POLLUTION COST AS A VARIABLE FOR CALCULATING GREEN GDP

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Abstract

Pollution cost is an important variable in the calculation of Green GDP, which is an indicator of economic development under the green economy concept. This paper relies on the SFA to estimate the cost of air and water pollution in Thailand. During the past 20 years, Thailand has been subject to an average pollution cost of about 2,209,936 million baht ($63,141 million). The average air pollution cost is about 827,383.11 million baht ($23,640 million) and average water pollution costs approximately 1,382,552.84 million baht ($39,501 million). This study also confirms that the pollution problems affecting health, quality of life, and human capital are worsening. Therefore, the government should take the necessary measures through regulations and strict penalties to control pollution. It should also raise awareness of the long-term impact of pollution on human capital and economic development.

Introduction

Sustainability was introduced under Agenda 21 as a guide for governments and policymakers in the implementation of alternative methods for development in the twenty-first century. Agenda 21 is a global voluntary action plan for the implementation of sustainable development in society, the economy, and the environment (Mebratu, 1998). The plan specifies population, consumption, and technology as forces of environmental change. Moreover, it is necessary to take steps to reduce the consumption pattern of luxuries and inefficiencies in certain areas of the world. While global support for sustainable development has grown, policies and plans are required to achieve a sustainable balance between consumption, poverty, human capital development, and technology in order to respond to human needs and manage natural resources (Todaro and Smith, 2012).

At the present time, the direction of economic development is based on the Adoption of the Post-2015 Development Agenda which is a sustainable development plan for the twenty-first century where every country in the world agrees upon a common aim of implementation in order to achieve sustainable development in the future. The implementation of Agenda 21 is fundamental to the Adoption of the Post-2015 Development Agenda and has resulted in the continuing development of true sustainability to balance economic, social, and natural resources, and aims to achieve the integration of people, planet, prosperity, peace, and partnership (the five Ps).

The basic concept of sustainable development must take into account economic, social and natural resources (OECD, 2014). The results from OECD countries indicate that sustainability is not only highlighted by economic development and the cost of social and natural resources, but also human capital (OECD, 2013). All of these factors influence the effect of sustainable development on the well-being of citizens (OECD, 2011). The OECD has reported increased overall social welfare along with economic growth, taking into account the effect on the environment and natural resources (OECD, 2008). This concept of a green economy clarifies and identifies sustainable development. The green economy is calculated by Green GDP and concerns the wastage of natural resources and well-being of citizens from the present through to the future (UNEP, 2011).

Under the concept of a green economy, the growth of income and employment is driven by public and private investment to reduce carbon emissions, pollution, and energy consumption, as well as making efficient use of resources to protect the loss of biodiversity and ecosystems (Bartelmus, 1999; Dasgupta, 2009). The most important aim of a green economy is economic growth with increased environmental quality and social equity (Fang et al., 2006). The key to its achievement is to create conditions for public and private investment which focus on the environmental and social effects (Frankel, Jeffrey A., 2003). The green economy concept of the UNEP is said to be an indicator of economic growth, whereby GDP will need to be adjusted by pollution, resource depletion, degenerative ecosystems, and the effect of natural capital loss. All of these indicators represent the green gross domestic product (Green GDP).

Green GDP is an indicator of a green economy, reflecting comprehensive sustainability under the concept of sustainable development and environmental accounting (Brekke, K. A., 1994). Currently, overall global consumption is growing at a higher rate due to the increasing size of the population. An increase in the global population has caused a reduction in resources, even though advances in technology have been developed to help address the issue. In fact, renewable resources are limited in both quantity and quality (Hartwick, 1994; Aaheim and Nyborg, 1995; Lintott, J., 1996). In addition, accelerating production to support economic growth also causes degradation of natural resources and the environment, and pollution problems are increasing since these costs are ignored because the value of environmental goods and services are not bought or sold in the market and seen as production costs (Vellinga and Withagen, 1996). For this reason, it can be said that the use of the Gross Domestic Product (GDP) may not reflect sufficiently comprehensive economic development (Costanza et al., 2009). GDP cannot distinguish between the economic activities enhancing the prosperity of the country and the negative impact on nature, pollution, and resource degradation (Fox, J., 2012), but Green GDP can (Solow, 1986; Hartwick, 1990; Maler, 1991; Asheim, 1994; and Pemberton and Ulph, 1997).

At present, Thailand follows the guidelines for developing countries that rely on the concept of sustainable development. Therefore, in order to encourage the development of Green GDP and support the country to achieve sustainable and balanced development in terms of economy, society, and environment this research aims to estimate the pollution cost (considering only air and water pollution) in the case of Thailand during the years from 1996–2016. This paper is part of the research on “Concepts and Measurements of the Green Gross Domestic Product of Thailand in the Context of Sustainable Development” by Sonthi (2019).

Linkage between pollution cost and Green GDP

Todaro and Smith (2012) reflected that “sustainable development remains a balance between economic growth and the conservation of natural resources” while at the same time “sustainable development responds to the needs of the current generation without losing sight of the needs of the future generation”. Economic growth and overall life quality in the future depends on the environment. The quality of natural resources in each country such as air, water, and soil form the basis for consideration.

Natural resources are crucial to the next generation. Economic growth and quality of life are calculated in the form of national income, and environmental accounting is therefore important. Policymakers will use national income or capital assets as key factors in the decision-making process. Currently, capital assets encompass only manufactured capital, except for human capital (knowledge, experience, and skills) and environmental capital (forests, soil quality, and rangeland), which are important factors closely related to economic growth and quality of life.

The basic concept of Green GDP involves bringing in traditional GDP to cut natural capital, which has a different definition. There is currently no clear method for calculating Green GDP, particularly in respect of natural capital. This remains a statistical limitation and the options continue to be debated, such as the cost of pollution, environmental degradation and destruction, and the cost of reducing pollution or damage resulting from it (Fang et al., 2006).

In the approach to green accounting, there is a simple model for computing Green GDP, as in the format selected by the Congressional Budget Office (CBO) (1994); Bartelmus (1999); Qi, Coggins and Lan (2000); Wang (2004); Fang et al. (2006); and Findiastuti (2011).

