Assessment of Eco-Efficiency in Vietnam during 1990-2017 under Tapio Decoupling Analysis and Malmquist Productivity Index Approach

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Abstract:

The relationship between economic development accompanied by environmental friendliness, and ecological balance is the top concern of the strategic planners of sustainable development in each country. Based on Tapio decoupling analysis and measure productivity index from Malmquist - Data Envelopment Analysis Vietnam's eco-efficiency during 1990-2017 was investigated. The outstanding results are as follows: Since 2004 onwards, the changes have been recorded in the relationship between affluence and the environment - the ecosystem under the gradual diversity of degrees: expansive decoupling; weak decoupling; expansive coupling, and strong decoupling under Tapio decoupling analysis. At the same time, the Malmquist productivity index has improved slightly with 4.4% over 28 studied years. It shows that Vietnam gradually approaching and implementing strategies for improving the quality of the environment and the ecosystem. However, there is still an upward trend in the amount of emission with an annual emission growth rate of 43.4% while the economic development rate has not shown balance and similarities. Therefore, the reform of management policy, scientific strategy, and updating of technology system should be considered and implemented synchronously to maintain this change and promote the development in a more positive direction.

Key words: *eco-efficiency, Malmquist productivity index, sustainable development, Tapio decoupling, Vietnam*

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Introduction

Recently, developing countries have faced up with serious environmental issues and ecosystem degradation. Since, many researchers have come up with ideas to measure impacts of development and environment. Therefore, ecological efficiency has been considered for sustainable development as a core strategy under the known-well "eco-efficiency" (Adb, 2013; Perkins and Anh, 2009). It has shown in many studies at variety of fields and levels (Li, 2009; Pai et al., 2018; Thieriot and Sawyer, 2015) economic policy, climate change and energy, and management of natural and social capital, as well as the enabling role of communication technologies in these areas. We report on international negotiations and disseminate knowledge gained through collaborative projects, resulting in more rigorous research, capacity building in developing countries, better networks spanning the North and the South, and better global connections among researchers, practitioners, citizens and policy-makers. IISD's vision is better living for all- sustainably; its mission is to champion innovation, enabling societies to live sustainably. IISD is registered as a charitable organization in Canada and has 501(c. Its theory aims to create greater affluence (economic growth) under fewer resource and less effects on ecosystem, and reducing pollution. Hence, it is an important analytical tool in determine and investigate sustainable development (Gudipudi et al., 2018) both being multidimensional concepts. Based on this approach, we benchmark 88 European cities using (i. In particular, the process of industrialization and urbanization is mainly accompanied by impacts on the environment. Since then, many regulations and emissions taxes have been officially enacted to balance the levers between affluence and environmental quality. In addition, this is also considered an important measure to evaluate the quality of governance (Sanjuan et al., 2011)we applied a DEA model to Spanish Mahón-Menorca cheese production to determine the most eco-efficient production techniques. To this end, 16 scenarios of Mahón-Menorca cheese production were built regarding technical (degree of automation. In 1990, Technical Committee on environmental performance assessment and standardization of environmental management, Sub-Committee of the International Organization for Standardization was formally issued the international standard ISO 14031:1999 "Guidelines for Environmental Management-Environmental Performance Evaluation" and the technical report ISO/TR 14032:1999 "Environmental Management Examples of Environmental Performance Evaluations" as a basic framework for measuring eco-efficiency (Liang et al., 2018). It highlights the importance of eco-efficiency and pay attention to environmental protection. Meanwhile, developed countries pioneering sustainable development research have been working to improve quality of life and ecosystems. In addition, using mathematical modeling approaches to observe and evaluate eco-efficiency performances.

In contrast, most of developing countries have not much concentrated on the field such as Vietnam, the country lacks of studies about measuring eco-efficiency and sustainable development in micro and macro levels. Vietnam is fast growing country with annual GDP/capita growth rate around 11.6% during 1990-2017 (Figure 1a). However, it led to increase total final energy consumption 10.68% annual growth rate during the period of time, while renewable share in total final energy consumption declined slightly 2% (Figure 1b). On the other hand, economic development also brought the emission growth (CO_2 emission annual growth rate was over 39.5% during 1990-2017; 3.75% for nitrous emission; and 1.43% for methane, respectively) (Figure 1c). Since, investigation the relationship between economic growth and environmental degradation in Vietnam is necessary. The study was chosen Tapio decoupling analysis and integrated with Malmquist data envelopment analysis (Malmquist DEA). Because, Tapio decoupling analysis is flexible with eight categories according to values of economic and environmental degradation values. For Malmquist DEA, it is known as standard approach to measure efficiency of decision-making units over time changes. It is calculated the productivity growth, which is relative to technological factor.

