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Strategic alliances for sustainable development: An application of DEA and Grey Theory Models

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Abstract: Sustainable development is a global trend and an economic priority for many nations. Although new energies can be considered good investments in green growth, it may lead to financial barriers to developing countries. The purpose of the study concentrates on an alternative solution that increasing the efficiency performance of current fossil energy industries. The study has combined two models of Data Envelopment Analysis (DEA) and Grey Theory in determining inefficiency units and proposed potential strategic alliances for sustainable development in the Vietnam Coal industry. Besides considering inputs and outputs in the models, the location of coal mines is also a key indicator in recommending good alliances. The results show that the collaborations between Cao Son coal mine and Coc Sau coal mine; between Nui Beo coal mine and Vang Danh coal mine brings the best improvement for sustainable development. The study suggests detailed strategies in action that enterprises and policymakers can refer to apply in practice.

Keywords: Strategic alliance; optimization algorithms; Grey forecasting model; Data envelopment analysis (DEA); sustainable development; Coal mining industry

1. Introduction

In 2020, given the impact of the Covid-19 pandemic, Vietnam is one of few countries keeping a positive GDP growth rate due to the successful efforts in containing the spread of the virus nationwide. Vietnam's economy is expected to develop by robust domestic demand and export-oriented manufacturing. It is accompanied by a surge in power demand and consumption to support its fast-growing economy. The energy demand is forecasted to rise by 8% per annum during 2021-2030 (Vietnam Coal supply & demand 2021, market report, 2/2021). It boosts the demand for coal since this is still a cheap fuel source for power generation in a developing economy as Vietnam.

Since 2015, coal has overtaken hydropower to rank the most important energy source for the power industry, making up 49.86% power generation share. With about 49 billion tons of coal reserves over the country, Vietnam has become a key coal supplier for both domestic and the Asia Pacific region. It has been attracted up to \$150 billion from energy investors in the coming decades, in which the coal set is to dominate. Hence, the coal mining sector has contributed significantly to the economic growth of Vietnam.

1.1. The coal mining sector in Vietnam

In Vietnam, all coal is owned by the government. Approximately 95% of the total coal is produced and mined by a state-owned holding company called Vietnam National Coal-Mineral Industries Group (VINACOMIN).

VINACOMIN is established in 2005 through the merger of Vietnam National Coal Corp. (Vinacoal) and the Vietnam National Minerals Corp. (Minh Chuan, 2019). The corporation has become a major coal producer in Vietnam and has various activities such as providing anthracite for the power sector, industries for both domestic and global markets.

Most of Vietnam's coal resources are located in the north. In the red river Delta coal basin 39.4 billion tons of Sub-bituminous accounted for 81% of four types of coal including Anthracite; Fat

coal; sub-bituminous; peat coal. VINACOMIN has operated five large surface coal mines with an annual capacity greater than 2 million tonnes (Cao Son, Coc Sau, Deo Nai, Ha Tu, and Nui Beo mines), 15 surface coal mines with production from 0.1 to 0.7 million tonnes per year.

1.2. Environmental issues from mining coal:

Vietnam's coal mining industry meets many difficulties in the increase of coal production, prospecting, and exploration, mining technologies. It would be more challenging when the Vietnamese government has much effort to go green, the environmental problems and sustainable development are two significant issues that the Vietnam coal mining sector could encounter. In terms of the environmental aspect, mining coal causes land subsidence, damages to the water ecology, mining waste disposal, and air pollution. It may change either environmental pollution or landscape (Zheng-fu et al., 2010)

Coal exploration could impact the water systems and extraction can affect groundwater levels and acidity. There is approximately 75 Tg / S per year of sulfur dioxide (SO₂) released from coal burning. It causes acid rain and acidification of ecosystems (EIA, 26 July 2020). Moreover, there are many problems from wasted coal mines such as occurring settlements in tunnels, infrastructure, or arable land damages. In 2013, the head of the UN climate agency argued that the inefficiency mining of underground coal contributes to global warming.

1.3. Strategic Alliance for sustainable development

There are many difficulties that an organization encounters if they have a sustainably developing orientation. These challenges are related to various aspects such as technical, social, and organizational innovations. Strategic alliances can be considered as an important sustainability innovation in improving resources efficiency (Chia-Nan et al., 2021)

The strategic alliance is a collaboration form to achieve mutual goals, for example, two different units collaborate to facilitate reciprocal learning processes (Nguyen & Nguyen, 2020). Across the world, there are many examples of alliances for sustainable development. The Central American Council for Sustainable Development has promoted alliance agreements designed to support sustainable development in Central America at both the national and regional levels (UNHR, 2015). The Italian landscape applied alliance strategies to enhance the importance of the Sustainable Development Agenda for Italian society and economic stakeholders. The participating in alliances support them to pursue the Sustainable Development Goals by United Nation (Martino, 2016)

This study aims to propose a model integrating Data Envelopment Analysis (DEA) and Grey theory, in which the authors determine the inefficiency units in the Vietnam coal mining sector and recommend potential alliances for sustainable development.

