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Exploring the Influence of Environmental Investment on Multinational Enterprises' Performance from the Sustainability and Marketability Efficiency Perspectives

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Abstract: Sustainable development strategies are necessary to ensure sustainable performance even though resources are scarce in a firm. In this study, a two-stage production process is designed to analyze a firm's performance, including sustainability and marketability, using a two-stage network data envelopment analysis. This process will help managers of a firm understand how to improve sustainability and marketability efficiency. The relationship between environmental investment and firm performance is also investigated using truncated regression. The results show that the environmental innovation score (EIS) and resource use score (RUS) have significant negative relationships with firm performance in the short term due to the fact of additional expenses incurred during the innovative research and development of new products and services. Moreover, the study reveals that the emission score positively affects both sustainability efficiency and marketability efficiency, while EIS and RUS have no effects on the efficiencies. These empirical findings are meant to assist managers in better comprehending the characteristics of business sustainability across industries with varying scales and performance levels, offer better business strategies for resource allocation, and enhance a firm's performance in the post-pandemic era.

Keywords: data envelopment analysis; truncated regression; sustainability; ESG; firm performance

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1. Introduction

The COVID-19 pandemic has had a profound impact on all aspects of life globally. The impact on a variety of areas, including the economy, education, society, ecology, and globalization, has spawned both favorable and unfavorable consequences [1]. In today's rapidly changing and competitive economy, multinational enterprises (MNEs) are faced with the pressure of developing corporate social responsibility and sustainability to enhance the firm's performance beyond financial performance [2,3]. In addition, MNEs are now confronting many more challenges in relation to supply chain resilience and risk control under the ongoing pandemic. Industry trends and market volatility are key to guiding business executives in making strategic decisions that are both directly and indirectly affected by the pandemic. They have been eagerly seeking to build an agile and innovative production model with more flexibility to maintain the firm's performance during the uncertain times that characterize the pandemic.

With the growth of global industrialization, MNEs have played a critical role in maintaining the ecological environment [4,5]. In 2008, the OECD published guidelines for the promotion and conduct of socially responsible businesses, ensuring that all MNEs aim to keep up with policies on the sustainable development of enterprises and societies and to devote themselves to stopping climate change [6]. Hence, managers of MNEs have mostly accepted corporate sustainability as a precondition for conducting their businesses.

The existing literature on corporate sustainability mostly focuses on discussing the relationship among three practical elements: (1) degree of a company's financial performance, (2) sustainability performance, and (3) caliber of its sustainability disclosure. In addition, the most wildly accepted assessment of sustainability is the three-pillar concept: environmental, social, and governance (ESG). The relationship between the organizational level and social responsibility is thus a common topic of ESG research [7]. Despite the concept of sustainability being viewed as a distinct research field, the definition of the concept is often found to be ambiguous and incoherent. Additionally, in searching for its universal applicability across different industries, the existing literature on sustainability is scares in terms of cross-industry research. Whereas research on a specific industry is limited in its generalizability, multi-industry research offers greater universal applicability to organizations in different industries [8]. With the growing interest in ESG across industries, the relationship between the sustainability and firm performance of an MNE in different sectors is hardly known, with very limited published literature [7]. Some researchers claim that there is a positive relationship between sustainability and profitability but not for all industries. In addition, recent studies on US MNEs suggests that prioritizing ESG goals in a firm may not make a positive difference in the firm's ESG performance but engender poor firm performances instead.

The objectives of this study are twofold. First, we investigated the competitiveness of MNEs across sectors from the perspectives of sustainability efficiency and marketability efficiency. Second, this study explored the relationship between environmental investment and firm performance in different sectors. Our research contributes to the development of production processes for multinational enterprises (MNEs) by introducing two stages of efficiency measurement, namely, sustainability efficiency and marketability efficiency, to evaluate the overall firm performance of MNEs. The traditional data envelopment analysis (DEA) model and other methods are limited in their ability to evaluate efficiency at different stages of production, which is where our two-stage network DEA model comes in. Our model allows for the decomposition of the efficiency value of a decision-making unit (DMU) and benchmarking of the best performance of firms across sectors in each stage. Since environmental investment has become an inevitable business strategy for MNEs, our study contributes to the existing literature by integrating undesired variables into the two-stage network DEA model as the mechanism through an investigation of the relationship between environmental investment and firm performance. Moreover, our model demonstrates that each MNE's performance can be measured by different returns to scale in order to study the effects of firm scale on a production process in the post-pandemic era for future decision-making reference.

We intend to use these empirical results to help managers of firms better understand the characteristics of sustainability in enterprises across industries with varying scales and performance levels. Moreover, we want to provide enterprises with useful business strategies for resource allocation to boost firm performance in the post-pandemic era.

2. Literature Review

2.1. Environmental Management and ESG

With the publication of the Brundtland Report, the idea of sustainability first became an international policy and has since been regarded as a crucial business and investment strategy [9] that aims to balance the demands of both present and future generations [10]. According to this definition, three critical elements of corporate sustainability can be identified as the integration of economic, ecological, and social aspects, known as Bennett and James's "triple-bottom line" [11,12]. Sustainability has been recognized as intergenerational equity, which has also become an essential core value and goal to contribute to global society and commit to preserving the natural environment for future generations [11]. The awareness of environmental issues by society and stakeholders influences a firm's behavior and strategies to implement sustainability practices [13]. In particular, an MNE plays a significant role in the advancement of ecological sustainability; thus, discussions about corporate behaviors and supervisors concerning ecological sustainability have rapidly increased through the corporate world [14].

Bowen proposed one of the very first definitions of CSR (corporate social responsibility) in 1953, stating that it is "the obligation of a businessman to pursue those policies, to make those decisions, or to follow those lines of actions which are desirable in terms of the objectives and values of our society" [15]. CSR refers to a firm's social responsibility towards society and aims to develop beneficial activities in different aspects, such as financial, environmental, and social influences. Later, the ESG principle was developed in 2004 and practiced eagerly in developed countries, mostly in Europe and North America. Firms from across countries joined together in promoting the development of ESG principles [16]. Following the European Banking Authority's Annual Report [17], the definition of ESG was addressed as follows: "ESG factors are environmental, social, or governance matters that may have a positive or negative impact on the financial performance or solvency of an entity, sovereign, or individual". Thus, ESG has been recognized as a standard and investment concept to evaluate the sustainable development of an enterprise with its corporate behavior and financial performance. The three factors are the key elements to be considered in decision-making process and investment strategy analysis [7,16]. Subsequently, a growing number of countries pay attention to sustainability due to the fact of severe environmental pollution and exhaustion of natural resources. To minimize negative environmental effects, many leading countries, such as the United States, enact related policies to promote sustainable manufacturing [18]. The number of ESG regulations has been rapidly growing globally. In the US, national regulations have become seriously strict since 2015, especially in the utilities, financial services, and health care pharmaceutical industries [19]. On the key issue of global carbon reduction, at the 2022 United Nations Climate Change Conference of the Parties (COP27), the US government launched the Net-Zero Government Initiative to invite 18 countries to lead and achieve net-zero emissions by the year 2050. Before this, MNEs announced that they would achieve net-zero emissions by 2030. In conclusion, based on prior literature reviews, it is generally understood that environmental managerial development inevitably becomes a priority for MNEs. The issues of environmental management ought to be discussed by different industries and enterprises associated with ESG in the major sectors in the US.

2.2. Firm Performance—Sustainability Efficiency and Marketability Efficiency

Farrell [20] was one of the first authors to define efficiency measurement and present techniques for evaluating efficiency scores. A mathematical programming technique called data envelopment analysis (DEA) uses a data-oriented approach to assess the performance of groups of entities known as decision-making units (DMUs), which transform numerous inputs into multiple outputs [21]. DEA is known as an effective tool to evaluate the efficiency of DMUs, which utilizes the concept of the efficient frontier as a measurement of performance. The efficient frontier shall be calculated by DEA and serve as an empirical standard of excellence appropriately [22,23]. Previous authors examined banks' marketability performance by the revenue and profit generated, which were found to serve as intermediate factors and outputs from the first stage and inputs into the second [24]. This research adopted a two-stage network DEA to characterize the relationships among multiple inputs and multiple outputs for measuring firm performance in sustainability and marketability perspectives. Since opportunities for production are so different among firms, such as the input–output combinations, efficiency researchers have examined separate production frontiers across industries [25]. In our analysis, we include desirable outputs and an undesirable output (CO_2 emission), which require distinct treatment for evaluating regional performance. By utilizing the classification invariance property [26], we can implement the two-stage network DEA model to improve performance through increased desirable outputs and decreased undesirable outputs.