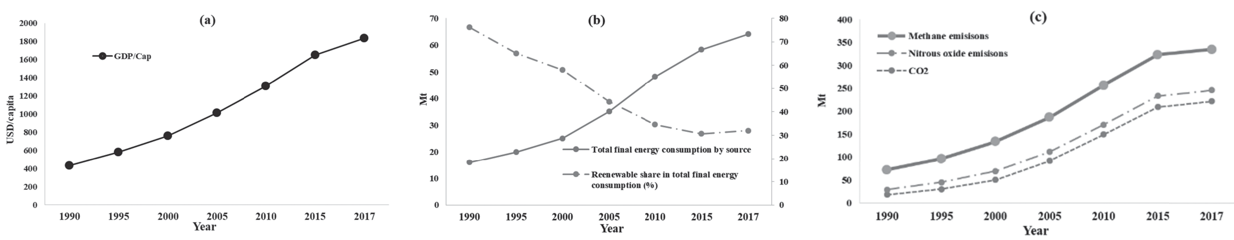

Figure 1. (a) Gross domestic product per capita (GDP per capita); (b) Total final energy consumption by source (Mt) and renewable share in total final energy consumption (%); (c) CO_2, nitrous, and methane emissions during 1990-2017 in Vietnam (Mt). (Note: GDP constant price in 2010)

Basically, our research aims to investigate eco-efficiency in several representative phases to withdraw the lessons for Vietnam. Because, under our perspective, tracking the eco-efficiency does not examine during many decades in developing countries. Since, policymakers do not have an entire evaluation to modify and make innovative strategies in the near-term and long-term solutions. Furthermore, our study integrated with emerged policies clarifying strong and weak points at each stage that could be a reference for decision-making unit. Moreover, analytical ecological tools as Taipo and data envelopment analysis (DEA) are well-supported the target for this study.

Data and methodology

Data

The data for Vietnam during 1990-2017 is from the International Energy Agency (IEA) (Baruya, 2010; IEA, 2017) and World Bank Development Indicators (Development et al., 2013; The World Bank, 2018, 2017). The research investigated the eco-efficiency during the period of time because data is available and synchronous. Furthermore, the starting and ending points in the study was based on the available data in the country. Particularly, input indicators comprise: Population (Million), total final energy consumption by source (Coal, natural gas, hydro, biofuels-waste, oil, wind, solar, etc in million tons); and renewable share in final energy consumption in percentage. For output indexes include: gross domestic product (GDP) per capita (USD constant price in 2010 per capita); total carbon emission (million tone); nitrous oxide emissions (thousand metric tons of CO_2 equivalent); and methane oxide emissions (thousand metric tons of CO_2 equivalent) during 1990-2017.

Methodology

Decoupling analysis

Based on the concept of elasticity Tapio proposed Tapio decoupling analysis, it reflects separation among variables and time frame under eight levels: recessive decoupling, recessive coupling, weak negative decoupling, strong negative decoupling, expansive negative decoupling, expansive coupling, weak decoupling, and strong decoupling (Figure 2). It was widely used to examine the relationship between economic development and environmental status (CO_2, SO_2 emissions) in China, Russia, Japan, and the United States (Wang et al., 2013). At provincial and city levels were also applied in Beijing and Shanghai (Wang et al., 2019). Checking the decoupling between CO_2 emissions and transportation factor in Finland (Tapio, 2005). The relationship between urban construction land expansion and economic growth at Cheng-Yu economic zone (WEI, 2020), etc… In the study, the decoupling method was proposed by Tapio, which was used to examine the link between environmental degradation and affluence (economic growth). In details, the starting year is represented by subscript 0 and t represents the end of period study; delta CO_2 (ΔCO_2) denotes the change of its emissions; similarly, delta nitrous and delta methane indicate the change of their emissions. Where, n_1; n_2; and n_3 are emission's growth of CO_2, nitrous, and methane, their growth rates are similarly described as equation (1):

$$n_1 = \frac{\Delta CO_2}{CO_2^0} \quad (1)$$

Similarly, nitrous and methane emissions;

$$n_2 = \frac{\Delta nitrous}{nitrous^0}; \quad n_3 = \frac{\Delta methane}{methane^0}$$

