Eco-Efficiency Consideration for Investment Portfolio Determination Via an Advanced Decision Architecture

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Abstract

In recent decades, there has been a notable surge in eco-friendly investments among prospective and current market participants. It has now evolved into an imperative standard for contemporary business decision-making. The critical challenge lies in the adept selection of investment portfolios that can effectively address both sustainability and profitability concomitantly. This task inherently involves a multi-dimensional nature, necessitating the consideration of various, sometimes conflicting, metrics. Consequently, this study proposes an advanced decision-making framework that amalgamates Data Envelopment Analysis (DEA) with Artificial Intelligence (AI). In contrast to prior research, which predominantly focused on determining investment portfolios based solely on target profitability, this study extends its purview to encompass sustainability considerations. This expansion aligns with the prevailing business trend that prioritizes fostering an eco-friendly atmosphere. While the DEA-based approach has demonstrated its supremacy in performance evaluation, it exhibits a notable limitation – a dearth of forecasting capability. To address this limitation, we introduce the Extreme Learning Machine (ELM), an AI methodology renowned for its superior predictive capacity. This integration is inspired by ensemble learning principles, aimed at harnessing complementary insights from diverse contributing models. Through the incorporation of this model, the role of market participants undergoes a profound transformation, shifting from retrospective and current monitoring to proactive future planning.

Keywords
Sustainability, eco-efficiency, data envelopment analysis, artificial intelligence, investment portfolio selection

1. Introduction
Global warming has caused international issues in recent years, prompting the whole world to take action to reduce greenhouse gas (GHG) emissions, enhance sustainability, and find ways to deal with it. According to the World Economic Forum's Global Risks Report 2023, more than half of global risks relate to the environment. Many countries have formulated related policies/strategies on sustainability issues, and Taiwan also follows this path and has announced its Climate Change Response Act handled by Environmental Protection Administration (EPA) and has set the goal of "net zero carbon emission by 2050". They aim to impose a carbon fee on 287 large carbon emitters that emit over the 25,000 metric tons. Furthermore, regulators also require publicly listed companies to disclose sustainability reports that cover greenhouse gas (GHG) emissions and how their operations affect the environment.

The semiconductor industry in Taiwan is a strong economic booster and also plays a core role in the supply chain for electronic devices. Even as this specific industry brings considerable economic benefits, it also is accompanied by large energy consumption and poisonous material generations, thus impeding sustainability development. Most studies formulate their investment portfolios by just consider the target's financial performance, ignoring the side effects generated from the investment target when they run their own business. To fill the gap in the literature, this study formulates an investment portfolio that considers both economic and sustainable performances of investment targets. How to develop an appropriate performance evaluation architecture turns out to be a critical task, especially in a highly turbulent economic atmosphere. Most studies rely heavily on financial ratio analysis, such as returns on assets, and returns on investment. However, these performance evaluation architectures just look at a one-input and one-output variable, which cannot capture the inherent business operations. To combat this, data envelopment analysis (DEA) with its merit of handling multiple input and output variables has been its usefulness in performance evaluation. By broadening the factors of investment portfolio generation, users have a higher chance to gain profitable returns under anticipated risk exposure.

The rest of the paper runs as follows. Section 2 discusses related studies. Section 3 introduces the research methods. Section 4 presents the data collection. Section 5 gives the results of the study and demonstrates the findings. Finally, section 6 summarizes the study's conclusions.

2. Literature Review

Profitability of enterprises was mostly reflected in the past through financial signals. Thus, investors only needed to refer to the financial signals released by each enterprise to accurately select investment targets. However, with the prevailing trend of sustainable development and the growing concern about extreme weather, greenhouse gases, climate change, and so on, companies need to change their business model from the past and not just focus on profitability, but also on environmental sustainability. The negative impacts of climate change are increasing, From reports of various events like typhoons, droughts, and record high average temperatures, many countries have jointly established guidelines requiring companies to produce annual sustainability reports and voluntary review reports. This helps stakeholders understand the contributions and feedback that companies and nations provide to the environment and society, as well as their future improvement goals. For example, the United Nations set Sustainable Development Goals in 2015, calling on all nations to promote economic prosperity while protecting the planet. The Kyoto Protocol's objective is to stabilize greenhouse gas concentrations in the atmosphere at a level that ensures ecosystem adaptation, food security, and sustainable economic development.