Accordingly, a firm's sustainability performance is measured by its utilization of resources, invested from the perspective of economic, environmental, social, and governance factors, making an impact on the firm and society [27,28]. The critical challenge of a business model is to gain economic value by delivering social and environmental benefits.

Previous authors examined the relationship between 243 firms' economic performance and their environmental performance over two years, and the results indicate that it pays to be green [29,30]. To analyze financial efficiency and eco-efficiency, a study used DEA to measure firm performance for 272 firms in 16 industries based in South Korea in 2010 with data on equity, assets, profit, and sales amounts. Some researchers pointed out that the key route of DEA applications in sustainability concentrates on environmental sustainability, with the research literature regarding corporate sustainability assessment, sustainability performance analysis, etc. [31,32]. This presents the academic trend of adopting the DEA method in sustainability issues. Compared to the traditional quantitative analysis of efficiency, DEA allows for assessing the relative efficiency by determining multiple inputs and outputs simultaneously with flexibility in a wide range of datasets. The advantage of DEA is to identify the most efficient unit by an optimization process. In summary, although many investigations have used DEA methods in firms and various industries worldwide, they mostly concentrated on a single industry's aggregated ESG dimensions with different DEA methods [33–35]. Very few studies precisely investigated and compared different sectors in this context. To address the aforementioned research gap, this study applied two-stage techniques to investigate the affiliation between environmental investment and firm performance within the US market, and this is first study that focuses on an environmental perspective using hybrid DEA methods and truncated regression.

2.3. Environmental Investment and Firm Performance

Environmental sustainability is increasingly becoming a crucial factor in determining a company's present performance and future promises [36]. The competitive advantages of ESG-responsible firms, including better efficiency and competitiveness, minimized operation costs and financial risks, and enhanced reputation and consumer trust, are factors that lead to higher organizational sustainable performance [37]. Numerous researchers have claimed that sustainability developments, including environmental investment [38], positively affect financial performance [39,40]. A bank's investment in social responsibility has positive effects on its firm performance, especially from an environmental aspect, according to stakeholder- and resource-based theories [41]. The leading corporate sustainability-developed firm had a much larger scale and a higher percentage of return on equity than its competitors in terms of financial performance [27], which is consistent with previous findings for those firms in the US. Targeting US firms, CSR performance is positively associated with firm value because of successful risk avoidance [41]. Again, a positive relationship was found between corporate environmental and financial performance from a total of 617 companies in Europe and the United States [42]. A meta-analysis suggested that pursuing corporate environmental management can be a strategy for raising corporate financial performance [43]. In addition, firms with a higher ESG performance were found to have higher firm profitability; however, it differed in Australia for financial firms and nonfinancial firms [44]. On the contrary, some researchers found a negative relationship between environmental investment and corporate efficiency. One discovered that corporate social responsibility measured by Tobin's Q had a negative influence on corporate value for Brazilian firms [45]. Some studies also investigated the banking sector to determine how ESG influences bank value and performance. Some found that their relationship may not be linear [42]. By examining the correlation between environmental performance and the value of shareholders, it was found that the market does not react significantly to corporate environmental initiatives [46]. Although ESG profile and events were claimed to be significantly related to its market, leadership, performance, and value [16], there still exist hypotheses that are not resolved. Management scholars often mention the ambiguity of this field [47,48], and Montiel and Delgado-Ceballos [49] highlighted evidence of a lack of a common definition for corporate sustainability. Researchers have struggled to discover a universal understanding of corporate sustainability and the proper way to measure individual factors associated with environmental practices [8]. An overview of the mixed empirical literature presented that a total of only 5 out of 24 works of literature focused on sustainability engagement from an environmental perspective [50]. This current research contributes to filling the gap in the literature by examining corporate performance and sustainability performance from an environmental perspective by applying the DEA method.

3. Research Method

3.1. Two-Stage Production Process of Multinational Enterprises

We utilized a two-stage network DEA to measure the technical efficiency in two performance models—sustainability efficiency and marketability efficiency—to assess firm performance.

Figure 1 illustrates that in stage one, sustainability efficiency estimates a firm's capability to transform its manpower and operating costs, including employee expenses, operating expenses, property, plant and equipment, and energy use as input variables [23,35,51], into two output items, namely, net sales and CO_2 emissions [23,52], which are considered undesired variables. In the DEA framework, various alternatives exist for addressing undesirable outputs, such as ignoring them or treating them as outputs and adjusting the distance measurement in a nonlinear DEA model, which restricts their expansion [53]. The approach proposed by Seiford and Zhu [26] for addressing undesirable outputs in the DEA framework can accurately reflect the actual production process and is insensitive to data transformation. Although these variables do not cover all factors of production, they are considered key factors in production effectiveness [54]. In stage two, marketability efficiency measures a firms' ability to increase the return from net sales from a market-oriented perspective. Property, plant, and equipment was chosen as a carryover variable of the input in the second stage; net incomes and market value are the output variables employed to measure financial factors. The definitions of input and output variables are described in Table 1.

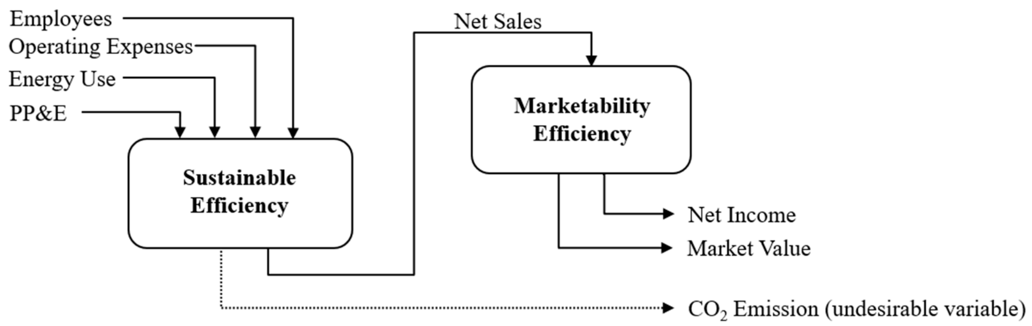

Figure 1. Two-stage production process of MNEs.

Table 1. Definition of variables.

Variable	Description	Unit	References
1st Stage Input			
Employees	Total number of people employed by the company including full time and part time workers.	Number of people	Sueyoshi and Wang [23], Wang and Feng [55], Belu [56]
Operating Expenses	The expense that incurs in a business through its daily operations.	USD	Wang and Feng [55]
Energy Use	The total direct and indirect energy that has been consumed within the boundaries of the company's operations.	Thousands of Tons	Sueyoshi and Wang [23];
Carry Over			
Property, Plant, and Equipment	The tangible assets, which are also called fixed assets, that are long-term and vital to business operations and not easily converted into cash.	USD	Wang and Feng [55], Chen, Liu [57]
1st Stage Output			
Link			
Net Sales	The sum of a company's gross sales deducting its returns, allowances, and discounts.	USD	Sueyoshi and Wang [23]

Table 1. *Cont.*

Variable	Description	Unit	References
CO_2 Emission	Total carbon dioxide and CO_2 equivalent emission released annually by the company.	Thousands of Tons	Sueyoshi and Wang [23], Wang, Li [54], Wang and Feng [55]
2nd Stage Output			
Market Value	The price or the value that the investment community gives to a particular equity or business, which is calculated by multiplying a company's outstanding shares by its current market price.	USD	Yang and Okada [58], Wang, Lu [59]
Net Income	The entity's sales income, deducting the cost of goods sold, administrative and operating expenses, and other expenses, including tax expenses and depreciation interest.	USD	Sueyoshi and Wang [23], Belu [56]

3.2. Measuring Efficiency Using a Two-Stage Network DEA Model

DEA is a well-known method for assessing the efficiency of DMUs. It is considered an indicator of the synthetic measurement of efficiency that allows for the evaluation of various units across disciplines [60]. The measurement of the efficiency score depends on the input and output indices applied in the DEA model. There are two commonly used DEA models: the CCR model, first developed by Charnes, Cooper [61], and the BCC model, later proposed by Banker, Charnes [62].

According to Farrell's concept of the frontier production function, the DEA technique analyzes efficiency using a nonparametric production function Farrell [20]. Nevertheless, the traditional models presented in [61] and [62] overlook the entirety of the production process, failing to capture crucial management information at different stages within the organization. A black-box system results from this assessment. An organization's overall efficiency is assessed by utilizing numerous stages as opposed to just one [24,63–65]. In this respect, the network DEA model may be created to investigate the entire production process, as well as the impacts on the internal process of financial operations within a firm [66]. The single-stage network-based ranking method was expanded by Liu and Lu [67] upon investigating DMUs' efficiency ranking, with a proposed benchmarking unit for improvements and acknowledgment of the advancements of the efficient units.

