Chapter 1
Introduction

1.1 Statement of the problem and significance of the study

In the 1980s, the concept of continuous economic growth could not be ecologically sustainable and it was replaced by the notion of "Sustainable development". (Beder, 2006) Among the various arguments on the sustainable growth path way and determinants, many ideas and international associations were published and articulated to the world to call for the concern on contribution of sustainable economic growth without creating too much pollutions or environmental degradation. The United Nations 2005 World Summit outcome document refers to the interdependent and mutually reinforcing pillars of sustainable development as (i) economic development, (ii) social development, and (iii) environmental protection. In addition, Agenda 21 has clearly emphasized everyone as a user and provider of information who needs to change from old sector-centered methods to new approaches that involve cross-sectoral co-ordination and the integration of environmental and social concerns into all development process together with broad public participation for achieving sustainable development. Consequently, the actions from both national and international cooperation have been done continually, and recently, the Copenhagen Climate Conference 2009.

Environmental quality has many dimensions, quality of our lives are affected by the air we breathe, the water we drink, the beauty we observe in the nature, and the diversity of species with which we come into contact. The productivity of resources in producing goods and services is influenced by the climate, rainfall, and the nutrients in the soil. Nowadays, we experience with the discomfort from the worsen environment change which is caused by both human and non-human activities. Such as from excessive noise and crowding, risk from nuclear catastrophe, each of these dimensions of environmental quality may respond to the economic growth in a different way. Therefore, a study of environment and growth should aim to be as comprehensive as possible. (Grossman and Krueger, 1995)

From the environmental problem that have been emerging rapidly all over the world since the middle of the 20th century and more severe in the 21st century, the problem includes climate change, waste problem, deforestation, natural source degradation and depletion and etc., all of them effect harmfully on human and ecological systems. The current major problem on climate change is believed that it emerges cruelly and suddenly in this century due to the stock pollutants which were ignored in the past when industrial revolution was started in 18th century, wastes and pollutions have been generated from both production and consumption sectors as well as the deforestation. Although the recent concern of environment and regulation of greenhouse gases emissions is taken, but decaying rate to restore naturally is limited and requires more time. At least, our concern should not be too late to protect and preserve the current environmental quality for ourselves and also for the future generations.

In the last decade, a new term has appeared in the economic literatures; Environmental Kuznets Curve (EKC) which introduced the inverted-U shaped relation ship between economic growth and environment. EKC hypothesizes in the early stages of economic growth that degradation and pollutions increase, but beyond some certain level of income per capita, the trend reverses. Thus, a high income levels of economic growth leads to environmental improvement. From various empirical and theoretical studies, there are many reasons support the hypothesis to exist, but results from some pollution indicators and different economy compositions do not support the validity of EKC. In addition, Time Series Analysis will help us for better understanding of causes and effects relationship in environmental pollution, to describe movement history of a particular variable in time or validity and trend in longer periods. In this case, we expect the forecast of future concentrations of air pollutants may lead to the recommendation of more effective instruments for environmental management.

