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# Evaluating Resource Efficiency in the Public Sector through Data Envelopment Analysis (DEA): A Practical Application and Bibliometric Insight

**Selma Smajlović[1], Amra Gadžo[1], Mirza Suljić[2]**

[1]Faculty of Economics, University of Tuzla, Tuzla, Bosnia and Herzegovina
[2]Center for Quality, University of Tuzla, Tuzla, Bosnia and Herzegovina
Email: amra.gadzo@untz.ba

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## Abstract

Data Envelopment Analysis (DEA), as a non-parametric method for measuring efficiency, serves as a powerful tool for detecting inefficient resource allocation in the public sector, including healthcare, education, energy, and public administration. This paper aims to demonstrate how to identify resource inefficiency in the public sector and provide a systematic bibliometric overview of DEA application in resource efficiency assessment. This study presents a comprehensive bibliometric analysis of research focused on resource efficiency using the Data Envelopment Analysis (DEA) method, based on data collected from the Dimensions research platform and database. A total of 130 documents published between 1996 and 2025 were analyzed. Furthermore, using primary data on asset values, number of employees, total expenditures, and total revenues from public enterprises managing Forest Resources in Bosnia and Herzegovina, we demonstrate a practical approach to detecting resource inefficiency through DEA application. Given the persistent fiscal constraints and increasing demands for accountability in public resource management, particularly in transition economies, systematic efficiency assessment has become critical for sustainable development and evidence-based policy-making.

## Keywords

Data Envelopment Analysis, Resource Efficiency, Practical Application, Bibliometric Analysis

## 1. Introduction

The primary objective of any profit-oriented enterprise is to ensure its survival in

the market. To achieve this, effective resource management is imperative. In the case of public sector organizations, which are goal-oriented, efficient resource management forms the foundation for fulfilling their raison d'être, namely, the provision of public services with the most efficient use of public resources. Resource efficiency implies achieving desired outcomes at the lowest possible cost. In other words, the cost-benefit ratio should be optimal, avoiding waste and inefficient expenditure.

Resources encompass all inputs necessary to generate desired outputs. These primarily include human capital, operational assets, material resources, financial resources, and informational resources. To analyze resource efficiency and detect inefficiencies, the Data Envelopment Analysis (DEA) method can be employed. DEA is a non-parametric approach for measuring relative efficiency among decision-making units (DMUs). It is used to assess efficiency by comparing multiple input parameters (resources) against output values (results). DEA enables efficiency analysis when multiple types of resources are used (e.g., labor, raw materials, capital, energy) while simultaneously producing multiple outputs (e.g., product quantities, services, revenues, net profits, etc.).

It is important to emphasize that DEA does not require prior knowledge of the precise mathematical form of the relationship between input and output indicators. This constitutes a significant advantage in complex systems where classical economic functions struggle to model processes accurately. DEA models can be input-oriented or output-oriented. In input-oriented analysis, the focus is on minimizing input resource usage relative to given output levels. The goal is to achieve the same level of results with the least amount of resources. This approach is particularly useful when reducing costs or resource consumption is critical. In output-oriented DEA models, the situation is reversed: the focus is on maximizing outputs relative to given input levels. The objective is to achieve the highest possible level of production or service using existing resources, making this orientation suitable when improving overall efficiency is the priority.

As a result, the DEA method identifies which DMUs are efficient and which are not, highlighting specific areas for improvement. It provides precise information on which resources are being used inefficiently. For all these reasons, DEA represents a highly valuable tool for measuring resource efficiency across all sectors, regardless of the type, size, or regional affiliation of the enterprise. Accordingly, this study investigates the scientific network surrounding DEA to better understand its development, significance, and frequency of application in practice. The aim is to provide a comprehensive bibliometric overview of the development, importance, and application frequency of the DEA method in resource efficiency research.

The study is structured into three sections. The first section provides the theoretical framework and a review of previous research on the DEA method, including its significance and applications. The second section explains the research methodology, the implementation of bibliometric analysis, and the practical application of the DEA model on a sample of public enterprises. The third section

presents the research results and discussion, followed by concluding considerations.

## 2. Theoretical Background and Literature Review

Efficient resource utilization is a concern that pertains both to individuals and to society as a whole. It represents a central theme in economics, a discipline that studies how to generate valuable wealth from scarce resources and allocate it among people. Consequently, the rational use of resources, whether human labor, natural assets, capital, or time, becomes a key task in achieving economic development and societal well-being. The issue of resource efficiency has become particularly urgent in light of the ecological crisis, climate change, population growth, and rising living standards. An increasing number of studies and scholarly works emphasize the need for more efficient utilization of natural resources and the transition from a linear to a circular economy (UNEP, 2011; Ellen MacArthur Foundation, 2013; OECD, 2015; World Bank, 2021). Efficient resource management has the potential to reduce material costs by 2% - 3% and overall resource usage by up to 28% globally by 2050 (Schmidt, 2010; Ekins et al., 2016).

On the other hand, the question of efficient resource management differentiates successful enterprises from unsuccessful ones. It forms the basis of sustainable competitive advantage. Enterprises that manage resources effectively are able to reduce costs, enhance the quality of their products, and deliver greater value to customers using the same level of resources (Schmidt, 2010; Lin & Wu, 2014; Koh et al., 2016; Bezerra, Gohr, & Morioka, 2020). Consequently, there is a need for objective measurement of resource efficiency and identification of resources whose efficiency can be improved. The method most commonly employed for this purpose is Data Envelopment Analysis (DEA). DEA was formally introduced in the work of Charnes, Cooper, and Rhodes (1978), who developed the CCR model as an extension of earlier productivity measurement approaches. Unlike previous methods that relied on a single input and a single output, the CCR model allowed for the simultaneous analysis of multiple inputs and outputs. For this reason, the CCR model is considered the first formal version of DEA analysis. The model uses linear programming to construct an efficiency frontier and enables the relative efficiency assessment of each decision-making unit (DMU) in comparison with the best performers within the group. A key assumption of the CCR model is constant returns to scale (CRS), meaning that a proportional increase in all inputs leads to a proportional increase in all outputs (Charnes, Cooper, & Rhodes, 1978; Cooper, Seiford, & Zhu, 2011).

Over time, DEA has evolved through extensions such as the BCC model (Banker, Charnes, & Cooper, 1984), dynamic DEA models, and integration with other techniques, including impact analysis and multi-criteria decision-making. The BCC model extends the original CCR model by introducing variable returns to scale (VRS) instead of the constant returns to scale (CRS) assumption of the CCR model (Banker, Charnes, & Cooper, 1984). This allows efficiency to be measured under conditions of increasing, decreasing, or constant returns to scale. By introducing the VRS as-

sumption, the BCC model separates managerial efficiency (technical efficiency) from scale efficiency, providing a more detailed insight into whether inefficiencies arise from management practices or the size of the unit. Further developments in DEA have focused on its combination with impact analysis (Fried, Lovell, & Schmidt, 2008), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Li, 2023), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Şenel, Rouyendegh, & Pınar, 2021), data mining (Akçay, Ertek, & Büyüközkan, 2012), and other approaches.