Kao and Hwang [63] crated a relational model that can be utilized to evaluate each division's efficiency in a two-stage production process. This model can also further be developed as a network DEA [68]. However, the relational model can only be used when constant returns to scale (CRS) are accepted. Network DEA was the first to use the slacks-based measure (SBM) to assess DMU performance [69]. This measurement of efficiency uses the probability of no proportional variations in both the input and output indicators and assigns weights to each division's significance when assessing both the overall and departmental efficiency. The two-stage production model was introduced by Chen and Cook [70]. They suggested the additive efficiency decomposition approach; the overall efficiency is the weighted sum of the efficiency of each stage. When considering CRS and VRS (variable returns to scale), this strategy can be used. The network DEA method was extended by Cook, Zhu [71], who also looked at the weighted outcome of each division.

The current study, therefore, used a two-stage network DEA [70] to assess both sustainability and marketability efficiency, while accounting for allocative inefficiency [72]. The following are explanations of the related mathematical equations:

The MNEs produce p outputs ($z_{dj},\ d = 1, \ldots, p$) in the first stage, utilizing m inputs ($x_{ij}, i = 1, \ldots, m$); in the 2nd stage, the outputs generated in the 1st stage are converted into intermediates to produce the final outputs $s(y_{rj}, r = 1, \ldots, s)$. v_i, w_d, and u_r are the multipliers for input i, intermediate d, and output r, respectively. Input- or output-oriented methods can be used to measure the technical efficiency (TE) of a firm. The input-oriented VRS-based network DEA model, described below, was developed in this study for predicting firm k's TE (TE_{VRS}), which is the overall efficiency, calculated as:

$$TE_{VRS} = Max \sum\nolimits_{r=1}^{s} u_r y_{rk} - \omega_1 - \omega_2 \tag{1}$$

$$\sum_{i=1}^{m} v_i x_{ik} = 1, \tag{2}$$

$$\sum_{d=1}^{p} w_d z_{dj} - \sum_{i=1}^{m} v_i x_{ij} - \omega_1 \leq 0, (j = 1, \ldots, n) \tag{3}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{d=1}^{p} w_d z_{dj} - \omega_2 \leq 0,\ (j = 1, \ldots, n) \tag{4}$$

$$v_i, w_d, u_r \geq 0; \omega_1, \omega_2 \in \text{free}.$$

Liang, Cook [73] used identical weights for excellent planning between the two stages. Constraints (3) and (4) correspond to stages TE^{S1}_{VRS} as sustainability efficiency and TE^{S2}_{VRS} as marketability efficiency, respectively, whose particular intercept multipliers are ω_1 and ω_2, i.e., addictive TE_{VRS}. This indicates that the multipliers of intermediate indicators, which are considered as both inputs and outputs, follow an additive structure. Using the optimal multipliers obtained from (1), we can determine the input-oriented technical efficiency of firm k as TE_{VRS} and the stages TE^{S1}_{VRS} and TE^{S2}_{VRS}, calculated as:

$$\begin{aligned} TE_{VRS,k} &= \left(\sum_{r=1}^{s} u_r^* y_{rk} - \omega_1^* - \omega_2^*\right) / \left(\sum_{i=1}^{m} v_i^* x_{ik}\right) \\ TE^{S1}_{VRS,k} &= \left(\sum_{d=1}^{p} w_d^* z_{dk} - \omega_1^*\right) / \left(\sum_{i=1}^{m} v_i^* x_{ik}\right) \\ TE^{S2}_{VRS,k} &= \left(\sum_{r=1}^{s} u_r^* y_{rk} - \omega_2^*\right) / \left(\sum_{d=1}^{p} w_d^* z_{dk}\right) \end{aligned} \tag{5}$$

It should be noted that the best multipliers found in (1) may not be distinguishable, indicating that TE^{S1}_{VRS} and TE^{S2}_{VRS} do not appear to be singular. According to Kao and Hwang [63], who consider that TE^{S1}_{VRS} is more significant, we initially presupposed the highest value of TE^{S1}_{VRS} via:

$$\begin{aligned} & TE^{S1}_{VRS} = Max \sum_{d=1}^{p} w_d z_{dk} - \omega_1 \\ & \sum_{i=1}^{m} v_i x_{ik} = 1, \\ & \sum_{r=1}^{s} u_r y_{rk} - \omega_1 - \omega_2 = TE_k \\ & \sum_{d=1}^{p} w_d z_{dj} - \sum_{i=1}^{m} v_i x_{ij} - \omega_1 \leq 0, (j = 1, \ldots, n) \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{d=1}^{p} w_d z_{dj} - \omega_2 \leq 0,\ (j = 1, \ldots, n) \\ & v_i, w_d, u_r \geq 0; \omega_1, \omega_2 \in \text{free}. \end{aligned} \tag{6}$$

To determine the returns to scale of network firm k, we used the dual model (7) of the multiplier model (1) to project the efficiency of the inefficient firm k. TE_{VRS} utilizes λ_j and γ_j as intensity weights to form a linear combination of n firms.

$$\begin{aligned} & TE_{VRS} = Min\ \beta_k \\ & s.t. \\ & \sum_{j=1}^{n} x_{ij}\lambda_j \leq \beta_k x_{ik}, \quad (i = 1, \ldots, m), \\ & \sum_{j=1}^{n} z_{dj}\lambda_j - \tilde{z}_{dk} \geq 0, \quad (d = 1, \ldots, p), \\ & \sum_{j=1}^{n} \lambda_j = 1, (\text{sub} - \text{technology } 1) \\ & \sum_{j=1}^{n} z_{dj}\gamma_j - \tilde{z}_{dk} \leq 0, \quad (d = 1, \ldots, p), \\ & \sum_{j=1}^{n} y_{rj}\gamma_j \geq y_{rk}, \quad (r = 1, \ldots, s), \\ & \sum_{j=1}^{n} \gamma_j = 1, (\text{sub} - \text{technology } 2) \\ & \beta_h \leq 1, \lambda_j, \gamma_j \geq 0, \tilde{z}_{dk} \in free. \end{aligned} \tag{7}$$

Let the optimum solution vector be $\left(\beta_k^*, \lambda_j^*, \gamma_j^*, \tilde{z}_{dk}^*\right)$. The inefficient company k can be projected onto the network frontier using the formula below:

$$\left(x_{ik}^* = \beta_{ik}^* x_{ik} - s_k^-, \tilde{z}_{dk}^*, y_{rk}^* = y_{rk} + s_k^+\right) \tag{8}$$

where s_k^- and s_k^+ are, respectively, the input and output slacks under model (7).

Baumol [74] and Sahoo and Zhu [72] defined the input-oriented RTS of firm k in TE_{VRS}, TE_{VRS}^{S1}, and TE_{VRS}^{S2}. RTS (returns to scale) describes the changes that occur in a production function with variable inputs as the scale effects change. There are three possible outcomes: increasing RTS, constant RTS, and decreasing RTS.

$$\varepsilon_{ik}^{N}\left(x_{ik}^{*}, \widetilde{z}_{dk}^{*}, y_{rk}^{*}\right) \equiv -\sum_{i=1}^{m} x_{ik}\frac{\partial F^N(\cdot)}{\partial x_{ik}} / \sum_{r=1}^{s} y_{rk}\frac{\partial F^N(\cdot)}{\partial y_{rk}} = \frac{\beta_k^* \sum_{i=1}^{m} v_i^* x_{ik}}{\sum_{r=1}^{s} u_r^* y_{rk}} \\ = \frac{\beta_k^*}{\beta_k^* + \omega_1^* + \omega_2^*}. \tag{9}$$

Note that in (9), $\sum_{i=1}^{m} v_i^* x_{ik} = 1$, due to the fact of (2), and $\sum_{r=1}^{s} u_r^* y_{rk} = \beta_k^* + \omega_1^* + \omega_2^*$. On the concept of duality, the objective function values of (1) and (7) are identical, for instance, $\beta_k^* = \sum_{r=1}^{s} u_r^* y_{rk} + \omega_1^* + \omega_2^*$. The input-oriented network is increasing returns to scale (IRS), according to (9) (i.e., $\varepsilon_{ik}^{N}(\cdot) > 1$) if $(\omega_2^* + \omega_2^*) < 0$ in all optimal solutions, constant (CRS) (i.e., $\varepsilon_{ik}^{N}(\cdot) = 1$) if $(\omega_2^* + \omega_2^*) = 0$ in all optimal solutions, and decreasing (DRS) (i.e., $\varepsilon_{ik}^{N}(\cdot) < 1$) if $(\omega_2^* + \omega_2^*) > 0$ in all optimal solutions. The RTS in TE_{VRS}^{S1} and TE_{VRS}^{S2} can be determined by utilizing the same approach.