1.4. Problem statement

Currently, these mining projects of VINACOMIN current are operating independently and lack efficient performance measurement. As mentioned above, the inefficiency of coal mining causes many environmental problems, especially significant barriers if the Vietnamese government wants to have sustainable development. It is necessary to study the effectiveness and efficiency of sub-projects that VINACOMIN operates, then having recommendations in improving its performance.

This study would use a novelty research model with a combination of Data Envelopment Analysis (DEA) and Grey-Theory models to evaluate the efficiency performance of major coal mines, then suggest possible strategic alliances. Such collaborations can improve the coal mining efficiency as well as contribute to reducing environmental issues from this industry.

2. Literature Review and Research Process:

2.1. DEA model, Grey Theory, and its application

Charnes et al. (1978) implemented Data Envelopment Analysis (DEA) to evaluate the performance of business units through estimating the ratio between inputs and outputs as efficiency index (Le, Wang, & Nguyen, 2020) (Nguyen & Nguyen, 2020). There are two traditional versions of DEA models, namely the Charnes–Cooper–Rhodes (CCR) and the Banker–Charnes–Cooper (BCC) model (Charnes, Cooper, & Rhodes, 1978). The former is used to determine the overall inefficiency, whereas the latter differentiates between technical efficiency and scale efficiency. After several years, the super slack-based measure (super SBM) model is developed to optimize the shortcomings

of the traditional DEA model and obtain reasonable metrics. It has eliminated the slack problems while accurately ranking the effectiveness of DMUs (Zhou, Min, Xu, & Cao, 2008; Nguyen & Nguyen, 2020). Many studies related to the application of DEA are studied across different fields such as logistics (Le, Wang, & Nguyen, 2020), automobile manufacturer (Wang, Nguyen, & Wang, 2016), coal mining industry (Nguyen & Nguyen, 2020), textile and Garment industry (Phu & Duy, 2019), seaport (Wang et al., 2021).

The research implemented in developing countries as Vietnam often encounters a problem of disorderly and unsystematic data. To deal with the small amount of random data, the authors take the advantage of the Grey system model introduced by Deng (1982). Grey theory has been a powerful tool in projecting historical business data with a limited amount (Gilliland, 2010; Phu & Duy, 2019; Le, Wang, & Nguyen, 2020).

There is much literature on the application of DEA in efficiency evaluation, however, a limited number of studies on environmental efficiency or sustainable development (Wang et al., 2021).

Table 1: Summary of methodologies and inputs/outputs selection in previous studies.

Authors	Inputs	Outputs	Methodologies	Applied Areas
(Zhou, Min, Xu, & Cao, 2008)	Net fixed asset Salaries and wages Operating expenses Current liabilities Fixed Assets	Operating income	CCR BCC	Logistics
(Wang, Nguyen, & Wang, 2016)	Cost of Good Sold Operating Expenses Long-term Investment	Revenue Total Equity Net Income	Hybrid DEA Grey Theory model	Automobile Industry
(Phu & Duy, 2019)	Fixed Assets Cost of Good Sold	Revenue Net Profit	DEA and Grey Theory	Textile and Garment Industry
(Nguyen & Nguyen, 2020)	Fixed Assets Cost of Good Sold Operating Cost Total Asset	Net revenue Net Profit	Super-SBM-I-V Grey Theory	Coal mining Industry
Wang et al. (2021)	Total Equity Liabilities Operating expense	Revenue Net profit	Malmquist EBM	Seaport

Note : Charnes–Cooper–Rhodes (CCR), Banker–Charnes–Cooper (BCC), slack-based measure (SBM), epsilon-based measure (EBM)

There has been no research implemented for the case of the Vietnamese coal mining industry to evaluate the performance efficiency and give suggestions for sustainable development. This study aims to fill the gap in the existing literature by evaluating the efficiency of 10 independent coal mining projects that are operated by VINACOMIN, then combining Grey Model (i.e GM (1,1)) to simulate strategic alliances between inefficiency projects

Figure 1: Research development

The authors implemented three phases in the research process as the Figure 1 below.

Phase 1: Literature review and variable selection

Step1: Data collection

There is 95% of total coal production in Vietnam explored by the VINACOMIN. Regarding underground mining, VINACOMIN has operated 30 coal mines in which some mines with production lower than 0.1 million tonnes per year.

In this study, the authors decided to select the top 10 major mines with high investments and a producing capacity greater than 1 million tonnes per year (see the list of mines in Table 2). These are referred to as DMUs in the research model.