Regarding the application of DEA in detecting resource inefficiency across different sectors, notable examples include public utilities for water supply and sewage services (Gadžo, Veledar, & Osmanović Đaković, 2024), healthcare (Zubir et al., 2024), higher education institutions (Chao & Chen, 2023), the banking sector (Khanal, 2023), and others.

## 3. Methodology

### 3.1. Methodology of Bibliometric Research

Bibliometric analysis employs a quantitative approach to examine scientific activity within a specific field and relies entirely on extant written publications that have been preserved and indexed in bibliographic databases (Babajić, Suljić, & Halilbegović, 2022; Smajlovic, Umihanic, & Turulja, 2025: pp. 14-15). This research is significant from two perspectives: first, a descriptive analysis of the available literature, and second, an analysis incorporating cluster analysis of the content of research papers in related domains.

Performance analysis focuses on measuring publication output and impact, often used as a proxy for quality, for authors, journals, institutions, and the country of origin of each publication. By applying text mining techniques, phrase frequencies were identified, along with the number of distinct documents in which individual phrases appeared, as well as the relative importance of each phrase within the overall corpus of publications. Finally, using the clustering analysis capabilities, relationships between phrases within the analyzed publications were examined.

*Choice of database*

The DIMENSIONS database currently contains 155,063,170 publications, 49,025,478 datasets, 950,032 clinical studies, 2,278,739 policy documents, 2,025,931 reports, and other scholarly outputs. To identify publications relevant to the research field, the DIMENSIONS database was utilized for the search. The search was conducted using a combination of the keywords "Data Envelopment Analysis" and "Resource Efficiency," and was limited to the title and abstract fields. To prevent continuous updates and repetitions, May 23rd, 2025, was selected as the cut-off date. DIMENSIONS is considered the most comprehensive global research database because it has the largest coverage of scientific publications, with over 155 million records across disciplines. It offers free basic access, unlike Scopus and Web of Science, and integrates diverse sources including grey literature, preprints, grants, patents, and policy documents. Dimensions also updates faster, often

indexing research outputs before Scopus or Web of Science.

The search strategy employed the following keywords: ("Resource Inefficiencies" OR "Resource Efficiency") AND ("DEA" OR "Data Envelopment Analysis"), using the Boolean operator 'OR' within the title and abstract fields. Furthermore, since the focus of this study is on the field of economics, an additional filter was applied accordingly. The search was conducted during the last week of May 2025, yielding a total of 130 publications from the primary query.

### 3.2. Methodology of the Practical Research

Our study employs an input-oriented DEA model. In the calculations, both the CCR (CRS) and BCC (VRS) methods are applied. The model includes three input variables (resources) for which efficiency is measured: total asset value, number of employees, and total expenses (covering costs of raw materials and supplies, energy, depreciation, and similar items). The selection of these inputs is grounded in production theory and reflects the fundamental resource categories utilized by public forestry enterprises: capital intensity (total assets, including forest land, machinery, and infrastructure), labor intensity (number of employees engaged in forest management, harvesting, and administrative activities), and operational intensity (total expenses capturing variable costs of production). The model considers a single output variable, namely total revenues, which represents the aggregated economic output of all forest-based activities and provides a holistic measure of enterprise performance consistent with the public policy objective of economic sustainability in the forestry sector.

The sample for determining resource (in)efficiency consists of public enterprises managing forest resources in the Federation of Bosnia and Herzegovina, totaling eight (8) entities. Data on revenues, expenses, asset values, and the number of employees were obtained from the publicly available database of the Financial-Information Agency.

**CCR (CRS)—Input-Oriented Envelopment Model**

For the observed DMU $\boldsymbol{o}$, the inputs are:

$\boldsymbol{x}_{j1}$ = total expenses, $\boldsymbol{x}_{j2}$ = total asset value, $\boldsymbol{x}_{j3}$ = number of employees

Output: $\boldsymbol{y}_{j1}$ = total revenues.

The linear programming problem is formulated as:

$$\theta^* = \min \theta \quad \text{s.t.} \begin{cases} \sum_{j=1}^{n} \lambda_j x_{j1} \le \theta x_{01} \\ \sum_{j=1}^{n} \lambda_j x_{j1} \le \theta x_{02} \\ \sum_{j=1}^{n} \lambda_j x_{j1} \le \theta x_{03} \\ \sum_{j=1}^{n} \lambda_j y_{j1} \ge y_{01} \\ \lambda_j \ge 0, \forall j \end{cases}$$

$\theta^* \in (0,1]$. A value of $\theta^* = 1$ indicates efficiency (subject to slack analysis).

**BCC (VRS)—Input-Oriented Envelopment Model**

The BCC model is formulated identically to the CCR model with the addition of the following constraint:

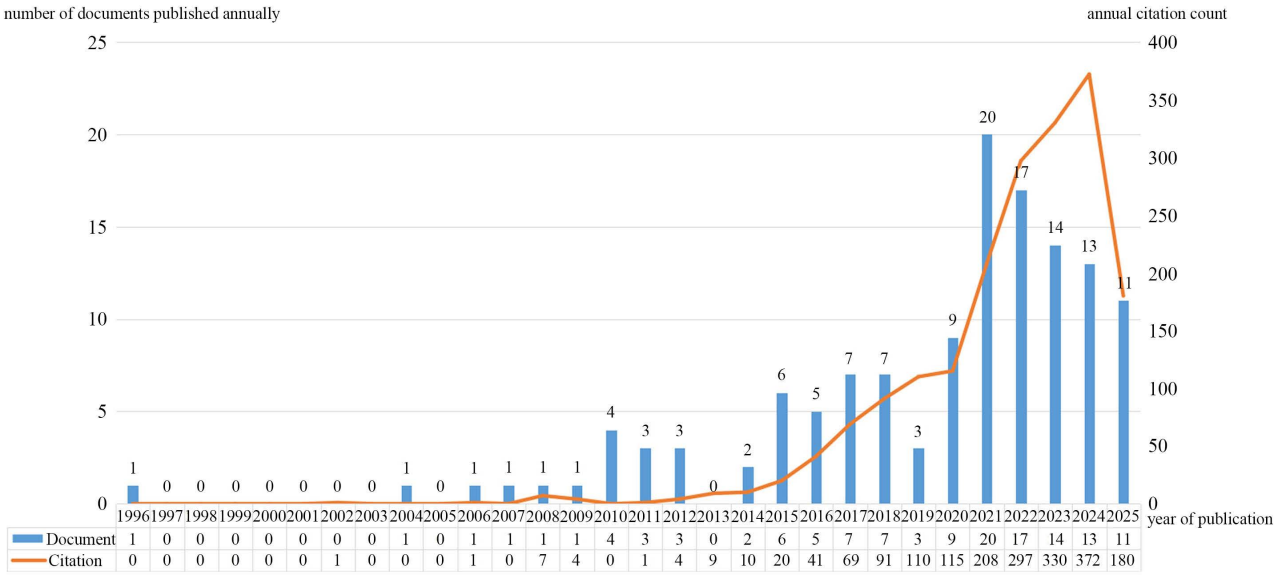
$$\sum_{j=1}^{n}\lambda_j = 1$$

This condition allows for variable returns to scale (VRS).