3.3. Measurement of Firm Performance

The stochastic frontier approach (SFA) DEA model was first proposed in 2002 by Battese and Rao [75]. Later, in 2004, O'Donnell et al. presented a modified model that enabled the calculation and comparison of the technical efficiencies of Indonesian companies employing various technologies [76]. In 2008, a study analyzed both the metafrontiers and group frontiers and used country-level data from the agricultural sector, which were classified into different country groups. The study broke down disparities in performance into technical efficiency and technological gap effects [25].

This study utilized the metafrontier approach to investigate the technology gap between the metafrontier and group frontier. The former are firms in all five sectors and the latter ones are those that belong to the same sector. DMUs from all groups comprise the metafrontier, and DMUs in individual groups comprise group frontiers, which are both utilized to examine the impact of technological heterogeneity. The technology gap for firms that were in different sectors under technological heterogeneity was further discovered.

We modified Equation (1) to include the input-oriented VRS model, which allowed us to assess the pure technical efficiency of all DMUs as the metafrontier, including those in all sectors. The optimized θ_o^{*VRS} represents the PTE of the DMUs, enabling us to identify the metafrontier that included firms in other sectors. To estimate the PTE value of the group frontier, which includes firms in the sth region, we need to estimate the individual sector frontiers. This is calculated by utilizing the input-oriented VRS model, as follows:

Consider n firms in H regions $\left(\sum_{h=1}^{H} n_h = n\right)$, where $h = 1, \ldots, H$; consequently, the linear programming for the target firm k can be explicated as:

$$TE_{VRS,k}^{h} = Max \sum_{r=1}^{s} u_r^h y_{rk}^h - \omega_1^h - \omega_2^h,\ (k = 1, \ldots, n_h; h = 1, \ldots, H) \tag{10}$$

$$\sum_{i=1}^{m} v_i^h x_{ik}^h = 1, \tag{11}$$

$$\sum_{d=1}^{p} w_d^h z_{dj}^h - \sum_{i=1}^{m} v_i^h x_{ij}^h - \omega_1^h \le 0,\ (j = 1, \ldots, n_h) \tag{12}$$

$$\sum_{r=1}^{s} u_r^h y_{rj}^h - \sum_{d=1}^{p} w_d^h z_{dj}^h - \omega_2^h \le 0,\ (j = 1, \ldots, n_h) \tag{13}$$

$$v_i^h, w_d^h, u_r^h \ge 0; \omega_1^h, \omega_2^h \in \text{free}.$$

Using the optimal multipliers from (10), we can acquire the input-oriented TE of firm k in TE_{VRS}^{hS1} and TE_{VRS}^{hS2} as:

$$TE_{VRS,k}^{hS1} = \left(\sum\nolimits_{d=1}^{p} w_d^{h*} z_{dk}^{h} - \omega_1^{h*}\right) / \left(\sum\nolimits_{i=1}^{m} v_i^{h*} x_{ik}^{h}\right) \tag{14}$$

$$TE_{VRS,k}^{hS2} = \left(\sum\nolimits_{r=1}^{s} u_r^{h*} y_{rk}^{h} - \omega_2^{h*}\right) / \left(\sum\nolimits_{d=1}^{p} w_d^{h*} z_{dk}^{h}\right) \tag{15}$$

where the superscripted h represents the sector frontier. The optimized TE_{VRS}^{hS1} and TE_{VRS}^{hS2} values that solve the linear program are defined in Equation (14) and stand for the TE of the target firm compared with the $region - h$ frontier. Furthermore, the closeness of the $region - h$ frontier and the metafrontier is measured. In particular, the technology gap ratio between the sector frontier and the metafrontier is defined as follows:

$$MTR_{h,k}^{S1} = TE_{VRS,k}^{S1*} / TE_{VRS,k}^{hS1*},\ k = 1, \ldots, n_h, h = 1, \ldots, H \tag{16}$$

$$MTR_{h,k}^{S2} = TE_{VRS,k}^{S2*} / TE_{VRS,k}^{hS2*},\ k = 1, \ldots, n_h, h = 1, \ldots, H \tag{17}$$

The metatechnology ratio ($MTR_{h,k}^{S1}$ and $MTR_{h,k}^{S2}$) is considered the same as the technology gap ratio, which is between 0 and 1. For participating firms between the metafrontier and sector frontier, the increases in $MTR_{h,k}^{S1}$ and $MTR_{h,k}^{S2}$ indicate decreases in the technology gap.

3.4. Truncated Regression

To assess the unit performance, numerous researchers have adopted Tobit regression, according to the literature review on DEA, and it was often affected by exogenous factors. In this study, the regression condition was applied as below:

$$TE_e = \alpha + X_e\beta + \delta_e, \quad e = 1, \ldots, n \tag{18}$$

As in Equation (7), α represents the intercept, δ_e represents the residual value, and X_e represents the vector variable, which is observed and assumed to be related to the efficiency score of the participating firms e, and it is expected to be related to the firms' efficiency score, which is a proxy by TE_e. Simar and Wilson [77] argued that Tobit regression was inappropriate for analyzing the efficiency score using the DEA approach. Hence, instead of the Tobit regression model, a truncated regression with bootstrap was developed, and it illustrated the satisfactory performance in the Monte Carlo method.

This study employed the methodology of Simar and Wilson to examine the environmental variables that would affect a firm's performance. Then, this study noted that the distribution δ_e was restricted by the condition in Equation (5). This study adapted Equation (5) and assumed that the distribution before truncation was a truncated normal distribution with zero means, unknown variance, and a truncation point that was selected by various factors. The consequence of the adjustment is Equation (6).

$$T\hat{E}_e \approx \alpha + X_e\beta + \delta_e, \quad e = 1, \ldots, n \tag{19}$$

where $\delta_e \sim N\left(0, \sigma_\varepsilon^2\right)$ such that $\delta_e \geq 1 - \alpha - X_e\beta,\ e = 1, \ldots, n$. This work employed the regression process of parametric bootstrap to estimate parameters $\left(\beta, \sigma_\varepsilon^2\right)$ and estimated Equation (5) by maximizing the associated likelihood function while taking into account the $\left(\beta, \sigma_\varepsilon^2\right)$ parameter. Readers unfamiliar with the algorithm for detail estimate are referred to Simar and Wilson [77].

4. Empirical Results

4.1. Data Collection and Descriptive Statistics

This study investigated 306 firms based on the S&P 500 listed firms in 2021 in the United States. They were categorized by GICS (Global Industry Classification Standard) as the leading performance firms divided into 11 groups [27]. Each firm was treated as a DMU as the sample in a two-stage DEA analysis. Financial and business data on these samples were collected from the Thomson Reuters DataStream database. The selected data year (2021) was the second year of the pandemic outbreak, which allowed for investigating a firm's performance across industries in the post-pandemic era. The ESG scores from the DataStream database are designed to measure a company's ESG performance and effectiveness based on publicly reported information, such as CSR reports or annual reports. They are categorized into 10 items that form three pillar scores. As for the environment pillar score, it measures resource use (such as energy and water), emissions (such as waste, CO_2 emissions, and environmental management system), and innovation (such as green revenues, product innovation, and R&D). The measurement definitions are described in Table 2 [78].

Table 2. Definitions of the environmental pillar score categories.

Environmental Pillar Score Category	Measurement Definition
Resource Use	The resource use score measures a firm's capacity to minimize the usage of energy, water, or materials and to find ecofriendly solutions by improving supply chain management, which reflects the firm's performance.
Emissions	The emission score measures a firm's environmental emissions in its production and operations, which reflects its commitment and effectiveness.
Environmental Innovation	The environmental innovation score measures a firm's capacity to create new market opportunities through innovative processes, technologies, and ecofriendly products that reduces environmental costs and burdens towards its customers.

The initial sample consists of 510 publicly listed firms. To maintain the sample's consistency and comparability, those with any missing financial data and ESG scores were eliminated, resulting in 306 DMUs. Table 3 shows the total number of observations in 11 sectors as the first tiers of S&P Global's GICS. The total assets of 306 DMUs accounted for 70.72% of the population which suggests that the sample can represent 500 S&P across industries.

Table 3. Sample analysis by sector of the S&P GICS.

