

A MULTIMETHODOLOGY APPROACH TO ASSESS THE DECARBONIZATION PATHWAYS IN BRICS NATIONS

Stela de Lurdes Ferrari Fumian
Universidade Federal Fluminense
Rua Passo da Pátria, 156, Praia Vermelha, Niteroi, RJ, 242210-240, Brazil
stelaferrari@id.uff.br

Lidia Angulo Meza
Universidade Federal Fluminense
Rua Passo da Pátria, 156, Praia Vermelha, Niteroi, RJ, 242210-240, Brazil
lidiaangulomeza@id.uff.br

Níssia Carvalho Rosa Bergiante
Universidade Federal Fluminense
Rua Passo da Pátria, 156, Praia Vermelha, Niteroi, RJ, 242210-240, Brazil
nissiabergiante@id.uff.br

ABSTRACT

Decarbonizing the economies of BRICS countries is a complex challenge due to their diverse institutional, technological, and socio-economic contexts. While traditional quantitative models can offer precious insights about the nations' decarbonization performance and gaps, problem structuring methods (PSM) can complement the view with systemic analysis when assessing national performance in low-carbon transitions. This paper proposes a multimethodology framework that integrates Soft Systems Methodology (SSM) with Data Envelopment Analysis (DEA) using SSM to identify context-sensitive variables, reflecting the specific drivers and constraints of each country. These variables are then characterized as inputs and outputs to be applied to a DEA model. The proposed framework enhances the robustness of efficiency analysis by aligning it with a systemically informed understanding of the problem, enabling more meaningful benchmarking and supporting the decision-making for policies and strategies.

KEYWORDS. Decarbonization. DEA. SSM.

Paper topics.
SE-DEA – Sessão Especial de Desenvolvimentos Teóricos e Aplicações de Análise Envoltória de Dados
DEA – Análise Envoltória de Dados

https://proceedings.science/p/212648?lang=pt-br

1. Introduction

The energy transition to cleaner and more sustainable sources is one of the greatest contemporary global priorities, given the urgency of mitigating the effects of climate change and promoting energy security. Amid this scenario, the BRICS countries (Brazil, Russia, India, China, and South Africa) emerge as crucial actors due to their economic, demographic, and environmental weight. These countries, with their fast-growing economies and vast energy needs, face unique challenges in implementing decarbonization strategies [Chang et al. 2018].

Carbon reduction pathways in BRICS countries are characterized by complex interdependencies among energy policy, economic development, institutional structures, and environmental objectives [Li et al. 2024]. In this context, a purely quantitative analysis is insufficient to capture the full scope of national efficiencies in decarbonizing. A structured systemic approach, in addition, can account for stakeholder perspectives, contextual constraints, and the rationale underlying policy choices. In this sense, using a Problem Structuring Method (PSM) is powerful to identify context-relevant variables and indicators that accurately reflect each country's performance in the decarbonization process.

This study explores a multimethodology framework in which Soft Systems Methodology (SSM) is applied to support the selection of input and output variables for subsequent efficiency analysis using Data Envelopment Analysis (DEA). Given the systemic and context-specific nature of decarbonization in BRICS countries, SSM can be used to structure the problem by identifying relevant variables that reflect the intricate dynamics of each country. Having these variables translated into inputs and outputs of the model, DEA can provide a comprehensive performance analysis of BRICS nations, allowing for the identification of gaps in their strategies and design improvement policies.

2. Literature Review

SSM is a qualitative approach to structuring complex problems involving multiple stakeholders and perspectives. Rather than seeking a single numeric solution, SSM helps identify key variables and system complexities through conceptual modeling. SSM has been applied in several fields of study, being a key tool for analyzing decarbonization initiatives [Aidy & Wijaya 2023], industry policies, and countries' benchmark [Zhou et al. 2007].

SSM helps the understanding of systemic challenges and can be an integrated qualitative approach to support the use of quantitative tools like DEA. Mingers et al. [2009] proposed for the first time the use of SSM to provide a more complete systemic view and tangible indicators for the inputs and outputs in a DEA efficiency evaluation. Susanty et al. [2022] combined the two methodologies but used SSM after DEA to provide rich ideas on the improvement proposals for the inefficient units.

DEA is a non-parametric method used in operational research and economics to assess the productivity of decision-making units (DMUs) based on the identified inputs and outputs of the given system. The method can give a final efficiency measure for each DMU and identify the most efficient DMUs as benchmarks for the inefficiency of others based on their distance from this maximum efficiency point [Golany & Roll 1989].

Several studies have applied DEA to evaluate energy transition, decarbonization, and sustainability strategies. Considering the comparison of countries' efficiency, Tu et al. [2016] applied DEA to G7 and BRICS countries to compare their energy efficiency. Similarly, Chang et al. [2018] compared resource efficiency in terms of carbon emissions in BRICS and G7 using DEA. Santana et al. [2014] used an output-oriented DEA to evaluate sustainable development in BRICS, showing Brazil as a positive outlier. Li et al. [2024] also showcased similar results by applying a DEA model for calculating the sustainability efficiency of BRICS.

3. Proposed Methodology

The proposed multimethodological approach integrates SSM and DEA to assess decarbonization pathways in BRICS nations. While DEA offers a robust tool for benchmarking efficiency across DMUs, its results heavily depend on the quality and contextual relevance of the selected input and output variables. To address this, SSM is employed as a problem structuring method to explore the complex socio-technical dynamics of decarbonization and to translate the complexity of the pathways into resources and outcome indicators. Through this process, SSM can guide and endorse the selection of DEA inputs and outputs, ensuring that the model reflects a deeper understanding of each country's context.

