.272,62
	Piauí	IFPI	395	31.670	2.538	104.893.173,46
	Rio Grande do Norte	IFRN	540	22.779	2.807	139.503.274,65
	Sergipe	IFS	123	11.543	1.275	58.564.465,69
	Total by Region		3.965	319.859	26.487	1.203.807.948,78
Midwest	Goiás	IF Goiano	251	18.193	1.463	73.276.885,30
		IFG	245	20.067	2.179	101.671.441,24
	Brasília	IFB	244	24.273	1.425	59.079.213,89
	Mato Grosso do Sul	IFMS	336	66.320	1.267	49.701.545,42
	Mato Grasso	IFMT	305	27.076	2.175	105.103.674,18
	Total by Region		1.381	155.929	8.509	388.832.760,04
Southeast	Minas Gerais	IF Sudeste	196	14.412	1.328	65.228.858,62
		IFMG	274	44.092	1.985	92.227.588,70
		IFNMG	272	21.917	1.449	60.475.220,53
		IFTM	182	11.992	1.159	53.524.268,72
		IF Sul de Minas	414	61.939	1.213	61.591.591,53
	São Paulo	IFSP	903	77.558	4.823	209.634.014,78
	Espírito Santo	IFES	342	62.843	2.975	158.525.166,25
	Rio de Janeiro	IFF	254	23.374	1.809	92.111.079,56
		IFRJ	169	43.483	2.040	92.785.102,12
	Total by Region		3.006	361.610	18.781	886.102.890,82
South	Rio Grande do Sul	IF Farroupilha	233	18.371	1.511	69.113.912,38
		IFRS	434	383.029	2.290	101.001.592,42
		IFSul	450	138.925	1.920	97.840.925,95
	Santa Catarina	IFC	192	20.195	1.898	82.769.802,00
		IFSC	512	40.970	2.782	126.694.996,86
	Paraná	IFPR	436	30.924	2.610	100.072.445,06
	Total by Region		2.257	632.414	13.011	577.493.674,66
Total			**12.156**	**1.591.126**	**75.956**	**3.443.492.437**

Source: Prepared by the author.

This study seeks to evaluate the efficiency and effectiveness of these institutions, considered units of analysis, based on a set of 38 IFs distributed nationwide. Between 2022 and 2023, IFs recorded a 13% increase in enrolment, rising from 1.4 to approximately 1.6

million students (MEC/PNP, 2023). Currently, the institutes have approximately 76,000 employees, including teaching and administrative staff. During the same period, the total budget for these institutions was approximately US$ 3.5 billion, which reinforces their educational relevance and importance in the allocation of public resources (MEC/PNP, 2023).

The choice of IFs as the object of analysis in this study is based on four main criteria: (i) their widespread reach and strategic role in regional development; (ii) institutional comparability, considering their common mission and course offering structure; (iii) the availability of consolidated and standardised data through the Nilo Peçanha Platform (PNP); and (iv) the existence of historical series organised in panel format, suitable for the application of benchmarking techniques.

5.3.2 Variable selection and data collection

After characterising the units analysed and defining the conceptual framework of the study, the variables and respective data sources were selected. To support this process, experts with recognised experience in topics related to public education management, public accounting, educational data registration and management, and efficiency assessment were consulted. The contributions of these professionals were fundamental in validating the methodological choices and ensuring the relevance and consistency of the information adopted.

Considering the longitudinal nature of the research, the time frame was defined based on the availability of data in the databases of the Federal Network for Professional, Scientific and Technological Education (RFEPCT), in particular the Nilo Peçanha Platform (PNP). The period analysed covers the years 2017 to 2023.

Data relating to academic and cost indicators were considered. Table 24 presents the variables used, accompanied by their respective descriptions. The selection was based on studies by Gori et al. (2025), Rella and Vitolla (2024), Witte and López-Torres (2017) and Johnes (2014), in addition to Ordinance No. 646, of 25 August 2022 (MEC, 2022).

In the academic sphere, four variables were considered: graduation rate per cycle (y_{g1}), student-teacher ratio (y_{g2}), occupancy rate (y_{g3}) and dropout rate per cycle (y_{b1}). As for the cost dimension, the variable current expenditure per enrolment (y_{b2}) was used.

All data were extracted from the PNP, fed by information from the National Professional and Technological Education Information System (SISTEC) and other official sources. The PNP was designed to gather data compatible with the specific characteristics of IFs, providing support for monitoring management indicators defined by the MEC in conjunction with control bodies (MEC/PNP, 2023). The data used are available in Appendices Chapter 5 – A5.1.

Table 24 – Variables used

Type	Variable	Name	Description	Unit
Desirable	y_{g1}	Graduation rate per cycle	This indicator measures the percentage of students who complete a cycle of enrolment	%
	y_{g2}	Student-teacher ratio	Ratio between total enrolments and total teachers	-
	y_{g3}	Occupancy rate	Ratio between enrolments per current cycle and vacancies in the current cycle	%
Undesirable	y_{b1}	Dropout rate per cycle	This indicator measures the percentage of dropouts in a cycle of enrolment	%
	y_{b2}	Current Expenditure per Enrolment	Indicates the average amount invested for each equivalent enrolment at the institution	R$

Source: Prepared by the author.

In addition to the variables used to assess efficiency, data on institutional goals were also collected throughout the period analysed. These data are essential for measuring effectiveness, allowing a comparison between the results achieved and the objectives previously defined. Both official goals established by MEC regulations and institutional goals present in the Institutional Development Plans (PDIs) of the IFs were considered.

5.3.3 Model configuration

This section presents the composite indicator (CI) model based on DEA-DDF to assess the performance of IFs. DEA measures the relative efficiency of homogeneous units (DMUs) by comparing multiple inputs and outputs, as proposed by Farrell (1957) and later developed by Charnes et al. (1978). Its application enables the comparison between units and the definition of benchmarks based on units operating at the efficiency frontier (Rostamzadeh et al., 2021). In addition, DEA optimises the weighting of variables, promoting equitable assessments. (Y. Zhao & Gong, 2023).

Although it was originally developed to measure efficiency, DEA has also been applied to the construction of ICs (Camanho et al., 2023b). An IC allows multiple dimensions to be aggregated into a single measure, facilitating the interpretation of results and the communication of findings (Calabria et al., 2018; Nardo et al., 2008).

In this study, the composite indicator was constructed based on a single, standardised fictitious input (value 1 for all DMUs), which eliminates differences in resource use and guides the analysis towards the results obtained, characterising an output-oriented modelling (Lovell & Pastor, 1995; Van Puyenbroeck, 2018). This formulation, aligned with the Benefit of Doubt (BoD) approach, is widely used in institutional evaluation (Cherchye et al., 2007). Additionally, the assumption of constant returns to scale (CRS) was adopted, as the focus lies on assessing performance outcomes rather than scale efficiency. This assumption ensures comparability across units by assuming a uniform production technology, consistent with the benchmarking rationale that underpins the construction of composite indicators (Camanho et al., 2023b).

The model considers six outcome variables: four desirable ones — enrolment per cycle, completion rate, student-teacher ratio, and occupancy rate — and two undesirable ones — dropout rate and current expenditure per enrolment. This combination allows for the integrated capture of different dimensions of institutional performance (Gulati et al., 2024). The construction of the IC, based on the approach of Camanho et al. (2023b), is presented below:

$$
\begin{aligned}
&\vec{D}\,(y, b, 1; g) = \max \beta \\
&s.t \sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{rj0} + \beta g_y \quad r = 1, \dots, s \\
&\sum_{j=1}^{n} b_{kj}\lambda_j \leq b_{kj0} - \beta g_b \quad k = 1, \dots, l \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \geq 0 \quad j = 1, \dots n
\end{aligned}
\tag{1}
$$

In formulation (1), b_{kj} are the indicators that must be reduced for DMU j, and y_{rj} are the indicators that must be increased. The variables λ_j represent the combination intensities, and the vector $g = (g_y, -g_b)$ defines the direction of adjustment. The parameter β indicates the degree of inefficiency of the DMU, that is, the maximum intensity of expansion of desirable indicators and contraction of undesirable indicators that can be achieved simultaneously. The efficiency measure can be expressed as $(1 - \beta)/(1 + \beta)$ when the directional vector uses observed values from the DMU itself.

In this study, the directional vector was defined as unitary and constant for all DMUs, with values of 1 for each input and output considered. This specification simplifies implementation and ensures comparability across institutions. However, it does not reflect the magnitude of the observed values, and the β values thus represent non-proportional directional distances from the frontier. Although the conversion formula Efficiency $= 1/1 + \beta$ is frequently used in the literature, its interpretation as a true efficiency measure assumes that the directional vector is proportional to each DMU's observed values. In this thesis, the formula is applied exclusively for comparative purposes, and the methodological implications of adopting a fixed vector are acknowledged as a limitation.

In addition, this formulation can be represented by its dual model, which seeks to minimise a weighted combination of desirable and undesirable indicators, with flexibility in the assignment of weights and the possibility of incorporating normative constraints (Camanho et al., 2023b). This dual version allows value judgements to be reflected and increases comparability between the units evaluated.

The analysis considered data from 2017 to 2023, with a single efficiency frontier applied to the entire time horizon. This ensures comparative consistency across the years evaluated (Panwar et al., 2022). The results were obtained using MAXDEA version 12.2 software (MaxDEA, 2025), which allows the explicit definition of undesirable variables and directional vectors.

In addition to efficiency assessment, the study also considered institutional effectiveness, measured based on the achievement of strategic goals. Effectiveness is treated as a complementary dimension to efficiency, allowing us to verify whether the units analysed not only optimise their resources but also achieve the established objectives. The effectiveness score (δ) of a DMU k in period t was calculated according to expression (2):

$$\delta_t^k = \frac{1}{2}\left(\frac{RDD_t^k}{20} + \frac{TO_t^k}{0{,}85}\right) \tag{2}$$

Two indicators were used: (i) Student-Teacher Ratio (RDD), whose target is defined in Law No. 13,005/2014 (National Education Plan), with a reference value of 20 students per teacher; and (ii) Occupancy Rate (TO), whose target is 85%, according to the Institutional Development Plans (PDIs) of the IFs themselves.

Each ratio expresses the degree of compliance with the respective target, with values equal to or greater than 1 indicating compliance or exceeding the target, and values less than 1 indicating a gap. The effectiveness score results from the simple arithmetic mean of these two ratios, reflecting the average degree of achievement of the targets by each unit. This approach provides greater analytical sensitivity by avoiding that different performances below the target are treated as equivalent (Gomes et al., 2023).

5.4 Analysis of Results

5.4.1 Efficiency scores

This stage of the analysis examined data from 2017 to 2023, covering the 38 IFs evaluated. Table 25 presents the results obtained over the period, highlighting the efficiency scores of each institution and their respective averages.

Among the IFs with the best average performance, the IF Sul de Minas, IFRS, IFRO, IFCE and IFB stand out, all with averages above 90% in the period analysed. The IF Sul de Minas recorded the highest average efficiency (94.5%), with three years of full efficiency and maintaining high levels in the others. This result indicates stability in institutional performance and proximity to the efficiency frontier. In total, 19 IFs (50% of the sample) exceeded the overall average for the period, which was 81.4%.