Delta GDP (gross domestic production) refers to the change of it. Its growth rate also can be measured by the following equation (2):

$$n_{GDP} = \frac{\Delta GDP}{GDP^0} \quad (2)$$

When the decoupling index (D) is presented by the ratio of changing emissions and affluence. Precisely, it was calculated by the equation (3):

$$D_1 = \frac{n_1}{n_{GDP}}; \quad D_2 = \frac{n_2}{n_{GDP}}; \quad D_3 = \frac{n_3}{n_{GDP}} \quad (3)$$

Assumption the environmental degradation in the study is presented by the total value of three gas emissions, when the decoupling index is more precisely shown by:

$$D = D1 + D2 + D3$$

The specific cases in decoupling analysis are performed under the decoupling metrics (Figure 2).

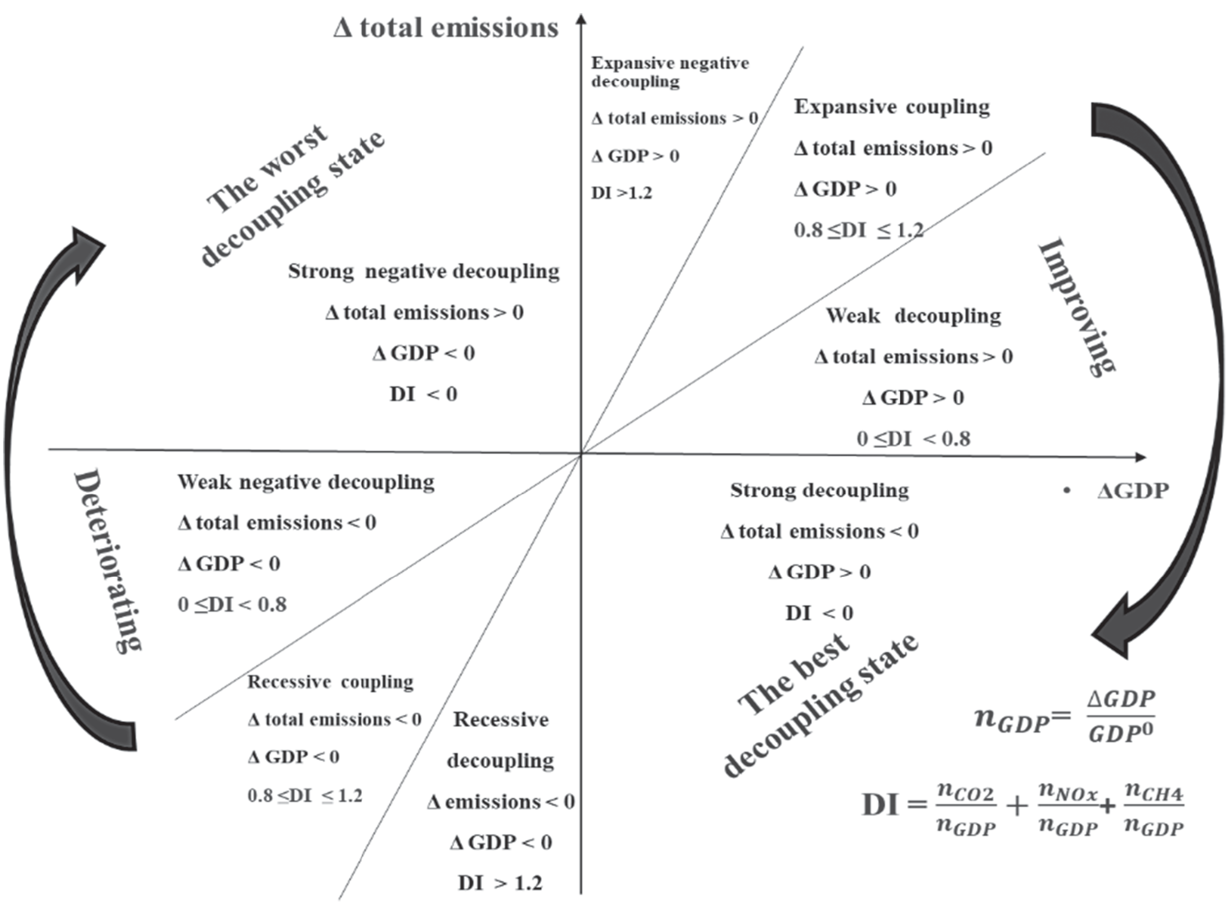

Figure 2. Decoupling metrics between affluence (economic growth) and environmental degradation.