Step 2: Inputs/ Outputs selection

- For manufacturing and producing firms, the cash flow will be allocated with the high weighted indicators such as Fixed Assets, Cost of Good Sold (COGS), and Operating Cost. These factors significantly impact the expenditure of DMUs (Chia-Nan et al., 2021)
- In addition, the final goal of any business is profit. The performance of a firm, hence, is well measured by two key indicators, namely Revenue and Operating Profit. (Nguyen & Nguyen, 2020)
- The recent relevant literature are reviewed to support the selection of variables as inputs/ outputs in the model.
- Table 1 presented the studies that applied DEA in evaluating the efficiency performance of DMUs across sectors.

For the reasons above, the authors selected three Input factors: (I1) Fixed assets; (I2) Cost of goods sold ; (I3) Operating Costs; and two Output factors : (O1) Revenues ; (O2) Operating profit.	138 139 140
Step 3: Pearson correlation	141
A requirement of applying DEA is the positive correlation between inputs and outputs. The Pearson correlation, hence, is implemented to make sure the accuracy of the selection of the indicators.	142 143 144
Phase 2: Grey Prediction	145
Step 4: Implementing Grey Model	146
The authors decide to use the Grey Model (1,1) model to forecast the inputs and outputs of each DMUs in the next 3-year period (i.e. 2021-2023).	147 148
Step 5: Checking the level of accuracy	149
To check the accuracy level of projections, the authors estimated the index of Mean Absolute Percent Error (MAPE). If the value of MAPE is higher than 20%, then the errors of forecasting are too high than the actual values (Gilliland, 2010; Wang, Nguyen, & Wang, 2016; Nguyen & Nguyen, 2020). It means that the data must be re-selected.	150 151 152 153
Phase 3: DEA application	154
Step 6: Choosing the DEA model	155
To eliminate the slack problems that traditional DEA models (i.e CCR and BCC) cannot deal with, the authors take the advantage of the Super -SBM-I-V of DEA to evaluate efficiency points and rankings of each coal mining project.	156 157 158
Step 7: Before collaboration	159
In this step, the SBM model established by (Tone, 2001) is used to evaluate the efficiency of DMU(x0, y0) over the period 2016-2020. It aims to define a target DMU that is received a high investment from VINACOMIN but has shown a low-efficiency score in performance.	160 161 162
Step 8: After Collaboration	163
After the target DMU is determined, the authors set up “virtual alliances” by getting the forecasted values between the target and other DMUs (see the list in Table 9). Then, the super SBM-I-V model is reimplemented to compare the difference.	164 165 166
Step 9: Alliance suggested a sustainable development	167
The study shows the coal mines operating inefficiency and then suggests possible strategic alliances for a sustainable development orientation at VINACOMIN as well as the government level.	168 169 170
3. Methodology	171
3.1. Grey theory model:	172
The GM(1,1) model has five main steps described as following:	173
Input original time series data $X^{(0)}$ (Deng, 1982)	174
$X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)), n \geq 4$ (1)	175
where $X^{(0)}$: a non-negative sequence; n: the number of data observed	176
then, generate time-series data $X^{(1)}(k)$ by 1-Accumulating Generation Operator AGO (1-AGO) of $X^{(0)}$ And Generate partial series data $Z^{(1)}(k)$ from $X^{(1)}(k)$ as equation (2) below	177 178

$$X^{(1)} = (x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(n)) , n \geq 4 \quad (2) \quad 179$$

$$\text{where } x^{(1)}(k) = \sum_{i=1}^k x^{(0)}(i) , k = 1, 2, \dots, n. \quad (3) \quad 180$$

Next, the data matrix is established by a least square method to acquire the value of coefficient a & grey input b 181
182

$$Z^{(1)} = (z^{(1)}(2), z^{(1)}(3), \dots, z^{(1)}(n)), \quad (4) \quad 183$$

$$\text{Where } z^{(1)}(k) = 1/2 (x^{(1)}(k) + x^{(1)}(k-1)) , k = 2, 3, \dots, n \quad (5) \quad 184$$

Construct GM(1,1) forecasting equation 185

$$\frac{dX^{(1)}(k)}{dk} + aX^{(1)}(k) = b \quad (6) \quad 186$$

where: parameters a and b are called the developing coefficient and grey input, respectively. 187
However, these parameters a and b are undetermined from Equation (6). Instead, the least square 188
method as the equations (7 – 11) below can be used : 189

$$\hat{X}^{(1)}(k+1) = \left(X^{(0)}(1) - \frac{b}{a} \right) e^{-ak} + \frac{b}{a} , k=1, 2, 3, \dots \quad (7) \quad 190$$