Table 25 – Efficiency scores

Classification	Institution	Period							Average
		2017	2018	2019	2020	2021	2022	2023	
1	IF Sul de Minas	93,5%	84,5%	92,5%	91,2%	100%	100%	100%	94,5%
2	IFRS	81,3%	84,0%	88,8%	90,5%	97,8%	100%	100%	91,8%
3	IFRO	93,9%	89,2%	93,0%	98,2%	100%	88,0%	79,9%	91,7%
4	IFCE	88,2%	93,8%	91,9%	86,0%	84,9%	95,3%	93,1%	90,4%
5	IFB	95,3%	86,7%	83,3%	92,2%	87,0%	100%	87,3%	90,2%
6	IFPB	76,8%	83,7%	95,5%	89,5%	97,4%	84,8%	82,5%	87,2%
7	IFRN	100%	87,5%	87,5%	85,6%	83,3%	83,2%	80,1%	86,7%
8	IF Goiano	82,5%	89,0%	90,9%	90,9%	83,9%	83,5%	79,8%	85,8%
9	IFSC	83,4%	87,7%	84,7%	82,4%	86,2%	92,1%	79,3%	85,1%
10	IFAM	85,5%	79,1%	86,5%	85,0%	83,4%	91,8%	84,5%	85,1%
11	IFMG	75,0%	78,3%	83,1%	81,0%	92,5%	88,8%	90,6%	84,2%
12	IF Sudeste MG	87,1%	93,4%	81,5%	79,9%	83,0%	82,9%	78,4%	83,7%
13	IFTO	90,3%	87,3%	85,9%	93,8%	79,6%	75,7%	73,3%	83,7%
14	IFAP	83,4%	89,9%	93,7%	80,8%	75,7%	76,6%	82,2%	83,2%
15	IFMA	77,2%	78,1%	86,2%	82,2%	84,4%	86,9%	85,7%	82,9%
16	IFMT	82,0%	81,3%	86,8%	83,3%	84,8%	83,8%	76,4%	82,7%
17	IFSUL	74,9%	81,0%	81,9%	77,3%	100%	84,7%	76,9%	82,4%
18	IFF	83,2%	78,6%	90,2%	80,1%	78,0%	86,4%	77,9%	82,0%
19	IFES	78,0%	79,3%	77,1%	80,3%	82,6%	86,8%	87,3%	81,6%
20	IFPR	88,4%	76,8%	80,0%	77,8%	92,1%	80,4%	72,0%	81,1%
21	IFPE	85,8%	80,8%	89,5%	79,2%	77,9%	76,3%	76,1%	80,8%
22	IFNMG	77,8%	81,3%	80,1%	84,4%	81,7%	81,9%	75,9%	80,4%
23	IFC	74,6%	75,6%	79,1%	79,9%	82,3%	89,2%	80,8%	80,2%
24	IFBA	88,2%	84,8%	88,3%	79,5%	75,8%	72,7%	70,7%	80,0%
25	IFPI	85,2%	81,5%	79,1%	77,5%	78,2%	82,4%	74,0%	79,7%
26	IFS	86,2%	74,9%	78,1%	75,9%	82,6%	81,6%	78,2%	79,6%
27	IFAL	82,0%	76,6%	81,2%	79,7%	75,6%	77,1%	78,4%	78,7%
28	IFPA	100%	76,8%	73,8%	73,1%	72,3%	72,8%	71,6%	77,2%
29	IFSP	74,5%	75,8%	77,1%	76,8%	79,1%	80,9%	72,9%	76,7%
30	IFMS	72,0%	71,2%	74,7%	77,4%	78,8%	83,4%	79,0%	76,6%
31	IF Sertão-PE	73,3%	74,6%	83,0%	82,0%	76,1%	73,7%	70,5%	76,2%
32	IF Farroupilha	71,9%	73,3%	86,0%	73,8%	73,6%	80,6%	72,2%	75,9%
33	IFG	70,5%	70,9%	66,5%	100%	71,3%	70,8%	65,9%	73,7%
34	IFAC	73,6%	73,8%	71,6%	75,6%	74,1%	73,8%	72,7%	73,6%
35	IF Baiano	76,9%	76,0%	76,8%	71,2%	68,8%	72,2%	67,5%	72,8%
36	IFTM	70,9%	72,5%	72,1%	75,7%	75,0%	72,0%	70,0%	72,6%
37	IFRJ	69,0%	69,3%	70,9%	68,5%	73,2%	74,0%	75,2%	71,4%
38	IFRR	65,5%	68,3%	79,8%	69,8%	72,1%	71,5%	71,8%	71,3%
	Average	81,5%	80,2%	82,9%	81,8%	82,2%	82,6%	78,7%	**81,4%**
	Median	82,0%	79,2%	83,0%	80,2%	82,0%	82,7%	78,1%	**-**

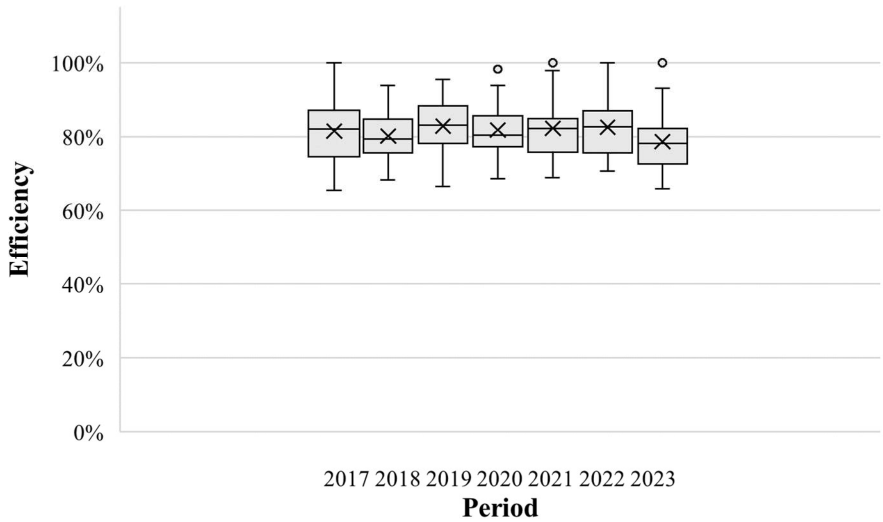
Source: Prepared by the author.

In contrast, institutions such as IFG, IFAC, IF Baiano, IFTM, IFRJ and IFRR had averages below 75%, reflecting a greater distance from the efficiency frontier. These results may be associated with structural or operational limitations, which reinforces the need for complementary analyses, such as the assessment of institutional effectiveness or the incorporation of context indicators.

The year 2022 recorded the highest number of IFs with full efficiency. In that year, three institutions operated exactly on the efficiency frontier, representing 8% of the total evaluated. Achieving this level indicates that these units maximised their results according to the DEA model criteria, with no additional room for improvement. Considering the period from 2017 to 2023, eleven DMUs (29%) achieved full efficiency and served as a benchmark for the evaluation of the other institutions in the sample.

Figure 12 shows the annual variation in the efficiency scores of the IFs between 2017 and 2023. It can be seen that, except for 2018 and 2023, the medians remained above 80%, with 2021 and 2022 standing out. This pattern suggests a concentration of institutions with higher performance in these periods. Between 2018 and 2021, the interquartile ranges were relatively narrow, indicating less internal variability. In contrast, the years 2020 and 2023 showed greater dispersion, in addition to the presence of outliers, reflecting greater heterogeneity among the IFs. Also noteworthy are the higher extreme values in 2021 and 2022, associated with units that operated at the efficiency frontier.

Figure 12 - Patterns of variability in efficiency scores



Source: Prepared by the author.

On average, 2022 showed the best institutional performance, with the highest average among the years evaluated. On the other hand, 2023 recorded the lowest average, as well as greater dispersion and a lower median, which may signal the effects of the post-pandemic period, with challenges associated with the resumption of in-person activities and the restructuring of institutional processes.

This scenario is supported by analyses from the OCDE (2021), which point to the impacts of the pandemic on the ability of educational institutions to maintain their performance levels. Such evidence reinforces the importance of longitudinal approaches, capable of capturing fluctuations in performance and revealing patterns of stability, decline, or recovery over time.

5.4.2 Inefficiency scores and benchmark pairs scores

The units classified as inefficient, according to the results of the DEA-DDF model applied to the construction of the IC, present margins for improvement measured by the inefficiency score (β). This measure expresses the relative distance of each unit from the efficient frontier and allows the definition of individualised targets, guiding the expansion of desirable variables and the reduction of undesirable ones.

The model also identifies, for each inefficient unit, a set of reference DMUs (pairs) located on the efficient frontier. These pairs are defined based on the λ (lambda) coefficients, which indicate the relative contribution of each efficient unit to the composition of the target. Higher values of λ represent greater influence in the construction of the projected efficiency point, serving as a reference for benchmarking actions.

Tables 26 and 27 illustrate the application of these concepts to two inefficient units: IF Baiano (2023) and IFSC (2023). In these tables, the pairs with the highest relative weight (λ) are highlighted in bold, indicating the main references for improvement.

Table 26 – DMU 7 assessment – IF Baiano 2023

Variables		Unit Evaluated		Pairs		
		DMU 7 - β= 0,4812		**DMU 190**	DMU 216	**DMU 252**
		Observed	Targets	**λ=0,214**	λ=0,184	**λ=0,514**
y_{g1}	Graduation rate per cycle	46,26	72,19	57,11	84,27	79,32
y_{g2}	Student-teacher ratio	17,18	25,44	30,76	23,40	25,60
y_{g3}	Occupancy rate	87,31	129,32	123,19	134,91	97,39
y_{b1}	Dropout rate per cycle	45,40	23,55	39,91	14,83	18,53
y_{b2}	Current Expenditure per Enrolment (R$)	23.245,67	12.059,63	11.073,07	16.627,95	7.989,95

Source: Prepared by the author.

Table 27 – DMU 231 assessment – IFSC 2023

Variables		Unit Evaluated		Pairs	
		DMU 231 - β= 0,2609		DMU 69	DMU 190
		Observed	Targets	**λ=0,109**	**λ=0,891**
y_{g1}	Graduation rate per cycle	34,61	54,35	31,62	57,11
y_{g2}	Student-teacher ratio	24,43	30,80	31,16	30,76
y_{g3}	Occupancy rate	90,54	123,03	121,75	123,19
y_{b1}	Dropout rate per cycle	55,84	41,27	52,51	39,91
y_{b2}	Current Expenditure per Enrolment (R$)	16.637,22	11.173,32	12.000,19	11.073,07

Source: Prepared by the author.

It should be noted that the Occupancy Rate may exceed 100%, especially in units that offer multiple intakes per year, use different shifts or adopt expanded forms of institutional space utilisation. In such cases, the number of enrolments may exceed the number of formal places provided for in the cycle, without constituting an error or inconsistency.

In the case of IF Baiano (β = 0,4812), the projected targets indicate a need for growth of approximately 56% in the completion rate per cycle, as well as significant reductions in undesirable variables, such as dropout rates and current expenditure per enrolment. For IFSC (β = 0,2609), it would be necessary to increase the graduation rate per cycle by approximately 57%, in addition to reducing the dropout rate and enrolment costs by approximately 30%.

A comparison between the ten most efficient DMUs and the ten least efficient DMUs shows an inverse relationship between efficiency and expenditure per enrolment. This indicator was adopted because it represents a measure of the use of operational resources in relation to the number of students served, allowing for a proportional assessment of institutional expenditure allocation. For this analysis, monetary values were converted from Brazilian reais (R$) to US dollars (US$), although the original data remain expressed in local currency. Units operating at the frontier recorded average current expenditure per enrolment of US$ 2,000. In contrast, the least efficient units had an average of US$ 4,000, twice as much as the efficient units.

These results indicate that institutional efficiency is more closely associated with resource management than with the volume available. The example reinforces the applicability of the DEA-DDF-IC model in setting targets compatible with the reality of each unit, through the weighted combination of efficient DMUs. Detailed data on inefficient units and projected targets can be provided upon request.

5.4.3 Effectiveness evaluation

The analysis of effectiveness showed variations in the achievement of institutional goals among IFs over the period from 2017 to 2023. Table 28 presents the annual effectiveness scores, organised by region, allowing direct comparison between institutions, based on the expression 2.