Sector	Initial Sample	After Deleting Missing Data	Total Assets Percentage
Industrials (IN)	86	55	79.87%
Consumer Discretionary (CD)	70	46	75.91%
Information Technology (IT)	66	42	75.17%
Health Care (HC)	66	32	73.35%
Financials (FI)	66	31	63.42%
Real Estate (RE)	32	21	78.09%
Energy (EN)	22	17	85.56%
Materials (MA)	23	17	81.92%
Utilities (UT)	34	17	44.10%
Consumer Staples (CT)	24	15	34.69%
Communication Services (CS)	21	13	60.06%
Total	510	306	70.72%

Table 4 presents the statistical descriptive results for the input and output variables dataset across all sectors. The results show that, firstly, the FI and HC sectors have the lowest energy use and CO_2 emissions, with IT ranking as the third lowest in energy use and RE ranking as the third lowest in CO_2 emissions. Secondly, the EN sector has the highest amount of energy use and the largest CO_2 emissions. The MA sector ranks second in energy use, and the CD sector ranks third. Thirdly, the average number of total employees in the UT and RE sectors is much less, resulting in the lowest net sales and net income, but they rank fifth and sixth in energy use. On the other hand, the CS sector holds both the largest operating expenses and net sales, with only half the energy use on average. Additionally, the normality test value (*p*-value) was less than 1%, which implies that all input and output variables used as DEA indicators have non-normal distributions and can effectively estimate the efficiency of all DMUs.

Table 4. Descriptive statistics summary of all sectors (2021).

Variables	Valid (N)	Mean	Median	Std. Dev.	Skewness	K-S Test
Employees	306	64,231	24,150	161,766	10.900	$p < 0.01$
Operating Expenses	306	24,231,496	10,094,731	40,431,944	3.456	$p < 0.01$
Property, Plant, and Equip.	306	13,648,924	4,468,500	24,568,103	4.356	$p < 0.01$
Energy Use Total	306	36,507,946	4,431,631	124,806,728	7.186	$p < 0.01$
CO_2 Emission	306	3,634,933	398,038	10,112,797	5.496	$p < 0.01$
Net Sales	306	29,126,665	12,732,103	47,449,442	3.553	$p < 0.01$
Net Income	306	3,877,359	1,467,256	9,226,225	6.185	$p < 0.01$
Market Capitalization	306	92,344,583	37,269,581	254,807,941	8.695	$p < 0.01$
Industrials (IN)						
Employees	55	65,732	45,000	83,521	3.812	
Operating Expenses	55	19,271,457	11,708,600	24,246,996	2.640	
Property, Plant, and Equip.	55	8,867,286	3,506,000	12,807,357	2.663	
Energy Use Total	55	25,791,868	5,945,576	54,378,234	3.811	
CO_2 Emission	55	2,299,678	580,100	4,288,631	2.729	
Net Sales or Revenues	55	21,925,779	13,750,000	26,015,483	2.619	
Net Income	55	2,063,123	1,356,000	3,362,134	2.332	
Market Capitalization	55	51,348,546	44,233,540	39,573,709	1.216	
Consumer Discretionary (CD)						
Employees	46	131,125	39,000	362,096	6.010	
Operating Expenses	46	33,459,426	9,945,677	55,932,468	2.932	
Property, Plant, and Equip.	46	14,273,209	5,667,363	20,079,721	2.700	
Energy Use Total	46	43,489,227	10,904,419	89,546,261	3.164	
CO_2 Emission	46	3,201,019	985,694	5,954,247	3.005	
Net Sales	46	35,721,059	12,034,595	58,425,140	2.890	
Net Income	46	1,556,643	1,338,138	3,417,321	−0.095	
Market Capitalization	46	52,336,938	33,627,109	62,538,320	2.399	
Information Technology (IT)						
Employees	42	57,350	18,191	108,811	4.043	
Operating Expenses	42	21,114,868	8,243,144	41,876,713	4.725	
Property, Plant, and Equip.	42	7,025,893	1,572,482	16,290,163	3.151	
Energy Use Total	42	5,126,194	1,221,300	10,996,470	3.149	
CO_2 Emission	42	692,016	141,128	1,476,101	3.248	
Net Sales	42	28,756,359	12,640,898	60,702,375	4.680	
Net Income	42	6,599,683	1,389,000	17,030,419	4.375	
Market Capitalization	42	227,186,335	52,924,800	580,812,069	4.129	
Health Care (HC)						
Employees	32	44,896	28,250	39,329	0.948	
Operating Expenses	32	27,674,963	7,927,050	44,093,202	2.368	
Property, Plant, and Equip.	32	4,661,437	2,647,500	5,307,405	1.957	
Energy Use Total	32	4,178,324	1,564,011	5,131,108	1.339	
CO_2 Emission	32	325,384	113,800	360,247	1.095	
Net Sales	32	32,914,122	10,884,850	47,203,673	2.014	
Net Income	32	4,103,396	1,713,800	5,596,644	2.148	
Market Capitalization	32	98,290,306	51,947,498	109,217,369	1.680	
Financials (FI)						

Table 4. *Cont.*

Variables	Valid (N)	Mean	Median	Std. Dev.	Skewness	K-S Test
Employees	31	52,651	19,112	74,769	2.171	
Operating Expenses	31	20,218,673	10,199,000	21,443,516	1.239	
Property, Plant, and Equip.	31	4,039,876	1,411,000	6,716,950	2.525	
Energy Use Total	31	1,437,894	616,439	2,292,423	2.311	
CO_2 Emission	31	133,151	50,480	217,256	2.308	
Net Sales	31	29,619,851	14,262,700	32,610,047	1.542	
Net Income	31	7,527,387	2,760,000	10,769,049	2.466	
Market Capitalization	31	88,974,875	34,036,402	124,961,400	2.217	
Real Estate (RE)						
Employees	21	7611	2053	22,510	4.456	
Operating Expenses	21	3,852,851	2,124,780	5,392,507	3.874	
Property, Plant, and Equip.	21	17,951,591	16,728,193	9,929,762	1.091	
Energy Use Total	21	8,059,360	2,640,247	11,925,509	1.673	
CO_2 Emission	21	395,179	113,525	673,342	2.234	
Net Sales	21	4,954,734	2,890,000	5,878,671	3.183	
Net Income	21	1,049,918	563,399	913,177	0.873	
Market Capitalization	21	41,904,363	33,985,211	35,854,964	1.558	
Energy (EN)						
Employees	17	21,276	9900	27,199	1.474	
Operating Expenses	17	46,087,427	13,483,000	68,956,421	2.110	
Property, Plant, and Equip.	17	41,863,689	23,485,000	58,000,653	2.519	
Energy Use Total	17	225,809,668	26,409,809	405,215,273	2.321	
CO_2 Emission	17	18,825,388	6,340,000	26,338,591	2.158	
Net Sales	17	51,686,736	17,870,000	73,806,805	2.179	
Net Income	17	4,256,908	1,517,000	6,468,980	2.032	
Market Capitalization	17	56,717,249	31,755,920	73,233,179	2.290	
Materials (MA)						
Employees	17	27,163	20,875	19,819	0.954	
Operating Expenses	17	13,939,366	10,233,000	11,658,370	1.786	
Property, Plant, and Equip.	17	11,824,162	6,238,200	11,968,261	1.710	
Energy Use Total	17	150,582,893	44,887,896	184,967,157	1.117	
CO_2 Emission	17	9,983,596	3,392,110	12,391,969	1.181	
Net Sales	17	17,049,148	11,656,000	14,296,112	1.677	
Net Income	17	1,931,127	1,129,900	1,867,781	1.331	
Market Capitalization	17	45,227,357	30,373,223	41,041,140	2.249	
Utilities (UT)						
Employees	17	10,357	9116	7593	1.139	
Operating Expenses	17	7,064,017	6,183,000	5,218,699	1.307	
Property, Plant, and Equip.	17	30,722,744	23,506,000	29,013,159	1.585	
Energy Use Total	17	25,655,405	5,077,246	56,826,007	3.386	
CO_2 Emission	17	15,492,051	8,205,060	19,798,286	2.181	
Net Sales	17	8,782,478	7,329,000	6,452,269	1.327	
Net Income	17	1,197,192	1,220,527	1,025,792	1.581	
Market Capitalization	17	29,484,926	24,102,382	18,763,484	1.617	
Consumer Staples (CT)						
Employees	15	157,724	100,000	166704	1.034	
Operating Expenses	15	35,369,789	18,214,000	38167288	1.488	
Property, Plant, and Equip.	15	9,869,718	5,925,799	10375204	1.328	
Energy Use Total	15	7,887,535	5,875,683	7647813	1.216	
CO_2 Emission	15	684,120	373,039	755759	1.168	
Net Sales	15	41,435,625	21,111,000	43164922	1.599	
Net Income	15	4,716,951	2,454,000	5052738	1.335	
Market Capitalization	15	86,986,759	40,194,562	106546924	2.675	
Communication Services (CS)						
Employees	13	77,289	55,600	68,565	0.846	
Operating Expenses	13	51,120,879	23,503,335	56,985,031	1.313	
Property, Plant, and Equip.	13	38,677,181	3,770,026	54,057,120	1.317	
Energy Use Total	13	18,186,004	2,283,350	24,095,115	1.200	

Table 4. *Cont.*

Variables	Valid (N)	Mean	Median	Std. Dev.	Skewness	K-S Test
CO_2 Emission	13	1,790,589	246,466	2,399,859	1.246	
Net Sales	13	64,695,594	28,586,000	77,530,395	1.621	
Net Income	13	10,861,440	2,699,000	20,841,736	2.961	
Market Capitalization	13	243,180,099	51,830,406	513,366,859	3.365	

Normality test: Kolmogorov–Smironv test, $p < 0.01$. Energy use is in units of gigajoules; CO_2 emission is in units of metric tons; market capitalization is in USD 1000; other variables are in units of USD, except for employees.

