GREENHOUSE GASES EMISSION IN THE MIDWEST: SYSTEM APPROACH TO POLICY AND PLANNING UNDER LIABILITY RULES

DISSERTATION

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ABSTRACT

The issue of global warming poses a daunting public economic policy design challenge, which has received the attention of economic theorists many of whom have recommended emission mitigation option schemes, based on the benefits and costs of mitigation, and the environmental consequences. Policy practitioners and the general public are increasingly enthusiastic in curtailing the magnitudes of these gaseous emissions, in particular, CO_2 emitted by coal-fired electricity generation. In this, the generating companies and the end-users have joint interest in profit maximization, but have dichotomy in their related activities. Tradition, in both law and economics, suggests that companies should be made to pay the costs of the pollution either through assignment and enforcement of full liability -- *Polluter Pays Principles* and, then pass these incurred costs on to the end-users by charging a higher rate per kWh of electricity they use. The results of the analytical investigation, in this thesis, which consists of three separate sections that attempt to put the issue in its proper context, have demolished the full liability doctrine and suggested an intermediate liability dogma. The first Section demonstrates that the overall total of CO_2 emissions from selected sources namely; coal, petroleum, natural gas, landfill and nitrogenous fertilizer, were significantly greater in the Midwest region, as a paradigm for the United States, from

1990 to 1998. The energy sources that contributed major portions to these trends were where coal combustion dominated the trends, in each state except in Michigan, where petroleum dominated the trend in 1998. Although Ohio contributed most to the region's overall total historical CO_2 emission trends, it was placed only fifth in *per capita* emission levels in 1998, whereas Indiana was placed first. Illinois was the largest emitter of both total N_2O and CH_4 emissions over this period with only a few minor exceptions in 1998. In the second Section, a theoretical framework and a flexible empirical methodology for measuring the degree of liability, based on economic efficiency and equity measures, where classical liberal maxim, regulatory axiom and ethical aspects act as catalysts, reveals that parties in question, that is, the generating company(s) and the end-user(s), should be liable for the externality dilemma. In other words, they should share the costs of the emission burdens that they create as results of their own acts. A finite number of intermediate liabilities were examined under a hypothesized federal CO_2 emission statute. Under the prescribed liability dogma, the third Section provides a background for regulators and stakeholders in optimizing policy design, to meet the stipulated emission standards, and choosing the best strategy for CO_2 mitigation, subject to a set of systemic constraints.

Dedicated to my parents

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2. Harunuzzaman and Akim M. Rahman, "Pipeline Capacity Turns Back: Problem and Options", Published in October 1997, *The National Regulatory Research Institute (NRRI)*, Columbus, OH 43210

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3. Agricultural Marketing Extension Service in Bangladesh: Proposal of Executive Structure and Its Functions, Submitted to the Director, Dept. Of Agricultural Marketing, Ministry of Agriculture, Bangladesh, March 1991

FIELDS OF STUDY

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Minor Field: Agricultural and Applied Economics

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CHAPTER 1

INTRODUCTION

I will tell you how the sun rose--
A Ribbon at a time -- Emily Dickinson

1.1 Introduction

The earth's surface appears to be warming as a result of the accumulation of greenhouse gases (GHGs) from myriad sources worldwide. None of the people emitting of these gases currently pays the cost to others of the adverse environmental effects of warming. No individual firm or any single country has had incentives to reduce emission significantly to protect the global environment against climate change. Individuals or each party have had an economic incentive to a *free ride* on the efforts of others. Without an international agreement limiting gaseous emissions, even if one region or country sharply reduced its emission unilaterally, GHGs emission from other regions or countries would continue to grow and the risks posed by climate change would not be reduced significantly. These political complexities, and the complexities of nature of the potential climate changes, require global cooperation. In essence to address the dual problems, the Framework Convention on Climate Change (FCCC), the first international agreement, was made in June of 1992 under the umbrella of United Nations (UN). The FCCC laid the foundation for international cooperation to reduce emissions of GHGs. The treaty encouraged industrial countries to reduce their GHG emissions to their 1990 levels in a specified period.

1.2 Background to the Greenhouse Gas Issues

The "greenhouse theory" -- that increases in atmosphere i.e. gases will cause the earth to warm -- was first developed by scientists before the turn of the century (Arrenhius, 1896). This theory holds that certain GHGs in the atmosphere allow the sun's ultraviolet and visible radiation to penetrate and warm the earth but absorb the infrared energy the earth radiates back into the atmosphere. By blocking the escape of this radiation, these gases effectively form a thermal blanket around the earth. To rebalance the incoming and out- going radiation, the earth's temperatures must increase. These effects often referred to as GHGs effects and the gases that are contributing to these effects are called GHG.

Within the popular press and literature, it is generally accepted that GHGs are the results of the availability of excess water vapor, CO_2 and other trace gases, namely, methane (CH_4), nitrous oxide (N_2O) and chloro-fluorocarbons (CFCs) in the atmosphere, that absorb the terrestrial radiation leaving the surface of the earth. Increases in the atmospheric levels of these trace gases could add significantly to future level of CO_2 induced global warming.

Most scientists and policy makers focus on CO_2 production since it includes the largest portion of emissions that are believed to induce environmental damages and future climatic changes. Moreover, human activities are suspected to have caused these large increases of CO_2 concentrations since pre-industrial times. Scientists believe that fossil fuel burning is a dominant human activity that has caused the increase of GHGs and especially, has increased the magnitude of CO_2 emissions. Philosophers, environmental economists and recently even traditional economists have demonstrated the links between increased CO_2 concentrations and human activities and found a parallel correlation of these two factors. Then the economists. especially. environmental economists have assessed two components of climate policy. Firstly. they have attempted to determine the value of damages that may arise from predicted environmental impacts. in essence. they have projected emission trends for various time spans. Secondly. they have estimated the costs of alternative options in searching for cost-effective options. They have gone further and attempted to connect "*free ride*" issues to the magnitudes of CO_2 emissions and the flows of economic gains to the party(s) who are responsible of these additional emissions. Moreover. they have prescribed different options to respond to policy maker's question about what can be done?