Where $X^{(1)}(k+1)$ denotes the prediction X at time point k+1 and the coefficients $[a, b]^T$ can be 191
obtained by the Ordinary Least Squares (OLS) method: 192

$$\begin{bmatrix} a \\ b \end{bmatrix}^T = \hat{\theta} = (B^T B)^{-1} B^T Y_N \quad (8) \quad 193$$

$$\text{And } B = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ \dots & \dots \\ -Z^{(1)}(n) & 1 \end{bmatrix} \quad (9) \quad 194$$

$$Y_N = \begin{bmatrix} X^{(0)}(2) \\ \dots \\ X^{(0)}(n) \end{bmatrix} \quad (10) \quad 195$$

(B is data matrix, Y_N is data series, $[a, b]^T$ is parameter series) 196

$\hat{X}^{(1)}$ is acquired from Equation (7). Let $\hat{X}^{(0)}$ be the GM(1,1) fitted and predicted series : 197

$$\hat{X}^{(0)} = (\hat{X}^{(0)}(1), \hat{X}^{(0)}(2), \dots, \hat{X}^{(0)}(n), \dots) \text{ where } \hat{X}^{(0)}(1) = X^{(0)}(1) \quad 198$$

Evaluate average residual γ , and calculate forecast values as equation (11): 199

$$X^{(0)}(k+1) = \left(X^{(0)}(1) - \frac{b}{a} \right) e^{-ak} (1 - e^a) \quad (k=1, 2, 3, \dots) \quad (11) \quad 200$$

3.2. Super Slacks-Based Measure model : 201

The non-negative data input is a compulsory requirement in the application of DEA models. 202

Tone (2001) developed the Slacks-based measure of efficiency (SBM) that supposes $y_{r0} \leq 0$ and 203

defines $\bar{y}_r^+$ and $\bar{y}_{-r}^+$ by equation (12) & (13): 204

$$\bar{y}_r^+ = \max_{j=1, \dots, n} \{y_{rj} | y_{rj} > 0\}, \quad (12) \quad 205$$

$$\bar{y}_{-r}^+ = \min_{j=1, \dots, n} \{y_{rj} | y_{rj} > 0\}, \quad (13) \quad 206$$

If the output r does not have positive values, then it is defined as $\bar{y}_r^+ = \bar{y}_{-r}^+ = 1$. 207

The value y_{r0} is never changed in the constraints. The term is s_r^+ / y_{r0} will be replaced by 208
equations (14) & (15) 209

$$s_r^+ / \frac{y_r^+ (\bar{y}_r^+ - y_{r0}^+)}{\bar{y}_r^+ - y_{r0}^+} \text{ if } \bar{y}_r^+ > y_{-r}^+ \quad (14)$$

$$s_r^+ / \frac{(y_{-r}^+)^2}{B(\bar{y}_r^+ - y_{r0}^+)} \text{ if } \bar{y}_r^+ = y_{-r}^+ \quad (15)$$

With B=100.

The estimated score is units' invariant that is independent of the measuring units (Düzakın & Düzakın, 2007)

4. Empirical Analysis And Results:

4.1. Collecting the DMUs

According to the rule of thumb from (Golany & Roll, 1989), the number of DMUs selected needs to be at least double the number of inputs and outputs in total. With 5 variables considered, hence, the authors decide to study 10 major coal mining projects of VINACOMIN as DMUs in the research model.

The financial statements during 2016-2020 are collected from a reliable database source, the State Securities Commission of Vietnam (ssc.gov.vn) and double-checked with the official reports of VINACOMIN. Table 2 presents the list of DMUs and their market capitals in Billions of Vietnam Dong (Bil. VND)

Table 2: The list of DMUs

No.	DMUs	Stock Code	Company Name	Market Capital (in Bil.VND)
1	DMU1	MVB	Vinacomin - Viet Bac Mining Industry Holding Corporation	1,627.50
2	DMU2	TVD	Vinacomin - Vang Danh Coal Joint Stock Company	350.71
3	DMU3	NBC	Vinacomin - Nui Beo Coal Joint Stock Company	270.09
4	DMU4	TDN	Vinacomin - DeoNai Coal Joint Stock Company	235.51
5	DMU5	TMB	Vinacomin - Northern Coal Trading Joint Stock Company	216.08
6	DMU6	TCS	Vinacomin - Cao Son Coal Joint Stock Company	214.07
7	DMU7	HLC	Vinacomin - Ha Lam Coal Joint Stock Company	210.95
8	DMU8	THT	Vinacomin - Ha Tu Coal Joint Stock Company	203.92
9	DMU9	TC6	Vinacomin - Coc Sau Coal Joint Stock Company	149.48
10	DMU10	MDC	Vinacomin - Mong Duong Coal Joint Stock Company	147.79

4.2. Variables Collection

By reviewing the relevant literature of DEA and coal mining industry reports, the authors decide to select inputs and output variables. According to step 2 in section 2.2, three key reasons are supporting to the selection of inputs. There are important factors to the sources of coal mining manufactures are fixed assets, operating cost, and cost of goods sold (COGS). In terms of outputs, Revenues and Operating profit are considered as two output factors because the indicators are good signals to analyze the company's financial effectiveness.