## 4. Results and Discussion

### 4.1. Results of the Bibliometric Analysis

In the contemporary research environment, monitoring and analyzing scientific publications have become essential tools for understanding the development of specific scientific fields. Therefore, having the purpose to be acquainted with the time frame of the collected publications, a graph as illustrated, based on a previously established search criteria (Figure 1), which can be seen in Figure 1, showing the number of articles published over the time.



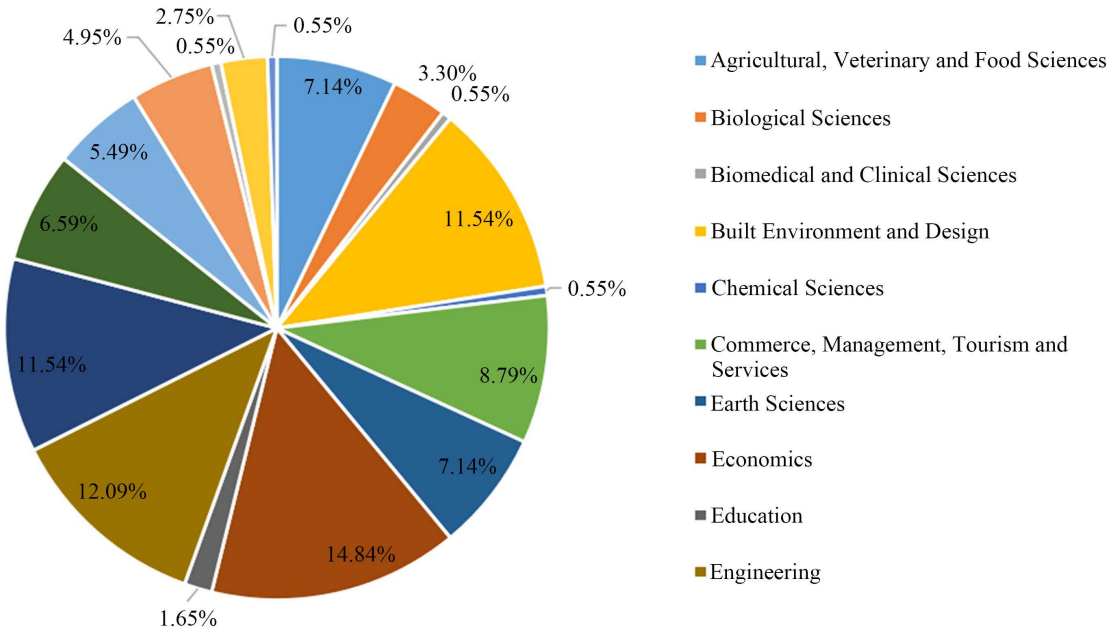

Source: Authors' own processing.

Figure 1. Publications related to "resource efficiency" and "data envelopment analysis" by year of publication.

The chart illustrates the annual number of publications addressing the topics of "Resource Efficiency" and "Data Envelopment Analysis" (DEA), alongside their yearly citation counts over the period 1996-2025. In the early years (1996-2007), both the number of publications and citations were negligible, indicating the initial stage of interest development in this field. The period from 2008 to 2014 shows a modest but steady increase in the number of publications. A more pronounced growth in citations begins in 2015, suggesting that publications from this period gained increasing significance within the scientific community. The highest number of publications was recorded in 2021. Correspondingly, citation counts also rose, peaking in 2024 with 372 citations. This reflects the strong impact

of earlier works and the maturation of the research area. Although the number of publications slightly declined after 2020, citations continued to increase until 2024, followed by a significant drop in 2025, which is attributable to incomplete data, as the analysis was conducted during 2025. Trend analysis indicates that research focus on resource efficiency and the DEA method has reached its peak, with prior studies continuing to be actively used and cited in contemporary research. This confirms the bibliometric relevance of the topic, not only in terms of the quantity of published works but also in terms of their scientific impact.

Although the absolute number of publications related to the keywords during the analyzed period is not large, the trends indicate a steady and significant growth in research output. The limited number of publications can be interpreted as indicative of a relatively specialized topic, often explored within specific research niches. Despite the smaller number of publications, their high citation rates point to the quality and relevance of existing studies. This implies that these works have found broader application and recognition within the scientific community. Such a discrepancy between the number of publications and citation counts highlights the high scientific value and influence of the field.




Source: Authors' own processing.

**Figure 2.** Percentage of publications on "resource efficiency" and "data envelopment analysis" published across different fields of research (ANZSRC 2020).

An analysis of the publication structure by research area shows that the topics "Resource Efficiency" and "Data Envelopment Analysis" are explored across a wide range of scientific disciplines (**Figure 2**). Research area classification was based on the Australian and New Zealand Standard Research Classification (ANZSRC, 2020). Most publications were related to Economics (14.84%) and Engineering (12.09%), while the remaining publications were categorized under

Built Environment and Design (11.54%), Environmental Sciences (11.54%), Commerce, Management, Tourism and Services (8.79%), Agricultural, Veterinary and Food Sciences (7.14%), Earth Sciences (7.14%), Health Sciences (6.59%), Human Society (5.49%), Information and Computing Sciences (4.95%), and Other (9.89%) (see Figure 2).

Table 1 presents the most influential authors based on the number of publications and citations per article. Displaying the leading authors according to publication count and citations per paper helps identify the key contributors and leaders in the research field.

Table 1. Most prominent authors who have published at least on resource efficiency and data envelopment analysis (Accessed 23/5/2025).

| Authors | Publications | Citations | Citations per publication |
|---|---|---|---|
| Cai-Zhi Sun (Liaoning Normal University, China) | 2 | 186 | 93.00 |
| Liangshi Zhao (Liaoning Normal University, China) | 2 | 186 | 93.00 |
| Qi-Ting Zuo (Zhengzhou University, China) | 2 | 75 | 37.50 |
| Tie Niu (First Affiliated Hospital of Dalian Medical University, China) | 2 | 49 | 24.50 |
| Kwok-Leung Tsui (Virginia Tech, United States) | 2 | 49 | 24.50 |
| Hainan Guo (Shenzhen University, China) | 2 | 49 | 24.50 |
| Gang Hao (City University of Hong Kong, China) | 2 | 21 | 10.50 |
| Hong Yan (Zhejiang Shuren University, China) | 2 | 21 | 10.50 |
| Rizwana Yasmeen (Panzhihua University, China) | 2 | 21 | 10.50 |
| Wasi Ul Hassan Shah (Zhejiang Shuren University, China) | 2 | 21 | 10.50 |
| Liang Dong (City University of Hong Kong, China) | 2 | 9 | 4.50 |
| Muzakir Muzakir (Syiah Kuala University, Indonesia) | 2 | 0 | 0.00 |
| Christian Angui Aboua (Université Jean Lorougnon Guédé, Ivory Coast) | 2 | 0 | 0.00 |
| Zainal-Putra (Universitas Teuku Umar, Indonesia) | 2 | 0 | 0.00 |
| Ishak Hasan (Syiah Kuala University, Indonesia) | 2 | 0 | 0.00 |

Source: Authors' research from dimensions database.