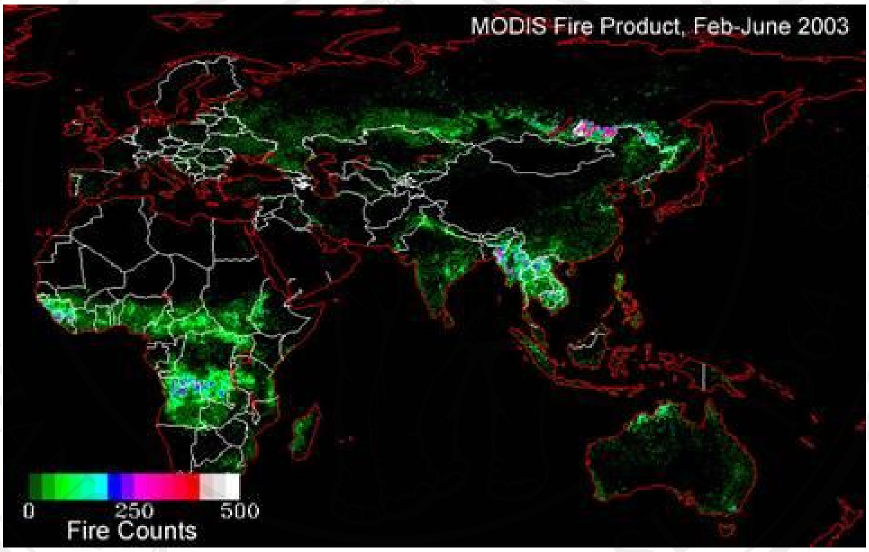
A systematic study of the EKC hypothesis, Time Series Analysis and its implications for policies to reduce chronic pollution in the Chiang Mai valley of Thailand is therefore urgently needed. The Valley is heavily polluted from open burning in the surrounding hills during the first three months of the year, this activity cause discomfort to tourists and chronic health problems to residents. The results of the study would illustrate the relationship between economic growth and environment (air quality) as the result of production and consumption in Chiang Mai province, so that people will realize the connection and should consider changing their behaviors in order to reduce pollutions, protect the natural resources and environment, especially the atmosphere, as the common properties. Such a study would also serve to evaluate the current urban atmosphere situation in Chiang Mai province as well as the effectiveness of existing government's tools (policies and regulations). For the policy maker side, the study result is useful for supporting the policy decision or being a policy guideline in order to reduce the air pollutants in Chiang Mai province.

Chiang Mai is the largest province outside Metropolitan Bangkok with a population of 1,650,000 residents. It is the economic, educational and tourism center of Northern Thailand with approximate 20 percent of Northern Region GDP and two percent of the country's GDP. Located in graphical area with a great number of popular tourist sites, Chiang Mai has become a world-class destination that attracts millions of local and international tourists each year. In 2004 alone, there were a total of 2,941,313 tourists visiting Chiang Mai; 55 percent of which are from other countries. Of the total GPP in 2008 of 127,602 million baht, agricultural production represented 16 percent, retail and wholesale trade industry presented 17 percent, industry 12 percent, hotels and restaurants 11 percent, transport and communication 7 percent and education a further 9 percent.

There are the arguments that Chiang Mai's quality of life has been deteriorating as the city has modernized and expanded, air pollution as a critical issue although it is one of a number of social problem and other environmental problem (e.g. inadequate solid waste disposal). Air pollution including haze appears to be the highest priority environmental problem with substantial impacts on the health of individuals, the costs treatment and lost production, and the negative impact on tourism.

The worst air pollution occurs during the dry cool season from December to February when a combination of agricultural burning external to the city, other internal stationary and mobile sources plus meteorological condition such as little wind and temperature inversions combined with Chiang Mai's location in a valley means that severe pollution is experienced. Resident's exposure is high particularly as the majority of transport to work, school, education and shopping is by open vehicle (i.e. motorcycle 43 percent; public bus 9 percent).

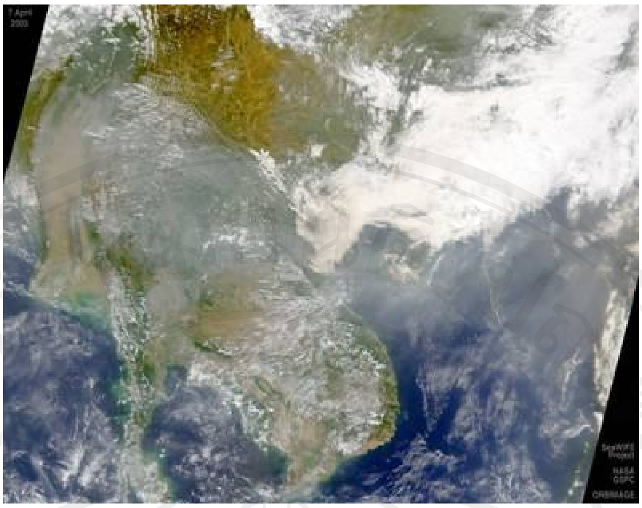
There is the working research project about climate change focusing on the influence of aerosols under the support of JGSEE (The joint of Graduate School of Energy and Environment), the research consortium. The research mentioned the severe evident from 2003 and 2004 as below figures. Figure 1.1 illustrates the critical area in South-east Asia of smoke problem from open burning during February – June 2003.