The statistics description on input and output data is presented in Table 3, in Millions of Vietnam Dong (Mil. VND)

Table 3: Input and output factors of 10 coal mining projects in 2016-2020 (in Mil. VND)

		Input Factors (in Mil. VND)			Output Factors (in Mil. VND)	
	Statistics	Fixed Assets	Operating Cost	COGS	Revenues	Operating profit
2016	Max	3,037,449	6,081,202	398,600	6,464,727	110,727
	Min	95,942	984,287	135,054	1,221,125	961
	Average	1,122,746	2,602,439	220,473	2,940,333	38,723
	SD	1,059,424	1,476,634	84,500	1,551,590	33,002
2017	Max	3,139,566	3,945,504	351,387	4,201,420	150,130
	Min	89,514	1,115,936	112,735	1,444,347	21,089
	Average	1,145,740	2,421,367	203,947	2,773,617	54,974
	SD	1,086,383	972,039	67,187	1,035,770	41,038
2018	Max	2,988,038	5,361,165	386,748	5,712,483	279,104
	Min	90,632	1,740,493	62,385	1,957,178	21,622
	Average	1,111,524	3,172,208	177,928	3,541,372	91,345
	SD	996,001	1,158,668	103,099	1,224,661	72,455
2019	Max	2,661,291	10,066,757	671,218	10,867,337	409,852
	Min	92,990	1,841,387	116,821	2,087,359	1,842
	Average	1,098,891	3,944,922	224,573	4,376,882	114,631
	SD	826,271	2,466,641	180,541	2,612,602	108,327
2020	Max	2,327,035	10,218,072	648,840	10,990,285	410,780
	Min	85,277	1,835,560	72,209	2,193,027	4,484
	Average	1,116,725	3,741,347	218,920	4,146,550	89,518
	SD	728,762	2,428,944	173,718	2,583,992	117,465

The inputs and outputs selection is also confirmed by the Pearson correlation test with all high positive correlations shown in Table 6, in section 4.5 below

4.3. Variables calculations – Forecast inputs/outputs by GM(1,1)

The authors run GM(1,1) model on the realistic inputs/outputs factors from 2016 to 2020 to predict the values of all DMUs in 2021- 2023. The results shown in Table 4 are the projection of data for DMUs in 2021

Table 4: Forecasted inputs/outputs data for the year of 2021

		Input Factors (in Mil. VND)			Output Factors (in Mil. VND)	
	DMUS	Fixed Assets	Operating Cost	COGS	Revenues	Operating Profits
1	DMU1	1,568,410.67	4,620,907.96	460,390.28	5,873,246.47	987,681.63
2	DMU2	736,729.29	6,501,211.17	200,846.25	6,762,141.97	119,246.68
3	DMU3	3,619,170.38	3,015,653.60	97,808.49	3,299,779.70	23,318.65
4	DMU4	1,139,007.68	4,045,995.06	127,167.52	4,338,518.08	110,239.34
5	DMU5	85,142.51	27,043,605.30	1,711,436.97	29,374,561.94	156,003.12
6	DMU6	674,020.88	6,258,457.75	108,106.44	6,503,059.47	96,354.96
7	DMU7	1,776,649.97	2,527,970.23	106,926.54	2,972,206.37	280,453.29
8	DMU8	5,631,005.94	3,402,431.90	82,722.93	3,659,750.22	67,407.18
9	DMU9	791,763.11	4,195,838.30	80,536.02	4,188,567.84	662.02
10	DMU10	513,921.22	4,020,468.91	104,228.95	4,090,241.67	58,895.59

4.4. Accurate checking

The imperfect information is a constraint in the prediction. To check the accuracy of applying GM(1,1), the authors estimate the MAPE score in percentage and shown as follows (Table 5)

Table 5 : Average MAPE of DMUs (in %)

DMUs	Fixed Assets	Operating Cost	COGS	Revenues	Operating Profits	Average MAPE of DMUs
DMU1	2.81	6.34	10.67	15.24	7.34	8.48
DMU2	10.28	3.38	7.72	12.11	14.75	9.648
DMU3	12.25	5.34	6.54	10.34	16.54	10.202
DMU4	14.28	10.55	12.91	5.22	13.43	11.278
DMU5	5.23	14.22	12.27	5.65	7.32	8.938
DMU6	4.76	12.02	9.65	4.78	4.71	7.184
DMU7	7.56	5.69	7.83	5.23	4.05	6.072
DMU8	3.09	2.35	8.34	4.87	12.31	6.192
DMU9	12.34	6.12	2.65	11.23	15.23	9.514
DMU10	5.43	7.23	15.34	5.12	3.78	7.38
Average MAPE of all 10 DMUs						8.49

The predicted values are good and qualified if the value of MAPE is less than 10% (Gilliland, 2010). In Table 5, the average MAPE of 8.49% confirms the estimations by using GM(1,1) are accurate to use in the study.