The results reveal that the overall average effectiveness was 1.15, indicating that, in aggregate terms, the IFs performed better than the established targets. The highest averages were observed in the Central-West (1.19) and Northeast (1.16) regions, while the Southeast recorded the lowest regional average (1.13). Among the positive highlights are the IFB (1.31), the IF Sul de Minas (1.25) and the IFPB (1.25), which maintained consistently high scores. In contrast, institutions such as IF Baiano (1.03), IF Farroupilha (1.03) and IFRR (0.99) had lower averages, with scores below 1 in some years, indicating recurring difficulties in meeting institutional effectiveness parameters.

Table 28 – Effectiveness scores

Region	Institution	Period							Average
		2017	2018	2019	2020	2021	2022	2023	
North	IFAC	1,02	1,04	1,01	1,12	1,09	1,11	1,10	1,07
	IFAM	1,12	1,19	1,28	1,22	1,19	1,29	1,22	1,22
	IFAP	1,18	1,14	1,26	1,18	1,11	1,21	1,36	1,20
	IFPA	1,45	1,10	1,04	1,02	1,03	1,05	1,04	1,11
	IFRO	1,28	1,08	1,24	1,21	1,22	1,12	1,11	1,18
	IFRR	0,96	1,01	0,99	0,95	0,96	1,10	0,99	0,99
	IFTO	1,35	1,29	1,21	1,22	1,10	1,07	1,11	1,19
								Average	**1,14**
Northeast	IF Baiano	1,13	1,10	1,08	0,96	0,97	1,05	0,94	1,03
	IFBA	1,33	1,26	1,22	1,14	1,08	1,10	1,00	1,16
	IF Sertão PE	1,01	1,00	1,08	1,13	1,06	1,04	1,00	1,04
	IFPE	1,29	1,21	1,28	1,19	1,17	1,15	1,07	1,19
	IFAL	1,24	1,14	1,16	1,16	1,11	1,14	1,12	1,15
	IFCE	1,20	1,25	1,22	1,17	1,18	1,34	1,29	1,24
	IFMA	1,13	1,12	1,22	1,14	1,20	1,28	1,25	1,19
	IFPB	1,13	1,22	1,31	1,34	1,39	1,18	1,15	1,25
	IFPI	1,25	1,17	1,14	1,09	1,16	1,21	1,06	1,15
	IFRN	1,49	1,15	1,17	1,16	1,21	1,23	1,09	1,22
	IFS	1,21	0,98	1,04	1,11	1,19	1,22	1,16	1,13
								Average	**1,16**
Midwest	IF Goiano	1,24	1,26	1,23	1,25	1,17	1,23	1,13	1,22
	IFG	1,04	1,08	0,92	2,29	1,09	1,10	0,93	1,21
	IFB	1,32	1,22	1,18	1,32	1,30	1,50	1,30	1,31
	IFMS	0,98	0,97	1,04	1,05	1,06	1,13	1,15	1,06
	IFMT	1,20	1,14	1,27	1,19	1,22	1,23	1,09	1,19
								Average	**1,19**
Southeast	IF Sudeste de MG	1,36	1,43	1,18	1,11	1,18	1,15	1,09	1,21
	IFMG	1,09	1,12	1,14	1,13	1,20	1,21	1,10	1,14
	IFNMG	1,04	1,18	1,09	1,13	1,15	1,21	1,08	1,13
	IFTM	1,06	1,06	1,03	1,08	1,12	1,08	1,03	1,07
	IF Sul de Minas	1,37	1,27	1,27	1,15	1,22	1,22	1,21	1,25
	IFSP	1,04	1,08	1,11	1,10	1,19	1,24	1,09	1,12
	IFES	1,15	1,17	1,09	1,15	1,11	1,20	1,01	1,13
	IFF	1,25	1,15	1,26	1,16	1,16	1,30	1,14	1,20
	IFRJ	0,99	1,00	1,01	0,99	1,07	1,05	1,07	1,03
								Average	**1,13**
South	IF Farroupilha	1,02	1,04	1,06	1,03	1,07	1,04	0,95	1,03
	IFRS	1,20	1,21	1,19	1,13	1,20	1,38	1,27	1,22
	IFSul	1,04	1,15	1,13	1,08	1,11	1,21	1,06	1,11
	IFC	1,07	1,06	1,12	1,13	1,17	1,29	1,22	1,15
	IFSC	1,22	1,23	1,20	1,15	1,23	1,31	1,14	1,21
	IFPR	1,19	1,02	1,06	1,07	1,25	1,17	1,05	1,12
								Average	**1,14**
Global Average									**1,15**

Source: Prepared by the author.

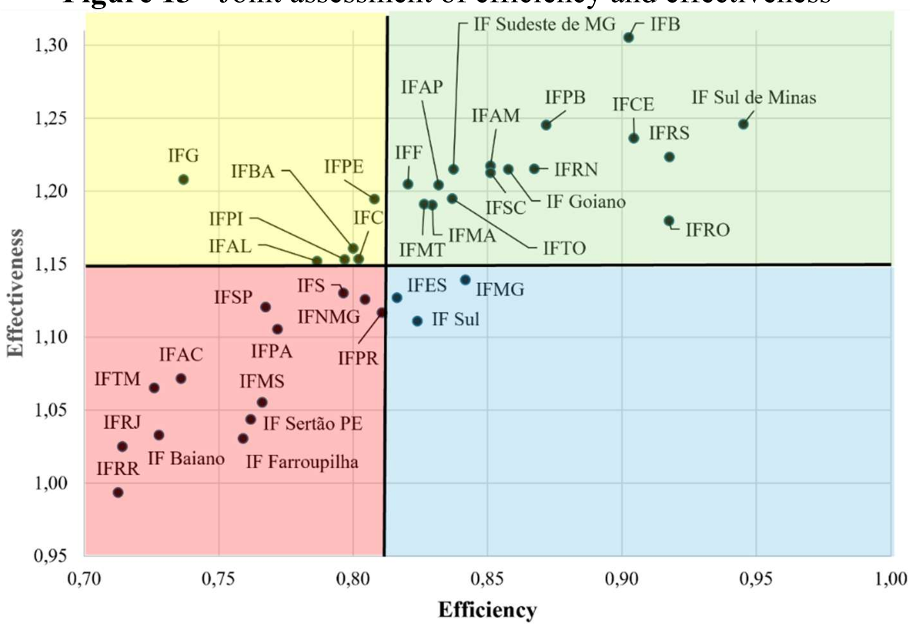
Although there are internal disparities, the results by region point to relatively consistent performance patterns among territorial groupings. This perspective allows for the identification of good institutional practices, as well as areas that require greater support, contributing to the improvement of management within the Federal Network.

To deepen our understanding of the factors associated with institutional performance, we conducted a correlation analysis between efficiency, effectiveness and the variables used in the model (Appendices Chapter 5 – A5.2 and A5.3). Efficiency showed a positive and statistically significant correlation with the student-teacher ratio ($r = 0{,}709; p < 0{,}001$), indicating that more efficient institutions tend to have more adjusted structures. A significant negative correlation was also observed with dropout rates per cycle and current expenditure per enrolment ($r = -0{,}749, p < 0{,}001$), suggesting that high levels of these variables are associated with lower performance.

In terms of effectiveness, positive correlations were found with the student-teacher ratio ($r = 0{,}737; p < 0{,}001$) and the occupancy rate ($r = 0{,}446; p < 0{,}001$), as well as a negative correlation with current expenditure per enrolment ($r = -0{,}575; r < 0{,}001$). These results suggest that more effective units tend to have more optimised academic structures and lower costs per student. In addition, the strong negative correlation between dropout rates per cycle and graduates per cycle ($r = -0{,}86,\ p < 0{,}001$) reinforces the consistency of the data, highlighting the antagonism between student retention and dropout rates.

To integrate the dimensions of efficiency and effectiveness, Figure 13 shows the average values of these indicators for the 38 IFs. The cut-off lines represent the averages of efficiency (X-axis) and effectiveness (Y-axis), allowing the identification of four performance groups.

Figure 13 - Joint assessment of efficiency and effectiveness



Source: Prepared by the author.

IFs with above-average performance in both dimensions are in the green area. The red area includes institutions with below-average results. Yellow represents effective but less efficient IFs, and blue represents efficient but less effective IFs. Sixteen institutions (42%) make up the best-performing group. Three IFs (8%) had above-average efficiency but below-average effectiveness. Six (16%) had above-average effectiveness but below-average efficiency. Thirteen IFs (34%) recorded the lowest results, indicating a need for institutional attention.

The analysis reinforces previous findings by showing that, although most institutions are well aligned with institutional goals, efficiency levels vary across cases. The joint assessment of efficiency and effectiveness provides a more complete understanding of performance and informs evidence-based management and public policy formulation.

5.5 Discussions and Conclusions

This study analysed the performance of Federal Institutes using an integrated approach based on efficiency and effectiveness. Efficiency was assessed using the DEA-DDF model, employing a composite indicator that incorporated desirable and undesirable variables. Institutional effectiveness was estimated based on the performance of institutions in relation to the targets set out in the Institutional Development Plans (PDIs) and regulations of the Brazilian Ministry of Education.

The results indicated that good institutional performance is not directly related to greater availability of resources. Institutions with higher budgets or larger numbers of staff did not necessarily perform more efficiently. Units that operated efficiently spent an average of US$ 2,000 per enrolment, while the least efficient spent around US$ 4,000 — twice as much. This contrast reinforces the importance of management in the rational use of public resources.

The DEA-DDF model, applied in conjunction with the Composite Indicator, made it possible to identify institutions with good performance and set individualised targets for those with lower efficiency, based on comparable units. This functionality contributes to the improvement of institutional management by providing objective inputs tailored to the reality of each IF.

Although most institutions reported average efficiency and effectiveness scores above the respective cut-off points, 34% of IFs scored below average in both dimensions. In addition, 8% combined high efficiency with low effectiveness, while 16% showed the opposite pattern, highlighting distinct institutional trajectories. These results indicate the importance of specific strategies to support the improvement of a significant part of the Federal Network.

The joint assessment of efficiency and effectiveness broadened understanding of how IFs work and revealed different institutional profiles. This integrated approach provides relevant inputs for strengthening public management and developing evidence-based education policies. As a future agenda, it is recommended to expand the model to include variables related to student retention, employability, and regional impact, in addition to revising institutional goals to better reflect local realities.

One limitation of this study concerns the level of analysis adopted. The assessment was conducted based on the 38 Federal Institutes as aggregate units, without considering the internal differences between the campuses that comprise them. Considering that the Network is made up of approximately 700 units with different realities, this approach may hide relevant inequalities within institutions. Future studies may explore more detailed analyses at the campus level, allowing for more accurate diagnoses and interventions tailored to local specificities.

6 FINAL CONSIDERATIONS

This research aimed to understand how Federal Institutes operate within complex and heterogeneous contexts by reconciling structural, operational, and performance-related dimensions at two analytical levels: intra and inter-institutional. The investigation was grounded in panel data and quantitative methods, allowing institutional behaviour to be observed over time and enabling the identification of contrasts between units and operational configurations.

To achieve this, a single and embedded case study was carried out, comprising two complementary strands of analysis. The first (Article 2), adopting an intra-institutional perspective, focused on the teaching units of a Federal Institute and assessed efficiency. Both desirable and undesirable variables were incorporated, and the analysis used panel data from 2017 to 2023, applying the Directional Distance Function under variable returns to scale. Units were categorised by institutional size, as defined in Ordinance No. 713/2021. This framework enabled the application of a metafrontier model, which revealed structural disparities across groups and supported the definition of individualised efficiency targets through internal benchmarking.