The CBO (1994) pointed out that national income accounting has been a policy priority over the last 50 years. Economic data can be useful for policymakers in the decision-making process. However, national income accounting currently has limitations because the support functions are based only on the economic interpretation regarding the wealth of nations, gauging income, and measuring the market value of goods and services. It is essential that in addition to traditional GDP, Green GDP is used to improve national income accounting based on the quality of air, soil, water, stock of natural resources, and the price of asset flows and stocks, as outlined by Bartelmus (1999), whose purpose was to assess the long-term sustainability of economic performance by Green GDP. Using the Rio Earth Summit concept with the System of Environmental and Economic Accounting (SEEA) by the UN and converting the natural production account into assets, three models can be used to obtain Green GDP. These are (1) Supply-use identify, (2) Value-added (environmentally adjusted), and (3) Domestic-product.

From the calculated model for Green GDP, the CBO concluded that it can reflect changes in the value of fixed capital consumption and environmental costs. During the period of operation, the ability to split the calculations to reflect unsustainability occurs when gathering the cost of natural capital. Environmentally-adjusted net capital formation is calculated by deducting consumption and environmental costs from fixed capital. The figures can reflect a country’s wealth through its capital accumulation and economic environment — Green GDP and natural capital are also subject to debate. Since the calculation is based on pricing, the valuation of natural phenomena is extremely important. Therefore, the variables of economic policy macroeconomics and expenditure on environmental costs created by economic agents have recently been adjusted.

In addition, Y Fang (2006) presented a method of calculating Green GDP in a similar way using the pollution cost approach with the SEEA of the UN, consisting of three ways. Qi, Coggins, and Lan (2000) chose the production approach. The three ways used by Fang et al. (2006) to calculate Green GDP are as follows:

(1) Production approach: EDP = aggregate output - intermediate input - environmental cost;

(2) Income approach: EDP = payment for labour + net production tax + consumption of fixed capital + operation surplus with deduction of environmental expenditure;

(3) Expenditure approach: EDP = terminal consumption + capital with deduction of environmental expenditure + net export

Moreover, the consideration of natural capital takes into account the pollution cost. Wang (2004) also calculated Green GDP and its effect on the accumulation of human capital. In addition, traditional GDP offsets the cost of natural resources resulting from environmental degeneration. Pollution levels across the country according to the theory and tools used for accounting environmental pollution loss; a primary factor in the preparation of Green GDP, also deducts the cost of human capital from traditional GDP in one step. However, this study examined a particular area in each community, rather than overall.

Findiastuti (2011) calculates environmental productivity (Green GDP) using a macroeconomic measure, TFP, and shadow prices (an important part of the environmental calculation). Furthermore, the concept presented by Herman E. Daly to calculate the sustainable social net national product deducts defensive expenditure and depreciation of natural capital, and can be expressed by the following equation:

$$SSNNP = NNP - DE - DNC \qquad (2.1)$$

where

SSNNP is the sustainable social net national product.

NNP is the net national product.

DE is defensive expenditure (damage to environmental resources caused by production and consumption).

DNC is the depreciation of natural capital.

In 2015, Malaysia calculated its Green GDP using Herman E. Daly's concept, based on the research by Vaghefi, Siwar, and Aziz (2015). This study defines Green GDP as being calculated from GDP by offsetting the loss of natural resources and deducting defensive expenditure. Data from the World Bank indicates that natural resource depletion is the sum of net forest depletion, energy depletion, and mineral depletion, while defensive expenditure merely uses carbon dioxide (CO_2). The growth of traditional GDP, real GDP, and Green GDP in Malaysia is still moving in a positive direction, indicating that the country is on the path towards sustainable growth and concerned about the issue of natural capital.

It can be seen that one very important variable in the calculation of Green GDP is the cost of pollution. Natural capital or pollution costs can be classified into two types: actual costs and imputed costs. The actual cost relates to expenditure for environmental protection, remediation, and treatment, which can be difficult to collect. The imputed cost is derived from the estimation method for the cost of maintaining the environment or the amount of pollution emitted into it.

Estimating the cost of pollution is known as shadow pricing. Shadow price estimates can vary widely depending on the estimation method used. The findings of the study indicate that the shadow price can be calculated as follows:

Willingness to pay (WTP)

WTP is the most each person is willing to pay for the direct and indirect benefits obtained from something, such as natural or ecosystem services for creating and maintaining well-being or helping it to increase. This is the difference between the maximum WTP and consumer surplus (Harris and Roach, 2018). The shadow price relies on WTP and its use in environmental valuation techniques can vary. For example, there is the cost of illness method, replacement cost method, and preference method, consisting of two categories: revealed preference and stated preference. The most common technique used in this approach is the travel cost model (TCM), hedonic pricing, and the contingent valuation method (CVM).

These approaches use surveys to ask individuals or a sample group to estimate the total economic value of what they are willing to pay for increases in welfare. The limitation of this approach is that it is costly, takes a lot of time, and requires a large sample size. Moreover, it is difficult to screen for facts because the participants may not have sufficient knowledge, and the questionnaire may be misinterpreted, etc.

Benefit transfer method

This method represents the estimation or transfer value of natural resources and the environment by relying on similar prior research (Harris and Roach, 2018). This technique can be performed in two ways: benefit function transfer or unit value transfer. The advantage of this technique is that it saves time and money but caution is required as to the accuracy of results (Johnston, R.J., et al., 2015).

Output distance function

Following Kumbhakar and Knox Lovell (2000), the output distance function [Do(x, y)] is an output-expanding approach to measure the distance between a point of production and the boundary of production possibilities. It characterises output sets, dualled with the revenue frontier based on Shephard's lemma in duality theory.

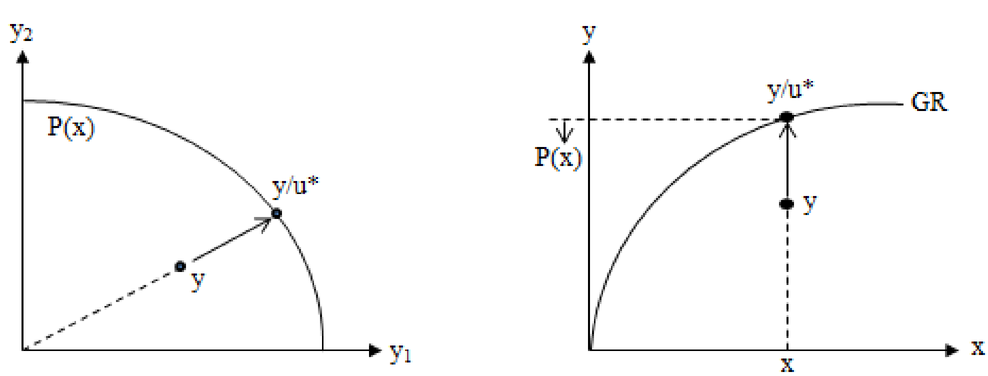

Figure 1 Output distance function

Source: Kumbhakar and Knox Lovell (2000)

In Figure 1, Do (x, y) is defined in terms of output sets P(x), y is the output vector producible with input x, but so is the radially expanded output vector (y/u*), and therefore Do (x, y) = u* < 1. Do (x, y) is a convex function in y, representing a core property of output distance function.