4.5. Pearson Correlation

Table 6 presents the results of the Pearson correlation test between inputs and outputs over the period 2016-2020. The significant positive associations confirm the “homogeneity” and “isotonicity” data that satisfied two requirements for applying the DEA model.

Table 6: Pearson Correlation of input and output data in 2016-2020

		FA	COGS	OC	RE	OP
Fixed Asset (FA)	Pearson Correlation	1	0.927**	0.841**	0.775**	0.673*
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	Sample	504	504	504	504	504
Cost of Good Sold (COGS)	Pearson Correlation	0.927**	1	0.912**	0.997**	0.812**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	Sample	504	504	504	504	504
Operating Cost (OC)	Pearson Correlation	0.841**	0.912**	1	0.612*	0.854**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	Sample	504	504	504	504	504
Revenue (RE)	Pearson Correlation	0.775**	0.997**	0.612*	1	0.572*
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	Sample	504	504	504	504	504
Operating Profit (OP)	Pearson Correlation	0.673*	0.812**	0.854**	0.572*	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	Sample	504	504	504	504	504

*,**. Correlation is significant at the 0.05; 0.01 level (2-tailed).

4.6. Analysis before alliance

The super-SBM-I-V algorithm based the business performance of all DMUs in 2020 to evaluate the efficiency of 10 major coal mines

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Table 7: Performance ranking of DMUs 2019

Rank	Score	DMUs	Rank	Score	DMUs
1 st	1.83798	HLC	6 th	1.00001	MVB
2 nd	1.45566	TCS	7 th	1	TMB
3 rd	1.26283	MDC	8 th	0.88751	TVD
4 th	1.18094	TDN	9 th	0.87454	TC6
5 th	1.06304	NBC	10 th	0.85346	THT

Table 8: Performance ranking of DMUs 2020

Rank	Score	DMUs	Rank	Score	DMUs
1 st	1.71416	HLC	6 th	1.02582	TDN
2 nd	1.30716	THT	7 th	1	MVB
3 rd	1.13554	MDC	8 th	1	TMB
4 th	1.1233	NBC	9 th	0.92088	TVD
5 th	1.06334	TCS	10 th	0.88667	TC6

Table 7 and Table 8 present the example of efficiency score ranking in 2019 and 2020 respectively, the authors considered all the performance rankings in the period of 2016-2020 to select the target DMU.

The Vang Danh coal mine referred to as TVD (i.e. DMU2) is one of the big projects invested by VINACOMIN and a major unit in exploring the coal industry that accounts for the second-highest market capital with 350.71 Bil. VND in 2020 (Table 2). However, the TVD has performed with the “less 1” efficiency score over the 5-year period (2016-2020). It means that there are some issues in operating despite having good potential inputs. Therefore, the authors consider TVD as the target DMU to set up different virtual alliances.

In terms of geography, the authors also consider 4 major coal mines namely Cao Son (TCS), Mong Duong (MDC), Deo Nai (TDN), and Coc Sau (TC6). Because the locations of these coal mines are very closed (as Figure 2). However, TC6 has performed inefficiency (i.e “less 1”) throughout 2016-2020. The authors set up 3 virtual alliances between TC6 with three neighbor coal mines.

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Figure 2 : Locations of Cao Son, Mong Duong, Deo Nai and Coc Sau coal mines. Source: (Nguyen B. ,

4.7. Analysis after alliance

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With the data forecasted by the Grey model, the authors formed 12 virtual alliances in total, including 9 collaborations between DMU2 (i.e. TVD) and other DMUs and 3 virtual alliances between TC6 and other coal mines nearby (TCS; MDC; TDN) as Table 9.

Then, Super-SBM-I-V is repeatedly implemented to estimate and rank the efficiency of these DMUs in 2021 and 2022.

4.8. Alliance selection:

Anand & Khanna (2000) argued that the advantages of alliances are improving performance; enhancing productivity; raising a firm's market power. A key motivation to form alliances is improving performance efficiency.

This study aims to figure out the inefficiency DMUs and suggest potential partners improve the performance. As the analysis in step 7, there are two target DMUs (i.e. TVD and TC6) that authors formed 22 virtual DMUs including 12 virtual alliances. Then, the super SBM-I-V model is applied to estimate the performance efficiency scores. Table 10 and Table 11 showed that five potential good alliances improve the efficiency ranking of TVD and TC6 after cooperating. However, the authors separated two groups of these alliances according to the level of priority.