Malmquist - Data envelopment analysis

Malmquist DEA, is a unique ability to measure the effectiveness of multiple inputs and outputs of decision-making units without prior weighting the inputs-outputs, as well as it seems to be emerge with several advantages other productivity indexes (Candemir et al., 2011). Firstly, it does not impose standard parametric restrictions on the underlying technology (Li et al., 2020). Secondly, no assumptions about profits and prices need to provide in Mamlquist DEA (Long et al., 2020a). It is helpful for situations about misrepresenting or nonexistent prices. Specially, it is widely used in many fields because it shows the technical performance and its changes. Thus, insight into its results can aid references to sources of productivity variation (Lee et al., 2011; Zhang et al., 2021). Hence, the study aims to apply the method to investigate the eco-efficiency in Vietnam during 1990-2017. Based on the input-orientated Malmquist DEA under the hypothesis of constant returns to scale, the Malmquist productivity index values were measured.

Particularly, x and y are respectively represented input and output with m inputs and n outputs. At time t, input and output can be shown as:

$x^t = (x_1^t, x_2^t, x_3^t, \ldots x_m^t)$ x^t denotes the input of period t

$y^t = (y_1^t, y_2^t, y_3^t, \ldots y_n^t)$ y^t denotes the output of period t

the study come up with following DEA models for measuring four distance function values: $D_0^t(x_0^t, y_0^t)$; $D_0^t(x_0^{t+1}, y_0^{t+1})$; $D_0^{t+1}(x_0^{t+1}, y_0^{t+1})$; $D_0^{t+1}(x_0^t, y_0^t)$. They can be calculated as below (Candemir et al., 2011; Pathak, 2019):

Where, $D_0^t(x_0^t, y_0^t)$ = maximize θ (4)

Such that: $\sum_{j=1}^{s} \alpha_j x_{ij}^t \geq \theta x_{i0}^t$ $i = 1,2,\ldots m$

$\sum_{j=1}^{s} \alpha_j x_{ij}^t \leq y_{k0}^t$ $k = 1,2,\ldots n$

$\theta_j \geq 0,$ $j = 1,2,\ldots s$

For $D_0^t(x_0^{t+1}, y_0^{t+1})$= maximize θ (5)

$\sum_{j=1}^{s} \alpha_j x_{ij}^t \geq \theta x_{i0}^{t+1}$ $i = 1,2,\ldots m$

$\sum_{j=1}^{s} \alpha_j y_{ij}^t \leq y_{k0}^{t+1}$ $k = 1,2,\ldots n$

$\theta_j \geq 0,$ $j = 1,2,\ldots s$

$D_0^{t+1}(x_0^{t+1}, y_0^{t+1})$ = maximize θ (6)

$\sum_{j=1}^{s} \alpha_j x_{ij}^{t+1} \geq \theta x_{i0}^{t+1}$ $i = 1,2,\ldots m$

$\sum_{j=1}^{s} \alpha_j y_{ij}^{t+1} \leq y_{k0}^{t+1}$ $k = 1,2,\ldots n$

$\theta_j \geq 0,$ $j = 1,2,\ldots s$

The last distance function value: $D_0^t(x_0^t, y_0^t)$ = maximize θ (7)

$$\sum_{j=1}^{s} \alpha_j x_{ij}^{t+1} \geq \theta x_{i0}^t \qquad i = 1,2,\ldots m$$

$$\sum_{j=1}^{s} \alpha_j x_{ij}^{t+1} \leq y_{k0}^t \qquad k = 1,2,\ldots n$$

The distance function values in equation (4) and (6) measure the efficiencies of decision-making units in time t and $t + 1$, similarly equation (5) calculates the efficiency of DMU_0 over the interval time $t + 1$ using the production technology of time . On the other hand, equation (7) measures the effective value of DMU_0 at time t using the production technology at time $t + 1$. The Malmquist productivity index (MPI) can be computed as the following equation (8) (Uddin, 2015; Zhou and Ang, 2008):

$$\text{MPI} = \left[\frac{D_0^t(x_0^{t+1}, y_0^{t+1}) \times D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{D_0^t(x_0^t, y_0^t) \times D_0^{t+1}(x_0^t, y_0^t)}\right]^{1/2}$$

$$\text{MPI} = \frac{D_0^t(x_0^t, y_0^t)}{D_0^{t+1}(x_0^t, y_0^t)} \times \left[\frac{D_0^t(x_0^t, y_0^t) \times D_0^t(x_0^{t+1}, y_0^{t+1})}{D_0^{t+1}(x_0^t, y_0^t) \times D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}\right]^{1/2}$$