To estimate the shadow price following this method, the stochastic production frontiers model (SFA model) can be used. This model allows for technical inefficiency and is based on the Log-Linear Cobb-Douglas form using the OLS estimation. Therefore, the equation can be written as:

$$\ln y_i = \beta_0 + \sum_n \beta_n \ln x_{ni} + v_i - u_i \quad (2.2)$$

where

yi is the output vector producible with input x.

x_{ni} is the inputs x.

v_i is error term in part the two-sided noise component. It is assumed to be iid and symmetric, distributed independently of u_i.

u_i is error term in part the nonnegative technical inefficiency component.

Therefore, the error term of this model is. It is asymmetric since $u_i \geq 0$, and v_i and u_i are distributed independently of x_i. This study uses this method to estimate shadow prices or pollution costs.

Methodology

This study uses the output distance function and its duality with the revenue function, relying on stochastic frontier analysis (SFA) to compute the shadow price of pollution; that is the pollution cost as a result of air and water pollution. The inclusion of air pollution is necessary to adjust the units from parts per billion (ppb) to milligrams per kilograms (mg/kg) before converting physical units into monetary units. SFA is used because of the fundamental idea in economic production that productive efficiency involves allocating inputs and seeking to avoid waste (Kumbhaker and Knox Lovell, 2003). Productive efficiency represents economic efficiency; a distance measurement to an economic frontier or boundary of production possibilities. Furthermore, the limitation of available data is the most important criteria applied in this method.

Following Färe et al. (1993); Kumbhaker and Knox Lovell (2003); and Dang and Mourougane (2014), shadow prices can be derived via the duality theory using Shephard's lemma from the output distance function to maximise the revenue function as follows:

$$\begin{aligned} r(x,p) &= \max_y \left\{ p_y^T y : y \in P(x) \right\} \\ &= \max_y \left\{ p_y^T y : D_o(x,y) \leq 1 \right\} \end{aligned} \quad (3.1)$$

Following Dang and Mourougane (2014), the above function can be applied to estimate shadow prices by the following definition:

$$D(x,y,w) = \inf \left[\varphi > 0 : (x, \frac{y}{\varphi}, w) \in T \right] \quad (3.2)$$

where D is the output distance function ranging from 0 to 1, defining a set of inputs (x) to produce vector outputs (y, w), whereby y represents good output and w bad output (pollutant). The properties of the output distance function satisfy at homogeneous degree 1 in good output, non-decreasing in good output, non-increasing in bad output and input, and weak disposability. This assumption infers that the summations of all bad outputs are not greater than the total outputs.

From (1) to (2), the model by Färe et al. (1993) is applied to derive bad output, shadow price (pw) is defined by the maximisation problem and pw is expected to be negative as follows:

$$\begin{aligned} &\max_{y,w} p_y y + p_w w \\ s.t. \quad &D_o(x,y,w) \le 1 \end{aligned} \quad (3.3)$$

The problem of maximising the Lagrangian is resolved. The shadow price of pollutants based on the output distance function is as follows:

$$p_w = p_y \frac{\partial y}{\partial w} \quad (3.4)$$

Finally, equation (3.4) is used to compute the shadow prices of pollutants with the elasticity obtained by stochastic frontier analysis (SFA).

The use of SFA to estimate elasticity relies on parametric functionality. This study applies the model of Kumbhaker and Knox Lovell (2003), Dang and Mourougane (2014), and Kumbhaker et al. (2015). The different parameters can be written as follows:

Model for air pollution

The model (3.5) define the air pollution, air_{ijt}, $j \in$ {SO2, NO2, CO, O3, the volume of air pollution consisting of SO2, NO2, CO, and O3} in region i and in year t as

$$\begin{aligned} -\ln grp_{it} = {}& \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln air_{ijt} + \beta_4 \ln pm10_{it} \\ & + \beta_5 \ln K_{it}\_sq + \beta_6 \ln L_{it}\_sq + \beta_7 \ln K_{it} \ln L_{it} \\ & + \beta_8 \ln K_{it} \ln air_{ijt} + \beta_9 \ln K_{it} \ln pm10_{it} + \beta_{10} \ln air_{ijt} \ln pm10_{it} + v + u \end{aligned} \quad (3.5)$$

Where

ln grp is the gross regional product.

ln K is the value of capital stock.

ln L is number of units in the labour force.

ln air is vector of air pollution.

ln pm10 is the volume of PM10.

ln K_sq is the square of capital stock.

ln L_sq is the square of the labour force.

ln K ln L is the interaction between the capital stock and the labour force.

ln K ln air is the interaction between the capital stock and air pollution.

ln K ln pm10 is the interaction between the capital stock and PM10.

ln air ln pm10 is the interaction between the air pollution and PM10.

v is the error term in part of the two-sided noise component. It is assumed to be iid and symmetric, distributed independently of u.

u is the error term in part of the nonnegative technical inefficiency component.

Water pollution model

The model (3.6) define the water pollution, $waterr_{ijt}$, $j \in$ {BOD, Total Coli, Fecal Coli, NH3-N, the volume of water pollution consisting of BOD and NH3N} in region i and in year t as

$$
\begin{aligned}
-\ln grp_{it} &= \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln K_{it} \ln L_{it} + \beta_4 \ln water_{ijt} \\
&+ \beta_5 \ln water_{ijt}\_sq + \beta_6 \ln K_{it}\_sq + \beta_7 \ln L_{it}\_sq \\
&+ \beta_8 \ln K_{it} \ln water_{ijt} + \beta_9 \ln L_{it} \ln water_{ijt} + v + u
\end{aligned}
\qquad (3.6)
$$

Where

ln grp is the gross regional product.

ln K is the value of capital stock.

ln L is the number of units in the labour force.

ln water is vector of water pollution.

ln K_sq is the capital stock squared.

ln L_sq is the labour force squared.

ln K ln water is the interaction between the capital stock and water pollution.

ln L ln water is the interaction between the labour force and water pollution.

v is the error term in part of the two-sided noise component. It is assumed to be iid and symmetric, distributed independently of u.

u is the error term in part of the nonnegative technical inefficiency component.