The analysis of the most influential authors who have published at least two

papers on the topics of Resource Efficiency and Data Envelopment Analysis reveals a relatively small number of publications per author. This indicates that a core group of highly prolific authors has not yet been established in this research area. Nevertheless, certain authors stand out due to their high citation counts. Notably, Cai-Zhi Sun and Liangshi Zhao, both affiliated with Liaoning Normal University in China, each have 186 citations, averaging 93 citations per publication. This underscores the exceptional scientific relevance and impact of their work. Most other influential authors are also based in China, highlighting a regional concentration of research interest. Overall, these data suggest a phase of expansion and diversification within the research network.

Table 2 presents the ten most cited publications according to the dimensions database. The most highly cited works represent studies that have shaped research directions, theoretical frameworks, or methodologies. They also frequently serve as reference points for subsequent research.

Table 2. Ten most frequently cited articles according to dimensions database, from the analyzed set of publication (Accessed 23/5/2025).

| Citat | | Author | Title | Year | Publisher |
|---|---|---|---|---|---|
| Dimensions | Google Scholar | | | | |
| 239 | 304 | Jianhuan Huang, Xiaoguang Yang, Gang Cheng, Shouyang Wang | A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China | 2014 | Journal of Cleaner Production |
| 133 | 198 | Murilo Pagotto, Anthony Halog | Towards a Circular Economy in Australian Agri-food Industry: An Application of Input-Output Oriented Approaches for Analyzing Resource Efficiency and Competitiveness Potential | 2015 | Journal of Industrial Ecology |
| 119 | 125 | Caizhi Sun, Xiaodong Yan, Liangshi Zhao | Coupling efficiency measurement and spatial correlation characteristic of water-energy-food nexus in China | 2021 | Resources Conservation and Recycling |
| 84 | 110 | Yong Liu, Yu Song, Hans Peter Arp | Examination of the relationship between urban form and urban eco-efficiency in China | 2012 | Habitat International |
| 75 | 107 | Lei Li, Tongtong Hao, Ting Chi | Evaluation on China's forestry resources efficiency based on big data | 2017 | Journal of Cleaner Production |
| 71 | 75 | Donglin Li, Qiting Zuo, Zhizhou Zhang | A new assessment method of sustainable water resources utilization considering fairness-efficiency-security: A case study of 31 provinces and cities in China | 2022 | Sustainable Cities and Society |
| 68 | 98 | Caizhi Sun, Liangshi Zhao, Wei Zou, Defeng Zheng | Water resource utilization efficiency and spatial spillover effects in China | 2014 | Journal of Geographical Sciences |

**Continued**

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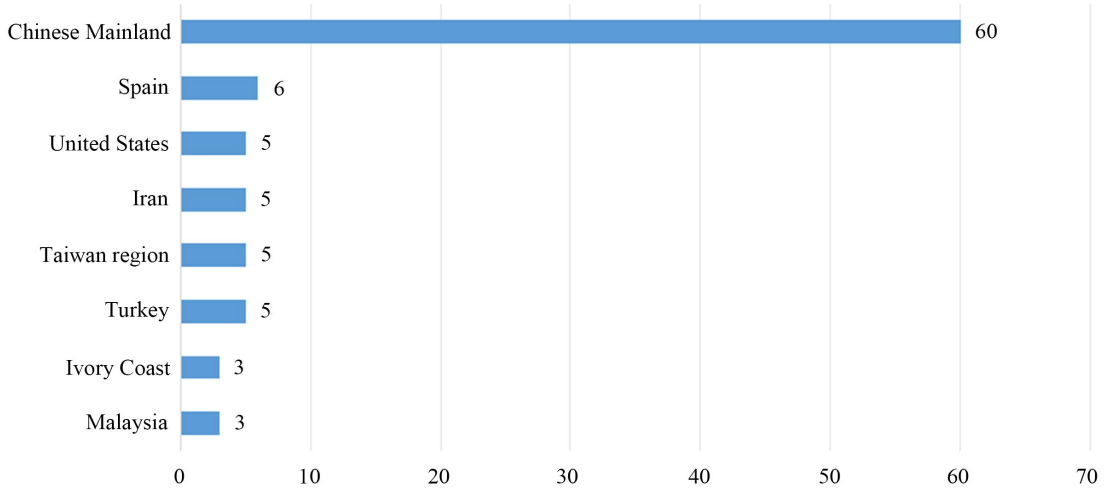
|---|---|---|---|---|---|
| 63 | 76 | Juan Wang, Jing Li, Qingjun Zhang | Does carbon efficiency improve financial performance? Evidence from Chinese firms | 2021 | Energy Economics |
| 53 | 66 | Wen-Chi Yang, Yuh-Ming Lee, Jin-Li Hu | Urban sustainability assessment of Taiwan region based on data envelopment analysis | 2016 | Renewable and Sustainable Energy Reviews |
| 53 | 96 | James Odeck | Congestion, ownership, region of operation, and scale: Their impact on bus operator performance in Norway | 2006 | Socio-Economic Planning Sciences |

Source: Authors' own processing.

The most cited publication is "A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China" (2014) by Jianhuan Huang, Xiaoguang Yang, Gang Cheng and Shouyang Wang published in the Journal of Cleaner Production with 239 citations. In addition, most of the highly cited publications focus on resource efficiency and sustainability within the Chinese context, including studies on water, energy, and food usage, forestry resources, as well as urban and regional ecological models. Notable exceptions include research on the circular economy in the Australian food industry and studies on sustainability in urban areas of Taiwan region, indicating a growing global interest in efficiency and sustainability topics.

The high citation counts of Chinese authors (e.g., Cai-Zhi Sun and Liangshi Zhao) confirm their significant role in this research field. Moreover, the presence of publications from diverse geographic regions, such as Norway, Australia, suggests that efficiency and sustainability issues are being considered in a broader international context, although China remains dominant in both the quantity and impact of publications.




Source: Authors' own processing.