Source: JGSEE (The joint of Graduate School of Energy and Environment)

Figure 1.1: Open burning spots all over the world (Feb – June, 2003)

As the research mentioned the critical area of the world is in Sout-east Asia during the severe situation of smoke problem in 2003, there is some evidence supports this problem for Thailand; figure 1.2 illustrates the smoke from biological burning over Thailand during April 2003.



Source: JGSEE (The joint of Graduate School of Energy and Environment)

Figure 1.2: Smoke from biological burning over Thailand (April 2003)

The satellite by Moderate Resolution Imaging Spectroradiometer (MODIS) illustrates the red burning spots of smoke problem in Chiang Mai in Mar 2007, see figure 1.3 for evidence.

Source: JGSEE (The joint of Graduate School of Energy and Environment)

Figure 1.3: Red Burning Spot in Chiang Mai, March 2007 by Satellite

This study will focus on the air pollution in Chiang Mai province, the air pollution problems were reported seasonally, especially a smoke during the winter that not only effects on routine activities of local people and ecological system but also the tourists who are considering to come to Chiang Mai province where is named as the second capital city of Thailand and attracts visitors from good climate condition, natural places, Lanna tradition, and etc. Five major air pollutants; PM_{10}, O_3, SO_2, NO_2, and CO, will be focused in the study for economic analysis in term of Time Series Analysis, Trends, Volatility and Economic Instruments for Air Pollution Control.

1.2 Objectives of the study

The overall goal is to try to make recommendations as to policies and practices that would reduce the level and volatility of major pollutants in Chiang Mai province. In order to achieve this goal, the following specific purposes have been set:

1.2.1 Time Series Analysis of 5 major air pollutants concentration (PM_{10}, O_3, SO_2, NO_2, and CO) in Chiang Mai from Yupparaj Wittayalai School monitoring station to see trends and volatility.

1.2.2 ARIMA modeling for critical air pollutants (high concentration level and/or exceed the National Ambient Air Standard) to see the correlation of air pollution concentration in time series and to forecast the future concentration.

1.2.3 To recommend the air pollution control policies in order to reduce air pollution trends and volatility.

1.3 Educational / Application advantages

The present study is developed among the concern on environmental protection for sustainable development reinforcing with the economic development and social development. After publishing and forwarding the results from this study to the concern parties, these results may be used at the highest benefit in term of making perception and recommendation to the all people who are the stake-holder in the same environment in this world and own the responsibility in preserving the quality of environment for the future generations.

Perception: The results from Time Series Analysis and ARIMA modeling will illustrate time path of air pollution concentration as well as emphasize the air quality problem. These results will lead to the perception.

Recommendation: The results from this study will make recommendations as to policies and practices that would reduce the level and volatility of major pollutants in Chiang Mai and neighboring valleys such as Lamphun, Mae Hong Son, Chiang Rai, and etc. where may be concerned on air pollution trans-boundary.

1.4 Research Scope

The study will focus on air pollution concentrations in Chiang Mai as following parts;

- Location: The data set of air pollution concentrations are obtained from Yupparaj Wittayalai School monitoring station in Chiang Mai city.
- Data: The original air data is measured in hourly basis, this will be transformed into daily data for analysis.
- Time: The air pollution data is measured from January 1996 – April 2010.
- Analysis Tools: Descriptive statistics, Time Series Analysis, ARIMA model.
- The preliminary hypothesis for Time Series Analysis:

(a) The day-to-day volatility (AR) of PM_{10} pollution is significantly greater than that of the other four types of pollutants.

- This is the most critical air pollutants
- Its time path is currently at a stable peak of Environmental Kuznets Curve (EKC)
- Critical period of severe problem is in March each year.