Table 5 presents the correlation coefficients matrix of the input and output variables adopted in the study. The results show that those indicators with statistical significance at 1% have a positive relationship in both stages, except for market capitalization, which has no significance. Thus, both variables, output and oriented-input, were "isotonicity" compliance alignments under the DEA framework [22], supporting the requirement of variable selection in a DEA evaluation.

Table 5. Correlations coefficients among the input and output variables.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1st Stage Input								
(1) Employees	1							
(2) Operating Expenses	0.2541 ***	1						
(3) Property, Plant, and Equip.	0.0938	0.5502 ***	1					
(4) Energy Use	0.0135	0.3982 ***	0.5764 ***	1				
(5) CO_2 Emission	−0.0102	0.3159 ***	0.6527 ***	0.8120 ***	1			
1st Stage Output								
(6) Net Sales (Link)	0.2513 ***	0.9839 ***	0.5651 ***	0.3617 ***	0.2877 ***	1		
2st Stage Output								
(7) Net Income	0.1901 ***	0.5790 ***	0.4283 ***	0.1296 **	0.1050 *	0.7109 ***	1	
(8) Market Capitalization	0.1244 **	0.4691 ***	0.3102 ***	0.0337	0.0264	0.5936 ***	0.8832 ***	1

*, **, and *** correlations are significant at the 10%, 5%, and 1% levels, respectively.

The descriptive statistics of the input and output variables with means in all sectors are presented in Table 6. Regarding the environmental dimension, energy use as an input variable was expected to decrease for a higher efficiency. CO_2 emission as an output variable was considered an undesirable variable, and it was moved to the input side in this study. In addition, the result of the K-W test shows that all variables are highly significant at the 0.01 level, except market capitalization is fairly significant at the 0.05 level, which indicates that all variables are remarkably different across industries.

Table 6. Variables difference test on all sectors.

Sector	Employees	Operating Expenses	Property, Plant, and Equip.	Energy Use	CO_2 Emission	Net Sales	Net Income	Market Capitalization
IN	65,732	19,271,457	8,867,286	25,791,868	2,299,678	21,925,779	2,063,123	51,348,546
CD	131,125	33,459,426	14,273,209	43,489,227	3,201,019	35,721,059	1,556,643	52,336,938
IT	57,350	21,114,868	7,025,893	5,126,194	692,016	28,756,359	6,599,683	227,186,335
HC	44,896	27,674,963	4,661,437	4,178,324	325,384	32,914,122	4,103,396	98,290,306
FI	52,651	20,218,673	4,039,876	1,437,894	133,151	29,619,851	7,527,387	88,974,875
RE	7611	3,852,851	17,951,591	8,059,360	395,179	4,954,734	1,049,918	41,904,363
EN	21,276	46,087,427	41,863,689	225,809,668	18,825,388	51,686,736	4,256,908	56,717,249
MA	27,163	13,939,366	11,824,162	150,582,893	9,983,596	17,049,148	1,931,127	45,227,357
UT	10,357	7,064,017	30,722,744	25,655,405	15,492,051	8,782,478	1,197,192	29,484,926
CT	157,724	35,369,789	9,869,718	7,887,535	684,120	41,435,625	4,716,951	86,986,759
CS	77,289	51,120,879	38,677,181	18,186,004	1,790,589	64,695,594	10,861,440	243,180,099
K-W Test (*p*-Value)	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0001 ***	0.0274 **

, and * correlations are significant at the 5%, and 1% levels, respectively.

4.2. Analysis of Environmental Pillar Score

The objective of an ESG evaluation is to promote corporate sustainability development, increase business profitability, improve risk management, and enhance corporate brand image, among other things [79]. Many studies have sought to measure the effect of the three overall dimensions of ESG on firm performance. Recent researchers have shown that estimating ESG tends to improve firm performance [80]. It was also found that positive ESG news can mitigate financial penalties resulting from negative ESG news in the market. Therefore, having a good ESG reputation not only enhances financial performance but also helps to alleviate risks that come with negative news [81]. Another study suggested that economic growth has a positive and significant effect on environmental degradation by examining the concept of the environmental Kuznets curve (EKC) [81]. However, some companies disclose ESG primarily for "legitimacy-seeking" rather than profit-oriented purposes. Consequently, opinions regarding the different dimensions of ESG and their effects on firm performance need to be discussed individually. Additionally, it is observed that research tends to focus predominantly on environmental factors.

Environmental sustainability is one of the fundamental dimensions of ESG, considered a critical core indication of the environmental pillar that consists of resource use, emissions, and environmental innovation categories. The score is a sum of these three categories weighted differently. Resource use and environmental innovation were both weighted at 11%, and emissions was weighted at 12%, summing to 34%. Prior research examined the relationship between environmental degradation and economic growth from the perspective of economic development and different industries in the United States. In this study, we intended to discuss the relationship between environmental investment and firm performance from both sustainability and marketability perspectives in the post-pandemic era.

Table 7 shows the environmental pillar scores and the three associated elements' indices in 11 sectors that have significant differences in environmental innovation as per the K-W test, and p-values are significant at the 0.05 level. According to Datamarnan's Global Insights Report in 2018, the total number of regulations covering environmental and social topics increased numerically in policies from 2015 to 2018. Practically in the environmental dimension, the number of regulations grew by 67% within those three years in the US [82]. Thus, most firms need to reach the minimum requirements in terms of resource use and CO_2 emissions during the production process for standard compliance. The results of the resource use and CO_2 emission scores range from 74 to 86 without significant differences. The MA, IN, and RE sectors are more efficient in environmental innovation, with scores over 50, indicating that they focus more on research and development to innovate green products and create green revenues. On the contrary, HC has the lowest score at 26.34 in environmental innovation, but the highest score (85.96) in resource use, which means it has better performance in saving water and energy, managing emissions and waste, biodiversity, and environmental management systems but lacks environmental innovation. Overall, RE, MA, and CD are evaluated as having higher environment pillar scores, and the FI sector has lower scores, indicating that financial firms need more endeavors for environmental innovation regarding sustainability.

4.3. Analysis of Sustainability Efficiency and Marketability Efficiency

Table 8 demonstrates the overall efficiency results, including both the sustainability and marketability efficiencies of 11 sectors. The MTE (meta technical efficiency) mean values of all sectors vary from 0.201 to 0.705, and the GTE (group technical efficiency) mean values vary from 0.387 to 0.956, resulting in the TGR (technological gap ratio) varying from 0.229 to 0.831. This outcome suggests that firms in different sectors face varying levels of technological gaps due to the fact of operating with the use of different technologies. The objective of MNEs is to achieve high efficiency while manufacturing or providing services. The model allows for the estimation of technological gaps for those relative to the potential technology available to the industry as a whole. The TGR values can be obtained from the group frontiers (GTE) and metafrontiers (MTE) together with the technical efficiency scores [76]. As a result, in the overall efficiency analysis, RE (0.705) and FI (0.619) have higher efficiencies with fewer technology gaps. CD, IN, MA, and CT are more inefficient, with mean scores under 0.3. The TGR shows that they only produce approximately 22.9% to 56.7%, on average, of the potential output. These results imply that firms with larger technological gaps are more inefficient. Therefore, all managerial administration should prioritize engaging new technology in their production process to raise their overall efficiency.

Table 7. Environmental pillar score difference in all sectors.

