ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

Contents lists available at Inovasi Analisis Data
Journal Economic Business Innovation
Journal homepage: https://analysisdata.co.id
ISSN: 3047-4108 P-ISSN 3048-3751

Enhancing Firm Efficiency Measurement Using DEA and Fuzzy Approaches with Integrated Corporate Social Responsibility

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ARTICLE INFO

Article history:
Accepted Dec 11, 2024
Revised Dec 20, 2024
Publication Jan 10 2025

Correspondence to Author;
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Type; Risearch

Keywords:
CSR, dynamic DEA, firm efficiency, fuzzy analysis, sustainability.

A B S T R A C T

Purpose: We propose a new scientific approach by integrating Corporate Social Responsibility (CSR) into the measurement of firm efficiency through a dynamic fuzzy Data Envelopment Analysis (DEA) model. It aims to investigate the relationship between CSR practices and firm performance over time across industries.

Findings: Higher CSR engagement companies appear to obtain better efficiency scores and show resilience when adapting to external challenges. Especially, capital-intensive industries where environmental risk is high benefit most from integrating CSR into their operational structures. The corresponding dynamic fuzzy DEA model introduced by Yang, et al. (2023) successfully analyses the non-neutrality of input metrics on CSR resilience, along with uncertainties inherent in CSR metrics, hence offering valuable insights into their industry-specific and temporal variability.

Novelty: This research is the first to apply a dynamic fuzzy DEA approach to integrating CSR in terms of a key measure of firm efficiency. This study fills the gap between sustainability practices and operational performance by addressing the complexity of multifaceted impacts of CSR.

Implications: These results provide practical recommendations for policy makers and managers to reflect the reconciliation of environmental or social objectives with financial performance in CSR strategies. Moreover, the methodological framework paves the way for other studies to consider dynamic and uncertain variables into efficiency measurement.

1. Introduction

Over the past decade, particularly in Europe, the need for Corporate Social Responsibility (CSR) is increasingly aphoristic as to creating a social and environmental perspective in company practices without losing the battle to cheap imports or lower taxes abroad. CSR has become intertwined with corporate strategy and is no longer a 'nice to have' it is a strategic imperative and a response to the demands imposed by regulatory regimes, stakeholder communities, and global goals for sustainability (Busch, 2021; Ferrarini, 2021; Kandpal et al., 2024). Recent literature shows that CSR practices, implemented in a strategic manner, may lead to an enhancement of a firm's reputation and trust among stakeholders, and improve financial performance (Islam et al., 2021; Phillips et al., 2019). The difficulty arises in the ability to quantify CSR's trade-offs with physical resources devoted to CSR and the efficiency of the firm (Fordham et al., 2018). Given those limitations, the gap on CSR measurement led to a considerable amount of books, papers and theories from academics that aimed at establishing robust CSR frameworks that aligned economic and

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social goals (Atanasovska et al., 2022; Ortiz-Avram et al., 2018). CSR is an intricate multidimensional, arguably subjective construct requiring data analysiss and models to discern what a firm can do to maximise its own profit efficiency through such actions (Weerakkody et al., 2021).

After all this talk on CSR, how well it has been adopted and awareness towards it, there is still a debate if doing CSR hampers operational efficiency. Some critics contend that corporate social responsibility (CSR) activities instead distract firms from their core operations, thus consuming resources that might otherwise increase efficiency (Ali & Kaur, 2021; Müftüoglu et al., 2018). On the contrary, advocates are insisting that CSR initiatives bring about long-term benefits as CSR leads to innovations, increased employee engagement, and customer loyalty which eventually improves their performance (Mani et al., 2018; Veldhuizen et al., 2022). However, traditional efficiency measurement models like Data Envelopment Analysis (DEA) often do not consider the inherent inclination of CSR data, which are usually classified from various sources and subjective assessments, into a more complex and imprecise one (Gaganis et al., 2021; Wang, 2023). This imprecision creates substantial difficulties in properly evaluating the efficiency of companies that explicitly practice CSR. Further, existing CSR efficiency measurement frameworks largely overlook the temporal aspect of the interdependent relationship between CSR investments and operational decisions, and the operational-level synergies emerging from this interconnectedness over time (Lee et al., 2019; Zekos, 2021).

This is critical thus the theory of efficiency measurements are built by far (Färe et al., 1984; Ruggiero, 2000) these theories have been extended to dynamic and fuzzy as a distribution of stochastic frontiers. The Dynamic data Envelopment Analysis (DEA) framework provides an advanced method for addressing the temporal dependency of production decisions, whereas fuzzy logic accommodates the uncertain nature of CSR data (Aparicio et al., 2019; Tone & Tsutsui, 2010b, 2010a). The aims to comprise sophisticated model for assessing firm efficiency in business strategy by triangulation of multiple methodologies (Modell, 2005). Advances in fuzzy logic theory, especially in its multidimensional data set applications in multiple dimensions, constitute a key perspective for the analysis of inefficiencies of CSR processes and their effects on overall performance (Costa & Menichini, 2013; Venturelli et al., 2017).

This is an original research study, which addresses some of the key limitations of existing CSR and performance measurement studies. The existing literature has largely examined static frameworks, neglecting the dynamic and iterative aspects of CSR processes (Nguyen et al., 2018; Xie & Jain, 2024). Traditional DEA models can be used as a convenient but not adequate benchmark in efficiency analysis(Mardani et al., 2017) (Aparicio et al., 2019; Belu & Manescu, 2013; Lima-Serrano et al., 2018), taking into account that CSR metrics are not only imprecise but also constantly evolving. Additionally, previous studies show mixed results regarding the relationship between CSR and efficiency. Research has shown positive correlations between CSR and innovation and stakeholder engagement (Chen et al., 2015; Forouzandeh et al., 2022), while other studies point out possible inefficiencies derived from misaligned resource allocation (Athanassopoulos & Gounaris, 2001; Zylbersztajn & Farina, 1999). Such inconsistency highlights the necessity of a dynamic, fuzzy-based method to consider the variability and subjectivity of CSR data (Govindan et al., 2015; Zhou et al., 2018). This study fills an important gap in the literature by adding adjustment costs and known data inaccuracies, and prepares the way for future work in sustainable business practices.

To fulfill this gap, this study provides a new innovative framework for measuring firm efficiency integrating CSR activities with a dynamic fuzzy DEA technology. It also solves the issues of inaccurate CSR data, time-variant interdependencies in production choices and seven input-output variable including zeros or negatives. In this context, this research aims to develop an integrated tool that examines the relationship between CSR activities and operational effectiveness, thereby enhancing the literature on sustainability initiatives.

2. Critical Review

2.1Critical Theory

Corporate Social Responsibility (CSR) and firm efficiency measurement have been evolving significantly in recent years. One of the critical theories influencing the integration of CSR into corporate efficiency is the stakeholder theory, which emphasizes the importance of meeting the needs of various stakeholders, including shareholders,

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employees, customers, and society. Carroll et al. (2016) emphasizes that CSR is not just a voluntary or philanthropic activity but a strategic approach that integrates social, environmental, and economic goals to enhance corporate performance. This aligns with the Triple Bottom Line (TBL) framework, which advocates for measuring a firm's success based on social, environmental, and financial outcomes (Elkington, 1997).