Where, $\frac{D_0^t(x_0^t, y_0^t)}{D_0^{t+1}(x_0^t, y_0^t)}$ denotes efficiency change, while $\left[\frac{D_0^t(x_0^t, y_0^t) \times D_0^t(x_0^{t+1}, y_0^{t+1})}{D_0^{t+1}(x_0^t, y_0^t) \times D_0^{t+1}(x_0^{t+1}, y_0^{t+1})}\right]^{1/2}$ shows the way to measure technical change from time t to t+1.

Results

Decoupling result

The figure 3 and table 1 show the emission growth and decoupling elasticity results of Vietnam from 1978 to 2017. Overall, economic growth is strongly affected gas emission growth and decoupling index trend. On the other hand, there is a similar trend between increasing emissions and decoupling index curves. For CO_2 emission growth was significantly reduced during 1990-1991; 2010-2011; 2011-2012; and 2016-2017 (Figure 3a), while nitrous gas reduction was dramatically decreased from 2000-2001; 2007-2008; 200-2010; 2010-2011; 2013-2014, and 2016-2017 (Figure 3b). In contrast, methane emission growth only performed one stage with high reduction (1992-1993) (Figure 3c).

Expansive negative decoupling occurred during most of time from 1990-2000; 2001-2004; 2006-2007; 2008-2009; 2012-2013; and 2014-2015. It notes that GDP and emissions increased, however, emissions grow faster than economic growth. The maximum emission growth was reported over 43.4% during 2008-2009, meanwhile economic growth rose around 4 to 8% (Table 1).

At expansive coupling (2005-2006; 2009-2010; and 2011-2012, affluence and emission growth accelerate simultaneously - it is not an ideal state. The economic growth model has shifted from expansion to in-depth development, but changing the mode of economic growth can only gradually reduce a small part of CO_2 emissions. Economic growth does not eliminate the increase in energy consumption and CO_2 emissions, and it does not achieve the transition to a segregated state.

Weak decoupling was determined during 2000-2001; 2013-2014, and 2015-2016, it means that economic growth shifts from relying on increased energy - material consumption to improve its efficiency. When the effect of energy consumption on affluence is weaker until it reaches a certain extent, affluence can be decoupled from emissions. It is only happened when the country performs strong solutions continuously.

Strong decoupling presents from 2010-2011 and 2016-2017, these stages show that economic growth increases with more efficient use of energy consumption and positive reflection from reasonable strategies and policies. At this point, energy consumption and emission growth both decrease with very small numbers, reaching the ideal state of less energy consumption and more economic growth.

In general, Vietnam has just begun to have a change in awareness about sustainable development, at the same time, the implementation of sustainable development programs has not yet brought about high efficiency. However, based on this analysis, it will help this country to more closely regulate and manage the implementation and quality monitoring of sustainable development models in the near future.