The second strand of analysis (Article 3), adopting an inter-institutional perspective, encompassed all 38 Federal Institutes operating in Brazil. It broadened the analytical scope by jointly assessing efficiency and effectiveness. A composite indicator was developed using the DEA-DDF model, incorporating desirable and undesirable variables in line with official educational goals. The panel data covered the same period (2017–2023), enabling the identification of regional and temporal patterns. Correlation analyses between efficiency, effectiveness, and operational variables were also performed.

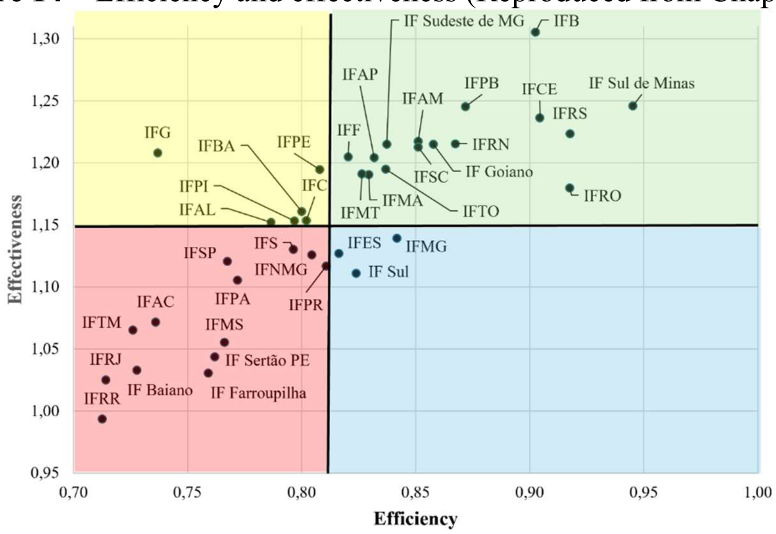
From a theoretical perspective, this research proposes an integrated model for institutional assessment by combining Data Envelopment Analysis (DEA), the Directional Distance Function (DDF), the application of metafrontier analysis, and the construction of a composite indicator. The first theoretical contribution lies in a systematic review of empirical applications of DEA in Higher Education Institutions. This review mapped predominant approaches, identified recurring methodological constraints, and highlighted the limited use of undesirable variables, longitudinal data, and studies addressing internal benchmarking or the evaluation of multi-campus institutions. The proposed model advances the field by aligning analytical methods with institutional characteristics, thereby supporting more accurate diagnoses.

In practical terms, the research findings are divided between the two strands of analysis. In the intra-institutional analysis (Article 2), key outcomes include the identification of efficiency in 11 teaching units over seven years, institutional segmentation based on official and operational criteria — which ensures greater equity in comparisons — and the definition of individualised targets based on internal benchmarking. In addition, the application of the metafrontier model enabled the identification of units whose practices were closer to the technological frontier. It was also observed that the least efficient units, on average, operated with input levels up to three times higher than those recorded in the most efficient ones, particularly in relation to the operating budget and student support.

In the inter-institutional analysis (Article 3), the main findings include the integrated assessment of efficiency and effectiveness across the 38 Federal Institutes from 2017 to 2023, the construction of a composite indicator capable of bringing together multiple dimensions of institutional performance into a single measure, and the identification of regional patterns and temporal variations that influence outcomes. Correlations were also observed, indicating that a higher volume of resources is not necessarily associated with better performance. Furthermore, it was found that the most efficient Institutes had, on average, approximately half the expenditure per enrolment compared to the least efficient ones, reinforcing the importance of management practices aimed at rationalising resources.

To summarise the inter-institutional analysis, Figure 14 — reproduced from Chapter 5 — presents the ranking of the 38 Federal Institutes based on their average efficiency and effectiveness scores over the period. The cut-off lines correspond to the average values of these indicators and allow for the identification of four distinct groups of institutional performance. The figure highlights the relative positioning of the Institutes in terms of efficiency and effectiveness, indicating that 16 institutions (42%) achieved above-average results in both dimensions. This representation consolidates the methodological approach by integrating multiple aspects of institutional performance into a single visual, thereby reinforcing its usefulness as a tool to support educational planning and management.

Figure 14 – Efficiency and effectiveness (Reproduced from Chapter 5)



Source: Prepared by the author

These results reinforce the role of integrated efficiency and effectiveness assessment as a strategic tool to support public education management. The adopted methodology enables the identification of asymmetries, the establishment of realistic targets, and the formulation of decisions grounded in empirical evidence. The articulation between theoretical and practical contributions demonstrates the applicability of the proposed model and its relevance across diverse institutional contexts.

One methodological consideration concerns the specification of the directional vector used in the DEA-DDF models. In this thesis, a unitary and fixed directional vector was adopted, with a value of 1 assigned to each input and output. While this simplifies implementation and ensures uniformity across DMUs, it does not reflect the actual magnitude of each variable. As a result, the estimated β values represent non-proportional distances from the frontier. Although the transformation formula $\text{Efficiency} = 1/1 + \beta$ is commonly used in the literature to interpret these results, it assumes proportionality between the directional vector and the observed values. In this study, this formula was used solely for comparative purposes, and this simplification is acknowledged as a limitation when interpreting efficiency scores.

Despite the methodological scope adopted, certain limitations must be acknowledged. The primary limitation concerns the reliance on secondary data from official sources, which restricted the inclusion of qualitative aspects such as student satisfaction, graduate employability, and regional impact.

By combining a systematic literature review, an intra-institutional analysis incorporating metafrontier modelling, and an inter-institutional analysis based on a composite indicator, this thesis presents a methodological framework for assessing performance in public educational institutions.

Future research could further explore the relationship between efficiency and effectiveness, aiming to identify consistent patterns or potential causal links. It is also recommended that qualitative and contextual variables be integrated into assessment models — either directly or through analytical segmentation — to better capture institutional specificities. The use of primary data and comparative case studies across educational networks represents a promising avenue for deepening the understanding of performance determinants and supporting the development of more context-sensitive policies.

APPENDICES CHAPTER 3

A3.1– Protocol for Systematic Literature Review - SLR

Research Protocol

Title: EFFICIENCY IN HIGHER EDUCATION INSTITUTIONS: AN ANALYSIS OF DATA ENVELOPMENT ANALYSIS APPLICATIONS.

Research Team:
Stakeholders: Higher Education Institutions, Managers and Researchers.

Review: Date: 2022/2023 Reviewed by:

1. Research Questions:
(1) How can the DEA technique be used to evaluate efficiency in HEIs? (2) What are the methodological approaches of the DEA technique (type, orientation, one-stage or two-stage analysis)? (3) What are the main input and output variables? (4) What are the main types of efficiency? (5) What are the main motivators and results of using the DEA technique when evaluating efficiency in HEIs?

2. Research Objective:
To provide a comprehensive and robust overview of academic publications on efficiency evaluation in Higher Education Institutions using the Data Envelopment Analysis (DEA) technique, identifying the type, orientation and main input and output variables of the DEA models used in the studies, as well as their main motivators and results.

3. Assess the Scope:

3.1 Width:	☐ narrow	☒ wide
3.2 Depth:	☐ superficial	☒ deep
3.3 Type of Review:	☐ aggregative	☒ configurative

4. Conceptual Framework:
The benefits of education accrue to both society and individuals and, as such, the provision of education in general in many countries is paid for, at least in part, by the public purse (J. Johnes, 2006; J. Johnes et al., 2017). Governments have generally allocated considerable portions of public resources to education, including higher education (Frio et al., 2018). These resources compete with other areas, such as health, security and the cost of the public structure (Henriques & Marcenaro-Gutierrez, 2021). According to Psacharopoulos (1996), it is essential to know the level of efficiency in relation to the use of these inputs, so that new allocations of resources can subsequently be justified.

Evaluating the efficiency of education spending in general has challenged researchers over the decades. The allocation of public resources and their efficient use are two closely related factors that force educational researchers to focus on evaluating the efficiency of institutions (Visbal-Cadavid et al., 2017). The education sector, especially higher education, is often characterized by being non-profit, the absence of product and input prices and the production of multiple outputs from multiple inputs, which makes it difficult to assess the efficiency of institutions (J. Johnes, 2006; Kristof de Witte & López-Torres, 2017).

Statistical methods are used to measure the level of efficiency of the higher education system. The options for frontier techniques to study the efficiency of this system include non-parametric methods based on mathematical optimization models - Data Envelopment Analysis - DEA and parametric methods - Stochastic Frontier Analysis - SFA (Kristof de Witte & López-Torres, 2017). Considering these techniques, it is important to highlight the application of DEA in education, as it is one of the five main areas of application of this methodological approach (Emrouznejad & Yang, 2018; Liu et al., 2013).

In this sense, the general objective of this study is to provide a comprehensive and robust overview of academic publications on the evaluation of efficiency in Higher Education Institutions (HEIs) using the DEA technique.

5. Time Horizon:
No time limit

6. *String* de Research:
*TITLE-ABS-KEY ((‘efficiency’ **OR** ‘economic efficiency’ **OR** ‘performance measurement’) **AND** (‘universities’ **OR** ‘higher education’) **AND** (‘data envelopment analyses **OR** ‘DEA’)) **AND** SUBAREA (‘BUSI’ OR ‘ECON’ OR ‘ENG’ OR ‘MULT’) **AND** LIMIT-TO (DOCTYPE, ‘ar’)*

7. Research Sources:
Scopus and Web of Science

8. Research Approach:

☒ Direct Search ☐ Contact Experts ☐ Snowball ☐ Other

9. Eligibility Criteria:

9.1 Inclusion Criteria:	Documents dealing with the DEA technique. Documents on efficiency evaluation in HEIs. Documents that present the results of implementing the DEA technique to evaluate efficiency in HEIs.
9.2 Exclusion Criteria:	Documents that do not meet the inclusion criteria.

10. Data Analysis:

10.1 Cintometric Analysis:	☒ Scientific Development		
10.2 Bibliometric analysis:	☐ Research Performance		☒ Scientific Mapping
10.3 Content Analysis:	☒ Aggregative	☐ Thematic Analysis	☐ Structural Analysis

11. Data Synthesis:

11.1 Aggregative Synthesis:	☐ Quantitative Meta-Analysis	☐ Qualitative Meta-Analysis
11.2 Configurative Synthesis:	☒ Meta-Synthesis	☐ Other

Source: Adapted from Cardoso Ermel et al. (2021).