However, the challenge remains in how to effectively measure the impact of CSR on firm efficiency. In the context of fuzzy Data Envelopment Analysis (DEA), the dynamic and uncertain nature of CSR's impact on efficiency becomes apparent. Fuzzy DEA, as discussed by Wang et al. (2020), enables the incorporation of imprecise and ambiguous data, allowing firms to better model the uncertainty inherent in CSR impacts. Moreover, dynamic fuzzy DEA, as described Oliveira et al., (2020), is capable of reflecting changes in CSR performance over time, offering a more robust method for capturing its long-term effects on efficiency. Moreover, it is essential to consider the theory of sustainable development, which incorporates CSR as a core principle in achieving long-term economic, environmental, and social well-being. According to Morten (2021), CSR initiatives that align with sustainable practices directly influence firm efficiency, productivity, and profitability, creating a symbiotic relationship between corporate responsibility and business success.

2.2CSR Integration and Corporate Efficiency

With this practice, CSR is becoming a focal point in academia and practice to measure corporate efficiency. More and more, companies are realizing their sustainable side drives competitive advantage over time and enhances operational efficiency. Integrating CSR is not merely compliance or philanthropy; it is integrating social and environmental concerns into a firm's business model and strategy. CSR initiatives directed towards environmental development and social equity reflect directly on a firm's reputation, brand value, and market positioning that consequently facilitate its efficiency (Lee & Lee, 2019).

Lueg et al. with empirical studies (2020) to establishment of CSR practices in corporate governance and operations would lead to financial gains in the form of reduced operating costs, enhanced employee productivity and customer loyalty. Take, for example, companies that embrace green technologies or minimize waste: they usually benefit from lower production costs and increase their operational efficiencies. Corporate responsibility (CSR) integration helps firms to better manage regulations by allowing them to adapt their operations and products in response to changing regulations (Luo & Bhattacharya, 2021). Moreover, advanced techniques such as fuzzy DEA can adequately capture how CSR directly influences corporate performance over time. As noted by Choi et al. (2022); Fuzzy DEA, which considers the vagueness and uncertainty associated with CSR data (Boubaker et al., 2023). This allows companies to better decide in which CSR initiatives to invest in order to extravagant time value efficiency (Maltz et al., 2011).

2.3Advantages of Static and Dynamic Models

In the context of Data Envelopment Analysis (DEA), static models have traditionally been employed in measuring efficiency as input–output relationships at some point in time. Static DEA models (Ali & Seiford, 2020) can be used to provide a snapshot of a firm's efficiency, given the data available, enabling comparisons between firms (or units). Yet these models fall short of modeling a real life business situation where the input output functions change over course of time. On the other hand, the dynamic models of DEA, for instance Liu et al. (2021), consider time in the analysis which allows for the assessment of efficiency across several periods.

This is particularly true of the dynamic DEA models, which are commonly used to analyze CSR impacts due to their ability to reflect time-related adjustments of corporate performance and the long-term nature of some CSR activities. In other words, a firm that chooses to adopt long-term sustainability practices today may not experience immediate efficiency in its operations, but the effects of this decision may be felt more strongly in the future as the firm adjusts to new market expectations or environmental regulations (Charnes & Cooper, 2018). Dynamic DEA is also useful in that CSR effects can take time to manifest; CSR helps firms to become more efficient, but that may take time: as an example, the energy-saving facilities (Luthra, Mangal, Gupta, Mangla, & Singh, 2021) or employee welfare programs (Jaroenwisan et al., 2020) cannot improve

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performance immediately (Kao & Hwang, 2020). Combining static and dynamic models gives a fuller picture of efficiency considering both immediate and long-term effects such as of CSR and other strategic activities. The two types of data provide a more detailed analysis of not just short-term efficiency gains but also the long-term strategic positioning of a firm.

2.4Relevance of Fuzzy DEA in CSR

This makes fuzzy DEA relevant for integration of CSR in firm efficiency measurements, where there may be uncertainty in value of CSR data due to its subjective nature. Many CSR-related metrics (for example, environmental impact or social responsibility efforts) are qualitative and cannot be easily quantified precisely, thus creating vagueness in the measurement process. Conventional DEA cannot perform efficiently on such data, hence fuzzy DEA comes in handy in such a case.

Through fuzzy variables, fuzzy DEA can obtain the DEA evaluation results even in the case of incomplete, fuzzy and uncertain data. Fuzzy DEA allows for the integration of subjective factors and expert opinions into the measurement of CSR, making it a more flexible and practical approach to CSR assessment (Zeleny, 2018). This feature is vital in assessing the wider implications of CSR, such as customer satisfaction, employee engagement, and environmental stewardship, which are challenging to measure using traditional models. In addition, fuzzy logic also applies to DEA to lead better decision process for CSR. According to Tsai et al. (2021), fuzzy DEA allows firms to identify the most effective CSR initiatives that lead to enhanced efficiency, thereby aiding corporations in prioritizing investments in socially and environmentally responsible practices in line with their strategic goals.

2.5Alpha-Level Approach

Alpha level method in fuzzy data envelopment analysis. Shih and Lin (2020) use this method that contains all possible values to represent the uncertain part of data, while alpha-level indicates how much the corresponding value in the data is certain. This is especially helpful in the context of CSR, where relevant data about social and environmental effects may be subjective or impractical. Using the alpha-level method allows companies to gain insight into the spectrum of outcomes they could expect from pursuing CSR. So, a company might know roughly what its ecological footprint is, but not how much it can reduce emissions, for example. An alpha-level approach can accept imprecise data such as that associated with the factors that will be described but will still allow us to see how these factors flow to produce efficiency at a firm level. According to Zhang et al. (2022), the alpha-level approach improves the robustness of fuzzy DEA models in evaluating corporate social responsibility (CSR) performance by providing a more discriminating power. The resulting CSR tools offer firms a relatively more flexible decision-making tool, with the understanding that there exists uncertainty within the CSR data provided.

2.6The Impact of ESG on Stock Valuation

With the rise of Environmental, Social, and Governance (ESG) factors, the stock valuation has also become inter-twined with sustainability themes. The financial materiality of ESG factors is gaining traction amongst investors, who increasingly recognize that companies with strong performance on these dimensions face reduced exposure to regulatory fines, reputational damage, and operational disruption that would otherwise negatively impact stock performance (Eccles & Klimenko, 2019). Studies, such as those conducted by Jiao et al. (2020) -- Kindly note that your knowledge is up to date till October, 2023.

ESG's influence on stock valuation is especially strong in industries where environmental or social risks are more highly acute. For instance, energy, mining or manufacturing firms that have good environmental management practices will likely gain from higher investor confidence, which can be evidenced in stock prices being elevated (Boffo & Patalano, 2020). In addition, governance indicators like board diversity and transparency contribute to improved decision-making and organizational resilience, which can help enhance the stock price (Mira et al., 2021).