Equations (3.5) and (3.6) are used to estimate the elasticity of good and bad output before applying the parameter received to calculate the pollution cost, representing the shadow prices of air and water pollution in equation (3.4).

The variables for SFA are based on the production function, data on good output as the gross regional product (GRPit), capital stocks (Kit), and labour force (Lit), divided into seven regions and taken from the Office of the National Economic and Social Development Board during the period from 1997 to 2016.

Results

The research methodology in this paper focuses on estimating air and water pollution using stochastic frontier analysis (SFA). The air pollution cost estimation is separated into six models according to gas emission type (SO2, NO2, CO, O3, and PM10). The total amount of gas emission in the air is included in a single model because all types of gas emission have the same units except PM10. Whereas water pollution is separated into five models to estimate the cost of pollution according to each type of pollutant value and those that combine water pollution values in a single model, as presented in parts I and II. The estimated costs of pollution is then tested in part III to establish its long-run relationship with health expenditure to confirm the validity of the estimated pollution costs and demonstrate the linkage between pollution problems and economic development.

Part I

The estimation results for elasticity, good output, and air pollution using SFA are shown in Table 1. The elasticity of gas emissions to output, separating each type of gas emission is shown to have a coefficient inconsistent with the conditions of the model. Based on the results, only one of the SO2 emissions to output has a statistically significant elasticity value consistent with the model conditions. This result may be because each type of air pollution was considered separately, indicating too little effect on the overall economy, and causing the test results to be unclear.

Whereas improving the model by combining the air pollutant values into a single value and entering the PM10 variable, the coefficient of statistical significance and sign were found to be consistent with the model conditions. The results reflect air pollution more comprehensively than models considered by gas emission type. In addition, when considering the goodness of fit, the model combining air pollution with a higher AIC value is shown to be a better fit. Therefore, the results of this model are used to estimate air pollution.

As in Table 1, the results of Model Air (A.6) which combines air pollution into a single value shows that labour force elasticity is around 2.5367. The capital stock squared elasticity is around 0.0373, implying that capital stock has a positive effect on good output in the long run. The interaction between capital stock and labour force elasticity is around 0.0693. These coefficients are statistically significant at the 0.05 level.

Moreover, the output production is statistically and significantly associated with air pollution which consists of sulfur dioxide emissions (SO2), nitrogen dioxide emissions (NO2), carbon monoxide emissions (CO), and ozone emissions (O3) but this paper ignores the particulate matter 10 (PM10) since the estimated results are not significant. Air pollution elasticity is estimated at around 0.1146 and the coefficient is statistically significant at the 0.1 level. This result implies that in every production the proportion of air pollution per good output is around 11.46%.

Table 1 SFA estimation in the case of air pollution, 1997–2016

Variables	**(A.1) Model SO^2**	**(A.2) Model NO^2**	**(A.3) Model CO**	**(A.4) Model O^3**	**(A.5) Model PM^{10}**	**(A.6) Model Air**
lnK	0.943	1.165	1.804	1.250	1.467*	-0.328
lnL	-9.748***	-9.025***	-13.019***	-8.983***	-8.894***	-2.537**
lnKsq	-0.049*	-0.049*	-0.069**	-0.046*	-0.005	-0.037
lnLsq	0.296**	0.281**	0.414***	0.284**	0.319***	0.051
lnKlnL	-0.010	-0.035	-0.037	-0.046	-0.125*	0.069**
lnSO2	-0.344*					
lnSO2sq	0.002					
lnKlnSO2	0.014					
lnLlnSO2	0.013					
lnNO2		-0.047				
lnNO2sq		-0.003				
lnKlnNO2		-0.008				
lnLlnNO2		0.007				
lnCO			-0.514			
lnCOsq			-0.003			
lnKlnCO			-0.002			
lnLlnCO			0.033			
lnO3				0.001		
lnO3sq				-0.004		
lnKlnO3				-0.009		
lnLlnO3				0.004		
lnPM10					-0.172	0.179
lnPM10sq					0.052**	
lnKlnPM10					0.087**	-0.009
lnLlnPM10					-0.051	
lnAirlnPM10						0.007
lnAir						-0.115*
lnKlnAir						0.006
_cons	64.871***	58.877***	84.497***	58.135***	54.272**	17.896
Standard deviation of technical inefficiency	0.646	0.617	0.791	0.612	0.495	0.533
Standard deviation of random error	0.092	0.092	0.093	0.092	0.084	0.044
Log likelihood	107.138	112.008	88.259	112.179	128.806	210.069
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000
Chi-square (X^2)	638.688	677.005	518.923	678.640	868.402	172.251
Converged (1 if converged, 0 otherwise)	1	1	1	1	1	1
AIC	-188.275	-198.015	-150.519	-198.358	-231.612	-390.139
BIC	-150.701	-159.961	-114.835	-160.304	-193.371	-346.015

*Note: * significant at the 90% level of confidence, ** significant at the 95% level of confidence, *** significant at the 99% level of confidence*
Source: Authors' estimations