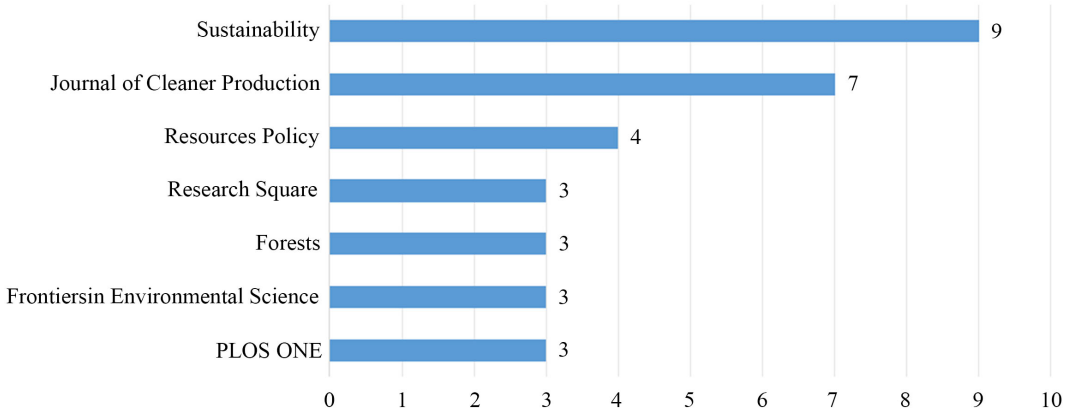
**Figure 3.** Countries or regions that published 3 or more publications on the topic.

The following figure presents the geographic distribution of publications.

Countries that have published three or more studies on the topic include China, Spain, the United States, Iran, Türkiye, Ivory Coast, and Malaysia (see Figure 3).

As an economic powerhouse, China invests intensively in resource optimization, production processes, and technological innovations to maintain competitiveness and accelerate economic development. Resource Efficiency and Data Envelopment Analysis (DEA) are methods and concepts used to measure and improve efficiency. Therefore, it is not surprising that authors from this region are among the most influential. This prominence may also reflect potential government support for scientific research in areas related to resource efficiency, measurement, and enhancement, as research funding is typically aligned with national priorities and strategic objectives.

The following figure (Figure 4) illustrates the most prominent journals publishing studies on resource efficiency and Data Envelopment Analysis (DEA). Identifying these journals helps to understand where relevant research is most frequently published and which sources are most important for professionals and researchers in the field. The dominance of certain journals may indicate specialized scholarly communities and focal areas within the broader topic of efficiency and performance evaluation. This information is valuable for guiding future research, selecting publication venues, and identifying the highest-quality and most influential sources of knowledge.



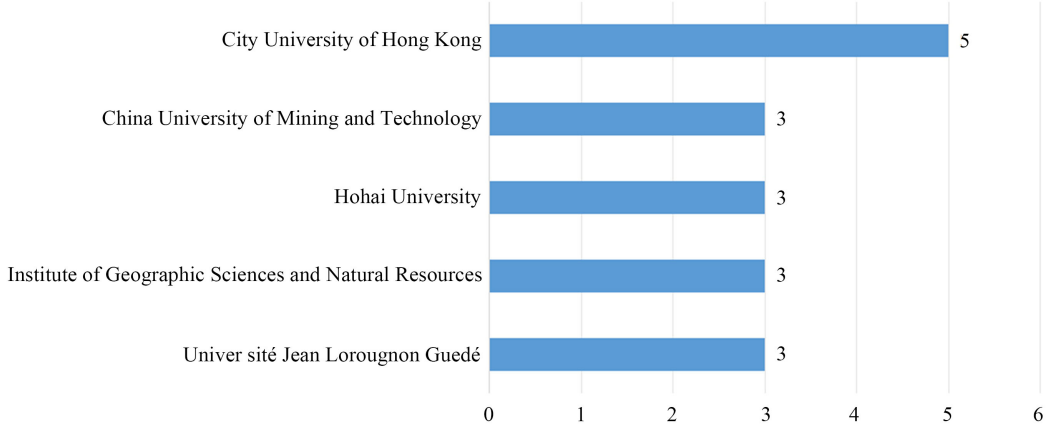

Source: Authors' own processing.

**Figure 4.** Most prominent journals on the topic of resource efficiency and data envelopment analysis.

The data reveal that *Sustainability* has the highest number of articles (9), followed by the *Journal of Cleaner Production* (7), *Resources Policy* (4), *PLOS ONE* (3), *Frontiers in Environmental Sciences* (3), etc. We can conclude that *Sustainability* holds a central role and is key for disseminating research in this field. This also indicates that the DEA method is frequently used in studies of resource efficiency, serving both financial and environmental sustainability objectives.

Institutions that had 3 or more publications were *City University of Hong Kong*, *China University of Mining and Technology*, *Hohai University*, *Institute of*

*Geographic Sciences and Natural Resources* and *Université Jean Lorougnon Guédé* (see Figure 5).

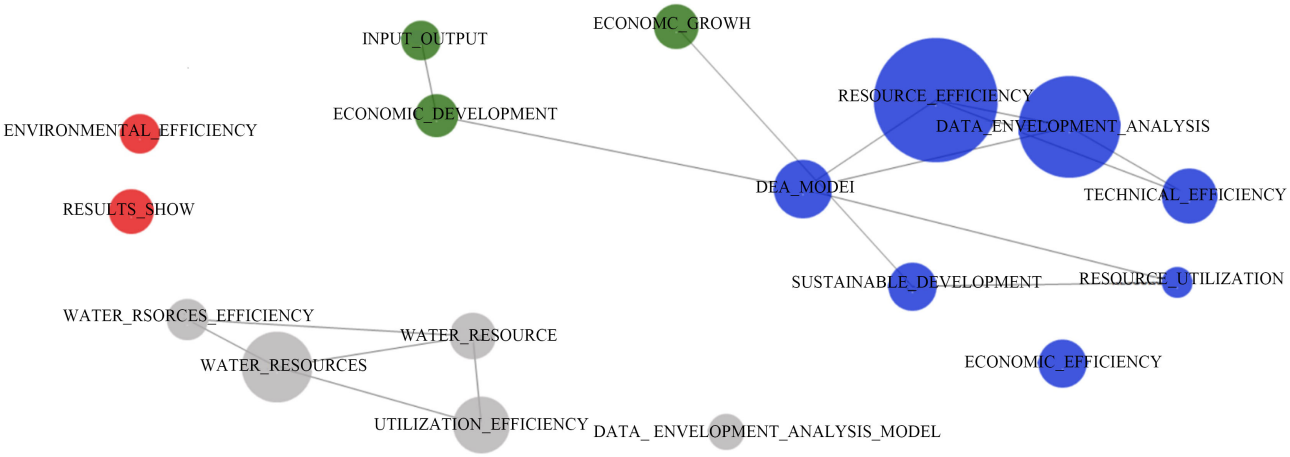



Source: Authors' own processing.

**Figure 5.** Institutions that published 3 or more publications on the topic.

This finding highlights the important role of these institutions in generating relevant research and contributing to the development of the scientific community in this field. The dominance of Chinese universities further reinforces the regional focus on resource efficiency and sustainability topics.