A3.2 – Primary Studies Included in the Review

Cód.	Title	Author(s), Year
I1	A Study on the Spatial–Temporal Evolution of Innovation Efficiency in Chinese Universities in the Context of the Digital Economy	Gao; Wang, 2023
I2	Benchmarking of academic departments using data envelopment analysis (DEA)	Alam; González; Raman, 2023
I3	Centralised resource allocation using Lexicographic Goal Programming. Application to the Spanish public university system	Lozano; Contreras, 2022
I4	Preventive Risk Management of Resource Allocation in Romanian Higher Education by Assessing Relative Performance of Study Programs with DEA Method	Olariu; Brad, 2022
I5	Effects of Local Government Behavior on University–Enterprise Knowledge Flow: Evidence from China	Zhang; Wang, 2022
I6	A Comparative Study on the Efficiency of R&D Activities of Universities in China by Region Using DEA–Malmquist	Du; Seo, 2022
I7	Efficiency measurement for hierarchical network systems using network DEA and intuitionistic fuzzy ANP	Shariatmadari Serkani et al., 2022
I8	Assessment of Research Efficiency in China's Universities Based on Data Envelopment Method	Qi; Dou; Li, 2022
I9	Evaluation of Learning Efficiency of Massive Open Online Courses Learners	Li, 2022
I10	Efficiency of the Education System (Primary, Secondary and Tertiary) in Particular Voivodeships of Poland	Brzezicki; Pietrzak; Cieciora, 2022
I11	Academic efficiency of engineering university degrees and its driving factors. A PLS-DEA approach	Zuluaga-Ortiz; Delahoz-Dominguez; Camelo-Guarín, 2022
I12	Analysis of regional differences in government funding performance in higher education – A case study of China	Fu; Heenko, 2022
I13	Chinese Provincial Difference in the Efficiency of Universities' Scientific and Technological Activities Based on DEA with Shared Input	Zhao et al., 2022
I14	Do socially responsible higher education institutions contribute to sustainable regional growth and innovation?	Pedro; Leitão; Alves, 2022
I15	Is There Complementarity between Teaching and Research? Evidence from Pakistani Higher Education Institutions	Gebru; Khan; Raza, 2022
I16	Operating efficiency in Chinese universities: An extended two-stage network DEA approach	Chen et al., 2021
I17	Research performance evaluation of Chinese university: A non-homogeneous network DEA approach	Ding et al., 2021
I18	Quality assessment of scientific papers: Excellence or legitimization of research practices?	De Almeida Vilela et al., 2021
I19	Efficiency of European universities: A comparison of peers	Herberholz; Wigger, 2021
I20	Measuring the Efficiency of Turkish State Universities Based on a Two-Stage DEA Model	Kocak; Orkcu, 2021
I21	Efficiency Analysis of Higher Education Institutions: Use of Categorical Variables	Ranjan; Singh, 2021
I22	The Scientific and Technological Innovation Performance of Chinese World-Class Universities and its Influencing Factors	Chen; Shu, 2021
I23	Allocation Efficiency of Higher Education Resources in China	Ma; Li, 2021
I24	Research on the Dynamic Evolution of Scientific and Technological Innovation Efficiency in Universities and Identification of Influencing factors - Based on Markov Chain Estimation and GMM Model	Luo, 2021
I25	The Construction and Empirical Research on the Dynamic Evaluation Model of University Science and Technology Output	Sun; Yuan; Chen, 2021
I26	Evaluation of expenditure efficiency of the Federal Institutions of Brazilian Higher Education	Rolim et al., 2020
I27	Assessing and classification of academic efficiency in engineering teaching programs	Hoz; Zuluaga; Mendoza, 2021
I28	DEA model and efficiency of universities - case study in Slovak Republic	Navickas; Grenčíková; Krajčo, 2021
I29	Efficiency of the teaching-industry linkage in the Australian vocational education and training	Tran, 2021
I30	A non-parametric assessment of efficiency of South African public universities	Nkohla et al., 2021
I31	An Empirical Study on Scientific Research Performance of Universities in Different Regions of China Based on PCA and Malmquist Index Method	Xia et al., 2021
I32	Incubator efficiency vs survival of start-ups	Zapata-Guerrero et al., 2020
I33	Relation between Russian universities and regional innovation development	Rodionov; Velichenkova, 2020
I34	Social media advertising efficiency on higher education programs	Cordero-Gutiérrez; Lahuerta-Otero, 2020
I35	A model for sector restructuring through genetic algorithm and inverse DEA	Guijarro; Martínez-Gómez; Visbal-Cadavid, 2020

Cód.	Title	Author(s), Year
I36	Factors affecting relative efficiency of higher education institutions of economic orientation	Blecich, 2020
I37	A DEA approach towards exploring the sustainability of funding in higher education. Empirical evidence from Romanian public universities	Dumitrescu et al., 2020
I38	The efficiency of universities in achieving sustainable development goals	Perović; Kosor, 2020
I39	Measuring the efficiency of the Colombian higher education system: a two-stage approach	Moreno-Gómez; Calleja-Blanco; Moreno-Gómez, 2020
I40	The Efficiency of Public Higher Education Institutions: A Meta-Analysis	Mikušová, 2020
I41	Measurement of efficiency of didactic activities of public universities of technology in Poland: Directional distance function with undesirable output approach	Brzezicki; Rusielik, 2020
I42	A Nonradial Super Efficiency DEA Framework Using a MCDM to Measure the Research Efficiency of Disciplines at Chinese Universities	Su et al., 2020
I43	The Total Efficiency of Teaching Activity of Polish Higher Education Institutions	Brzezicki; Pietrzak; Cieciora, 2020
I44	The Efficiency of Public and Private Higher Education Institutions in Poland	Brzezicki, 2020
I45	Accelerating a technology commercialization; with a discussion on the relation between technology transfer efficiency and open innovation	Sutopo; Astuti; Suryandari, 2019
I46	Technical efficiency heterogeneity of tertiary institutions in Vietnam: A meta-frontier directional technology approach	Villano; Tran, 2019
I47	Efficiency and productivity in transfer units of scientific research results in Mexico	Juárez; Sánchez, 2019
I48	Measuring the efficiency of higher education: Case of Bosnia and Herzegovina	Figurek et al., 2019
I49	How efficiently do elite US universities produce highly cited papers?	Wohlrabe; Anegon; Bornmann, 2019
I50	Efficiency evaluation of parallel interdependent processes systems: an application to Chinese 985 Project universities	An et al., 2019
I51	Assessing the performance of UK universities in the field of chemical engineering using data envelopment analysis	González-Garay et al., 2019
I52	Efficiency of public spending on higher education: A data envelopment analysis for Eu-28	Kosor; Perovic; Golem, 2019
I53	Efficiency assessment of public universities in South Africa, 2009-2013: Panel data evidence	Myeki; Temoso, 2019
I54	Does merging improve efficiency? A study of English universities	Papadimitriou; Johnes, 2019
I55	How to measure research efficiency in higher education? Research grants vs. publication output	Gralka; Wohlrabe; Bornmann, 2019
I56	University Brand as a key factor of Graduates Employment	Blanco; Bares; Hrynevych, 2019
I57	Exploring efficiency differentials between Saudi higher education institutions	Mousa; Ghulam, 2019
I58	Efficiency in public higher education on Argentina 2004–2013: institutional decisions and university-specific effects	Quiroga-Martínez; Fernández-Vázquez; Alberto, 2018
I59	Shapley value-based multi-objective data envelopment analysis application for assessing academic efficiency of university departments	Abing et al., 2018
I60	Approaching effects of the economic crisis on university efficiency: a comparative study of Germany and Italy	Lehmann et al., 2018
I61	Measuring the Efficiency of Colleges at the University of Al-Qadisiyah-Iraq: A Data Envelopment Analysis Approach	Drebee; Razak, 2018
I62	Data envelopment analysis techniques – DEA and Malmquist indicators, in CRS mode, for measuring the efficiency of Romanian public higher education institutions	Lita, 2018
I63	A research framework for data envelopment analysis with upper bound on output to measure efficiency performance of higher learning institution in Aceh province	Abdullah et al., 2018
I64	The influence of regulatory frameworks on research and knowledge transfer outputs: An efficiency analysis of Spanish public universities	Berbegal-Mirabent, 2018
I65	An efficiency analysis of grant awarded research projects: A case study of a Malaysian public university	Khurizan; Mustafa; Abd Hamid, 2018
I66	The Index Number Problem with DEA: Insights from European University Efficiency Data	Klumpp, 2018
I67	Assessment of TFP in European and American higher education institutions - Application of Malmquist indices	Wolszczak-Derlacz, 2018
I68	Transfer Benefit Evaluation on University S&T Achievements based on Bootstrap-DEA	Di, 2018
I69	Measuring efficiency of teaching process and faculty in transition states using DEA analysis	Perovic; Bojanic; Nerandzic, 2017
I70	The efficiency of higher education institutions in England revisited: comparing alternative measures	Johnes; Tone, 2017

Cód.	Title	Author(s), Year
I71	Exploring the efficiency of Mexican universities: Integrating Data Envelopment Analysis and Multidimensional Scaling	Sagarra; Mar-Molinero; Agasisti, 2017
I72	Efficiency of state universities in Turkey during the 2014–2015 academic year and determination of factors affecting efficiency	Türkan; Özel, 2017
I73	Productivity development of Norwegian institutions of higher education 2004-2013	Edvardsen; Førsund; Kittelsen, 2017
I74	Quality of teaching and research in public higher education in Poland: Relationship with financial indicators and efficiency	Kudła; Stachowiak-Kudła; Figurski, 2016
I75	A three-stage DEA model to evaluate learning-teaching technical efficiency: Key performance indicators and contextual variables	Fuentes; Fuster; Lillo-Bañuls, 2016
I76	A network DEA quantity and services model: An application to Australian university research services	Lee; Worthington, 2016
I77	Comparing the Efficiency of Italian Public and Private Universities (2007–2011): An Empirical Analysis	Agasisti; Ricca, 2016
I78	Parametric and non-parametric methods for efficiency assessment of state higher vocational schools in 2009-2011	Rządziński; Sworowska, 2016
I79	How efficient are Malaysian public universities? A comparative analysis using data envelopment analysis	Hock-Eam et al., 2016
I80	The efficiency of regional higher education systems and competition in Russia	Leshukov; Platonova; Semyonov, 2016
I81	The relative efficiencies of research universities of science and technology in China: Based on the data envelopment analysis and stochastic frontier analysis	Chuanyi; Xiaohong; Shikui, 2016
I82	Exploring efficiency differentials between Italian and Polish universities, 2001-11	Agasisti; Wolszczak-Derlacz, 2016
I83	Do the autonomous region financial models influence the efficiency of Spanish national universities?	Larrán-Jorge; García-Correas, 2015
I84	Efficiency Analysis of Foundation Universities in Turkey	Kadilar, 2015
I85	Efficiency and mergers in English higher education 1996/97 to 2008/9: Parametric and non-parametric estimation of the multi-input multi-output distance function	Johnes, 2014
I86	Evaluating the performance of university course units using data envelopment analysis	El-Mahgary et al., 2014
I87	Performance Efficiency Measurement in the Nigerian Public Sector: The Federal Universities Dilemma	Inua; Maduabum, 2014
I88	Efficiency in Foundation Provisioning in a Selected University	Nkonki; Ntlabathi; Ncanywa, 2014
I89	Application of DEA method in efficiency evaluation of public higher education institutions	Nazarko; Šaparauskas, 2014
I90	An investigation of technical and scale efficiency of public universities in Saudi Arabia	Al Kahtani; Malik, 2014
I91	Measuring the institutional efficiency using DEA and AHP: The case of a Mexican university	Altamirano-Corro; Peniche-Vera, 2014
I92	Network DEA: an application to analysis of academic performance	Saniee Monfared; Safi, 2013
I93	Accounting for economies of scope in performance evaluations of university professors	De Witte et al., 2013
I94	The Relative Efficiency of Education and R&D Expenditures in the New EU Member States	Aristovnik, 2012
I95	University Technology Transfer: How (in-)efficient are French universities?	Curi; Daraio; Llerena, 2012
I96	Efficiency and Performance in Higher Education: A Frontier Analysis of the Educational Productivity of the Brazilian Federal Institutes of Higher Education	Costa et al., 2012
I97	Performance of the Different Methods of Study Financing: A Measurement through the Data Envelopment Analysis Method	Vierstraete; Yergeau, 2012
I98	Identifying the Best Buys in U.S. Higher Education	Eff; Klein; Kyle, 2012
I99	Assessment of Academic Departments Efficiency using Data Envelopment Analysis	Agha et al., 2011
I100	Efficiency of Research Performance of Australian Universities: A Reappraisal using a Bootstrap Truncated Regression Approach	Lee, 2011
I101	Costs and efficiency of higher education institutions in England: A DEA analysis	Thanassoulis et al., 2011
I102	The efficiency of German universities - some evidence from nonparametric and parametric methods	Kempkes; Pohl, 2010
I103	Comparing efficiency in a cross-country perspective: The case of Italian and Spanish state universities	Agasisti; Pérez-Esparrells, 2010
I104	Is the new ECTS system better than the traditional one? An application to the ECTS pilot-project at the University Pablo de Olavide	Herrero; Algarrada, 2010

Cód.	Title	Author(s), Year
I105	Beyond frontiers: Comparing the efficiency of higher education decision-making units across more than one country	Agasisti; Johnes, 2009
I106	An evaluation of the dynamics of the plan to develop first-class universities and top-level research centers in Taiwan	Chang et al., 2009
I107	Measuring the research performance of Chinese higher education institutions using Data Envelopment Analysis	Johnes, 2008
I108	Does expansion cause congestion? The case of the older British universities, 1994-2004	Flegg; Allen, 2007
I109	Measuring productivity of research in economics: A cross-country study using DEA	Kocher; Luptacik; Sutter, 2006
I110	Data Envelopment Analysis and its application to the measurement of efficiency in Higher Education	Johnes, 2006
I111	Is government funding critical to the operating performance of technology universities? A case study of Taiwan	Sing; Imen, 2022
I112	Does econometric methodology matter to rank universities? Na analysis of Italian higher education system	Barra; Lagravinese; Zotti, 2018
I113	Technical efficiency in Chile's higher education system: A comparison of rankings and accreditation	Cossani et al., 2022

Source: Prepared by the author.