A good strategic alliance should be a collaboration that brings benefits to every counterpart.

Table 9: Forecasted inputs/outputs data for the year of 2021

		Input Factors (in Mil. VND)			Output Factors (in Mil. VND)	
	DMUs	Fixed Assets	Operating Cost	COGS	Revenues	Opertaing Profits
1	MVB	1,568,410.67	4,620,907.96	460,390.28	5,873,246.47	987,681.63
2	TVD	736,729.29	6,501,211.17	200,846.25	6,762,141.97	119,246.68
3	NBC	3,619,170.38	3,015,653.60	97,808.49	3,299,779.70	23,318.65
4	TDN	1,139,007.68	4,045,995.06	127,167.52	4,338,518.08	110,239.34
5	TMB	85,142.51	27,043,605.30	1,711,436.97	29,374,561.94	156,003.12
6	TCS	674,020.88	6,258,457.75	108,106.44	6,503,059.47	96,354.96
7	HLC	1,776,649.97	2,527,970.23	106,926.54	2,972,206.37	280,453.29
8	THT	5,631,005.94	3,402,431.90	82,722.93	3,659,750.22	67,407.18
9	TC6	791,763.11	4,195,838.30	80,536.02	4,188,567.84	662.02
10	MDC	513,921.22	4,020,468.91	104,228.95	4,090,241.67	58,895.59
11	TVD+MVB	2,305,139.96	11,122,119.13	661,236.53	12,635,388.44	1,106,928.31
12	TVD+NBC	4,355,899.67	9,516,864.77	298,654.74	10,061,921.67	142,565.33
13	TVD+TDN	1,875,736.97	10,547,206.23	328,013.77	11,100,660.05	229,486.02
14	TVD+TMB	821,871.80	33,544,816.47	1,912,283.22	36,136,703.91	275,249.80
15	TVD+TCS	1,410,750.18	12,759,668.92	308,952.69	13,265,201.44	215,601.63
16	TVD+HLC	2,513,379.27	9,029,181.40	307,772.79	9,734,348.34	399,699.97
17	TVD+THT	6,367,735.24	9,903,643.07	283,569.18	10,421,892.19	186,653.85
18	TVD+TC6	1,528,492.41	10,697,049.47	281,382.27	10,950,709.81	119,908.69
19	TVD+MDC	1,250,650.51	10,521,680.08	305,075.20	10,852,383.64	178,142.27
20	TC6+ TCS	1,465,784.00	10,454,296.04	188,642.46	10,691,627.32	97,016.97
21	TC6 + MDC	1,305,684.33	8,216,307.21	184,764.97	8,278,809.52	59,557.61
22	TC6+TDN	1,930,770.79	8,241,833.36	207,703.54	8,527,085.92	110,901.36

In this context, the first group includes DMUs that improve the efficiency scores of the target DMUs and themselves. In Table 10 and Table 11, the virtual alliances in green cells (TCS & TC6; TVD & NBC) have increased the performance of counterparts. If there is a cooperation between

TCS & TC6, the position in the efficiency ranking of both is 6th in 2021 (Table 10). It is better than the position of TCS and TC6 if they operate independently. Similarly, the virtual alliance TVD & NBC improves significant performance scores of TVD and NBC in 2021 and 2022. Without collaboration, the performance of TVD and NBC is ranked at 16th and 17th in 2021 according to the authors' estimation in Table 10 & Table 11. Hence, the authors have the most priority in strategic alliance recommendation for VINACOMIN; including TCS & TC6 (Cao Son coal mine & Coc Sau coal mine) and Nui Beo coal mine & Vang Danh coal mine (TVD).

In addition, the authors consider the second priority group including potential DMUs that support the target DMU to improve performance although it may influence its performance. However, the study recommends them to VINACOMIN since the efficiency scores are still higher 1 that is an acceptable level. In addition, these DMUs are all under-managed by VINACOMIN, so such alliances are possible to implement toward a common goal of sustainable development.

Table 10 : Performance ranking of virtual alliance 2021

Rank	DMU	Score	Rank	DMU	Score
1 st	TMB	1.89008	12 th	TVD+TMB	1
2 nd	THT	1.72023	13 th	TDN	0.94399
3 rd	MVB	1.6074	14 th	TVD+MDC	0.8995
4 th	HLC	1.43775	15 th	TVD+TC6	0.86549
5 th	MDC	1.22765	16 th	TVD	0.86385
6 th	TC6+TCS	1.19298	17 th	NBC	0.8582
7 th	TVD+ NBC	1.11977	18 th	TVD+TDN	0.84941
8 th	TCS	1.09497	19 th	TC6 + MDC	0.83482
9 th	TC6	1.09339	20 th	TC6+TDN	0.75497
10 th	TVD+MVB	1.02966	21 st	TVD+TCS	0.73032
11 th	TVD+HLC	1.0028	22 nd	TVD+THT	0.71258