Sector	Environmental Dimension			
	Environment Pillar Score	Environmental Innovation	Resource Use	Emissions
IN	69.63	52.21	81.62	75.90
CD	72.79	42.98	79.78	76.29
IT	63.40	41.39	82.27	79.69
HC	69.60	26.34	85.96	80.25
FI	59.79	43.79	80.67	82.08
RE	76.55	54.30	77.01	81.70
EN	69.86	38.43	82.00	79.08
MA	75.78	56.26	79.46	84.43
UT	65.12	44.99	74.44	74.02
CT	69.02	41.44	77.06	77.98
CS	62.99	34.48	79.42	76.96
K-W Test (*p*-Value)	0.0321 **	0.0386 **	0.6356	0.6267

** correlations are significant at the 5% levels.

In the sustainability analysis, the MTE mean values of all sectors vary from 0.535 to 0.830, which is more efficient than the marketability analysis (from 0.151 to 0.378). The GTE mean values vary from 0.826 to 0.991, and the TGR varies from 0.229 to 0.831. FI still performs the highest for sustainability efficiency (MTE = 0.830) and has very few technology gaps (TGR = 0.971). MTE for IN, CD, and MA is lower than 0.6, which is considered relatively inefficient. It is generally perceived that corporations that provide service products are less harmful to the environment than those that produce tangible products, such as manufacturing industries [83], which may be caused by higher pollutant emissions during production processes. The GTE of all sectors is fairly high, from 0.826 to 0.975. This indicates that all firms pay great attention to sustainability development and compliance with related industry regulations in terms of energy use and CO_2 emissions.

As for the marketability analysis, IT performs the highest efficiency (MTE = 0.378) and has smaller technology gaps (TGR = 0.670). EN performed technically inefficient (0.151) but with fairly high level in GTE (0.744), with the largest gaps (TGR = 0.194). Furthermore, there are a total of 45 efficient firms, as the benchmark was distributed mainly in IT (8), FI (10), RE (6), and EN (8) in terms of sustainability efficiency, and only 6 firms are considered the benchmark for marketability efficiency.

The findings suggest that corporate management must reconsider the technological differences and refer to the clear benchmark firms that are both within and across sectors, especially for firms in MA. Improving technical inefficiency and reducing technical gaps in sustainability efficiency need to be given priority.

Table 8. Efficiency analysis by sector using metafrontier and group frontier analysis.

	Overall Efficiency			**Sustainability Efficiency**			**Marketability Efficiency**		
Sector	**MTE**	**GTE**	**TGR**	**MTE**	**GTE**	**TGR**	**MTE**	**GTE**	**TGR**
Mean									
IN	0.252	0.499	0.567	0.583	0.880	0.661	0.187	0.534	0.342
CD	0.201	0.387	0.548	0.535	0.826	0.632	0.204	0.413	0.491
IT	0.499	0.671	0.717	0.719	0.870	0.815	0.378	0.555	0.670
HC	0.386	0.797	0.468	0.678	0.902	0.745	0.302	0.625	0.472
FI	0.616	0.718	0.831	0.830	0.854	0.971	0.330	0.572	0.578
RE	0.705	0.947	0.750	0.783	0.935	0.837	0.356	0.767	0.474
EN	0.435	0.956	0.446	0.814	0.975	0.832	0.151	0.744	0.194
MA	0.208	0.916	0.229	0.550	0.950	0.577	0.169	0.766	0.220
UT	0.357	0.848	0.438	0.620	0.991	0.625	0.184	0.689	0.254
CT	0.261	0.466	0.505	0.623	0.917	0.670	0.236	0.466	0.475
CS	0.350	0.574	0.517	0.705	0.871	0.809	0.276	0.568	0.472
K-W Test (*p*-Value)	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***
Std. Dev.									
IN	0.269	0.356	0.291	0.156	0.126	0.134	0.138	0.284	0.099
CD	0.206	0.309	0.194	0.195	0.183	0.127	0.209	0.310	0.182
IT	0.310	0.299	0.202	0.189	0.134	0.112	0.250	0.275	0.212
HC	0.265	0.283	0.221	0.182	0.109	0.138	0.176	0.320	0.089
FI	0.293	0.254	0.163	0.157	0.148	0.041	0.245	0.248	0.249
RE	0.262	0.113	0.264	0.159	0.094	0.136	0.155	0.242	0.147
EN	0.298	0.099	0.290	0.229	0.060	0.218	0.094	0.285	0.075
MA	0.101	0.187	0.098	0.111	0.067	0.095	0.072	0.248	0.045
UT	0.286	0.250	0.296	0.156	0.022	0.154	0.109	0.225	0.090
CT	0.339	0.398	0.268	0.195	0.086	0.159	0.241	0.311	0.164
CS	0.336	0.331	0.237	0.182	0.147	0.145	0.247	0.320	0.237
Minimum Value									
IN	0.033	0.087	0.055	0.319	0.586	0.523	0.044	0.133	0.164
CD	0.011	0.019	0.145	0.115	0.225	0.435	0.022	0.094	0.200
IT	0.053	0.055	0.351	0.410	0.608	0.674	0.017	0.021	0.263
HC	0.052	0.174	0.194	0.435	0.681	0.567	0.010	0.033	0.178
FI	0.186	0.334	0.499	0.544	0.559	0.856	0.086	0.148	0.161
RE	0.118	0.599	0.118	0.504	0.733	0.638	0.102	0.218	0.163
EN	0.056	0.690	0.056	0.424	0.817	0.424	0.025	0.183	0.095
MA	0.094	0.485	0.118	0.416	0.801	0.419	0.072	0.301	0.102
UT	0.062	0.085	0.144	0.498	0.931	0.498	0.042	0.326	0.129
CT	0.044	0.096	0.155	0.418	0.747	0.484	0.060	0.145	0.293
CS	0.068	0.183	0.223	0.482	0.569	0.543	0.061	0.171	0.202
Number of Efficient Firms									
IN	4	15		3	20		0	7	
CD	1	7		2	10		2	4	
IT	7	12		8	16		3	6	
HC	2	15		3	14		0	8	
FI	9	12		10	12		0	3	
RE	7	16		6	13		0	5	
EN	2	13		8	14		0	7	
MA	0	13		0	9		0	6	
UT	2	8		2	14		0	4	
CT	2	5		2	5		1	2	
CS	0	4		1	6		0	4	
Total	36	120		45	133		6	56	

*** correlations are significant at the 1% levels.

The study of the reasons for the wide variations in the TGRs and technical efficiencies in different sectors as a benchmark is worthy of further investigation, as technical inefficiency could be caused by scale inefficiency. We further investigated the returns to scale (RTS) of firms across 11 sectors. Table 9 presents the RTS efficiency of firms in two stages. In the overall efficiency, only 6.2% of the firms are managed at CRS, 74.5% at IRS, and 19.28% at DRS (59 DMUs). In stage one, approximately 7.5% of the firms manage at CRS (23 DMUs) as the benchmark, while approximately 63.07% manage at IRS (193 DMUs). On the contrary, nearly 29.41% manage at DRS (90 DMUs). In stage two, 304 firms manage at DRS, accounting for 99.3%, while only 1 firm manages at IRS and 1 manages at CRS. These results indicate that for marketability, all firms were still affected by the changes due the pandemic, even after reopening. The consideration of its scale development would still be critical. However, overall, firms managed at IRS take a larger proportion, which might be caused by the reopening and increase in raw material prices, especially in the RE and UT sectors.

Table 9. Returns to scale on all sectors.

	Overall Efficiency			**Sustainability Efficiency**			**Marketability Efficiency**		
Sector	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**IRS**
IN	4	11	40	2	14	39	0	55	0
CD	1	2	43	1	17	28	1	44	1
IT	4	14	24	3	13	26	0	42	0
HC	2	9	20	6	11	14	0	31	0
FI	1	10	21	3	9	20	0	32	0
RE	4	0	17	3	1	17	0	21	0
EN	1	4	12	3	5	9	0	17	0
MA	0	3	14	0	4	13	0	17	0
UT	1	0	16	1	2	14	0	17	0
CT	1	2	12	1	7	7	0	15	0
CS	0	4	9	0	7	6	0	13	0
Total	19	59	228	23	90	193	1	304	1

Real estate plays a crucial role in driving economic growth in the US and can be affected by the local economy and employment rates. The number of housing starts and residential construction projects are key economic indicators. In addition, clean energy has initiated analysts' forecasts for strong growth in the utility industry from 2020.