APPENDICES CHAPTER 4

A4.1 – Data collected – inputs and outputs

Teaching Unit (TUs)	DMU	Inputs				Outputs		
		Number of Courses (x_1)	Total Budget Costing (R$) ($x_2$)	PNAE Budget (R$) ($x_3$)	Number of Enrolments (x_4)	Number of Graduates (y_{g1})	Institutional Projects Volume (y_{g2})	Volume of Evaded (y_{b1})
Araguaína	1	9	13.883.038,41	496.757,71	1124	256	2	150
	2	10	14.315.931,09	484.170,40	1148	225	5	153
	3	10	16.185.581,70	520.239,26	1393	333	7	127
	4	14	16.775.575,82	535.740,00	1489	436	5	671
	5	11	16.645.749,01	421.592,00	1232	165	13	113
	6	11	17.295.504,04	527.242,69	1322	397	43	168
	7	12	19.966.666,34	471.905,61	1098	200	26	177
	Average	11	16.438.292,34	493.949,67	1258	287	14	223
	Median	11	16.645.749,01	496.757,71	1232	256	7	153
	Mode	10	-	-	-	-	5	-
	Standard deviation	2	2.018.193,75	39.520,23	148	103	15	199
Araguatins	8	11	26.312.760,86	1.451.468,48	1970	340	21	374
	9	8	27.604.479,97	1.788.123,26	1673	242	40	183
	10	7	29.688.583,97	1.649.667,69	1698	423	31	268
	11	10	27.372.853,00	1.140.830,21	1746	159	30	204
	12	11	27.921.135,43	1.660.700,00	1844	305	31	388
	13	11	28.947.168,09	853.264,68	1619	305	45	176
	14	12	32.666.393,68	1.142.457,73	1644	285	48	249
	Average	10	28.644.767,86	1.383.787,44	1742	294	35	263
	Median	11	27.921.135,43	1.451.468,48	1698	305	31	249
	Mode	11	-	-	-	305	31	-
	Standard deviation	2	2.082.319,98	345.003,31	125	82	10	87
Formoso do Araguaia	15	9	2.813.099,01	116.976,77	228	75	13	53
	16	6	3.472.457,41	149.782,96	342	83	6	127
	17	11	5.072.632,44	134.142,16	370	47	4	139
	18	13	4.942.939,83	127.069,66	500	85	6	235
	19	9	4.527.578,48	137.336,80	308	24	11	42
	20	9	5.296.554,67	134.058,00	312	32	25	156
	21	8	6.047.109,86	139.387,42	250	16	12	29
	Average	9	4.596.053,10	134.107,68	330	52	11	112
	Median	9	4.942.939,83	134.142,16	312	47	11	127
	Mode	9	-	-	-	-	6	-
	Standard deviation	2	1.109.790,35	10.222,71	90	29	7	74
Lagoa da Confusão	22	7	2.495.729,47	129.616,30	438	134	5	218
	23	5	3.899.262,48	120.220,98	438	71	7	260
	24	6	4.115.905,31	120.015,81	297	18	12	87
	25	9	4.381.930,65	121.934,31	378	43	10	189
	26	9	4.787.772,37	104.909,00	375	36	12	117
	27	7	5.294.376,97	142.850,10	343	10	19	91
	28	5	5.032.534,27	148.216,50	349	60	25	58
	Average	7	4.286.787,36	126.823,29	374	53	13	146

Teaching Unit (TUs)	DMU	Inputs				Outputs		
		Number of Courses (x_1)	Total Budget Costing (R$) ($x_2$)	PNAE Budget (R$) ($x_3$)	Number of Enrolments (x_4)	Number of Graduates (y_{g1})	Institutional Projects Volume (y_{g2})	Volume of Evaded (y_{b1})
	Median	7	4.381.930,65	121.934,31	375	43	12	117
	Mode	7	-	-	438	-	12	-
	Standard deviation	2	932.619,79	14.812,15	51	42	7	77
Pedro Afonso	29	9	3.743.664,78	215.453,25	415	115	10	144
	30	12	4.268.362,25	179.905,10	499	172	14	214
	31	12	4.761.530,02	152.170,44	487	146	7	150
	32	9	4.446.240,35	186.491,36	476	91	18	121
	33	10	5.390.754,40	160.454,00	514	80	17	203
	34	7	5.712.502,81	159.446,36	442	75	11	110
	35	9	6.077.166,11	203.904,94	691	179	16	231
	Average	10	4.914.317,25	179.689,35	503	123	13	168
	Median	9	4.761.530,02	179.905,10	487	115	14	150
	Mode	9	-	-	-	-	-	-
	Standard deviation	2	841.272,35	23.975,10	89	43	4	48
Colinas do Tocantins	36	11	9.109.931,96	384.152,10	863	166	8	253
	37	13	11.022.004,12	375.886,90	833	206	10	207
	38	7	12.060.320,91	392.446,38	722	25	15	99
	39	10	12.702.031,75	316.270,00	1068	343	15	123
	40	7	12.506.371,48	330.544,00	956	150	16	150
	41	7	12.305.143,28	353.372,36	911	99	11	68
	42	11	13.634.341,89	370.261,88	916	13	17	261
	Average	9	11.905.735,06	360.419,09	896	143	13	166
	Median	10	12.305.143,28	370.261,88	911	150	15	150
	Mode	7	-	-	-	-	15	-
	Standard deviation	2	1.458.529,69	28.332,71	107	114	3	76
Dianópolis	43	5	10.090.280,67	360.256,84	709	70	13	143
	44	5	11.715.960,28	341.874,84	725	110	18	134
	45	4	12.078.668,23	359.490,04	673	101	22	49
	46	4	12.553.283,75	633.190,00	676	24	9	55
	47	5	10.692.712,83	348.000,00	778	132	11	107
	48	6	13.360.580,18	333.029,46	732	99	47	126
	49	13	14.762.762,36	440.385,07	837	165	50	186
	Average	6	12.179.178,33	402.318,04	733	100	24	114
	Median	5	12.078.668,23	359.490,04	725	101	18	126
	Mode	5	-	-	-	-	-	-
	Standard deviation	3	1.581.577,17	107.826,31	58	45	17	49
Gurupi	50	12	11.985.569,23	382.131,60	770	122	7	247
	51	14	14.185.954,46	360.854,40	716	111	19	133
	52	15	15.194.021,68	381.082,65	839	133	19	116
	53	16	14.461.991,73	374.385,00	842	95	21	143
	54	17	14.866.851,63	351.360,00	927	163	24	151
	55	17	15.881.366,45	365.971,33	874	75	36	61
	56	17	18.300.904,51	485.328,51	1026	152	49	210

Teaching Unit (TUs)	DMU	Inputs				Outputs		
		Number of Courses (x_1)	Total Budget Costing (R$) ($x_2$)	PNAE Budget (R$) ($x_3$)	Number of Enrolments (x_4)	Number of Graduates (y_{g1})	Institutional Projects Volume (y_{g2})	Volume of Evaded (y_{b1})
	Average	15	14.982.379,96	385.873,36	856	122	25	152
	Median	16	14.866.851,63	374.385,00	842	122	21	143
	Mode	17	-	-	-	-	19	-
	Standard deviation	2	1.904.595,01	45.228,07	101	31	14	61
Palmas	57	51	50.734.308,85	2.160.556,15	5190	449	57	1927
	58	57	55.689.550,69	1.912.473,40	5323	613	57	1471
	59	53	59.497.783,07	2.316.375,76	4676	627	47	781
	60	53	59.514.080,53	1.997.075,90	5552	743	49	1250
	61	49	61.462.405,01	1.961.912,00	5003	787	61	684
	62	47	62.139.259,25	2.278.975,23	4994	435	110	1157
	63	44	71.593.979,45	1.836.028,61	4625	528	152	881
	Average	51	60.090.195,26	2.066.199,58	5052	597	76	1164
	Median	51	59.514.080,53	1.997.075,90	5003	613	57	1157
	Mode	53	-	-	-	-	57	-
	Standard deviation	4	6.403.121,86	186.649,92	335	136	40	436
Paraíso do Tocantins	64	12	16.290.913,99	651.953,99	1377	190	11	326
	65	9	17.837.044,34	589.185,81	1218	165	27	266
	66	9	18.743.315,13	647.209,28	1124	173	18	160
	67	16	18.631.077,98	586.895,00	2234	703	10	685
	68	10	18.942.420,85	548.506,31	1164	125	15	258
	69	12	19.124.339,46	553.356,31	2092	216	36	233
	70	14	20.371.946,59	586.207,16	2151	635	48	187
	Average	12	18.563.008,33	594.759,12	1623	315	24	302
	Median	12	18.743.315,13	586.895,00	1377	190	18	258
	Mode	12	-	-	-	-	-	-
	Standard deviation	3	1.255.513,48	40.910,12	509	244	14	177
Porto Nacional	71	10	13.927.490,21	452.267,98	1180	210	7	88
	72	8	15.255.497,67	403.078,00	1393	199	6	341
	73	8	16.367.495,05	459.214,38	1270	144	12	56
	74	9	16.578.677,69	491.585,00	1600	220	1	598
	75	12	16.140.264,66	383.238,00	1142	154	2	107
	76	14	16.389.450,55	408.622,33	1306	92	19	316
	77	21	18.704.715,27	456.220,39	1878	192	25	334
	Average	12	16.194.798,73	436.318,01	1396	173	10	263
	Median	10	16.367.495,05	452.267,98	1306	192	7	316
	Mode	8	-	-	-	-	-	-
	Standard deviation	5	1.445.723,91	38.554,35	261	45	9	193

Source: Prepared by the author based on SIAFI, SUAP/IFTO and PNP (2023).