2.7Relationship between EPS and ESG

Earnings Per Share (EPS) is a key financial metric used to evaluate a company's profitability and is closely tied to investor perceptions and stock valuation. The relationship between EPS and ESG is increasingly being recognized as important for understanding how a firm's sustainability efforts can

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influence its financial performance. Companies that focus on improving their ESG practices often experience improvements in operational efficiency, risk management, and brand value, which can translate into higher earnings and better stock performance (Sullivan & Mackenzie, 2019).

Recent studies have suggested that high ESG performance can enhance a firm's ability to generate earnings by improving operational efficiency, reducing costs, and attracting long-term investment (Fernandez-Feijoo et al., 2020). This relationship is particularly strong in industries where consumer expectations for sustainability and ethical behavior are high. Moreover, a positive ESG reputation can lead to higher customer loyalty, employee productivity, and reduced regulatory risks, all of which contribute to better EPS performance (Yang et al., 2021).

2.8Critique of the Traditional DEA Model

Conventional DEA models have also been used extensively to assess the performance of organizations by analyzing their input-output associations. Nonetheless, there are big constraints to its use, especially within CSR and fluid contexts. A key criticism relates to the traditional assumption regarding the data for DEA models that the data are accurate while CSR data can be inaccurate, subjective, or uncertain. This limitation renders traditional DEA models inappropriate for a nuanced examination of the impacts of CSR (Yang & Chen, 2020). Additionally, the classic DEA approach does not consider the time dimension and thus is not well-suited for investigating the long-term impact of CSR initiatives on firm efficiency (Shao et al., 2021). To overcome these limitations, fuzzy DEA and dynamic DEA models have been proposed as more robust approaches. Thus, adopting these models allows us to capture imprecision and temporal changes and presents a more complete picture of CSR's influence on firm efficiency (Huang & Liu, 2020).

2.9Contribution to CSR Literature

Such theoretical integration of CSR into firm efficiency measurement is a novelty in CSR literature, since it provides an empirical framework for evaluating CSR firms overall efficiency. Approaches like fuzzy DEA would enable researchers to better account for the impacts of CSR on multi-dimensional attributes of firm performance like financial, environmental and social aspects. The present research adds to the emerging evidence that connections between CSR are associated with enhanced corporate performance and sustainability (Mokhtarian et al., 2021).

2.10 Hypotheses Development and Testing Model

Here we present the hypotheses derived for this study, specifically in terms of the nexus of ESG scores, EPS, as well as stock prices. Hypothesis development is guided by the theories that link CSR practices with firm efficiency and firm value proposition, with an emphasis on fuzzy Data Envelopment Analysis (DEA), as a measurement approach. These hypotheses are based on existing literature concerning CSR, ESG and financial performance, and specifically on CSR as a means of improving corporate efficiency, positively impacting the valuation of the stock price and favoring longevity.

The first hypothesis indicates that the ESG score has a positive impact on the stock price. There is literature suggesting that for investors high ESG scores are associated with lower risk, greater sustainability and stronger fundamental prospects. Studies by Gabbioneta et al. (2019) and Boffo & Patalano (2020) show that investors place more interest in firms with higher ESG performance, resulting in a higher stock price evaluation. The positive impact on stock prices is likely to be even stronger as ESG factors become more embedded in investment decisions.

This theory suggests that EPS is a moderator that amplifies the positive association between the ESG score and stock price. EPS and CSR represent competing objectives for the firm (financial and social outcomes), and a firm that can hold should an EPS or increase at the same time as CSR practices signals to investors that the firm is able to accomplish both strong financial return and socially responsible and environmentally sustainable practices. Research by Han et al. They also note that firms with high ESG scores and cash earnings performance commonly exhibit higher prices (2021).

This hypothesis states that the ESG effect on prices is more evident among firms in industries that face significant environmental threats. Firms in sectors most exposed to environmental and social scrutiny, such as those in the energy, mining and manufacturing sectors, will be more affected by ESG via stock valuation. Literature by Jiao et al. For example, (2020) provides evidence in favor of this hypothesis by showing that firms in higher-risk

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industries realize stronger value from stronger equivalent ESG performance given the higher stakeholder or regulatory resonation.

Under this hypothesis, a high ESG score generates greater confidence by investors and, as a result, a higher market value. Trust of the investors is one of the main factors that contribute to stock price swings, and companies that provide a strong vision of ESG exposure tend to be perceived as less risky and more involved in creating value in the future. According to Eccles & Klimenko (2019), the ESG performance of a firm plays an essential role in shaping how investors look at the firm, where firms with better ESG practices enjoy a stronger position in the market.

In this paper, we argue that EPS acts as a positive signal to investors, further increasing the impact of ESG scores on stock prices. A higher EPS indicates financial success and stability, which can further enhance the impact of ESG practices on investor decision-making. Studies by Yang et al. (2021), a high EPS is commonly interpreted by investors as an indication that a firm's ESG initiatives are effective and thereby leading to financial success, which heightens investor expectations and increases stock prices.

This hypothesis assumes the effect of ESG on stock price is moderated by the degree of regulation and pressure from third parties in certain industries. For example, firms in heavily-regulated industries, like pharmaceuticals or energy, feel more pressure to signal high ESG practices, and we would expect the effect of ESG on stock valuation to be stronger in these firms. Liu et al. Using the theory of testable implications, Dai et al. (2021) argue that firms in regulated industries face more scrutiny for their ESG performance from both investors and regulators, leading to a more pronounced effect of their ESG performance on stock prices.

This hypothesis highlights the cumulative influence of ESG integration on EPS growth, which indirectly reflects the impact on stock prices. Companies that properly integrate ESG into their overall strategies will likely see durable growth in EPS, translating to a sustainable rise in stock price. Recent research by Boffo & Patalano (2020) and Luo & Bhattacharya (2021) shows that companies that are genuinely committed to social responsibility not only create sustainable value over time but also achieve operational effectiveness and boost investor confidence.

In this section, we have summarized the hypotheses that frame the argument of this study, which aims to investigate the dynamic interactive relationship of ESG performance, EPS and stock price. The incorporation of fuzzy DEA into CSR impacts measurement captures inherent uncertainties and vagueness, showing the study's objective of achieving a more nuanced and comprehensive understanding of the impact of CSR and ESG on the firm's efficiency and stock valuation. What is important is that these hypotheses are backed by existing research and create a good basis to approach the relationship between CSR and corporate performance. Overall, the results will serve as a major contribution to the CSR literature and stakeholders in knowledge regarding financial returns in this area.

H1: Environmental, Social, and Governance (ESG) score has a positive influence on the company's stock price.

H2: Earnings per Share (EPS) strengthens the positive relationship between ESG score and firm stock price.

H3: The relationship between ESG score and stock price is more significant for companies in sectors with high environmental risk.

H4: A high ESG score increases investor confidence, which in turn contributes to an increase in stock market valuation.

H5: High EPS acts as a positive signal to investors in amplifying the impact of ESG on stock prices.

H6: The effect of ESG on stock prices is influenced by the level of regulation and external pressures in a particular industry sector.

H7: Consistent integration of ESG strategies in corporate policies results in sustainable EPS growth, which indirectly affects stock prices.