Table 2 SFA estimation in the case of water pollution, 1997–2016

Variables	(W.1) Model BOD	(W.2) Model Total Coli	(W.3) Model Fecal Coli	(W.4) Model NH3-N	(W.5) Model Water
lnK	1.937*	0.875	0.944	1.503*	-0.465
lnL	-11.512***	-7.715***	-8.223***	-11.249***	-2.376**
lnKsq	-0.0418	-0.063**	-0.044*	-0.054*	-0.039**
lnLsq	0.362***	0.234*	0.264**	0.346***	0.043
lnKlnL	-0.074	-0.002	-0.035	-0.043	0.076**
lnBOD	0.641				
lnBODsq	-0.027				
lnKlnBOD	0.071				
lnLlnBOD	-0.112				
lnTotal Coli		-0.272			
lnTotal Colisq		0.017**			
lnKlnTotal Coli		0.017			
lnLlnTotal Coli		-0.006			
lnFecal Coli			0.258		
lnFecal Colisq			0.005		
lnKlnFecal Coli			0.028**		
lnLlnFecal Coli			-0.040**		
lnNH3-N				0.720	
lnNH3-Nsq				-0.005	
lnKlnNH3-N				0.011	
lnLlnNH3-N				-0.603	
lnWater					-0.192**
lnWatersq					-0.002
lnKlnWater					0.001
lnLlnWater					0.010*
_cons	74.518	49.518	52.367	75.478	19.142**
Standard deviation of technical inefficiency	0.638	0.468	0.521	0.587	0.526
Standard deviation of random error	0.093	0.083	0.086	0.093	0.044
Log likelihood	113.267	130.499	124.803	113.382	211.705
Prob>chi2	0.000	0.000	0.000	0.000	0.000
Chi-square (X^2)	675.245	897.717	820.575	673.291	178.574
Converged (1 if converged, 0 otherwise)	1	1	1	1	1
AIC	-200.533	-234.997	-223.605	-200.765	-395.409
BIC	-162.292	-196.756	-185.364	-162.523	-354.226

*Note: * significant at the 90% level of confidence, ** significant at the 95% level of confidence, *** significant at the 99% level of confidence*
Source: Authors' estimations

Part II

The estimation results for elasticity, good output, and water pollution using SFA are shown in Table 2. Estimation of the elasticity of water pollution to output in each model indicates that all coefficients considered for each water pollutant in the model were not statistically significant. Whereas the model combining water pollution (W.5) into a single value has a statistically significant coefficient according to the model conditions. In addition, when considering the goodness of fit of the model with the AIC value, this model has the highest AIC, indicating that its goodness of fit is better than the others. Therefore, the results for this model are used to estimate the water pollution cost.

As in Table 2, Model Water (W.5), the results indicate that labour force elasticity is around 2.3756. The square of capital stock elasticity is around 0.0387, implying that capital stock has a positive effect on good output in the long run. The interaction between capital stock and labour force elasticity is around 0.0758. These coefficients are statistically significant at the 0.05 level. In addition, the interaction between the labour force and water pollution elasticity is around 0.0101 and statistically significant at the 0.1 level. The water pollution elasticity is around 0.1915 and the coefficient is statistically significant at the 0.05 level. These results imply that in every production, the proportion of water pollution per good output is around 19.15%.

According to the SFA results, the average air pollution cost for the years from 1997–2016 was about 827,383 million baht ($23,639 million at an exchange rate of 35 baht/USD). The water pollution cost was about 1,382,552 million baht ($39,501 million) as shown in Table 3.

Furthermore, the estimated elasticity results for both air and water pollution are close to those achieved by Dang and Mourougane (2014) in their research on the estimation of shadow prices for pollution in selected OECD countries (around 0.021 for air pollution only). Considering the air and water pollutant costs as shown in Table 3 and Figures 1, the results indicate that the pollution cost in Thailand from 1997–2016 is around 2,209,935 million baht ($63,141 million).

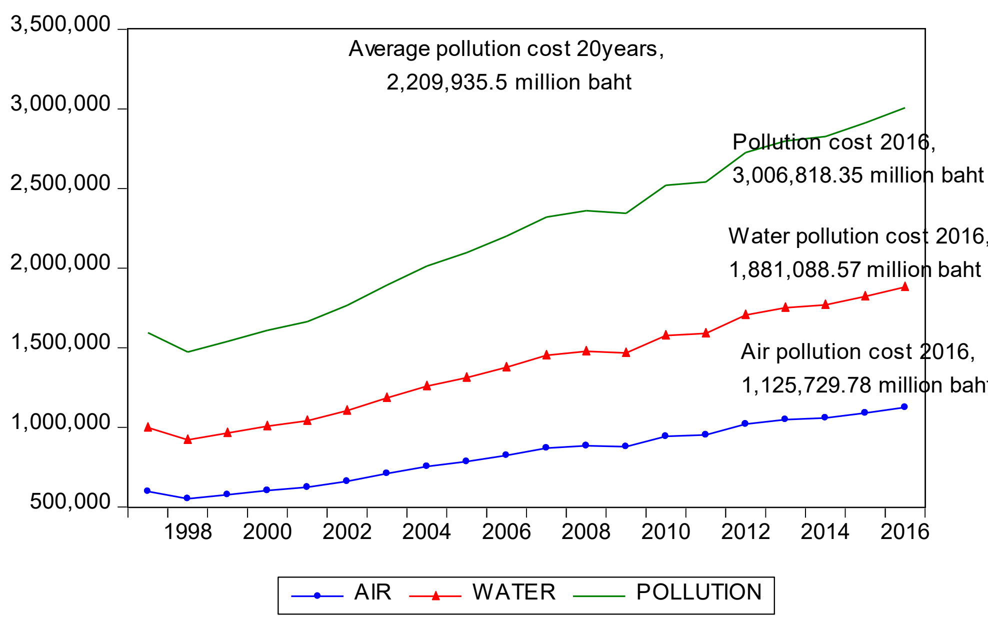

Figure 1 Pollution cost in Thailand during the years 1997-2016

Source: Authors' calculations

Table 3 The Shadow prices of the cost of air and water pollution for Thailand over 20 years

Years	Air pollution cost		Water pollution cost	
	million baht	**million dollar us**	**million baht**	**million dollar us**
1997	596,822.02	17,052.06	997,286.47	28,493.90
1998	551,262.21	15,750.35	921,156.27	26,318.75
1999	576,467.57	16,470.50	963,274.29	27,522.12
2000	602,153.09	17,204.37	1,006,194.67	28,748.42
2001	622,892.71	17,796.94	1,040,850.46	29,738.58
2002	661,193.64	18,891.25	1,104,851.11	31,567.17
2003	708,729.03	20,249.40	1,184,282.50	33,836.64
2004	753,303.05	21,522.94	1,258,765.44	35,964.73
2005	784,850.13	22,424.29	1,311,480.46	37,470.87
2006	823,840.83	23,538.31	1,376,633.72	39,332.39
2007	868,617.35	24,817.64	1,451,455.04	41,470.14
2008	883,606.80	25,245.91	1,476,502.33	42,185.78
2009	877,503.43	25,071.53	1,466,303.64	41,894.39
2010	943,435.45	26,955.30	1,576,475.69	45,042.16
2011	951,359.92	27,181.71	1,589,717.45	45,420.50
2012	1,020,264.89	29,150.43	1,704,857.29	48,710.21
2013	1,047,683.28	29,933.81	1,750,673.28	50,019.24
2014	1,057,996.83	30,228.48	1,767,907.16	50,511.63
2015	1,089,950.17	31,141.43	1,821,301.03	52,037.17
2016	1,125,729.78	32,163.71	1,881,088.57	53,745.39
Average	827,383.11	23,639.52	**1,382,552.84**	**39,501.51**