A4.2 – Estimated targets for DMUs

Teaching Unit (TUs)	DMU	β	Number of Courses (x_1)	Total Budget Costing – R$ (x_2)	PNAE Budget – R$ (x_3)	Number of Enrolments (x_4)
Araguaína	1	0,1473	8	11.838.090	423.586	958
	2	0,2663	7	10.504.166	355.255	842
	3	0,1173	9	14.287.317	459.225	1230
	4	0,0831	13	12.744.237	384.108	1365
	5	0,4180	6	8.362.893	245.354	713
	7	0,3485	8	8.713.898	278.402	715
Araguatins	8	0,2978	8	18.478.122	879.356	1338
	9	0,1825	7	20.084.525	871.090	1153
	11	0,4723	5	14.444.705	484.529	861
	12	0,3445	7	18.302.038	882.755	1209
	13	0,2131	9	17.520.599	575.486	1274
	14	0,2464	9	16.206.723	432.967	1239
Formoso do Araguaia	17	0,1752	9	3.849.836	110.641	305
	18	0,0772	8	3.641.751	117.263	407
	19	0,0511	9	4.296.309	127.260	238
Lagoa da Confusão	25	0,0851	8	4.009.095	111.560	342
	27	0,0775	6	4.628.445	131.784	316
Pedro Afonso	29	0,1085	8	3.131.052	136.690	370
	32	0,0946	8	4.025.542	143.655	338
	33	0,1678	8	3.682.204	133.530	295
	34	0,1466	6	4.007.529	136.075	360
	35	0,0526	9	5.327.676	193.170	610
Colinas do Tocantins	36	0,3479	7	5.058.783	239.351	563
	37	0,2402	10	5.977.406	200.685	633
	38	0,3415	5	7.782.647	230.677	475
	40	0,1825	6	9.112.365	270.226	726
	41	0,2946	5	8.422.329	249.279	553
	42	0,5555	5	5.528.140	164.577	407
Dianópolis	43	0,1214	4	8.865.091	265.484	581
	44	0,0915	5	10.463.387	310.579	659
	47	0,0042	5	10.647.963	318.267	717
Gurupi	50	0,4459	7	3.032.771	138.027	427
	51	0,4391	8	4.998.555	171.667	402
	52	0,4512	8	5.542.136	191.327	460
	53	0,5502	7	5.037.028	165.264	379
	54	0,3676	8	6.996.522	222.213	586
	56	0,1718	10	14.556.943	401.929	850
Palmas	57	0,5602	16	22.314.004	630.210	1851
	58	0,5578	17	24.625.086	689.740	2328
	59	0,5466	14	20.213.259	583.884	2120
	60	0,2307	36	45.784.833	1.448.114	3953
	62	0,2116	31	48.988.671	1.281.850	3230
Paraíso do Tocantins	64	0,4444	7	9.051.500	362.236	765
	65	0,3622	6	11.310.816	375.782	777
	66	0,3360	6	10.970.454	429.754	746
	68	0,4699	5	8.958.814	290.789	617

Teaching Unit (TUs)	DMU	β	Number of Courses (x_1)	Total Budget Costing – R$ (x_2)	PNAE Budget – R$ (x_3)	Number of Enrolments (x_4)
	69	0,3866	7	11.731.133	326.931	927
Porto Nacional	71	0,2806	7	10.020.041	293.721	848
	72	0,2021	6	10.894.265	321.615	891
	74	0,2679	7	12.137.818	359.906	967
	75	0,4558	7	7.471.646	208.563	621
	76	0,6121	5	5.332.055	158.504	471
	77	0,4948	9	7.274.170	230.473	694

Source: Prepared by the author.

APPENDICES CHAPTER 5

A5.1 – Data set

Institutions	DMU	Graduates per cycle y_{g1}	Student-teacher ratio y_{g2}	Occupancy rate y_{g3}	Dropout rate per cycle y_{b1}	Current expenditure per enrolment y_{b2}
IF Baiano	1	48,16	21,84	99,05	46,83	17.807,74
	2	51,88	20,22	100,83	43,99	18.067,78
	3	52,47	21,13	93,67	45,14	16.046,46
	4	52,70	18,32	86,13	39,14	18.340,96
	5	24,98	17,41	90,45	45,98	19.667,39
	6	35,40	18,41	100,01	42,85	20.832,60
	7	46,26	17,18	87,31	45,40	23.245,67
IF Farroupilha	8	42,06	20,81	85,68	53,33	19.321,99
	9	47,19	20,82	88,45	48,48	19.982,38
	10	71,94	20,83	91,03	24,40	19.586,93
	11	49,14	20,49	88,28	43,57	18.729,99
	12	46,18	20,76	93,36	48,90	19.561,80
	13	63,57	20,59	89,70	32,09	21.512,22
	14	56,84	18,34	83,62	36,33	25.116,26
IF Goiano	15	39,39	24,67	105,28	48,31	16.147,99
	16	41,54	27,53	97,16	51,81	15.509,17
	17	41,57	27,53	92,07	41,96	15.078,42
	18	41,22	27,82	94,78	43,53	14.632,60
	19	44,72	24,94	93,29	43,51	18.231,98
	20	33,86	25,5	100,58	48,51	19.081,69
	21	42,02	22,97	93,66	42,31	22.881,61
IF Sertão PE	22	42,57	21,4	80,85	51,20	16.388,42
	23	46,13	22,1	75,77	52,49	18.099,11
	24	49,04	25,03	76,90	46,62	17.497,44
	25	43,17	25,16	84,40	50,54	15.617,86
	26	39,94	22,64	83,50	51,30	17.556,09
	27	32,70	22,05	82,32	55,99	18.797,98
	28	31,08	21,1	80,32	61,78	22.041,59
IF Sudeste de MG	29	40,48	25,81	120,74	49,30	17.138,44
	30	42,14	28,21	123,40	52,26	15.153,55
	31	44,52	23,88	99,91	44,64	18.274,11
	32	44,16	22,56	92,86	39,17	18.508,82
	33	45,52	23,6	100,69	38,87	17.594,20
	34	40,09	23,55	95,98	37,45	18.593,37
	35	38,76	22,94	87,34	45,51	20.920,65
IFAC	36	34,09	19,76	89,33	61,86	15.767,34
	37	44,19	19,18	95,33	53,22	16.400,17
	38	36,04	21,21	82,30	57,73	17.189,41
	39	37,14	20,65	102,94	51,71	16.894,52
	40	34,05	19,97	100,95	48,01	17.832,03
	41	32,01	20,14	103,23	51,32	19.155,04
	42	34,67	19,65	103,78	50,90	22.590,62
IFAL	43	41,56	22,05	117,71	43,88	15.362,05
	44	43,00	22,02	99,38	50,43	16.583,81
	45	46,79	24,27	93,38	46,85	16.206,65
	46	44,29	23,37	98,04	46,22	16.472,62
	47	35,36	21,61	97,58	49,97	17.639,05
	48	33,18	22,48	97,66	49,39	17.817,29
	49	48,27	22,14	95,92	41,95	20.307,65
IFAM	50	44,61	25,77	80,93	44,54	12.958,38
	51	44,20	21,9	108,54	46,14	16.020,73
	52	43,75	24,01	116,23	37,70	16.655,26
	53	36,67	22,11	113,70	31,50	16.035,57
	54	42,54	20,61	115,53	27,29	18.706,44
	55	42,27	25,62	111,04	31,79	15.701,43
	56	46,18	22,68	110,96	33,31	18.645,56
IFAP	57	53,53	23,05	103,26	42,55	13.114,90
	58	72,09	22,72	97,27	25,88	13.773,32
	59	63,56	25,62	104,72	26,96	14.202,05
	60	41,23	23,01	101,97	43,65	14.541,30
	61	30,32	18,71	109,43	43,94	17.076,44
	62	19,89	19,44	122,28	56,16	18.721,68
	63	37,32	22,84	133,56	52,58	17.797,61

Institutions	DMU	Graduates per cycle y_{g1}	Student-teacher ratio y_{g2}	Occupancy rate y_{g3}	Dropout rate per cycle y_{b1}	Current expenditure per enrolment y_{b2}
IFB	64	30,24	29,34	99,76	61,11	11.749,17
	65	35,32	25,78	98,26	59,70	12.282,18
	66	38,39	25,5	92,38	51,61	13.720,46
	67	38,81	28,38	103,93	51,92	12.137,17
	68	29,64	26,85	106,75	50,92	13.789,11
	69	31,62	31,16	121,75	52,51	12.000,19
	70	33,99	27,06	105,74	56,13	15.208,88
IFBA	71	30,46	27,08	110,70	58,18	13.416,34
	72	42,61	26,12	102,62	50,42	13.623,45
	73	33,93	26,86	94,03	44,10	15.368,42
	74	32,04	23,34	94,73	45,82	15.428,47
	75	32,16	20,57	96,85	42,04	17.987,56
	76	28,07	20,33	99,90	55,44	19.167,01
	77	39,31	18,41	90,93	41,41	22.620,11
IFC	78	48,45	20,55	95,34	45,38	18.348,62
	79	49,61	21,19	89,49	42,57	18.593,13
	80	48,46	22,88	93,91	43,97	18.458,13
	81	48,17	23,06	94,29	42,74	17.907,69
	82	50,17	22,29	104,95	34,58	19.573,29
	83	41,92	24,4	116,23	32,95	18.433,14
	84	45,22	22,71	110,96	44,75	21.251,89
IFCE	85	40,81	26,7	90,51	51,76	12.434,21
	86	44,88	28,98	88,71	48,77	12.902,48
	87	46,06	28,33	87,09	46,05	12.692,88
	88	44,16	25,99	88,44	44,74	14.169,65
	89	34,13	26,18	89,82	51,71	14.298,70
	90	23,01	29,67	102,47	54,62	12.907,06
	91	38,16	28,81	96,68	50,01	14.675,24
IFES	92	50,80	21,03	105,57	41,83	17.730,43
	93	51,80	21,99	105,16	43,26	17.140,20
	94	54,60	20,93	97,18	40,08	19.113,12
	95	54,98	21,57	104,43	35,47	20.057,10
	96	66,86	20,3	102,10	23,24	18.855,33
	97	69,21	21,43	113,56	24,58	20.080,32
	98	74,01	18,44	94,07	22,61	19.812,58
IFF	99	36,47	24,91	107,33	55,04	14.267,35
	100	38,29	24	94,29	53,57	15.323,80
	101	48,13	27,48	96,86	43,33	14.936,15
	102	46,22	23,02	99,06	43,38	16.265,65
	103	38,55	22,21	103,24	47,61	17.740,92
	104	37,64	25,45	113,58	44,40	15.828,76
	105	39,13	22,9	96,81	48,89	19.275,57
IFG	106	38,83	18,17	100,33	52,61	19.977,88
	107	44,25	17,43	109,50	49,59	21.131,72
	108	43,72	16,93	85,17	47,23	23.562,69
	109	41,52	15,77	321,53	46,47	24.426,97
	110	42,47	17,36	110,90	45,81	23.183,52
	111	32,76	18,9	107,22	59,03	21.953,40
	112	40,71	16,35	88,86	46,59	27.239,12
IFMA	113	47,51	18,97	112,06	38,72	16.552,49
	114	50,15	20,11	105,13	37,19	16.199,50
	115	50,68	22,84	110,17	30,84	15.382,42
	116	48,73	20,74	105,96	29,32	15.055,58
	117	46,10	20,29	116,94	25,94	15.992,92
	118	37,75	22,2	122,68	32,36	14.781,68
	119	42,24	22,24	117,44	31,57	16.724,42
IFMG	120	47,01	20,61	97,41	45,63	18.171,92
	121	51,43	21,74	97,86	40,35	18.658,30
	122	57,28	22,47	98,71	31,88	16.525,06
	123	54,31	22,53	95,64	36,67	16.892,36
	124	70,81	23,46	103,78	19,39	16.927,80
	125	58,98	24,49	100,89	30,11	17.376,46
	126	75,38	22,07	92,71	17,35	20.664,52
IFMS	127	32,95	19,28	84,31	64,61	15.956,71
	128	36,28	20,14	79,05	60,73	16.108,43
	129	33,03	21,42	86,11	59,12	15.134,57