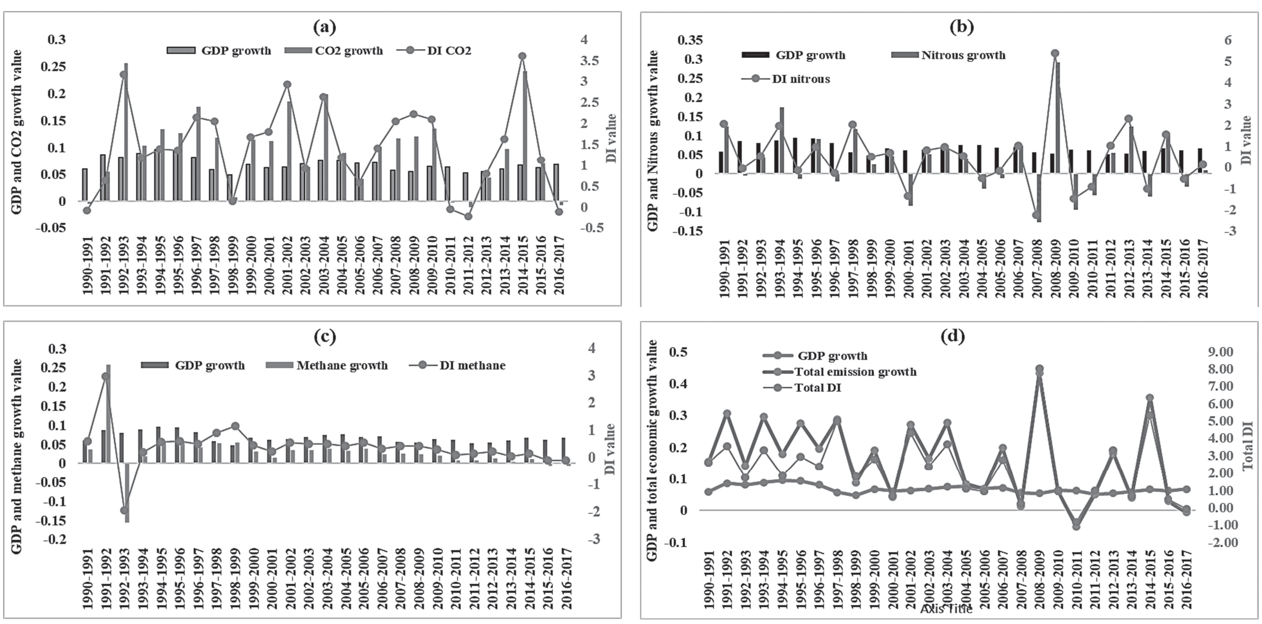

Figure 3. Economic, total emission growth in Vietnam during 1990-2017.
(Note: The secondary horizontal presents the decoupling index in each figure).

Table 1. The decoupling states in Vietnam

Year	GDP growth	Total emission growth	Total DI	Adjusted decoupling
1990-1991	0.060	0.155	2.60	Expansive negative decoupling
1991-1992	0.086	0.308	3.56	Expansive negative decoupling
1992-1993	0.081	0.142	1.76	Expansive negative decoupling
1993-1994	0.088	0.296	3.34	Expansive negative decoupling
1994-1995	0.095	0.178	1.86	Expansive negative decoupling
1995-1996	0.093	0.277	2.96	Expansive negative decoupling
1996-1997	0.082	0.196	2.40	Expansive negative decoupling
1997-1998	0.058	0.289	5.01	Expansive negative decoupling
1998-1999	0.048	0.087	1.82	Expansive negative decoupling
1999-2000	0.068	0.192	2.82	Expansive negative decoupling
2000-2001	0.062	0.041	0.67	Weak decoupling
2001-2002	0.063	0.272	4.30	Expansive negative decoupling
2002-2003	0.069	0.165	2.40	Expansive negative decoupling
2003-2004	0.075	0.278	3.68	Expansive negative decoupling
2004-2005	0.075	0.084	1.11	Expansive decoupling
2005-2006	0.070	0.067	0.97	Expansive coupling
2006-2007	0.071	0.199	2.79	Expansive negative decoupling
2007-2008	0.057	0.014	0.25	Weak decoupling
2008-2009	0.054	0.434	8.04	Expansive negative decoupling
2009-2010	0.064	0.061	0.95	Expansive coupling
2010-2011	0.062	-0.051	-0.82	Strong decoupling
2011-2012	0.052	0.051	0.98	Expansive coupling
2012-2013	0.054	0.181	3.34	Expansive negative decoupling
2013-2014	0.060	0.041	0.68	Weak decoupling
2014-2015	0.067	0.357	5.35	Expansive negative decoupling
2015-2016	0.062	0.030	0.48	Weak decoupling
2016-2017	0.068	-0.006	-0.090	Strong decoupling

Malmquist DEA analysis

The study applied Malmquist DEA to monitor ecological performance in Vietnam during the period 1990-2017 (Figure 4). Its value is higher than 1 - that is, the ecological efficiency is improved. On the contrary, eco-efficiency is inefficient if the value is less than 1. Besides, if its value is equal to 1 - noting that eco-friendliness and efficiency are stagnate (Long et al., 2020b; Roh et al., 2011). In the Malmquist DEA result in the study has reported efficiency change is unchangeable value over period of time, since the technical change is equal to MPI. Therefore, only MPI was presented in the part.