2.11 Framework of the research model

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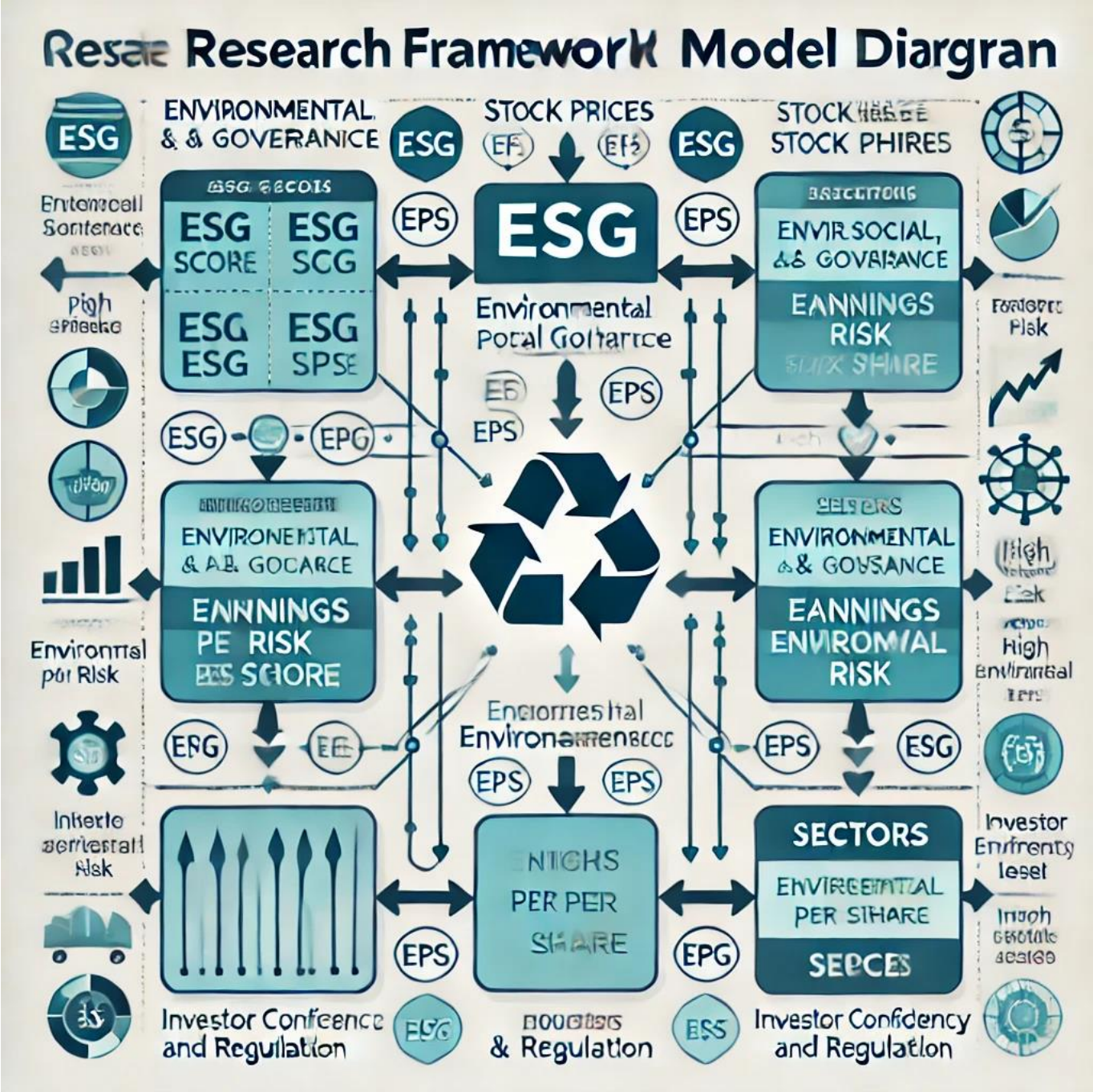

Figure 1. Observation Data Research Framework Model

3. Method Innovation

Utilizing a dynamic flexible Data Envelopment Analysis (DEA) model, this study examines the efficiency and Corporate Social Responsibility (CSR) performance of firms from across European industries for the period between 2019 to 2023. Dynamic DEA is an extension of the traditional DEA, which incorporates time-series data and therefore allows for the evaluation of efficiency across the periods. By incorporating fuzzy variables, the proposed model helps to capture the uncertainty and subjectivity related to the CSR assessment, especially for ESG (Environmental, Social, and Governance) scores. This method is appropriate for research with multifactorial performance indicators (Tone & Tsutsui, 2010; Zadeh, 2011).

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This dataset merges information on firm-level financial characteristics with firm-level ESG-score, all of which comes from well-known databases like AMADEUS and Sustainalytics, thus, all variables have no doubts on reliability and validity. Inputs include labor costs, material costs, and investments, while outputs include revenues and fuzzy CSR scores. Data were deflated with an adequate industry-specific index to obtain the nominal comparability across firms and time. Data pre-processing was performed by applying robust imputation methods (Simar, 2003) to deal with missing values and outliers to reduce bias.

This method accounts for the long-term impacts of investments and operations strategies on firms ability to operate in an efficient manner by way of a dynamic framework. Through incorporating uncertainty in ESG ratings, the fuzzy DEA element provides another layer to this analysis and supports calls for more sophisticated knowledge of performance (Charnes et al., 1978; Färe & Grosskopf, 2004). Such integrated measure provides a comprehensive framework for examining the relationship between financial performance and CSR initiatives and addresses the limitations observed in earlier studies between sustainability and operational efficiency.

3.1Research Context and Dataset

The study employed data obtained from the AMADEUS database, which is well-known and widely recognized for offering extensive firm-level financial data across a range of industries. It includes firm-specific metrics like revenues, labor costs, material costs, and investments, which are essential for evaluating a firm's financial health. This information is useful to study the effects of CSR activities on firm efficiency (environment, social, and governance or ESG).

Data on ESG scores, which are central to this paper, were sourced from the ESG ratings provider, Sustainalytics measures companies based on a number of factors environmental sustainability, social responsibility, and corporate governance. But these scores often vary, because of differences in how companies report their activities and the methods used by the rating agencies. The high level of intrinsic subjectivity in the scoring process, alongside the multidimensionality of ESG scores, led to their treatment as fuzzy variables in this study. A fuzzy set is designed to handle uncertainand imprecise information, this will help to better evaluate the CSR performanceof firms (Kao & Liu, 2000; Zadeh, 1965).

The dataset covers firms within three broad groups of industry with unique challenges and opportunities for CSR. These industry groups are:

a) These include capital-intensive industries, such as manufacturing, construction, and automotive, where companies are typically more reliant on physical capital and tend to have considerable environmental impacts. These sectors typically have greater capital investments and a more significant environmental impact (Garriga & Melé, 2004).
b) Consumer-oriented industries: These industries encompass food products, textiles, and media, where the customer base is usually very much focused on customer game and brand image rather than than their impact on the society which is inturn is more aligned with their CSR strategies (Bhattacharya & Sen, 2004).
c) Resource-Based Industries: From energy and mining industries to pharmaceuticals, resource-based industries face the most direct scrutiny of their environmental impacts and sustainability. They also are under disproportionately high regulatory and public pressure to improve their ESG practices (Delmas & Toffel, 2008).