Table 11: Performance ranking of virtual alliance 2022

Rank	DMU	Score	Rank	DMU	Score
1 st	TMB	2.43506	12 th	TVD+TMB	1
2 nd	THT	1.86798	13 th	TVD	0.959
3 rd	MVB	1.65072	14 th	TVD+TC6	0.92934
4 th	HLC	1.56983	15 th	TVD+TDN	0.87388
5 th	TC6+TCS	1.20859	16 th	TDN	0.86126
6 th	MDC	1.20185	17 th	TC6+MDC	0.85962
7 th	TCS	1.16004	18 th	NBC	0.76097
8 th	TC6	1.13052	19 th	TC6+TDN	0.74546
9 th	TVD+NBC	1.06859	20 th	TVD+MVB	0.72076
10 th	TVD+MDC	1.06054	21 st	TVD+THT	0.70813
11 th	TVD+HLC	1.00084	22 nd	TVD+TCS	0.36444

5. Discussion :

As mentioned above, sustainable development has become a global trend and long-term orientation in most countries. There are many various approaches to achieve this goal, however, each government will choose different ways that are suitable for its contexts. For example, some nations have applied the environmental tax on sectors that have significant negative impacts on the environment such as steel manufacturing, mining, etc. On the other hand, some countries choose to support using alternative renewable energies such as hydrogen (water, solar, wind, etc.). Nevertheless, in developing countries such as Vietnam, economic growth is still the most priority and fossil energies such as the coal mining industry have an important role in economic development. Although the Vietnamese Government has some commitment to climate change, the internal energy market is still dominated mainly by fossil fuel-based technologies, and new thermal coal power plants are heavily invested during the last two decades. Therefore, if the Vietnam Government wants to integrate with global tendency as well as keeping growth in the economy, it is necessary to improve efficiency performance of current sectors.

There is no denying that the coal industry has a significant impact on the environment, especially in global climate change. If coal mines have the inefficient operation, it causes serious problems in terms of environmental, social, and economic aspects. Therefore, it is necessary to define the inefficiency of coal mines and have solutions such as M&A or involving partnership; because this is not only a common motivation among units but also is aligned with the orientation of the government.

The findings of this study are valuable references to answer the questions “what” and “how” to have good strategic alliances in sustainable development.

Which are inefficiency units?

The authors take advantage of combining two models of DEA and Grey Theory to define inefficiency units. The study has considered the ratio between the outputs that units have created and the inputs that units have been invested, then has made comparisons among units. Table 7 and Table 8 present the performance estimation of the top 10 coal mines managed by VINACOMIN. There are two units namely “Coc Sau coal mine” (TC6) and “Vang Danh coal mine” (TVD) obtained performance scores less than 1, i.e. these mines have not optimized investments from the head

corporation, VINACOMIN, to achieve an efficient performance as other units. Hence, these two coal mines are selected as target units by the authors to propose virtual alliances.

How to improve its performance?

Eliminating under-performance units is necessary for sustainable development. This is more important in sectors related to fossil energy such as coal mining due to its environmental impacts. A strategic alliance, hence, is worth taking into account as a solution.

Various enterprises with different missions and visions will have different forms of alliances (Nguyen & Nguyen, 2020). For example, two firms will sign a formal contract regarding equity ownership; shared managerial control; cross-selling; or shared resources (Phu & Duy, 2019; Nguyen & Nguyen, 2020). Chen & Chen (2002) introduced asymmetric alliances in which small firms accept to invest more than a larger partner, but they expect to gain more reputable in the market.

There are two key reasons that strategic alliance is a suitable and less costly solution. Firstly, an agreement toward a correlating business goal such as developing a more effective process; sharing the resources and risks; etc. is the foundation of strategic alliance (Kogut, 1988). The scope of this study is regarded to all coal mines under operated by VINACOMIN, hence, the goal of sustainable development is a key motivation in strategic alliances. In addition, setting alliances is possible to implement since all units are under-controlled by VINACOMIN.

Secondly, the authors also consider the location of units as a key indicator in selection. Most coal mines in the study are located nearby areas, hence, the process of cooperating is easy and feasible.

The finding and recommendations in this study can be seen as a good reference for managers due to the advantage of the research model. The authors made estimations based on the realistic data during many consecutive years from 2016 to 2020. It is better than the only 3-year period in many previous studies (Wang C. N., Nguyen, Tran, & Huong, 2015; Wang, Nguyen, & Wang, 2016; Nguyen & Tran, 2018). In addition, policymakers can apply the proposed model to evaluate the performance in various fields for a common goal of sustainable development.

Declarations

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