Source: Authors' calculations

The air and water pollution costs are not as high in Thailand at around 33.6% of GDP compared to 24.0% in OECD countries (which only consider air pollution cost). As a developing country, Thailand needs high production capacity and economic activity in order to further develop. For this reason, it seems that pollution emissions and the loss of natural resources are increasing in line with the country's development. Other studies on the environmental cost such as that of Attavanich et al. (2016), adopted the Economic Input Output-Life Cycle Assessment (EIO-LCA) approach. However, this is only a one-year study, based on the 2005 economic input-output table database, and indicates that the cost of environmental damage is approximately 14.6% of GDP. The pollution cost is different due to this paper has been conducted for 20 years and more current but Attavanich's research has been conducted for one year only, and using the calculation of different pollution costs as well as the proportion of pollution costs that appear in Attavanich's research is measured by the total value added but this paper is measured proportion per GDP.

When comparing the previously mentioned work on environmental cost with the environmental cost results in this paper, the proportion per GDP in the earlier study is less than half that reported in this paper. This is due to the different methods used to convert physical units of pollution into different monetary units, variation in the years of study, and the alternative definition and scope of environmental cost, and the fact that the earlier work only involved air pollution.

Part III

This section provides the results of the long-run relationship between pollution cost and health expenditure. Based on a review of past empirical studies, pollution problems have contributed to an increase in health expenditure, which is a secondary data that is taken from the World Bank, in the long run (Yu, et al., 2018) and also affected economic growth (Yazdi, K. S. and Khanalizadeh, B., 2017). This implies that the negative impact of pollution problems is reflected in the relationship between health expenditure and labour productivity which is shown to have a negative effect in the long term. Therefore, this part of the paper provides a cointegration test for the long-run relationship and Pairwise Granger Causality Tests to confirm the validity of the estimated pollution cost and demonstrate that pollution problems have a negative impact on human capital by directly affecting health and indirectly affecting learning. The results are shown in Tables 4 and 5.

Table 4 Cointegration test

Unrestricted cointegration rank test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.667046	20.17807	12.32090	0.0020
At most 1	0.021028	0.382535	4.129906	0.5994

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
** denotes rejection of the hypothesis at the 0.05 level*
***MacKinnon-Haug-Michelis (1999) p-values*

Unrestricted cointegration rank test (Maximum eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.667046	19.79553	11.22480	0.0013
At most 1	0.021028	0.382535	4.129906	0.5994

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
** denotes rejection of the hypothesis at the 0.05 level **MacKinnon-Haug-Michelis (1999) p-values*
Source: Authors' estimations

Table 4 shows that the trace statistic is greater than the critical value of 20.17807 > 12.32090 in the case of a null hypothesis at rank = 0. In addition, in the case of a null hypothesis at rank 1, the results show that the trace statistic is less than the critical value of 0.382535 < 4.129906. Therefore, these statistics can indicate that the pollution cost and health expenditure have a statistically significant cointegrated long-run relationship at the 0.05 level. This finding is consistent with Yazdi et al. (2017) and Yu et al. (2018). The test results also confirm that the calculated pollution costs are valid.

Table 5 Pairwise Granger causality tests

Null hypothesis:	F-Statistic	Prob.
There is no Granger causality between health expenditure and pollution cost	0.90792	0.4275
There is no Granger causality between pollution cost and health expenditure	3.52775	0.0597

Source: Authors' estimations

In Table 5, the results of the linkage between pollution problems and human capital through health expenditure by causality testing show that pollution costs cause a statistically significant change in health expenditure at the 0.10 level. This finding is consistent with Yazdi et al. (2017) and Yu, et al (2018) which believes that pollution affects health expenditure in the long run as well as economic growth. This result implies that the impact of pollution has an effect on human capital and labour productivity in the long term through learning and work efficiency (Becker, 1960).

In part of validity tested, it shows that the pollution issues have an effect on human capital through health expenditure. Pollution has increased along with economic growth and although an expanding economy creates more income and may increase the ability to address health issues, in the long term, policymakers should consider the consequences by comparing the marginal cost and marginal benefit to support sustainable economic development.

The population provides labour for the country, and the health of its workers has a positive effect on production and affects economic development because when the labour force or population is in good health they learn more effectively. This is consistent with the concept of Gary Backer who believed that human capital is a measure of the future income of a person. For this reason, the government should have measures to strictly regulate the amount of air and water pollution in order to prevent a negative impact on long-term economic development. Penalties and tax measures could be implemented to regulate gas and wastewater emissions in industrial, logistics, and other economic activities. The government and related sectors should then integrate cooperation by focusing on participation and awareness of the negative effects of pollution that affect human capital and sustainable economic development. In addition, the government can rely on the results of pollution cost estimation in this dissertation as a framework for determining the budget for controlling pollution in Thailand.

Conclusion and suggestions

Under the concept of sustainable development, traditional GDP cannot comprehensively reflect sufficient economic development, but Green GDP is a better indicator. One of the important variables in calculating Green GDP is pollution cost. This paper estimates the air and water pollution costs by relying on SFA for the years 1997–2016 according to case studies in Thailand. During the past 20 years, Thailand has been subject to an average pollution cost of about 2,209,936 million baht ($63,141 million). The average air pollution cost during this period is about 827,383.11 million baht ($23,640 million) and water pollution costs of approximately 1,382,552.84 million baht ($39,501 million). However, this paper define the boundaries of air pollution cost, consisting sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), particulate matter 10 (PM10). The water pollution cost is limited to only biochemical oxygen demand (BOD) and nitrogen-ammonia (NH_3-N). There should be air pollution included, such as carbon dioxide (CO_2) and particulate matter 2.5 (PM2.5). Total coli and fecal coli in water pollution cost should also be included for further study.

In addition, the co-integrated long-run relationship test of pollution cost and health expenditure also shows that the pollution issues have an effect on human capital through health expenditure. Pollution has increased along with economic growth and although an expanding economy creates more income and may increase the ability to address health issues, in the long term, policymakers should consider the consequences by comparing the marginal cost and marginal benefit to support sustainable economic development.