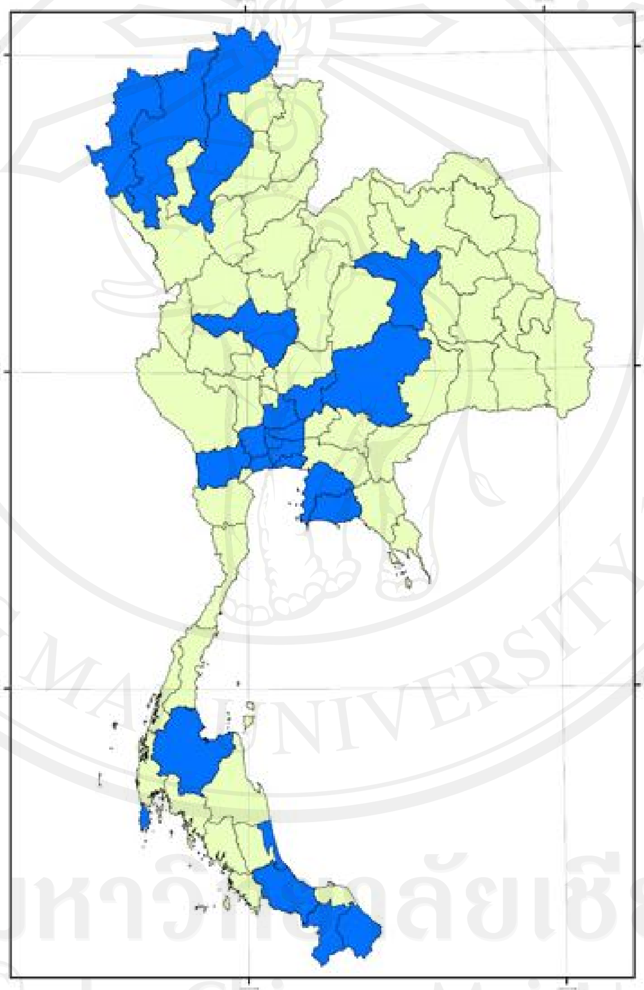
(b) CO and/or SO_2 and/or NO_2 has a significantly higher trend (I) over time than the four types of pollutants.

(c) The cyclical variations (MA) in O_3 are significantly more pronounced than those of the other four pollutants.

1.5 Sources of Data

Air pollution concentration data is obtained from Pollution Control Department. The data from Yupparaj Wittayalai School monitoring station is selected to be the representative of Chiang Mai Valleys.

There are 53 air quality monitoring stations; see map of stations in blue shaded areas below, and 5 meteorological stations in Thailand.



Source: Pollution Control Department

Figure 1.4: Maps of 53 air quality monitoring stations

There are seven Air quality monitoring stations in the Northern part of Thailand currently, see table 1.1. The measurement methods for each air pollutants are described in table 1.2.

Table 1.1: Air quality monitoring stations in the Northern part of Thailand

No.	Station ID.	Station Name	Province
1	35T	Chiang Mai City Hall	Chiang Mai
2	36T	Yupparaj Wittayalai School	
3	37T	Lampang	Lampang
4	38T	Sob Pad Health Center	
5	39T	Ta See Health Center	
6	40T	Mae Moh – The Provincial Waterworks Authority	
7	41T	Nakhonsawan Technical College	Nakhonsawan

Source: Pollution Control Department.

Table 1.2: Monitoring data and measurement methods

No.	**Pollutants**	**Measurement Method**	**Height (m.)**	**Range**
1	Carbon Monoxide (CO)	Non-Dispersive Infrared Detection	3	0 - 50 ppm
2	Nitrogen Dioxide (NO_2)	Chemiluminescence	3	0 - 500 ppb
3	Sulphur Dioxide (SO_2)	UV - Fluorescence	3	0 - 500 ppb
4	Ozone (O_3)	UV Absorption Photometry	3	0 - 500 ppb
5	Particulate Matter with Diameter < 10 microns (PM_{10})	Taper Element Oscillating Microbalance (TEOM)	3	0 - 1000 ug/m3

Source: Pollution Control Department.