Institutions	DMU	Graduates per cycle y_{g1}	Student-teacher ratio y_{g2}	Occupancy rate y_{g3}	Dropout rate per cycle y_{b1}	Current expenditure per enrolment y_{b2}
	130	34,51	22,13	84,70	56,39	13.645,22
	131	30,26	22,04	87,14	65,53	12.976,97
	132	21,10	23,88	91,25	76,52	12.106,68
	133	21,41	22,63	99,34	76,61	14.779,44
IFMT	134	39,81	23,93	102,48	44,58	14.934,63
	135	50,55	23,71	93,41	42,13	15.637,10
	136	47,24	24,95	109,57	38,85	15.999,69
	137	49,65	23,67	101,24	38,60	16.158,92
	138	39,52	23,3	108,27	34,75	16.721,54
	139	40,51	23,24	109,71	37,89	17.769,81
	140	45,82	20,79	97,58	39,85	20.742,07
IFNMG	141	38,69	23,12	78,25	56,64	14.567,03
	142	42,74	21,92	107,62	55,85	14.346,74
	143	51,20	22,12	90,66	41,97	12.785,63
	144	50,13	22,16	97,64	43,20	11.711,09
	145	43,68	22,13	101,83	52,84	13.460,83
	146	46,22	23,88	104,79	46,22	14.454,35
	147	40,69	21,55	92,23	45,30	17.099,24
IFPA	148	37,81	26,01	136,63	55,35	11.209,36
	149	43,98	19,99	102,03	49,61	15.660,71
	150	47,19	20,49	90,16	46,23	16.833,58
	151	42,39	19,52	90,60	44,59	16.298,54
	152	39,04	18,64	95,10	42,10	18.594,32
	153	36,58	19,37	96,20	46,75	17.950,19
	154	41,74	19,24	95,80	49,15	20.063,89
IFPB	155	28,60	23,25	92,60	63,15	15.442,41
	156	26,50	25,97	96,62	65,50	14.556,62
	157	32,35	29,67	97,31	51,75	14.059,72
	158	38,74	27,52	111,38	49,54	13.430,56
	159	31,82	30,28	106,82	61,07	12.153,50
	160	38,52	26,04	89,48	48,22	15.693,81
	161	41,08	24,44	92,01	43,88	17.783,13
IFPE	162	38,39	26,28	107,40	51,82	13.549,36
	163	38,67	24,03	104,36	49,77	15.522,71
	164	41,78	26,61	104,54	39,81	15.750,61
	165	34,41	23,11	103,31	49,19	16.453,25
	166	32,64	22,68	103,21	51,01	17.464,73
	167	35,55	22,75	98,31	55,43	18.716,57
	168	39,60	22,29	87,58	48,27	20.975,50
IFPI	169	40,76	23,34	113,27	54,97	13.560,68
	170	42,32	23,07	100,69	51,26	13.708,14
	171	45,32	23,41	94,65	47,85	14.648,78
	172	49,93	21,95	91,87	43,65	14.481,62
	173	41,52	22,8	99,94	50,24	15.513,54
	174	45,21	24,06	102,75	43,78	15.550,31
	175	42,78	20,92	91,04	47,67	18.592,31
IFPR	176	40,25	18,8	121,93	57,85	11.955,23
	177	42,54	19,28	91,47	54,14	13.743,00
	178	46,59	20,69	92,41	39,62	12.572,83
	179	45,43	19,77	98,16	44,93	14.301,54
	180	21,66	20,18	127,55	21,03	14.885,86
	181	40,86	20,48	112,25	36,48	15.345,24
	182	41,76	17,79	102,90	43,29	19.044,69
IFRJ	183	35,43	17,25	94,88	56,97	20.175,38
	184	37,04	18,06	92,67	54,94	19.767,85
	185	41,97	19,77	88,12	50,12	21.345,54
	186	38,09	16,77	96,42	44,75	22.410,51
	187	36,98	18,56	102,71	40,76	21.428,87
	188	33,25	19,09	97,83	37,34	21.481,84
	189	34,29	19,24	100,11	34,26	23.083,80
IFRN	190	57,11	30,76	123,19	39,91	11.073,07
	191	61,08	24,46	91,70	36,24	14.138,11
	192	57,84	25,18	91,90	38,73	14.363,28
	193	60,41	23,59	97,19	33,82	14.693,63
	194	51,00	23,72	105,56	41,03	14.909,96
	195	48,54	23,78	107,73	41,87	16.235,98

Institutions	DMU	Graduates per cycle y_{g1}	Student-teacher ratio y_{g2}	Occupancy rate y_{g3}	Dropout rate per cycle y_{b1}	Current expenditure per enrolment y_{b2}
	196	59,08	21,32	94,46	34,75	20.646,10
IFRO	197	54,68	22,01	123,66	41,41	11.011,52
	198	69,44	18,47	105,68	28,10	11.691,61
	199	41,21	19,88	125,56	31,96	11.271,65
	200	41,56	19,91	120,93	38,28	9.255,92
	201	43,24	19,69	124,34	38,21	9.102,23
	202	57,20	19,21	109,13	38,18	11.203,83
	203	52,03	18,76	108,31	34,99	14.210,56
IFRR	204	36,94	15,27	97,89	48,24	26.760,27
	205	48,66	16,09	103,01	46,50	24.136,76
	206	68,84	17,74	92,80	28,83	25.964,13
	207	57,27	16,58	91,00	33,56	25.868,09
	208	58,59	13,23	106,63	35,61	28.238,24
	209	52,74	15,62	120,91	38,12	27.477,78
	210	60,00	16,32	98,92	29,84	28.251,17
IFRS	211	41,90	23,29	105,09	44,62	15.524,82
	212	55,10	23,71	104,32	37,91	16.569,38
	213	64,83	23,48	102,61	25,74	15.303,96
	214	69,22	21,49	100,16	28,21	10.041,31
	215	84,47	19,46	120,47	14,94	20.749,28
	216	84,27	23,4	134,91	14,83	16.627,95
	217	87,29	22,95	117,73	12,23	21.221,09
IFS	218	34,96	26,75	92,35	59,14	15.796,67
	219	43,73	22,35	72,39	53,43	19.978,37
	220	35,96	24,04	75,30	55,83	20.898,23
	221	27,21	23,15	90,40	56,94	20.654,07
	222	36,95	24,52	97,55	44,38	20.113,70
	223	31,70	24,96	100,59	50,84	19.832,20
	224	33,40	24,09	94,37	57,67	22.605,32
IFSC	225	46,56	25,28	100,51	52,07	13.483,58
	226	45,92	27	94,16	52,43	12.975,30
	227	45,56	26,1	92,80	50,93	13.862,49
	228	44,90	25,03	89,84	48,46	14.187,66
	229	34,25	26,6	96,43	51,14	13.794,79
	230	35,27	28,6	100,76	53,28	13.361,37
	231	34,61	24,43	90,54	55,84	16.637,22
IFSP	232	50,29	19,51	93,49	46,71	15.701,96
	233	49,39	20,97	95,10	47,48	15.620,25
	234	49,15	22,28	93,91	47,64	15.879,62
	235	49,66	21,46	95,94	44,26	16.187,50
	236	42,20	22,75	105,57	49,26	15.987,02
	237	40,15	24,09	107,88	51,47	15.896,94
	238	34,96	21,51	93,33	58,24	18.995,74
IF Sul	239	41,08	22,19	82,91	51,98	17.263,80
	240	43,63	22,1	101,15	37,22	15.243,92
	241	42,94	22,58	96,30	34,65	16.918,92
	242	34,55	21,43	92,97	50,45	14.496,26
	243	33,94	20,19	102,27	61,56	7.233,80
	244	24,20	21,67	113,63	74,14	13.315,17
	245	58,29	19,13	98,28	40,76	17.375,15
IF Sul de Minas	246	45,93	26,59	120,53	51,14	11.894,00
	247	32,32	26,08	104,62	66,13	14.332,21
	248	46,34	27,31	99,61	51,41	11.162,88
	249	70,82	23,75	94,54	25,28	10.332,47
	250	79,82	25,15	101,15	17,58	8.387,09
	251	78,47	26,05	97,39	18,53	7.989,95
	252	79,32	25,6	97,45	16,00	8.744,22
IFTM	253	38,93	18,9	100,66	57,78	19.986,42
	254	43,97	19,73	95,77	50,07	18.167,08
	255	44,78	19,68	91,28	48,05	18.572,54
	256	47,43	20,87	95,30	43,69	17.248,10
	257	46,56	19,96	105,32	45,11	20.140,74
	258	39,54	19,32	101,16	50,64	21.834,72
	259	43,33	18,67	95,18	49,13	25.192,31
IFTO	260	41,45	27,9	111,24	54,15	13.726,07
	261	39,31	26,92	105,03	49,99	14.261,09

Institutions	DMU	Graduates per cycle y_{g1}	Student-teacher ratio y_{g2}	Occupancy rate y_{g3}	Dropout rate per cycle y_{b1}	Current expenditure per enrolment y_{b2}
	262	41,59	26,38	93,63	47,53	13.469,82
	263	42,53	27,29	91,49	48,91	10.678,67
	264	43,19	23,31	88,49	49,01	13.584,67
	265	22,37	22,9	85,03	58,05	15.857,78
	266	27,51	21,3	98,93	64,97	18.425,86

Source: Prepared by the author.

A5.2 – Correlation matrix (r) between efficiency, effectiveness and the model variables

Variables	y_{g1}	y_{g2}	y_{g3}	y_{b1}	y_{b2}	Efficiency	Effectiveness
Graduates per cycle (y_{g1})	1						
Student-teacher ratio (y_{g2})	-0,184	1					
Occupancy rate (y_{g3})	0,274	-0,276	1				
Dropout rate per cycle (y_{b1})	-0,860	0,220	-0,462	1			
Current expenditure per enrolment (y_{b2})	0,067	-0,623	0,006	-0,092	1		
Efficiency	0,297	0,709	0,232	-0,321	-0,749	1	
Effectiveness	0,021	0,737	0,446	-0,120	-0,575	0,823	1

Track	Colour	Review
$r \geq 0{,}70$		Strong positive correlation
$0{,}30 \leq r \leq 0{,}70$		Moderate positive correlation
$0{,}10 \leq r \leq 0{,}30$		Weak positive correlation
$-0{,}10 \leq r \leq 0{,}10$		No linear correlation
$-0{,}30 \leq r \leq -0{,}10$		Weak negative correlation
$r \leq -0{,}70$		Strong negative correlation

Source: Prepared by the author.

A5.3 – Significance matrix

Correlation	r	n	Degree of Freedom (n-2)	t	p-value	Significant ($p < 0{,}05$)?
Efficiency × Graduates per cycle (y_{g1})	0,297	38	36	1,866208	0,070176	No
Efficiency × Student-Teacher Ratio (y_{g2})	0,709	38	36	6,032259	6,29E-07	Yes
Efficiency × Occupancy Rate (y_{g3})	0,232	38	36	1,431045	0,161041	No
Efficiency × Dropout Rate per cycle (y_{b1})	-0,321	38	36	-2,03362	0,049411	Yes
Efficiency × Current Expenditure per Enrolment (y_{b2})	-0,749	38	36	-6,78268	6,34E-08	Yes
Effectiveness × Graduates per cycle (y_{g1})	0,021	38	36	0,126028	0,900411	No
Effectiveness × Student-Teacher Ratio (y_{g2})	0,737	38	36	6,542458	1,32E-07	Yes
Effectiveness × Occupancy Rate (y_{g3})	0,446	38	36	2,989834	0,005009	Yes
Effectiveness × Dropout rate per cycle (y_{b1})	-0,12	38	36	-0,72524	0,472993	No
Effectiveness × Current Expenditure per Enrolment (y_{g2})	-0,575	38	36	-4,21681	0,000159	Yes
Effectiveness × Efficiency	0,823	38	36	8,693029	2,28E-10	Yes
Graduates per cycle (y_{g1}) × Dropout rate per cycle (y_{b1})	-0,86	38	36	-10,1118	4,61E-12	Yes

Source: Prepared by the author.

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