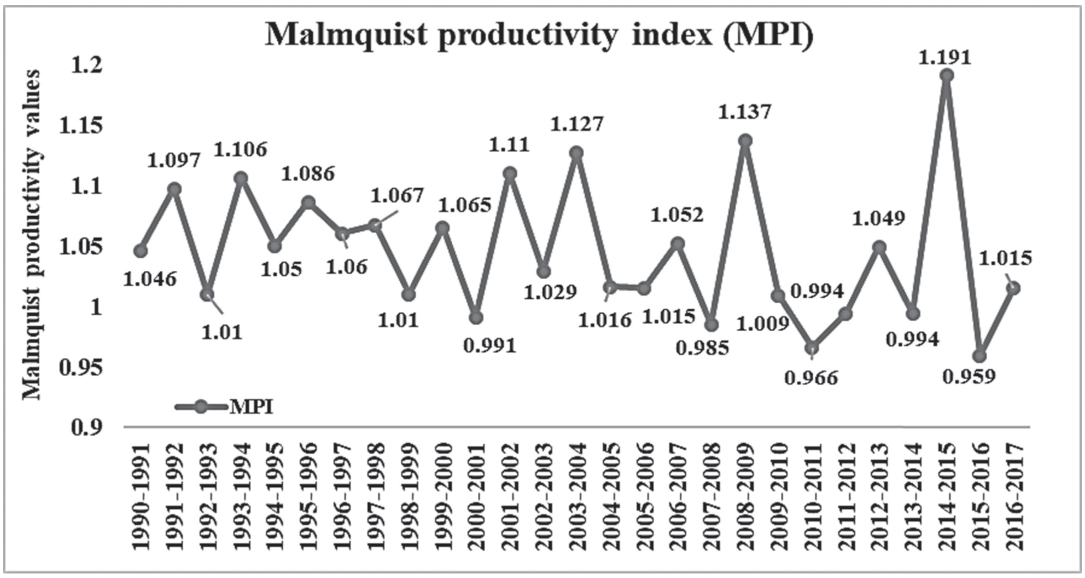

Figure 4. Malmquist productivity index during 1990-2017 in Vietnam.

Basically, over the past time, Vietnam has done better and better to improve ecological efficiency at most stages with MPI values higher than 1. Except, the years 2000-2001, 2007-2008, 2010-2012, 2013- 2014 and 2015-2016, its performances were lower than the standard value = 1. It is also consistent with Tapio decoupling analysis, these periods vary significantly for weak or strong separations. It shows how dramatically manufacturing technology has changed in these stages, as well as it plays a key role in advancement of eco-friendly environmentally. In summary, the mean of technical change is equal MPI in the study (its mean value = 1.044), it rose by an average 4.4% from 1990-2017 (it was measured by (1.044 - 1)*100). Although, its average growth is small value - meaning that technical efficiency has not satisfactory during the period of time, the eco-efficiency in Vietnam has been slowly and continuously improved in reasonable conditions.

In summary, Vietnam is trying to improve ecological efficiency, but improving only one factor will not be able to drastically change ecological efficiency. Even at some point, the imbalance in scale and technology will bring the country into a state of systemic weakness in management and disparity perception. Therefore, it is necessary to set up synchronously in management, production structure with technological innovation needs to be re-established at the same time to avoid degradation and imbalance in the ecosystem.

Conclusion

This study examined the interaction between economic growth and environmental status in Vietnam for nearly three decades (1990-2017) by integrating Tapio decoupling analysis and Malmquist DEA model. The results show that the ecological efficiency in Vietnam is still in its nascent stage, with less significant breakthrough. At the same time, the Tapio assessment shows that efforts are not worthy of expectations, and sometimes even show instability in the implementation of sustainable development programs. Besides, although the value of productivity index has slightly higher than 1, tended to decrease in recent years, showing the lack of seriousness in monitoring and management, and technology improvement is only average. This country needs to make breakthroughs in improving the scale and structure of the economy and the strategy of efficient energy exploitation and use in a scientific manner in the coming time.

Data availability: It will be provided with reasonable requests to the corresponding author.

Author contributions: T.T.H; collecting database, methodology, analysis, writing, and revised the manuscript.

Conflict of Interest: author declares no interest of conflicts.

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Ethical approval: This article does not contain any studies with human participants performed by any of the authors.

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