Figure 6 illustrates the proximity of the most frequent phrases within clusters. This analysis reveals research clusters, demonstrates thematic connections between terms, and aids in mapping research directions.




Source: Authors' own processing.

**Figure 6.** Co-occurrence network of key phrases in the context of resource efficiency within the DEA method (text mining).

The blue cluster dominates the analysis of Resource Efficiency and the DEA model. Key themes include resource efficiency, DEA, sustainable development, technical efficiency, and economic efficiency. The green cluster addresses issues of economic development and growth, linking economic development with input-

output analysis, which indicates a research focus on the impact of economic flows on efficiency. The red cluster focuses on ecological efficiency. This cluster highlights the analysis of ecological efficiency and the presentation of results from such studies. Its weak connections with other clusters may suggest a separate research trajectory or insufficient integration with economic topics. The gray cluster relates to water resource management. The emphasis is on the efficiency of water use, which is closely connected to sustainable development and DEA models, yet represents a somewhat distinct group.

Phrases are an important part of the publication that represents the core content; the specific associations formed between the phrases will identify the degree of academic interest in the field of research through a phrase analysis. In this paper, we use phrases co-occurrence analysis to address the highly popular topics in the field of Resource Efficiency and Data Envelopment Analysis. The 130 publications had 468 phrases, most of which are not frequently used, in which there is a small group of often used phrases. Of course, the most frequently used phrases are "resource efficiency" with the highest frequency of occurrence, followed by "data envelopment analysis", "water resources", "utilization efficiency", "technical efficency", "circular economy", "eco efficiency", etc. Twenty-eight (28) phrases with the appearance of more than 15 are shown in Table 3.

Table 3. Most frequent and most important phrases, from the analyzed set of publication (Accessed 23/5/2025).

| Keyword | Frequency | No. Cases | % Cases | Length | TF-IDF |
|---|---|---|---|---|---|
| RESOURCE EFFICIENCY | 181 | 101 | 77.69% | 2 | 19.8 |
| DATA ENVELOPMENT ANALYSIS | 133 | 96 | 73.85% | 3 | 17.5 |
| WATER RESOURCES | 77 | 16 | 12.31% | 2 | 70.1 |
| UTILIZATION EFFICIENCY | 38 | 12 | 9.23% | 2 | 39.3 |
| TECHNICAL EFFICIENCY | 35 | 26 | 20.00% | 2 | 24.6 |
| CIRCULAR ECONOMY | 32 | 9 | 6.92% | 2 | 37.1 |
| ECO EFFICIENCY | 29 | 8 | 6.15% | 2 | 35.1 |
| SUSTAINABLE DEVELOPMENT | 27 | 16 | 12.31% | 2 | 24.6 |
| DEA MODEL | 26 | 22 | 16.92% | 2 | 20.1 |
| ECONOMIC EFFICIENCY | 26 | 11 | 8.46% | 2 | 27.9 |
| TOTAL FACTOR | 26 | 11 | 8.46% | 2 | 27.9 |
| WATER RESOURCES | 24 | 12 | 9.23% | 2 | 24.8 |
| ECONOMIC GROWTH | 23 | 14 | 10.77% | 2 | 22.3 |
| RESULTS SHOW | 23 | 20 | 15.38% | 2 | 18.7 |
| ECONOMIC DEVELOPMENT | 21 | 13 | 10.00% | 2 | 21.0 |
| HUMAN RESOURCES | 21 | 5 | 3.85% | 2 | 29.7 |
| WATER RESOURCES UTILIZATION EFFICIENCY | 21 | 5 | 3.85% | 4 | 29.7 |

**Continued**

| | | | | | |
|---|---|---|---|---|---|
| WATER RESOURCES EFFICIENCY | 20 | 10 | 7.69% | 3 | 22.3 |
| ENVIRONMENTAL EFFICIENCY | 18 | 11 | 8.46% | 2 | 19.3 |
| INPUT OUTPUT | 18 | 11 | 8.46% | 2 | 19.3 |
| NATURAL RESOURCE | 18 | 6 | 4.62% | 2 | 24.0 |
| RESOURCE UTILIZATION | 18 | 13 | 10.00% | 2 | 18.0 |
| RESOURCE ALLOCATION | 17 | 10 | 7.69% | 2 | 18.9 |
| ELDERLY CARE | 16 | 2 | 1.54% | 2 | 29.0 |
| WATER CONSUMPTION | 16 | 5 | 3.85% | 2 | 22.6 |
| DATAENVELOPMENT ANALYSIS MODEL | 15 | 11 | 8.46% | 4 | 16.4 |
| FISH FARMERS | 15 | 3 | 2.31% | 2 | 24.6 |
| RESOURCE MANAGEMENT | 15 | 6 | 4.62% | 2 | 20.0 |

Source: Authors' own processing.

This phrase analysis provides valuable insights into the thematic priorities and research focus of the scholarly community. By employing co-occurrence analysis of phrases, it is possible to effectively identify the key concepts that appear most frequently in the relevant literature, thereby mapping dominant research directions. Although a large number of phrases (468) were identified, only a small subset exhibits high frequency of use, suggesting that the field is broad, yet research interest is concentrated around a limited set of thematic cores.

The most frequently occurring phrases, such as "resource efficiency," "data envelopment analysis," and "technical efficiency", indicate that efficiency measurement models in the context of sustainable resource management represent a central component of the research. The presence of phrases such as "circular economy" and "eco-efficiency" highlights the connection to broader concepts of sustainable development and the green economy. This demonstrates that DEA models are increasingly used as tools for quantitatively assessing the impact of sustainable policies and practices.

### 4.2. Results of DEA Model Application for Public Enterprises Managing Forest Resources

Data Envelopment Analysis (DEA) enables the assessment of the relative efficiency of decision-making units (DMUs) through two primary models: the CCR (Charnes, Cooper, Rhodes) model, which assumes constant returns to scale (CRS), and the BCC (Banker, Charnes, Cooper) model, which allows for variable returns to scale (VRS). The CCR model measures overall technical efficiency, while the BCC model measures pure technical efficiency, excluding the effects of scale.

The CCR model assumes constant returns to scale, meaning that inputs and outputs change proportionally. It therefore measures overall technical efficiency,

combining both managerial efficiency and efficiency related to operating at the optimal scale. The BCC model allows variable returns to scale, recognizing that units may operate under increasing or decreasing scale conditions. It isolates pure technical efficiency, capturing only managerial or operational efficiency and excluding the effects of scale.

The difference between these two models allows for the identification of the sources of inefficiency, determining whether the problem lies in poor resource management (pure technical inefficiency) or in a suboptimal scale of operations (scale efficiency). In our analysis, the DMUs considered were public enterprises managing forest resources. The inputs included the value of assets, number of employees, and total expenses, while total revenue was used as the output. The results of the BCC and CCR models for measuring technical efficiency are presented in Table 4.