4.4. Influence of Environmental Investment on Firm Performance—Truncated Regression

We further adopted the truncated regression model to evaluate the impact of exogenous factors [71], specifically the proxy variable of environmental investment, on firm performance. The dependent variables employed in this regression analysis were the environmental innovation score (EIS), resource use score (RUS), and emissions score (ES), while sustainable performance (MTE1) and corporate performance (MTE2) were the independent variables. The truncated regression model is estimated as follows:

$$TE_{\mathrm{e}} = \beta_0 + \beta_1 EIS_{\mathrm{e}} + \beta_2 RUS_{\mathrm{e}} + \beta_3 ES_{\mathrm{e}} + \beta_4 DEBT_{\mathrm{e}} + \beta_5 \mathrm{ROA}_{\mathrm{e}} + \beta_6 \mathrm{ROE}_{\mathrm{e}} + \varepsilon_{\mathrm{e}} \quad (20)$$

Here, TE_{e} represents firm e's performance score, and β_0 is the intercept; ε_{e} is the error term, and subscript e represents the firm.

Three control variables, namely, debt ratio, ROA, and ROE, were introduced as independent variables. The debt ratio is generated by calculating the ratio of total liabilities to total assets. The ROA is calculated by dividing a company's net income by the average total assets, while ROE is calculated by dividing the firm's net income by its average shareholders' equity. Table 10 presents the relationship between environmental investment and firm performance using truncated regression model analysis.

Table 10. Truncated regression result on overall efficiency.

Item	MTE		MTES1		MTES2	
Environmental Innovation Score (EIS)	−0.003656	***	−0.000939		−0.000266	
Resource Use Score (RUS)	−0.006789	***	−0.001130		−0.001582	
Emissions Score (ES)	0.003012		0.005343	**	0.003903	**
ROA	0.017618	***	0.017379	***	0.013102	***
ROE	−0.000041		−0.000219		−0.000121	
Debt Ratio	−0.004864	**	0.000429		−0.000489	
_cons	0.623627	***	−0.426119	**	−0.141300	
/sigma	0.329686	***	0.302446	***	0.2416755	***
Log Likelihood	92.1760		130.3373		150.3907	
Wald chi2(6)	16.9		37.09		21.33	
Prob > chi2	0.0096		0.0000		0.0016	

, and * correlations are significant at the 5%, and 1% levels, respectively.

The study's findings reveal that the independent variables EIS and RUS had a negative relationship with overall efficiency (MTE) and were statistically significant ($p < 0.01$). On the other hand, ES had a significantly positive effect on sustainability efficiency (MTE1) and marketability efficiency (MTE2) in both stages ($p < 0.05$). These results suggest that higher EIS and RUS could lead to a significant decrease in overall firm performance, potentially due to the high costs associated with investing in environmentally friendly products or services. The short-term increase in expenses could negatively impact firm performance. However, upon examining the two-stage results, there were neither significant relationships between EIS and MTE1 and MTE2 nor between RUS and MTE1 and MTE2.

In this study, a high emission score (ES) means lower CO_2 emissions. The results indicate a significant relationship between ES and both sustainability efficiency (MTE1) and marketability efficiency (MTE2) but no significant relationship between ES and overall firm performance. These findings may be due to the US government's recent announcement of its goal to achieve net zero emissions by 2050, which requires action across all economic sectors. As a result, multinational enterprises (MNEs) are transforming their operations to develop a green supply chain and partner with leading organizations to accelerate progress towards a clean energy economy [19]. Therefore, energy use and CO_2 emissions are critical input and output items regarding firm performance for all MNEs worldwide. Although the results indicate that environmental investment may have negative economic benefits for firms, the importance of environmental investment must be considered for firms in all sectors.

5. Conclusions

This study presents the first assessment of multinational enterprise (MNE) performance across sectors in the United States using a two-stage data envelopment analysis (DEA) method. The research framework offers an in-depth perspective on the environmental dimension of ESG, accompanied by a comprehensive empirical analysis of firm performance. The analysis identified sustainability and marketability efficiencies of firms and explored the influence of environmental investment on firm performance. The findings suggest that the environmental innovation score (EIS) and resource use score (RUS) have significantly negative impacts on firm performance in the short term due to the additional expenses incurred during the innovative research and development of new products and services, while the emission score (ES) has positive effects on both sustainability and marketability efficiencies. The energy, utilities, and materials sectors were found to be the most severely impacted from an environmental perspective, with high levels of CO_2 emissions and energy and material used for energy production. Conversely, the finance and health care sectors had the lowest energy use and CO_2 emissions.

It is suggested that environmental investment significantly influences firm performance for firms across sectors. Thus, decision-makers in multinational enterprises (MNEs) must reconsider their sustainability development policy to improve firm performance and strive for higher marketability. While it can be challenging to operationalize environmental investments in traditional industrial sectors, such as consumer discretionary and industrials, due to the differences in the environmental conditions across locations, emphasizing such investments is expected to bring more opportunities and competitive advantages in the future.

In summary, there has been the question of which factors related to the ESG components actually impact on sustainability and marketability performance. Business models that prioritize environmental innovations for sustainability may not be financially feasible initially but could become so in the future due to the fact of regulatory or societal changes. To improve firm performance from both the sustainability and marketability perspectives, managers should prioritize environmental management, leading to better resource allocation and business opportunities.

5.1. Implications

This study offers critical implications for firm managers of MNEs practicing ESG.

First, our research data were gathered from the 2021 DataStream database, which covers the COVID-19 pandemic period. The pandemic had a significant impact on the marketability of the MNEs under study, particularly in the real estate and utility sectors, with respect to the ESG factors. Despite this, the firms that operated at increasing returns to scale still had a larger proportion in 2021. However, we also observed the global issue of inflation, which emerged in 2021 and continues now, and this could potentially slow down the environmental investments of MNEs. Nevertheless, ESG investment is a strategic decision for a firm's long-term sustainability. Therefore, it is crucial to consider a firm's scale development for maintaining or enhancing its competitiveness in its sector, even after the pandemic and regardless of the inflation factor.

Second, analysts predicted robust growth for the utility industry for 2020 and onwards, thanks to the adoption of clean energy. Energy usage and CO_2 emissions are crucial factors that impact the performance of multinational enterprises (MNEs) worldwide. Although short-term financial benefits may not always be evident, environmental investment, particularly in green energy, is crucial for all firms in all sectors. MNEs must take charge of their operational processes and participate in the journey towards achieving net-zero emissions to comply with updated mandatory regulations and achieve sustainable development. Furthermore, developing new environmental technologies that effectively meet market demands will be critical to firms' future success.

Moreover, this study highlights the importance for corporate management to address technical inefficiencies, particularly for MNEs in traditional industries. Firms operating in sectors such as materials, utilities, consumer staples, consumer discretionary, and industrials should prioritize efforts to bridge technical gaps in order to enhance both their sustainability and market efficiency and gain a competitive edge. While some of these industries may already be investing in environmental innovations during their business operations, they continue to face challenges in reducing resource usage and emissions during production processes and in establishing a green supply chain to achieve the objective of zero carbon.

5.2. Limitation and Future Research

To evaluate firm performance across sectors, this study applied DEA to integrate multiple input and output variables. CO_2 emission and energy use were employed as indicators of environmental investment collected from financial statements to evaluate sustainability efficiency. CO_2 emission was also used as a variable to link the two stages, and net sales were used to evaluate marketability efficiency. Furthermore, net sales were connected to the two stages using carry-over. Therefore, we suggest adding ROE, ROA, and debt ratio as control variables to the framework.

However, we were unable to obtain the dataset we initially expected due to the fact of missing data. After screening out the missing data, we collected data from 306 DMUs across 11 sectors. Different scales of the dataset could result in different empirical results regarding the relationship between environmental investment and firm performance. The quality and impact of corporate environmental management will depend on how well it matches the specific company's situation and its market, political, and social circumstances.

Thus, we suggest further studies that focus on individual industries and consider their characteristics to explore the crucial factors for the efficiency analysis of a particular industry, especially for industrials, consumer discretionary, information technology, and health care, which have received less attention in previous studies.

In addition, the number of ESG regulations has been rapidly growing globally. National regulations have become increasingly strict after 2015, especially in utilities, financial services, and health care pharmaceutical industries in the US, the UK, and Canada. Previous authors have proposed that the positive relationship between corporate environmental management and corporate financial performance seems to be stronger when regulatory scrutiny is less restrictive. Therefore, regulatory restrictions can also be considered control variables.

Moreover, sustainability is a major trend and requires continuous effort from MNEs to move forward. Future research should investigate the changes in the relationship between environmental investment and firm performance from panel data over the long term.

Finally, while our study focused on financial variables, we agree that the nonfinancial firm characteristic variables were limited in this study. We think that nonfinancial variables could also be considered a control variable or a potential factor for future research to complete the investigation.

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