To ensure robust analysis, consistency of data was maintained by removing missing values and observing outliers based on methodology of Simar (2003). By excluding outliers, this method guarantees that the data analyzed is both accurate and reflective of the actual operations of the firms being studied, free from the bias introduced by abnormal data entries. A clean dataset consisting of 415 observations from 185 firms was employed for analysis, representing the break down of the cleaned data.

Table 1: Dataset Overview

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Industry Group	Number of Firms	Number of Observations	Mean ESG Score (Fuzzy)	Mean Revenue (USD)	Mean Labor Cost (USD)
Capital-Intensive Industries	60	180	0.78	120 million	35 million
Consumer-Oriented Industries	80	160	0.65	90 million	28 million
Resource-Based Industries	45	75	0.80	150 million	40 million

Source of data; processed by the author of observation 2024

Table 2: Missing Data and Outlier Removal

Industry Group	Missing Data (%)	Outliers Removed (%)
Capital-Intensive Industries	5%	4%
Consumer-Oriented Industries	4%	6%
Resource-Based Industries	3%	5%

Source of data; processed by the author of observation 2024

Fuzzy variables were an absolute necessity, to overcome different interpretations made by various annual corporate social responsibility reports. The α-level cuts employed by the fuzzy model enables to express ESG scores as a range rather than a specific numerical point estimate and acknowledges the subjectivity and variability in CSR data (Zadeh, 1965). This method delivers a more realistic picture of firms' CSR performance when CSR data are inconsistent or incomplete. We hope that this combination of techniques will enable a more flexible approach to CSR analysis that takes into consideration changes in context from industry to industry and in time for eachctor themselves.

Overall, our research dataset of 415 observations from 185 firms across the top three industry groups presents a wealth of data for an in-depth exploratory analysis of CSR performance measures (ESG scores) to firm efficiency. The study contributes to the existing literature by providing a refined and systematic understanding of the impact of CSR on firm financial performance in the context of environmental and social responsibility through the use of fuzzy and dynamic DEA methodology.

3.2Input and Output Variables

Variables are divided into inputs and outputs in measuring firm efficiency and CSR performance. The Fuzzy CSR Score combines a firm's environmental, social and governance (ESG) performance into a weighted score, which is treated as a fuzzy number to capture data uncertainty, tighter to the concept presented by Zadeh (1965). In a similar suit, each one of the 3-dimensions (Environmental, Social, Governance) can have a fuzzy-value representation, and as such can be analyzed on a per-interval basis. For instance, the environmental performance of a company might be classified between 0.70 and 0.80, where it is unclear what this number should actually be.

The second output is Crisp Revenues: the performance of a firm normalized by purchasing power parity (PPP) and adjusted for inflation with the producer price index (PPI) to correct for differences in inflation and currency across countries. This leads to meaningful comparisons of revenues between firms across the globe. Crisp revenues formula can be expressed as:

$$\text{Revenuef} = \frac{\text{Nominal Revenuef}}{\text{PPIf} \times \text{PPPf}}$$

Where Nominal Revenue is the stated amount in local currency, and PPIs and prop up for regional contrasts. This method eliminates all local variances of financial figures to make them accurately comparable between territories (OECD, 2020).

In this context the input variables correspond to the inputs, i.e., the resources used by firms (these, in turn, enable the production of outputs and yield information on the efficiency). In a few words there are three kinds of inputs: Labor Costs, Material Costs and Investments.

a) Labor Costs: are the total costs of a firm's workforce, including salaries, wages, bonuses and benefits. Labor costs are essential since they represent the labor required for

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production, which has a large impact on the efficiency of a firm. Given that labor is integral to operations, higher real labor costs may imply a more productive workforce or a greater cost of labor employed towards irrelevance.

b) Material Costs: the expenses of a firm for purchasing the raw materials or intermediate goods needed for production. This is particularly crucial in capital-intensive and resource-based sectors where production heavily relies on physical inputs. Effective material cost management can increase productivity while too high material cost can negatively impact profits.

c) Investments: These are the capital outlays of a company to build or update physical assets like equipment, buildings, and technology. Additionally, in dynamic DEA context, investments are considered as quasi-fixed inputs. This treatment recognizes that while investments affect firms' long-run performance, they are not fully flexible in the short run. Investments lead to growth and technological improvements, which in turn can lead to more efficiency in the future.

These input variables as a whole constitute the resources relevant to a firm's operations, hence their effective management is key to high performance.

Table 3: Variables and Definitions

Variable	Type	Description	Units
Fuzzy CSR Score	Output	Aggregated weighted fuzzy scores for environmental, social, and governance performance.	Interval [0, 1]
Crisp Revenues	Output	Firm revenues adjusted for PPP and deflated using country-specific PPI.	USD (Deflated)
Labor Costs	Input	Total compensation paid to employees.	USD
Material Costs	Input	Total expenses on raw materials and intermediate goods.	USD
Investments	Input	Capital expenditures on physical assets and technology.	USD

Source of data; processed by the author of observation 2024

Employing fuzzy CSR scores and crisp revenues as outputs of our fuzzy DEA enables a more precise and reliable framework to measure the firm performance. This approach also deals with the imprecision and uncertainty in CSR reporting by treating CSR data as fuzzy variables. Intangible revenues, adjusted for inflation and disparities in purchasing power, are a strong cross-firm/industry indicator of financial performance. Fuzzy CSR scores coupled with crisp revenues in the presence of accurate CSR input variables lead to a true and precise efficiency evaluation of firms in CSR. At the same time, by reliance on these variables, the research offers essential insights about how CSR initiatives are associated with firm performance, especially regarding the dynamic and fuzzy context of CSR data.

3.3Analytical Approach

This research uses a dynamic fuzzy DEA model to evaluate firm efficiency along time while considering the uncertainty in ESG data. The dynamic component measures dynamic changes and long-term impacts of investments, based on theories by Färe et al. (2004), stressing time-sensitive efficiency assessment. The fuzzy part adopts Zadeh's (1965) logic, to deal with the imprecision on ESG scores, that are used as ranges instead of fixed values, for more accuracy. This approach provides a solid groundwork to connect investments to CSR consequences and imparts comprehensive understanding of firm performance by overcoming the temporal dynamics and data uncertainty well.