Table 4. Results of technical efficiency calculations.

| DMU | TE (theta, CCR) | TE (theta, BCC) |
|---|---|---|
| DMU1 | 1.00 | 1.00 |
| DMU2 | 1.00 | 1.00 |
| DMU3 | 1.00 | 1.00 |
| DMU4 | 0.981138 | 1.00 |
| DMU5 | 1.00 | 1.00 |
| DMU6 | 0.738744 | 0.757987 |
| DMU7 | 0.960891 | 1.00 |
| DMU8 | 1.00 | 1.00 |

Source: Authors' own processing.

Five out of the eight analyzed enterprises (DMU1, DMU2, DMU3, DMU5, and DMU8) achieve maximum efficiency ($\theta = 1.00$) in both models, indicating that they operate on the production possibility frontier and represent benchmark units. These enterprises optimally utilize available resources (assets, employees, and financial capital) to generate revenue, regardless of the returns-to-scale assumption.

For DMU4 (CCR = 0.981 vs. BCC = 1.00) and DMU7 (CCR = 0.961 vs. BCC = 1.00), a slight inefficiency is observed exclusively in the CCR model, while the BCC model indicates full efficiency. This discrepancy suggests that these enterprises exhibit pure technical efficiency (efficient resource management) but operate at a suboptimal scale. DMU4 has scale efficiency of 98.1%, implying that adjusting the scale of operations could achieve an additional 1.9% efficiency, while DMU7 could improve by 3.9% through scale optimization.

DMU6 shows the poorest performance with a CCR score of 0.739 and a BCC score of 0.758, indicating significant inefficiency of over 24%. Two main issues are identified:

- Pure technical inefficiency (24.2% in the BCC model): This reflects operational

management problems, as the enterprise does not optimally utilize its inputs to generate output, even assuming an ideal scale of operations.

- Scale inefficiency (additional 2.5%): This suggests that the enterprise operates at an inappropriate scale (Table 5).

One of the key advantages of the DEA method is the ability to identify specific sources of inefficiency through the analysis of slack variables. Input slack variables indicate by how much a particular input could be reduced without affecting the output level, even after proportional (radial) reduction of all inputs. In the context of analyzing public enterprises managing forest resources, the number of employees represents a critical operational input that directly affects operational costs and productivity.

Table 5. Results of human resource efficiency calculations.

| DMU | Slack-Number of Employees (CCR) | Slack-Number of Employees (BCC) | Comment |
|---|---|---|---|
| DMU1 | 0.00% | 0.00% | Efficient in terms of employees |
| DMU2 | 0.00% | 0.00% | Efficient in terms of employees |
| DMU3 | 0.00% | 0.00% | Efficient in terms of employees |
| DMU4 | 16.07% | 15.58% | **Inefficiency excess employees of approximately 16%** |
| DMU5 | 0.00% | 0.00% | Efficient in terms of employees |
| DMU6 | 5.74% | 5.69% | **Moderate inefficiency excess employees of approximately 6%** |
| DMU7 | 0.00% | 0.00% | Efficient in terms of employees |
| DMU8 | 0.00% | 0.00% | Efficient in terms of employees |

Source: Authors' own processing.

The greatest inefficiency in terms of the number of employees is observed in DMU4, with approximately 16% excess staff compared to the efficient level (i.e., the same revenue could be generated with 16% fewer employees). This means, for example, if DMU4 has 100 employees, the efficient number would be around 84 employees. Reducing the workforce by 16 employees would allow the enterprise to maintain the same productivity while significantly lowering labor costs. Alternatively, with the current staffing level, the enterprise would need to generate approximately 19% higher revenue $[(1/(1-0.16)-1)\times 100\%]$.

Nearly identical slack values in the CCR and BCC models (difference of only 0.49 percentage points) suggest that the issue of overstaffing exists independently of the scale of operations; it is not a matter of the enterprise being too large or too small, but rather a fundamental issue in workforce structure and utilization.

For DMU6, a moderate excess of employees was detected at 5.74% (CCR) and 5.69% (BCC). Although this inefficiency is significantly lower than that of DMU4, it still indicates potential for optimization. For an enterprise with 100 employees, this represents an excess of 5 - 6 staff members. The consistency of results between

models (difference of only 0.05 percentage points) again confirms that this is a pure workforce management issue, rather than a consequence of an inappropriate scale of operations.

Assets represent the most capital-intensive resource in the forestry sector, including land, forest roads, machinery, vehicle fleets, buildings, and infrastructure. Efficient management of these assets is critical for the financial sustainability of public enterprises, particularly in the context of limited budgetary resources and the need for reinvestment in modernization. DEA analysis allows the identification of enterprises holding unproductive or underutilized assets—resources that do not contribute proportionally to revenue generation compared to efficient enterprises. Slack values for assets indicate the absolute amount of excess capital that could be reduced, repositioned, or more productively utilized without affecting output levels. Table 6 presents the results of the asset use efficiency analysis, with absolute slack values expressed in Convertible Marks (BAM, 1 BAM = 0.51 EUR; 1 BAM = 0.59 USD) and relative indicators expressed as a percentage of the enterprise's total assets.

Table 6. Results of asset utilization efficiency calculations.

| Relativna neefikasnost imovine (slack/ukupna imovina) | | | | | | |
|---|---|---|---|---|---|---|
| DMU | Θ_CCR | Slack imovine (CCR) | Relativna neefikasnost (%) | Θ_BCC | Slack imovine (BCC) | Relativna neefikasnost (%) |
| DMU1 | 1.00 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |
| DMU2 | 1.00 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |
| DMU3 | 1.00 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |
| DMU4 | 0.981138 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |
| DMU5 | 1.00 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |
| DMU6 | **0.738744** | **263,275,527** | **≈70.23%** | **0.757987** | **271,250,894** | **≈72.36%** |
| DMU7 | 1.00 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |
| DMU8 | 1.00 | 0.0 | 0.0 | 1.00 | 0.0 | 0.0 |

Source: Authors' own processing.

Seven out of the eight analyzed enterprises show zero slack values for assets, indicating that their capital base fully corresponds to the level of revenue they generate. These enterprises utilize their assets optimally. Notably, even DMU4, which exhibits a slight overall inefficiency of 1.9% in the CCR model, shows no issues with asset utilization; its inefficiency stems exclusively from scale inefficiencies rather than unproductive capital.

DMU6 is the unit with the highest inefficiency. Its primary issue is inefficient asset utilization: an enormous absolute and very high relative slack value (~72% of assets). This means that, while maintaining revenue, DMU6 could theoretically reduce (or reallocate) approximately 72% of its reported assets to become efficient according to this model, suggesting problems in asset structure or in how assets are employed relative to revenue.

In the CCR model: θ = 0.7387, indicating that, while maintaining the same revenue, DMU6 would need to proportionally reduce all inputs (expenses, assets, number of employees) by 26.13%, and additionally, it has a non-proportional asset surplus (slack) of 263,275,527 KM.