Figure 1 presents the combined workflow proposed:

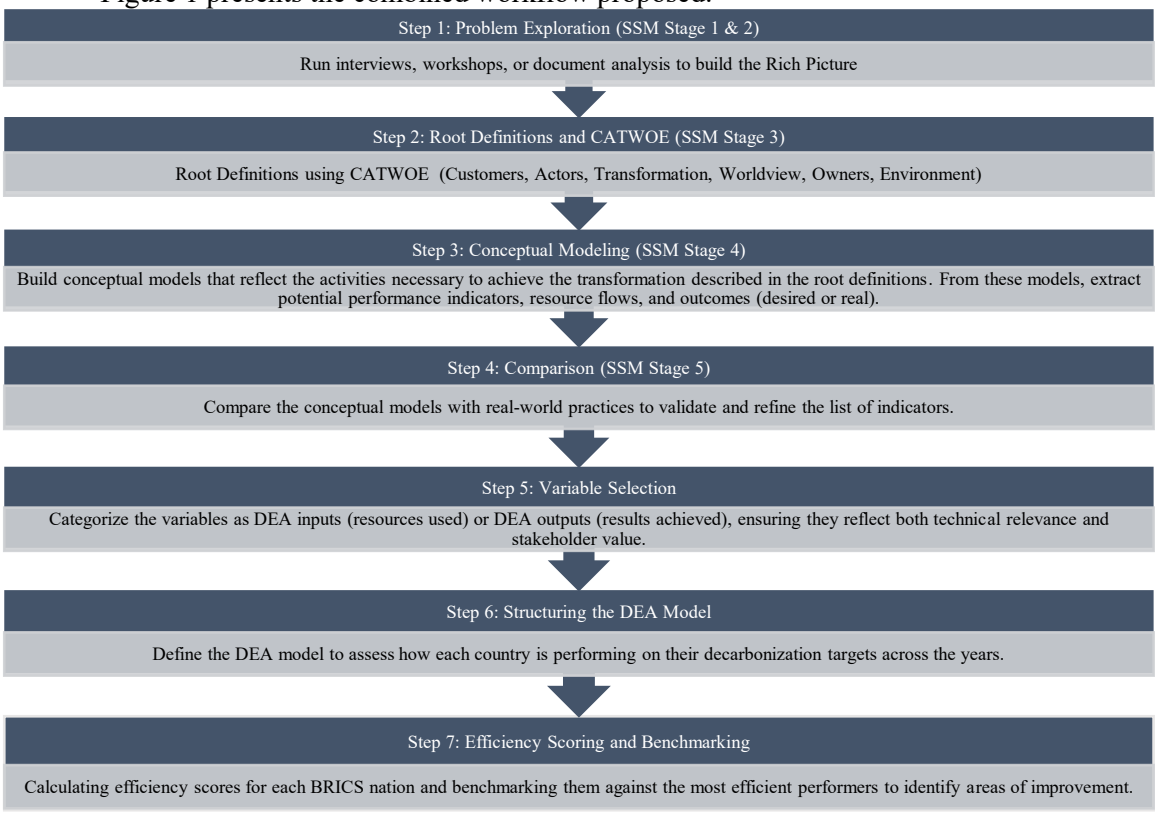


Figure 1. SSM and DEA integrated framework.

SSM, through its structured stages - such as rich picture development, CATWOE analysis, and conceptual modeling - facilitates a deep exploration of the problem situation by incorporating multiple perspectives and mapping the system's relations. This process helps uncover the critical resources (inputs) and desired outcomes (outputs) relevant to the DMUs under analysis. Assessing decarbonization efforts, SSM can highlight technological capabilities, institutional constraints, policy frameworks, and socio-environmental priorities that influence national performance.

Given the complexity and heterogeneity of the BRICS nations, from differences in energy infrastructure and regulatory environments to socio-economic priorities, SSM facilitates the identification of critical resources (e.g., energy consumption, fossil fuel dependence, investment in R&D) and desired outcomes (e.g., CO_2 emission reductions, renewable energy adoption, energy efficiency) that accurately reflect each country's context. This participatory and context-sensitive process ensures that the DEA model is not only methodologically sound but also aligned with the reality faced by each nation. As a result, the integration of SSM to guide the selection of DEA variables offers insights in a way that is aligned with the real-world functioning of the system, enhancing the validity, interpretability, and policy relevance of the efficiency results.

4. Final Considerations

The use of SSM to identify and select DEA inputs and outputs provides a comprehensive and systemic evaluation framework for analyzing decarbonization efforts. SSM is used as a PSM to explore the complexity of the decarbonization landscape and to identify, through a participatory and context-sensitive approach, the most relevant variables that reflect each country's specific conditions. One key advantage of using SSM in this context is its ability to incorporate multiple views of the system and reveal causal relationships, institutional constraints, and value-based factors that might otherwise be overlooked in purely quantitative approaches.

By supporting the definition of meaningful inputs and outputs for the DEA model, SSM ensures that the efficiency assessment is based on a broader understanding of the challenges and enablers of decarbonization. Once these variables are defined, DEA can be applied to quantify and compare the relative efficiency of BRICS nations in implementing low-carbon strategies. This benchmarking allows for the identification of best practices and underperforming areas, offering valuable policy insights and strategic recommendations.

This combined methodology enables a holistic understanding of decarbonization performance, facilitating evidence-based decision-making for policymakers and stakeholders involved in the discussion of new low-carbon industry processes, investments, subsidies, and technology development.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

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