There are many papers that have illustrated the impact of CSR on the efficiency of countries and enterprises. Studies have used cross-efficiency DEA of financial ratios to create investment portfolios. For example, Sungmook Lim et al. (2013) collected data of 490 to 557 companies in the South Korea stock market for the period 2001-2009 to compare investment portfolios formed with KOSPI150 by using inputs of turnover rate, leverage, return on equity, EPS, and outputs of the Sharpe ratio. Juan Wang et al. (2021) evaluated whether carbon efficiency enhances financial performance from data of 38 companies for 2015-2019. He explored whether carbon efficiency impacts short-term accounting performance, long-term market performance, and financial risk, finding a significantly positive impact on short-term accounting performance, a significantly positive impact on long-term market performance (Tobin's Q), and a significantly negative impact on risk.

Matsumura (2014) examined the impact of carbon emissions and the behavior of voluntary disclosure of carbon emissions on firm value using data on carbon emissions voluntarily disclosed by S&P 500 companies from 2006 to 2008. The study found for every 1,000 metric tons of carbon emissions that firm value decreased by $212,000, concluding that carbon emissions negatively correlate with firm value. Thi Ngan Pham et al. (2022) investigated whether ESG composite scores affect operating performance in the transportation industry for 56 companies located in the U.S. and China. With 2019 data from Refinitiv, they found that ESG composite scores have a significantly positive relationship with operating performance. Evidence from Derwall et al. (2005) showed that companies actively engaged in environmental protection activities have higher financial benefits than those not actively involved in such activities, with a difference of up to 6%. This suggests that the market should no longer underestimate and ignore the messages and impacts related to sustainable development.

3. Methods

3.1 Super-SBM

Traditional DEA is an efficiency assessment model developed based on technical efficiency to compare decision making units (DMUs) to one another so as to find their relative efficiency values, with efficiency values ranging from 0 to 1. The advantage of DEA is that there is no need to preset the production function. It can handle multiple inputs and outputs. Its assessment constraints must be input-oriented and output-oriented, but this is not applicable to all situations.

Tone (2001) introduced the slack-based measure (SBM), which utilizes the variance variable as the measurement basis for presenting SBM efficiencies. Using unguided estimates that take into account the difference between inputs and outputs, the SBM model has the following characteristics.

1. Units' invariance: The efficiency values of the assessment unit do not change with variations in the units of input and output.
2. Monotone: The difference between excess inputs and shortages of outputs is monotonically decreasing.
3. The efficiency indicator value is only affected by the efficiency reference set. When a DMU has an efficiency value of 1, it means that the DMU is on the efficiency frontier and there is no slack in either inputs or outputs.

Super (Super-Efficiency)-SBM (Tone, 2002).

The method of DEA helps measure the technical and scale efficiencies of businesses. To address the issue where DEA often results in multiple decision-making units (DMUs) having an efficiency score of 1, Tone introduced the Super-SBM in 2002. It effectively assesses inefficient DMUs, resolves the problem of traditional DEA where efficiency scores are simultaneously 1, and provides a ranking of super-efficiency scores. Therefore, this study employs the Super-SBM method for efficiency analysis of businesses.

3.2 Extreme Learning Machine - ELM

Even though DEA poses outstanding ability to handle performance evaluation tasks, it still comes with some weakness, such as a lack of forecasting ability. When new data are inserted into DEA, the whole calculation procedure needs to be re-run again to establish an efficient frontier and to assign the relative performance for each DMU. Extreme learning machine (ELM) (Huang et al., 2006) with the advantage of superior forecasting performance and higher tolerance can be employed. It is inspired by ensemble learning that aims at complementing the error made by a singular model. By joint utilization of DEA and ELM, users can shift from monitoring the past/current situation to planning for the future.

4. Data Collection

Because the semiconductor industry in Taiwan receives considerable government support/resources and tax incentives and also brings a large amount of profits, this specific industry has gradually become the backbone of the domestic economy and the main investment target in the local capital market. Thus, we take this industry as our research sample with a time range from 2021 to 2022. Financial data are collected from the Taiwan Economic Journal (TEJ) databank, and the sustainable related indicator (GHG) comes from companies' sustainability reports.

Table 1 displays the selected input variables and output variables for DEA, and their descriptive statistics appear in Table 2. To demonstrate the selected inputs and outputs are appropriate, the Pearson correlation is calculated (see Table 3). We see that all the selected variables reach statistical significance - that is, all the selected variables are representative. To demonstrate a portfolio selection strategy with GHG outperforms the selection strategy without considering GHG, this study considers five criteria (i.e., daily return, weekly return, monthly return, quarterly return, and annual return). Figures 1-2 show the portfolio selection strategy that takes GHG into consideration, which performs better than the strategy without considering GHG.