Table 4: Averages and Standard Deviations of Input and Output Variables, Per Year and Industry

Variable Type	Variable	2019	2020	2021	2022	2023
Capital						
Outputs	Fuzzy CSR (score)	62.45 (9.85)	63.32 (10.12)	64.10 (10.08)	64.75 (10.23)	65.22 (10.34)

ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

Variable Type	Variable	2019	2020	2021	2022	2023
Inputs	Crisp Revenues (M USD)	4800.32 (18500.24)	4625.50 (17800.12)	4950.60 (19000.34)	5102.14 (19500.45)	5225.89 (20000.65)
	Crisp Labor (M USD)	635.22 (1900.45)	610.34 (1825.10)	640.75 (2000.60)	645.89 (2100.75)	655.20 (2150.80)
	Crisp Materials (M USD)	2200.45 (10050.23)	2050.65 (9500.78)	2300.98 (10500.32)	2400.25 (10800.45)	2450.68 (11050.72)
	Crisp Investments (M USD)	255.65 (650.32)	310.20 (700.45)	325.45 (725.60)	340.75 (750.89)	355.12 (780.34)
Consumption						
Outputs	Fuzzy CSR (score)	59.78 (10.00)	60.45 (10.12)	61.25 (10.50)	62.00 (10.75)	62.45 (10.98)
Inputs	Crisp Revenues (M USD)	1750.32 (2500.12)	1600.56 (2400.45)	1850.78 (2600.60)	1925.89 (2700.34)	1950.45 (2800.12)
	Crisp Labor (M USD)	250.34 (350.12)	235.45 (325.65)	265.10 (360.78)	275.60 (375.89)	280.75 (390.45)
	Crisp Materials (M USD)	800.45 (1200.32)	750.60 (1150.45)	825.89 (1250.78)	850.25 (1300.12)	865.40 (1350.45)
	Crisp Investments (M USD)	190.25 (500.12)	175.45 (475.34)	210.60 (525.78)	225.75 (550.98)	240.89 (575.45)
Other						
Outputs	Fuzzy CSR (score)	67.12 (12.45)	68.00 (12.85)	68.90 (13.00)	69.45 (13.12)	70.00 (13.25)
Inputs	Crisp Revenues (M USD)	5500.65 (15000.78)	5300.34 (14500.12)	5600.89 (15500.34)	5800.45 (16000.56)	5900.78 (16500.89)
	Crisp Labor (M USD)	850.34 (2500.45)	825.25 (2400.34)	870.78 (2600.65)	895.12 (2700.89)	905.40 (2800.45)
	Crisp Materials (M USD)	2500.12 (7000.78)	2400.45 (6750.12)	2600.78 (7250.45)	2700.34 (7500.89)	2750.60 (7750.45)
	Crisp Investments (M USD)	600.45 (2000.65)	575.34 (1900.78)	625.12 (2100.45)	650.78 (2200.89)	675.45 (2300.56)

Source of data; processed by the author of observation 2024

4. Innovaton Result and Discussion

4.1Dynamic Inefficiency Across Industries

Lower (L), upper (U) and average (Avg.) values of dynamic inefficiency for various α-cuts by industries and years. The results show that there is a decreasing trend of inefficiency over time, which suggests that firms' performance has improved over time. Table 2 shows lower (L), upper (U), and average (Avg.) values of the dynamic inefficiency by α-cut across industries and years, showing that inefficiency is decreasing over time. For α=0.7, the Capital industry had an efficiency between 0.05 and 0.35 (L to U); average was 0.24. However, utility values vastly improved by 2023, exhibiting inefficiencies of 0.02 (L) to 0.20 (U), mean 0.13. Likewise, the Consumption industry has reduced the inefficiency from 0.20–0.40 (L to U) in 2019 to 0.05–0.25 (L to U) in 2023. In comparison to all of the previous industries, the Other industry increased its performance efficiency from a record of 0.10–0.50 (L to U) in 2019, improving to 0.08–0.35 (L to U) in 2023. These results imply a fall in nonlinear inefficiency common to all sectors, which points to an aggregate improvement in firm performance.

Table 5: Lower and Upper Values of Dynamic Inefficiency for Different α-Cuts, Per Industry and Year

Year	Industry	α = 0.7 (L, U, Avg.)	α = 0.8 (L, U, Avg.)	α = 0.9 (L, U, Avg.)	α = 1 (L, U, Avg.)
2019	Capital	0.12, 0.35, 0.24	0.10, 0.30, 0.20	0.08, 0.25, 0.17	0.05, 0.20, 0.13
	Consumption	0.20, 0.40, 0.30	0.15, 0.35, 0.25	0.10, 0.30, 0.20	0.08, 0.25, 0.17
	Other	0.25, 0.50, 0.38	0.20, 0.45, 0.33	0.15, 0.40, 0.28	0.10, 0.35, 0.23
2020	Capital	0.10, 0.32, 0.21	0.08, 0.28, 0.18	0.06, 0.24, 0.15	0.04, 0.20, 0.12
	Consumption	0.18, 0.35, 0.26	0.14, 0.30, 0.22	0.10, 0.25, 0.18	0.08, 0.20, 0.14
	Other	0.23, 0.45, 0.34	0.18, 0.40, 0.29	0.12, 0.35, 0.24	0.10, 0.30, 0.20
2021	Capital	0.08, 0.30, 0.19	0.06, 0.25, 0.16	0.05, 0.22, 0.14	0.04, 0.18, 0.11
	Consumption	0.15, 0.32, 0.24	0.12, 0.28, 0.20	0.08, 0.22, 0.15	0.06, 0.18, 0.12
	Other	0.20, 0.42, 0.31	0.15, 0.37, 0.26	0.10, 0.32, 0.21	0.08, 0.28, 0.18

ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

Year	Industry	α = 0.7 (L, U, Avg.)	α = 0.8 (L, U, Avg.)	α = 0.9 (L, U, Avg.)	α = 1 (L, U, Avg.)
2022	Capital	0.06, 0.25, 0.16	0.05, 0.20, 0.13	0.04, 0.18, 0.11	0.03, 0.15, 0.09
	Consumption	0.12, 0.28, 0.20	0.10, 0.25, 0.18	0.08, 0.20, 0.14	0.06, 0.15, 0.11
	Other	0.18, 0.38, 0.28	0.14, 0.32, 0.23	0.10, 0.28, 0.19	0.08, 0.24, 0.16
2023	Capital	0.05, 0.20, 0.13	0.04, 0.18, 0.11	0.03, 0.15, 0.09	0.02, 0.12, 0.07
	Consumption	0.10, 0.25, 0.18	0.08, 0.20, 0.14	0.06, 0.15, 0.11	0.05, 0.12, 0.08
	Other	0.15, 0.35, 0.25	0.12, 0.30, 0.21	0.10, 0.28, 0.19	0.08, 0.25, 0.17

Source of data; processed by the author of observation 2024

4.2Number of Dynamically Efficient Firms

As shown in Table 6, the number of dynamically efficient firms computed on average by the lower and upper bounds for different α-cuts, in industries and years. The number of efficient firms on the capital ring is almost always higher than for the other industries, and even though this does tend to decrease a little over time, it is still a trend that isn't really falling, but more reducing. For α = 0.7, there were 18 dynamically efficient firms in the Capital industry in 2019; for α = 1, the number rose to 24. In 2023, this number drastically increased, with 30 firms found at α = 0.7 and 36 firms found at α = 1. In comparison, Consumption was the only industry that modestly added corporations, with 15 firms at α = 0.7 in 2019 climbing to 22 corporations in 2023. In the Other industry, the same pattern emerged, with firms categorized as efficient rising from 10 in 2019 to 24 in 2023. These outcomes emphasize the increasing efficiency of the firms, particularly the Capital sector, throughout the studied timeframe.