1.6 Definition of Air Pollutants

Particulate Matter (PM)

Particulate matter, also known as particle pollution, is a complex mixture of extremely small solid particles and liquid droplets in the air. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.

The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. EPA groups particle pollution into two categories:

(i) Inhalable coarse particles: such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.

(ii) Fine particles: such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

Major sources of PM in Northern Thailand are open agricultural burning, forest fires, construction sites, unpaved roads, and etc. Health effects from PM10 pose the greatest problems, because they can get deep into your lungs, and some may even get into your bloodstream. These particles also reduce the visibility, damage environmental; making lakes and streams acidic, depleting the nutrients in soil, affect the diversity of ecosystems, damage aesthetic buildings and places.

Ozone (O_3)

Ozone is a gas composed of three oxygen atoms. It is not usually emitted directly into the air, but at ground-level is created by a chemical reaction between oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of sunlight. Ozone has the same chemical structure whether it occurs miles above the earth or at ground-level and can be "good" or "bad," depending on its location in the atmosphere.

In the earth's lower atmosphere, ground-level ozone is considered "bad." Motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents as well as natural sources emit NO_x and VOC that help form ozone. Ground-level ozone is the primary constituent of smoke. Sunlight and hot weather cause ground-level ozone to form in harmful concentrations in the air. As a result, it is known as a summertime air pollutant. Many urban areas tend to have high levels of "bad" ozone, but even rural areas are also subject to increased ozone levels because wind carries ozone and pollutants that form it hundreds of miles away from their original sources. "Good" ozone occurs naturally in the stratosphere approximately 10 to 30 miles above the earth's surface and forms a layer that protects life on earth from the sun's harmful rays.

Breathing ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen bronchitis, emphysema, and asthma. Ground-level ozone also can reduce lung function and inflame the linings of the lungs. Repeated exposure may permanently scar lung tissue. Ground-level ozone can also have detrimental effects on plants and ecosystems.

Sulfur dioxide (SO_2)

Sulfur dioxide is one of a group of highly reactive gasses known as oxides of sulfur which is the chemical compound, is produced by volcanoes and in various industrial processes. Since coal and petroleum often contain sulfur compounds, their combustion generates sulfur dioxide unless the sulfur compounds are removed before burning the fuel. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, and thus acid rain.

Statistical data from Thailand Energy Report 2008 shows the largest sources of SO_2 emission are from power plant 53percent, other industrial facilities 44percent, transportation 2percent from total SO_2 emission 0.66 million of ton. The smaller sources are from agriculture, construction and mining. Health effects are particularly important for asthmatics at elevated ventilation rates (e.g., while exercising or playing.)

Nitrogen dioxide (NO_2)

Nitrogen dioxide is one of a group of highly reactive gasses known as "oxides of nitrogen," or "nitrogen oxides (NOx)." Other nitrogen oxides include nitrous acid and nitric acid. NO_2 is the component of greatest interest and the indicator for the larger group of nitrogen oxides. NO_2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with a number of adverse effects on the respiratory system.

Carbon Monoxide (CO)

Carbon monoxide is an odorless, colorless and toxic gas. Because it is impossible to see, taste or smell the toxic fumes, CO can kill us before we are aware it is in our home. At lower levels of exposure, CO causes mild effects that are often mistaken for the flu. These symptoms include headaches, dizziness, disorientation, nausea and fatigue. The effects of CO exposure can vary greatly from person to person depending on age, overall health and the concentration and length of exposure.

Sources of CO such as unvented kerosene and gas space heaters, back-drafting from furnaces, gas water heaters, wood stoves, fire places, gas stoves, and tobacco smoke. Incomplete oxidation during combustion in gas ranges and unvented gas or kerosene heaters may cause high concentrations of CO in indoor air. Worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces) can be significant sources, or if the flue is improperly sized, blocked, disconnected, or is leaking. Auto, truck, or bus exhaust from attached garages, nearby roads, or parking areas can also be a source.