Table 1. Variables

Variable category	Variable name	Definition
Input	Number of employees	Total number of employees.
	Total assets	Combined value of all the assets owned by the company.
	Operating expenses	The direct costs associated with producing or delivering the goods or services that a company sells.
Output	Operating revenue	Income or revenue generated by a company.
	Greenhouse gases	Quantity of total emitted greenhouse gases.

Table 2. Descriptive statistics of variables

	Employees	Assets	Operating expenses	Operating revenue	Greenhouse gases
Max	97,198.00	4,964,778,878	915,536,486.00	2,263,891,292.00	20,111,078.00
Min	75.00	1,565,450	269,723.00	542,232.00	340.00
Average	7434.05	193,503,971.33	59,092,842.41	108,798,238.82	1,039,099.32
SD	18,720.37	713,329,434.23	158,369,365.81	332,465,672.72	3,695,197.75

Table 3. Result of Pearson correlation

2021	X1	X2	X3	Y1	Z1
X1 Employees	1				

X2 Assets	.684**	1			
X3 Operating expenses	.891**	.929**	1		
Y1 Operating revenue	.788**	.979**	.981**	1	
Y2 Greenhouse gases	.748**	.511**	.653**	.564**	1

Note: ** denotes the 0.05 significance level.

Figure 1. Comparison outcome in 2021 under two dissimilar strategies

Figure 2. Comparison outcome in 2022 under two dissimilar strategies

A lack of forecasting ability is one of the critical weaknesses of the traditional DEA-based approach. To reduce this gap, this study applies ELM with its superior forecasting ability. Accuracy or error rate is widely adopted to judge a model's forecasting performance. Root mean square error (RMSE) is taken as our performance measure. The results show that ELM under the consideration of GHG reaches the lowest error (RMSE=0.2372) compared to that without GHG (RMSE=0.63095) (see Figure 3). The results show that the sustainability indicator is extremely useful in the decision-making task.

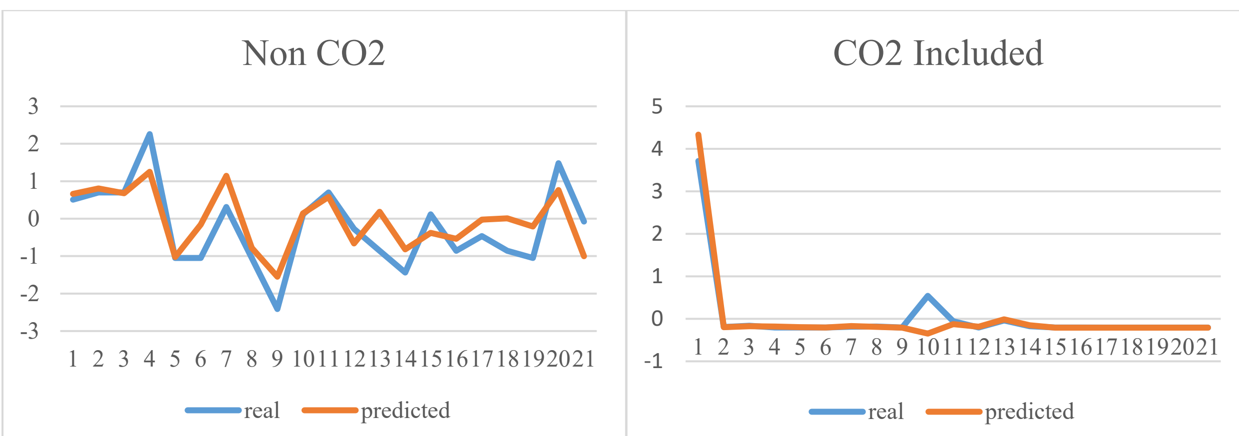

Figure 3. Comparison outcomes

6. Conclusion

This study introduces an innovative investment portfolio selection strategy that integrates DEA and AI techniques by considering financial and sustainable indicators. The results show that the investment portfolio selection strategy that considers the sustainable indicator performs better than the strategy without considering the sustainable indicator. Users can thus consider the potential implication of formulating a future investment strategy as well as maximizing their personnel wealth through this model.

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