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In addition to the results of this study, it shows the cost of air and water pollution that has occurred in Thailand over the past 20 years, which is a cost that has been neglected to cause a negative impact on human capital. The resulted can also be used as a framework for determining policies and guidelines for national development, both in the dimensions of the development of the manufacturing sector, investment support, long-term economic development plans, etc. Further, the calculated pollution cost can also be used to calculate the Green GDP, which is an indicator of sustainable development.

This study suggests that the government should pay more attention to the issue of pollution control in industrial production. In this study, air and water pollution costs are counted as production expenditure and negative impact on human capital and long-term development. Moreover, related agencies should pay attention to the regular and systematic collection of information on the amount of pollution.

Because of the amount of air and water pollution is not consistent, this study requires using mathematical techniques to help manage pollution data.

The problem of incomplete data is caused by the record of pollution from government agencies. Therefore, relevant government agencies should be such information disclosed to the public with easy access and linkage to a database in the form of Big Data for academic and administrative benefits.

References

Aaheim, A. A., and Nyborg, K. 1995. On the Interpretation and Applicability of a "Green National Product". *The review of income and wealth 41* (1): 57-71, http://www. roiw. org/1995/57.pdf.

Asheim, G. B. 1994. *Green Accounting-the environment and natural resources in national accounts.* http://www.balticuniv.uu.se/index.php/component/docman/doc_ download/1199-sbr-session-8-chapter-4-green-accounting.

Bartelmus, P. 1999. Greening the National Accounts Approach and policy use. *Internationalization of the Economy and Environmental Policy Options*. http://www.un.org/esa/esa99dp3.pdf.

Becker, G. S. 1960. *An Economic Analysis of Fertility.* http://www.nber.org/chapters/ c2387.pdf.

Brekke, K. A. 1994. Net National Product as a Welfare Indicator. *Scandinavian Journal of Economics 96* (2): 241-252. http://www.ssb.no/a/publikasjoner/pdf/DP/ dp_065.pdf.

Congressional Budget Office (CBO). 1994. *Greening the National Accounts, Washington, D. C.: CBO.* http://www.cbo.gov/sites/default/files/doc11.pdf.

Costanza, R., Hart, M., Posner, S., and Talberth, J. 2009. Beyond GDP: The Need for New Measures of Progress. *The Pardee papers, Boston University January 2009* (4).

Dasgupta, P. 2009. The Welfare Economic Theory of Green National Accounts. *Environmental and Resource Economics. January 2009* (42): 3. http://www.as. huji.ac.il/sites/default/files/The%20.

Färe, R., Grosskopf, S., Lovell, C. K., and Yaisawarng, S.. 1993. Derivation of shadow prices for undesirable outputs: a distance function approach. *The Review of Economics and Statistics,75(2)* 374-380.

Findiastuti, W., Anityasari, M., and Singgih, M. L.. 2011. *Green Productivity Index: Do Different Terms Measure The Same Things?*. Proceeding of Industrial Engineering and Service Science, September 20-21. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.296.6555&rep=rep1&type=pdf.

Fox, J. 2012. The Economics of Well-being. *Harvard Business Review 90* (1–2): 78-83.

Frankel, J. A. 2003. The Environment and Globalization. *The National Bureau of Economic Research Working Paper No. 10090.* http://www.nber.org/papers/w10090.pdf.

Hao, Y., Liu, S., Lu, Z. N., Huang, J., and Zhao, M. 2018. The impact of environmental pollution on public health expenditure: dynamic panel analysis based on Chinese provincial data. *Environmental Science and Pollution Research 2018* (25): 18853–18865. https://link.springer.com/article/10.1007/s11356-018-2095-y.

Harris, J. M., and Roach, B. 2018. Environmental and Natural Resource Economics: *A Contemporary Approach. Four Edition.* New York: Routledge.

Hartwick, J. M. 1990. Natural resources, national accounting and economic depreciation. *Journal of Public Economics 43* (3): 291-304.

Hartwick, J. M. 1994. National Wealth and Net National Product. *Scandinavian Journal of Economics 96* (2): 253-256. http://www.jstor.org/discover/10.2307/3440602?sid=21106361630423&uid=3739136&uid=2&uid=4.

Johnston, R.J., Rolfe, J., Rosenberger, R. S., and Brouwer, R. 2015. Introduction to Benefit Transfer Methods. *Benefit Transfer of Environmental and Resource Values 14:* 19-59. https://link.springer.com/chapter/10.1007/978-94-017-9930-0_2.

Kumbhakar, S. C., and Knox Lovell, C. A. 2003. *Stochastic Frontier Analysis.* Cambridge University Press: the United States of America.

Kumbhaker, S. C., Wang, H. J., and Horncastle, A. P.. 2015. *A Practitioner's Guide to Stochastic Frontier Analysis Using Stata.* Cambridge University Press: the United States of America.

Lintott, J.. 1996. Environmental Accounting: Useful to Whom and for What?. *Ecological Economics 16:* 179-190. http://www.sciencedirect.com/science/article/pii/0921800995000976.

Maler, K. G. 1991. National Accounts and Environmental Resources. *Environmental and Resource Economics 1:* (1-15). http://link.springer.com/article/10.1007%2FBF00305948#page-1.

Mebratu, D. 1998. Sustainability and sustainable development: Historical and conceptual review. *Environmental Impact Assessment Review 18* (6): 493-520. http://www.is.cnpm.embrapa.br/bibliografia/1998_Sustainability_and_sustainable_development_Historical_and_conceptual_review.pdf.

OECD. 2008. What is the impact of globalization on the environment?. *Economic Globalisation: Origins and consequences.* OECD Publishing. http://dx.doi.org/10.1787/9789264111905-8-en.

OECD. 2011. *How's Life?: Measuring well-being.* OECD Publishing. http://dx.doi.org/10.1787/9789264121164-en.

OECD. 2013. *OECD Guidelines on Measuring Subjective Well-being.* OECD Publishing. http://dx.doi.org/10.1787/9789264191655-en.

OECD. 2014. *Green Growth papers.* http://www.oecd.org/greengrowth.