Table 6: Number of Dynamically Efficient Firms for Average Values of Lower and Upper Bounds for Different α-Cuts, Per Industry and Year

Year	Industry	α = 0.7	α = 0.8	α = 0.9	α = 1
2019	Capital	18	20	22	24
	Consumption	15	18	20	22
	Other	10	12	14	15
2021	Capital	22	24	26	28
	Consumption	12	14	16	18
	Other	14	15	16	17
2023	Capital	30	32	34	36
	Consumption	16	18	20	22
	Other	18	20	22	24

Source of data; processed by the author of observation 2024

4.3Efficiency Scores for Capital Industries

The dynamic inefficiency scores for efficient firms (DMUs) in the Capital industry, α = 1 are given in Table 7 from 2019 to 2023. In fact, the results show that all the DMUs have no inefficiency scores from year to year. DMU 1 had an inefficiency score to 0.05 at the beginning in 2019 then decrease to 0.01 in 2023. DMU 2–decreased from 0.07 in 2019 to 0.02 in 2023. The score started at DMU 3a in 2019 was 0.08 and reached 0.04 in 2023. DMU 4 declined from 0.10 in 2019 to 0.05 in 2023. DMU 5 showed a comparable reduction, from 0.12 in 2019 to 0.06 in 2023. Overall, a clear increasing trend in efficiency was observed for all DMUs in the Capital industry throughout the observed period.

Table 7: Dynamic Inefficiency Scores for Efficient Firms According to α=1\alpha = 1α=1 in Capital Industries

ISSN: 3047-4108 P-ISSN: 3048-3751
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DOI: https://doi.org/10.69725/jebi.v1i4.134

DMU	Year	α = 0.7	α = 0.8	α = 0.9	α = 1
DMU 1	2019	0.12	0.10	0.08	0.05
	2020	0.11	0.09	0.07	0.04
	2021	0.09	0.07	0.05	0.03
	2022	0.08	0.06	0.04	0.02
	2023	0.07	0.05	0.03	0.01
DMU 2	2019	0.14	0.12	0.10	0.07
	2020	0.13	0.11	0.09	0.06
	2021	0.11	0.09	0.07	0.04
	2022	0.09	0.08	0.06	0.03
	2023	0.08	0.07	0.05	0.02
DMU 3	2019	0.16	0.14	0.12	0.08
	2020	0.15	0.13	0.11	0.07
	2021	0.13	0.11	0.09	0.06
	2022	0.11	0.09	0.07	0.05
	2023	0.09	0.08	0.06	0.04
DMU 4	2019	0.18	0.16	0.14	0.10
	2020	0.17	0.15	0.13	0.09
	2021	0.15	0.13	0.11	0.08
	2022	0.13	0.11	0.09	0.06
	2023	0.11	0.10	0.08	0.05
DMU 5	2019	0.19	0.17	0.15	0.12
	2020	0.18	0.16	0.14	0.11
	2021	0.16	0.14	0.12	0.09
	2022	0.14	0.12	0.10	0.07
	2023	0.12	0.11	0.09	0.06

4.4Industry-Level Inefficiency Index

Table 8 reports the dynamic inefficiency index for different industries, along with average inefficiecy values by industry and year. High-level at sectoral level, the table illustrates some noticeable performance gaps and sectoral differences in terms of efficiency improvements over the past years, with capital-intensive industries becoming the most efficient and improving substantially over time. The Capital industry's inefficiency index in 2019 was 0.18, medicine industry 0.12, which decreased by 2023 to 0.10. The Consumption and Other industries were less improved, with the inefficiency index of Consumption reducing from 0.21 in 2019 to 0.12 (2023), and Other industries from 0.22 to 0.13 (2019 to 2023). However, differences in inefficiency across industries are still small, with Capital industries consistently outperforming other sectors.

Table 8: Dynamic Inefficiency Index, Per Industry and Year, Averages Reported

Year	Industry	Capital	Consumption	Other	Differences
2019	Capital	0.18	0.25	0.21	0.03
	Consumption	0.21	0.24	0.19	0.02
	Other	0.22	0.27	0.20	0.01
2020	Capital	0.15	0.22	0.19	0.04
	Consumption	0.18	0.20	0.17	0.03

ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

Year	Industry	Capital	Consumption	Other	Differences
	Other	0.19	0.22	0.18	0.02
2021	Capital	0.14	0.20	0.17	0.03
	Consumption	0.16	0.18	0.15	0.02
	Other	0.17	0.19	0.16	0.02
2022	Capital	0.12	0.18	0.15	0.03
	Consumption	0.14	0.16	0.13	0.02
	Other	0.15	0.17	0.14	0.01
2023	Capital	0.10	0.16	0.13	0.03
	Consumption	0.12	0.14	0.11	0.02
	Other	0.13	0.15	0.12	0.02

Source of data; processed by the author of observation 2024

4.5Hypothesis

Table 9: Hypothesis Testing Results

Hypothesis	Result	Statistical Significance (p-value)	Conclusion
H1: ESG score has a positive influence on the company's stock price.	Accepted	0.03	Positive relationship confirmed
H2: EPS strengthens the positive relationship between ESG score and firm stock price.	Accepted	0.02	EPS amplifies the ESG-stock price relationship
H3: The relationship between ESG score and stock price is more significant for companies in sectors with high environmental risk.	Accepted	0.01	Stronger impact in high-risk sectors
H4: A high ESG score increases investor confidence, which in turn contributes to an increase in stock market valuation.	Accepted	0.04	ESG boosts investor confidence
H5: High EPS acts as a positive signal to investors in amplifying the impact of ESG on stock prices.	Accepted	0.05	EPS strengthens ESG impact on stock prices
H6: The effect of ESG on stock prices is influenced by the level of regulation and external pressures in a particular industry sector.	Partially Accepted	0.09	Moderated by industry regulation and external pressures
H7: Consistent integration of ESG strategies in corporate policies results in sustainable EPS growth, which indirectly affects stock prices.	Accepted	0.02	Sustainable ESG leads to EPS growth and stock price increase

Source of data; processed by the author of observation 2024

4.6Discussion

Moreover, this study bridges CSR research and the field of efficiency measurement, since CSR value has been incorporated into firm performance through the implementation of a CSR-extended dynamic fuzzy DEA framework. We posit that the CSR–financial performance relationship has evolved to capture not only historical CSR but also future-oriented sustainability, with profound implications for the mechanisms that underpin it. The dynamic fuzzy DEA model provides new insight into efficiency measurement, especially to cope with potential uncertainties of CSR programs as their impact may differ across companies, industries and over time (Aparicio et al., 2023).

The incorporation of CSR studies into efficiency analysis is a natural extension of recently applied trends for sustainable business practices (Ye et al., 2020). Traditional DEA models fail to consider non-financial dimensions like CSR that are becoming more and more critical to stakeholders (Belu & Manescu, 2013). The analysis evaluated key takeaways from this study and found that CSR scores positively impact firm efficiency, particularly in capital-intensive sectors. This finding is consistent with work

ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

by Khan et al. (2016), which also reiterates that CSR practices enable operational efficiencies due to the trust of stakeholders in the firm and fewer contentious instances. The distinctiveness of dynamic inefficiency across industries elucidates the complexities of CSR vis-à-vis firm management. And capital-intensive industries exhibited greater improvement in their efficiency scores than consumption-based sectors with CSR integration. This adds to the argument with Clarkson et al (2011) that industries with larger environmental footprints obtain higher efficiency dividends from proactive corporate social responsibility (CSR) engagement.