In the BCC model: θ = 0.7580 under Variable Returns to Scale (VRS), high inefficiency remains, meaning that assets could still be reduced by 27.4% plus an additional 72% of asset slack. This indicates that the asset surplus is significant and structural, not merely proportional.

In relative terms: Total assets of DMU6 = 374,864,924 KM, Asset slack ≈ 271,250,894 KM (72.36%). Thus, of nearly 375 million KM in assets, approximately 270 million KM can be considered unproductively employed, as it does not contribute to revenue generation at a rate comparable to efficient units. If assets were efficiently optimized (through sale, better utilization, or leasing), the same revenue could be generated with 27% - 72% fewer assets, which would drastically improve the return on assets (ROA).

No other enterprise in the sample shows asset slack, indicating that DMU6's problem is not systemic or sectoral but idiosyncratic and specific to this unit. Even DMU4 and DMU7, which have slight overall inefficiencies, use their assets efficiently, their issue lies in suboptimal scale rather than unproductive capital.

The DEA findings enable evidence-based policy interventions tailored to each enterprise's inefficiency profile. DMU6 requires urgent comprehensive restructuring including an asset audit to identify divestment opportunities for the 72% (≈271M BAM) of unproductive capital and a human resource audit to address the 5.7% workforce surplus, while DMU4 should implement immediate workforce optimization targeting the 16% excess staffing through hiring freezes and voluntary separation programs. Scale-inefficient units (DMU7, DMU4) should explore merger strategies or output diversification to achieve optimal operating scale. Sector-wide reforms should mandate annual DEA benchmarking with efficiency-based budget allocation and introduce performance contracts linking management compensation to measurable efficiency targets. These concrete interventions could generate millions of BAM in annual fiscal savings while enhancing sustainable forest management.

## 5. Conclusion and Research Opportunities

The results of our study provided a comprehensive bibliometric analysis and a practical insight into the significance of applying the DEA model for measuring the efficiency of public resource utilization by public enterprises. This study demonstrated the use of Data Envelopment Analysis (DEA) as a powerful analytical tool for evaluating resource efficiency in the public sector, with a specific focus on public enterprises managing forest resources in Bosnia and Herzegovina. By combining bibliometric analysis with the empirical application of DEA methodology, the research achieved a dual contribution: theoretical mapping of scientific production in this field and practical demonstration of method operationalization

on real-world data.

The empirical analysis of eight public enterprises managing forest resources in BiH, using assets as inputs (asset value, number of employees, total expenses) and total revenue as output, revealed significant heterogeneity in the level of resource efficiency. The results identified three categories of enterprises:

1) Fully efficient enterprises (62.5% of the sample): Five enterprises (DMU1, DMU2, DMU3, DMU5, DMU8) achieved maximum technical efficiency ($\theta$ = 1.00) in both DEA models, positioning them as benchmark units that optimally transform inputs into output. These enterprises represent best practices in the sector and can serve as models for organizational and operational reforms in inefficient units.

2) Enterprises with scale inefficiency (25% of the sample): DMU4 and DMU7 exhibit pure technical efficiency (BCC $\theta$ = 1.00) but slight overall inefficiency (CCR $\theta$ = 0.981 and 0.961, respectively), indicating that their issue is not resource management but suboptimal operational scale. These enterprises could improve performance by 1.9% and 3.9%, respectively, through strategic scale adjustment—either by expansion or consolidation with other units, depending on the nature of returns to scale (increasing or decreasing).

3) Enterprise with critical multiple inefficiencies (12.5% of the sample): DMU6 represents the most concerning case, with total technical inefficiency exceeding 26% (CCR $\theta$ = 0.739). In-depth slack analysis revealed the structure of the problem:

- Moderate human resource inefficiency: A surplus of approximately 6% of employees, equating to 5 - 6 unnecessary positions for a company with 100 employees.
- Extreme capital inefficiency: Around 72.36% of assets (271 million KM out of a total 375 million KM) do not contribute to revenue generation proportionally compared to efficient units.

This study demonstrated that DEA is not merely an academic exercise but an actionable tool for public sector transformation. The inefficiency identified in DMU6, with over 70% unproductive assets and a 6% surplus of employees, represents an urgent call to action for decision-makers. However, the transition from diagnosis to efficiency requires more than technical solutions; political will, institutional support, and societal consensus on public sector efficiency priorities are essential.

In the context of Bosnia and Herzegovina, where public enterprises often function as instruments of political patronage and social policy, introducing rigorous performance standards constitutes a profound institutional change. The findings of this research provide an empirical foundation for such transformation, demonstrating that efficiency is not only a desirable goal but an operationally achievable reality, five out of eight enterprises in the sample already operate at best practice levels, proving that optimal resource utilization is attainable.

Based on the results of our bibliometric and conceptual analysis, the Data

Envelopment Analysis (DEA) method is widely accepted as a tool for evaluating efficiency across various sectors, particularly in contexts involving multiple inputs and outputs. Although the absolute number of publications is relatively modest, their scientific impact is notably high, as evidenced by increasing citation rates, especially over the last decade. This indicates a mature phase of development in the field and a high degree of recognition of existing research.

Particularly notable is the dominance of Chinese authors and institutions, which can be linked to China's national priorities in sustainable development and resource optimization. However, the presence of studies from other geographical regions (Norway, Australia, etc.) reflects a global interest in the topic, with China leading both in the number of publications and citation impact.

Structural analysis shows that research is conducted across multiple scientific disciplines, ranging from economics and engineering to environmental sciences, health sciences, and information technology, confirming the interdisciplinary nature of the field. Co-occurrence analysis of phrases further reveals that research interest is concentrated around thematic cores such as "resource efficiency," "DEA," "technical efficiency," and "circular economy," forming clearly defined research clusters. The blue cluster, which dominates the topic of resource efficiency, highlights the central role of DEA models in evaluating sustainability and system performance. Other clusters (green, red, gray) reflect specific subtopics, including economic development, ecological efficiency, and water resource management, indicating a diversification of approaches within the broader field.

This study demonstrates several methodological advantages of the DEA approach in public sector evaluation: multidimensional analysis, identification of sources of inefficiency, separation of management problems from scale issues, and a benchmark-based approach. Despite these strong findings, the study has several limitations that open avenues for future research. These include sample size, the use of aggregated financial input and output indicators, and the temporal dimension: a cross-sectional design provides only a snapshot of efficiency at a single point in time. Using the Malmquist index or window analysis would allow for tracking efficiency dynamics and identifying trends of improvement or decline over time.

Future research could apply more advanced DEA methodologies, such as network DEA to model the multi-stage nature of forestry operations (e.g., forest management, harvesting, timber processing) or dynamic DEA to analyze efficiency trajectories over time and assess the impact of specific policy interventions or external shocks (e.g., climate events, market fluctuations) on enterprise performance.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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