Pemberton, M., and Ulph, D. 1997. *On the Measurement of National Income.* Department of Economics and ESRC Center for Social and Economic Research on the Global Environment (CSERGE). University College, London. http://www.researchgate.net/profile/David_Ulph/publication/242567680_ON_THE_MEASUREMENT_OF_NATIONAL_INCOME_1/links/02e7e5298650aa68e3000000.pdf.

Qi, S., Coggins, J. S., and Xu, L. 2000. Methodology for Integrated Environmental and Economic Analysis of GDP and Productivity. *Paper presented at the annual meeting of the American Agricultural Economics Association in Chicago, August* 5 - 8. http://ageconsearch.umn.edu/bitstream/20682/1/sp01qi02.pdf.

Solow, R.M. 1986. On the Intergenerational Allocation of Natural Resources. *Scandinavian Journal of Economics 88* (1): 141-149. http://www.jstor.org/discover/10.2307/3440280?sid=21106361630423&uid=3739136&uid=2&uid=4.

Sonthi, C. 2019. *Concepts and Measurements of the Green Gross Domestic Product of Thailand in the Context of Sustainable Development.* The Degree of Doctor of Philosophy (Economics), Graduate Scholl, Kasetsart University.

Thai-Thanh, D., and A. Mourougane. 2014. Estimating Shadow Prices of Pollution in Selected OECD Countries. *OECD Green Growth Papers 2014* (02). OECD Publishing: Paris.

Todaro, M. P., and Smith, S. C.. 2012. *Economic Development. Eleven Edition;* 467-468.

UNEP. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication.* http://web.unep.org/greeneconomy/sites/unep.org.greeneconomy/files/publications/ger/ger_final_dec_2011/Green%20EconomyReport_Final_Dec2011.pdf .

Vaghefi, N., C. Siwar, and Abdul Ghani Aziz, S. A.. 2015. Green GDP and Sustainable Development in Malaysia. *Current World Environment 10* (1): 01-08.

Vellinga, N., and Withagen, C. 1996. On the Concept of Green National Income. *Oxford Economic Papers 48:* 499-514. http://oep.oxfordjournals.org/content/48/4/499.short.

Wang, J., Jiang, H., and Yu. F. 2004. *Research on Green GDP Accounting in China: Review and Outlook.* http://www.caep.org.cn/english/paper/A-Review-on-Research-of-Green-GDP-and-Environmnetal-Accounting-in-China.pdf.

Yazdi, S.K., and Khanalizadeh, B.. 2017. Air pollution, economic growth and health care expenditure. *Economic Research-Ekonomska Istrazivanja 30* (1): 1181-1190. http://doi.org/10.1080/1331677X.2017.1314823.

Yu, F., Jiang, H., Cao, D., Wang, J., and Ge, C.. 2006. *Integrated Environmental and Economic Accounting in China: Proposed Framework and Preliminary Findings.* http://unstats.un.org/unsd/envaccounting/ceea/archive/Framework/China_SEEA.pdf.

Appendix

Table 1 Summary and descriptive statistics of the air pollutions

	Mean	Std. Dev.	Min	Max	Observations
SO2	45.99	34.64	7.00	184.00	140
NO2	80.04	23.03	30.33	132.76	140
CO	4.44	2.03	1.90	12.67	140
O3	112.54	25.99	40.90	197.60	140
PM10	156.91	57.36	64.48	355.70	140

Table 2 Summary and descriptive statistics of the air pollutions classified by region

Region	Pollution	Mean	Std. Dev.	Min	Max
North East	SO2	27.87	26.52	7.00	114.00
	NO2	96.93	13.46	78.00	129.00
	CO	5.75	2.08	3.05	10.80
	O3	91.48	13.34	74.00	122.00
	PM10	145.28	45.61	88.40	267.25
North	SO2	42.68	49.58	11.57	159.24
	NO2	69.19	9.17	49.27	86.57
	CO	5.46	3.09	2.91	12.67
	O3	118.75	30.19	93.38	197.60
	PM10	217.07	45.51	114.14	293.28
Southern	SO2	21.54	14.09	8.00	67.53
	NO2	54.87	24.45	30.33	108.33
	CO	3.28	1.25	2.08	5.87
	O3	73.55	15.06	40.90	109.33
	PM10	112.79	47.12	64.48	230.70
East	SO2	70.18	20.56	36.44	118.88
	NO2	71.28	9.94	60.11	98.00
	CO	3.65	1.53	2.30	6.77
	O3	125.27	8.87	104.04	143.17
	PM10	121.40	23.65	78.89	171.00
West	SO2	60.20	42.40	16.00	184.00
	NO2	67.28	14.67	49.00	107.00
	CO	2.97	1.34	1.90	8.10
	O3	126.18	14.35	105.00	151.00
	PM10	128.84	32.84	76.00	186.20
Central	SO2	39.91	19.15	9.67	85.00
	NO2	89.96	11.77	72.00	120.00
	CO	4.50	2.60	2.20	12.67
	O3	118.89	13.97	95.00	146.50
	PM10	210.26	52.94	152.25	355.70
Bangkok and its vicinity	SO2	59.55	27.99	25.00	109.82
	NO2	110.76	11.13	89.25	132.76
	CO	5.49	2.08	3.36	9.65
	O3	133.65	12.60	111.40	157.74
	PM10	162.77	45.47	96.11	276.83

Table 3 Summary and descriptive statistics of the water pollutions

	Mean	Std. Dev.	Min	Max	Observations
BOD	1.77	0.42	0.94	4.40	140
NH3N	0.26	0.13	0.05	0.85	140

Table 4 Summary and descriptive statistics of the water pollutions classified by region

Region	Pollution	Mean	Std. Dev.	Min	Max
North East	BOD	1.61	0.21	1.04	1.89
	NH3N	0.30	0.12	0.11	0.56
North	BOD	1.76	0.28	1.08	2.31
	NH3N	0.21	0.18	0.05	0.85
Southern	BOD	1.92	0.36	1.27	2.55
	NH3N	026	1.58	0.07	0.61
East	BOD	1.65	0.36	0.94	2.34
	NH3N	023	0.08	0.12	0.41
West	BOD	1.56	0.33	0.99	2.22
	NH3N	0.19	0.07	0.08	0.40
Central	BOD	1.77	0.36	1.06	2.56
	NH3N	0.27	0.11	0.12	0.63
Bangkok and its	BOD	2.13	0.64	1.53	4.40
vicinity	NH3N	0.37	0.12	0.20	0.57