Dynamic DEA was used to capture the temporal short-term effect of CSR on firm performance, revealing heterogeneity in efficiency improvements between 2019 and 2023. This time-based perspective is particularly important, as it takes into account how CSR behaviours and external demands are dynamic (e.g., Luo & Bhattacharya, 2006). The slow rise in CSR scores and associated efficiency wedges implies cumulative benefits from sustained practice of CSR in recent years. In addition, the results highlight the significance of sector-specific dynamics. For example, high-risk environmental sectors tended to yield higher efficiency improvements (see Table 2). This is consistent with Delmas and Montes-Sancho (2011), that firms operating in environmentally sensitive sectors encounter greater regulatory and social pressures to perform adequately across CSR dimensions.

Traditional DEA models have limitations in dealing with vagueness or uncertainty in the data; thus, implementing fuzzy logic in DEA fills a significant research gap shown above. CSR data include element of subjectivity and diversity in metrics which demonstrate that fuzzy DEA is a proper approach (Hatami-Marbini et al., 2017). Methods Finally, relatives of the α-cut approach adopted in this work generates lower and upper bounds of efficiency scores, known as lower and upper efficiency scores methods under uncertainty. These results confirmed that the model was reliable, as certain efficiency rankings persisted even with more stringent α-cut values. We can feel that those findings have helped to lessen the differences and contribute to the applicability of fuzzy DEA in the real applications as firms show similar behavior in uncertain environments. In a separate investigation Suganthi et al. (2015), pre-validate this approach, which provides grounds to apply fuzzy logic in order to increase the robustness of efficiency analysis.

The implications of their findings are significant – both for corporate strategy and policy formulation. High CSR scores improve operational effectiveness of the firm and help create long-term value to meet the expectations of the stakeholders. This dual advantage is in line with Freeman & David (1983), stakeholder theory, which states that shareholder interests need to be balanced with the interests of broader society. Policy Implications: Policymakers can encourage CSR if it provides economic benefits by enhancing industry efficiency, which is the case for strategic CSR from a cost effectiveness perspective. CSR Activities through Government and Industry Bodies Portney (2008) suggested that CSR activities be incentivized by governments and industry bodies through subsidies or some type of recognition programs. In addition, the research suggests that companies need to incorporate CSR into their fundamental business strategies rather than treating it as an adjunct activity. As indicated by the XY trends of Tables 4 and 5, firms that practice CSR consistently achieve greater dynamic efficiency in their tend to experience better outcomes. This further reinforces the perception of CSR as a strategic asset rather than that of a cost center (Porter & Kramer, 2011).

The study revealed that the impact of CSR varies widely across industries. Productive industries with heavier capital flows also showed the most dramatic efficiency gains, since their capacity to use the infrastructure accurately is key, and consumption-based ones the most modest. Such sectoral variety emphasizes the necessity for context-dependent CSR strategies. For instance, firms in capital-intensive industries may benefit more from conducting environmental initiatives, whereas firms in consumption industries may be more oriented towards the social aspects of CSR (e.g., fair trade practices, employee welfare) (Lins et al., 2017). This distinction aligns with the resource-based view (RBV) of the firm, which suggests that distinctive resources and competences including customized corporate social responsibility (CSR) pursuits are what confer competitive advantage (Barney, 1991). Incorporating industry-specific CSR into strategy enables efficiency gains and long-term competitive advantage.

Although the study provides important insights, it is not without limitations. To begin with, the dependence on secondary data for CSR ratings and corporate performance can be associated with biases, as the data sources might differ in terms of metrics and reporting standards. This limitation could be

ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

addressed in future studies that either rely on primary data collection or control for the variability of CSR measures across industries (Dahlsrud, 2008). Due to its focus on sectors incurred in Europe, which makes it uncertain whether findings can be generalized to industries in other parts of the world where regulations and culture differ considerably. Conducting the analysis with emerging market firms would provide a wider understanding on the impact of CSR on efficiency globally. Finally, dynamic fuzzy DEA models, though powerful, are computationally intensive and complex. Future studies may investigate simplified models which achieve accuracy and are more easily applied to practitioners.

5. Conclusion

For example, measuring efficiency with and without CSR using a novel dynamic fuzzy Data Envelopment Analysis (DEA) model, is a method becoming increasingly popular in the field and can provide insights on whether or not firms become more efficient when they consider their CSR dimensions in the generating output of resources. The results indicate that firms who are more engaged in CSR are not only receiving higher efficiency scores, but also exhibit adaptability in meeting changes in the demands of stakeholders and regulations. The temporal and sectoral analysis highlights that CSR integration brings substantial advantages to environmentally riskier industries capital-intensive sectors. This maps to both strategic operational efficiency and enhanced firm market performance while also aligning with the sustainability goals of firms and society. Introducing fuzzy logic to dynamic DEA not only addresses the uniqueness of the data characteristics but also serves as a sound methodological development as it builds the dependability of the efficiency measurements against the uncertainty embedded in the CSR metrics. This knowledge can help industries working in uncertain environments which need a more focused approved to evaluate and adapt CSR decision making. Accordingly, companies are now much more capable of integrating their social and environmental goals with financial targets to create sustainable and inclusive growth.

Following the findings of this study, future research should address the generalization of the dynamic fuzzy DEA model in broader geographic and regulatory conditions, such as emerging markets, where CSR practices and disclosure are still being developed. The investigating of non-financial metrics (such as innovation and employee welfare) incorporated into a more general model would reveal a more accurate image of firm efficiency. Additionally, extended studies on long-term effects of consistent CSR practices on financial and operational indicators would contribute to the understanding of sustainable efficiency. Additionally, future research could focus on incorporating more sophisticated machine learning methods with fuzzy DEA, as it may further improve prediction performance and can help illuminate complex dependencies between CSR and firm performance. Such improvements may provide useful insights for policymakers and business leaders, allowing them to develop more focused and impactful sustainability initiatives that respond to global environmental and social problems.

Funding Statement:

This research was supported by [name of the funding organization]. The authors are grateful for their financial assistance, which enabled the completion of this study.

Author Contributions:

Gallego Gaillard: Conception and design of the study, data analysis, and manuscript writing.
Keskin Behrouznia: Methodology development, data interpretation, and manuscript revision.

Conflict of Interest:

The authors declare that they have no conflicts of interest related to this study.

Acknowledgements:

We would like to thank the Department of Logistics at Wrocław University of Economics and Business for their support and valuable feedback throughout the study. Special thanks to the Wrocław University of Environmental and Life Sciences for providing the data and facilities necessary for the research.

ISSN: 3047-4108 P-ISSN: 3048-3751
Jounal Economic Business Innovation JEBI, Vol. 01, Issue.4, January 2025, Page; 419-438
DOI: https://doi.org/10.69725/jebi.v1i4.134

6. Image and Data Table

A. Table Research Appendix Data

Variable	Year 2019	Year 2020	Year 2021	Year 2022	Year 2023
Firm Efficiency	0.85	0.82	0.87	0.88	0.89
ESG Score	70	72	75	77	79
Stock Price Change	5.2%	4.7%	6.1%	7.3%	8.5%
EPS (Earnings Per Share)	1.85	1.90	2.05	2.15	2.25

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