Statistical data from Thailand Energy Report 2008 shows the largest sources of CO emission are from residence and commerce 75 percent, transportation 14 percent, manufacturing 6 percent. The smaller sources are from power plant and other including agriculture, construction and mining.

Health Effects: At low concentrations, fatigue in healthy people and chest pain in people with heart disease. At higher concentrations, impaired vision and coordination; headaches; dizziness; confusion; nausea. Can cause flu-like symptoms that clear up after leaving home. Fatal at very high concentrations. Acute effects are due to the formation of carboxyhemoglobin in the blood, which inhibits oxygen intake. At moderate concentrations, angina, impaired vision, and reduced brain function may result. At higher concentrations, CO exposure can be fatal.

Air Quality Index (AQI)

The AQI is an index for reporting daily air quality, it indicates how clean or polluted that location's air is, and what associated health effects might be a concern for that area. The AQI focuses on health effects people may experience within a few hours or days after breathing polluted air. EPA (United States Environmental Protection Agency) calculates the AQI for five major air pollutants regulated by the Clean Air Act. The AQI is reported as the highest of the five pollutant-specific index values for that day and signifies the worse daily air quality in an urban area over a given time period.

Here is the list of average concentration and time for monitoring stations to be reported to PCD and to be used for this study.

Table 1.3: Ambient Air Standard

Air Pollutants	**Ambient Air Standard**	
	Average	**Standard**
1. PM_{10}	24 hour	Not exceed 120 µg/m^3
	1 year	Not exceed 50 µg/m^3
2. O_3 (Ground-level)	1 hour	Not Exceed 0.10 ppm. (200 µg/m^3)
3. SO_2	1 hour	Not exceed 0.3 ppm.(780 µg/m^3)
	1 year	Not exceed 0.04 ppm. (100 µg/m^3)
4. NO_2	1 hour	Not exceed 0.17 ppm. (320 µg/m^3)
5. CO	1 hour	Not exceed 30 ppm. (34.2 mg/m^3)

Source: Pollution Control Department

The descriptor words and color codes that identify the health effects associated with various ranges of the AQI are shown in the following table.

Table 1.4: AQI and level of health concern

Color	AQI Numerical Value	Levels of health concern	Meaning
Blue	0 - 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
Green	51 - 100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Yellow	101 - 200	Unhealthy for sensitive group	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Orange	201 - 300	Very unhealthy for sensitive group	Health alert: everyone may experience more serious health effects.
Red	More than 300	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.

Source: Pollution Control Department

The concentration data is calculated from this below formula by the monitoring stations.

$$I_i = I_{ij+1} + I_{ij}\left(X_i - X_{ij}\right) + \left(\frac{I_{ij}}{X_{ij+1} - X_{ij}}\right) \qquad (1.1)$$

where

X_i = Numerical concentration data of air pollutant i

X_{ij} = Minimum Numerical data of X_i range

X_{ij+1} = Maximum Numerical data of X_i range

I_i = Sub-AQI

I_{ij} = Minimum Numerical data of I_i range

I_{ij+1} = Maximum Numerical data of I_i range

The comparison between air pollution concentration and AQI are shown in the table below.

Table 1.5: Comparison of concentration data from five air pollutants and AQI

AQI	PM_{10} (24 hrs)	O_3 (1 hr)		SO_2 (24 hrs)		NO_2 (1 hr)		CO (8 hrs)	
	$\mu g/m^3$	$\mu g/m^3$	ppb	$\mu g/m^3$	ppb	$\mu g/m^3$	ppb	$\mu g/m^3$	ppb
50	40	100	51	65	25	160	85	5.13	4.48
100	120	200	100	300	120	320	170	10.26	9.00
200	350	400	203	800	305	1,130	600	17.00	14.84
300	420	800	405	1,600	610	2,260	1,202	34.00	29.69
400	500	1,000	509	2,100	802	3,000	1,594	46.00	40.17
500	600	1,200	611	2,620	1,000	3,750	1,993	57.50	50.21

Source: Pollution Control Department