After all these developments to recommend feasible responses. we must ask question (s). "how do we allocate these costs among party(s) in question? The answer to this question. assisted by law and economics. in a one party case. is quite simple. However. "what about two party cases where one party is the producer and the other is the consumer. especially. in relation to the electricity generation"? The electric company(s) produces electricity using coal combustion to *"Supply safe and reliable energy to the end-users at a reasonable price and make available a reasonable rate of return to the investors "*. Based on this regulatory maxim. policy makers struggle to balance both parties' gains or losses. Recently. this issue became much more sensitive since the recent International Emissions Agreement -- *Kyoto Protocol.*

The policy-makers. especially. domestic policy makers. require conclusive studies on the issues. particularly. on electricity generation using coal combustion that has dominated the emission trends. Since the Midwest region of the United States produces a greater percentage of emissions from electricity generation, the policy makers of this region are concerned about options, available in the scientific literature to bring to a discussion table aimed at developing regulations that preserve that the generating company's benefits as well as the end-user's.

The thrust of my dissertation is to explore how a *CO_2 emission burden sharing policy (s)* can be assigned so as to maximize economic welfare. This will be accomplished using concepts and theories from both fields of economics and law. Classical liberal maxims and ethics will be catalysts to resolve *CO_2 emission burden sharing dogma*.

1.3 Organization of Dissertation

My dissertation consists of three distinct sections. Chapter II is Section one entitled: Greenhouse Gases Emission Trends in the Midwest. In this Section, a computable model was designed to estimate emission trends for each state in the Midwest, considering specific sources of emissions such as coal, petroleum, natural gas, fertilizers and landfills. The study will summarize emissions trends for each state and offers insight in the questions concerning the grading of CO_2 emission sources on an *a priority* basis.

Chapter III is Section two entitled: Sharing Emission Burdens under Liability Rules: Theory and Application. It reflects the main thrust of my dissertation. The purpose of this Section is to assign liability rules for CO_2 emission: such as those emitted by electricity generating company(s) to provide energy service to the end-users at a reasonable price. Traditionally, electricity company(s) could be made to pay the costs of the pollution either through the assignment and enforcement of full liability or through payment of Pigovian tax aimed to internalize the emission costs. The generating company(s) can then pass these incurred costs on to the end-users by charging a higher rate per kWh of electricity usage. The methods of charging for the emission costs may vary from the regulated utility era to a deregulated utility era. However, the goals and ideas remain unchanged.

The main question addressed in this Section is whether this policy(s) maximizes social welfare. To answer this question, I propose to first examine the relationships between the assignment of liability for abatement costs and the levels of CO_2 emitted from power plants, a paradigm of the *status quo* using the basic principles of "new" welfare economics, where peoples' willingness to pay are financial measures of welfare gains and losses. Finally, I will attempt to layout how the emission burdens can be shared among involved parties where these parties are homogeneous in goals but have dichotomy in activities. The third party, the pollutees or victims -- future generation, is included to include the effects on future generations. Policy makers, in general, connect this segment in debates where they struggle to preserve both party(s) political supports.

Chapter IV consists of the Section three entitled: A System Approach to Emission Reduction Options under Liability Rules. This Section attempts to demonstrate decision support and planning tools for regulators, stakeholders and for the end-users, in order to curtail the CO_2 emission levels that are caused by electricity generation using coal combustion. To reach the goal, I first investigated various feasible options that are currently available in the popular and scientific literature and then incorporated them into decision and planning support mathematical models with the aim to use these models, while related information are available, to develop computable models.

Finally, Chapter V summarizes the results from each of three sections and suggests future directions for research related to CO_2 gases issues and electricity generation using coal combustion.

CHAPTER 2

GREENHOUSE GASES EMISSION TRENDS IN THE MIDWEST

There once was a boy in Quebec, who was buried in snow to his neck, when asked, "Are you frizz", he replied, "Yes, I is". But we don't call this cold in Quebec -- (unknown)

2.1 Introduction

Historical records indicate that the average global temperature increased by 0.5^0 to 1^0 Fahrenheit (F) between 1890 and 1990 (Mella and Barrett, 2000). In the next hundred years, scientists predict that the temperatures may rise another 2^0 to 6^0F (Mella and Barrett, 2000). Such increases have occurred previously in Earth's history, but never over such a short time span. In fact the average global temperature has risen more in the last century than at any time in the past 10,000 years (Mella and Barrett, 2000). The question is what is causing this warming trend? Scientists agree that the answer hinges on the effect of greenhouse gases. Elevated levels of greenhouse gases could raise the average temperature and modify general air circulation patterns so that the trend is attracting increasing considerable attention and concern. The conclusions from authoritative scientific studies in 1990 and 1991 are powerful stimuli for a broad variety of national and international proposals for actions and policies. [1]

To explore alternative policies that are consistent with law and economics, and are acceptable to different political perceptions on mitigating GHGs emissions, it is important to understand the major trends in emission levels. As a prelude to this task, this chapter attempts to integrate historic developments related to global warming issues and strives for displaying emission trends for Midwestern states, namely the State of Ohio, the State of Indiana, the State of Illinois, the State of Michigan, the State of Missouri, the State of Iowa, the State of Wisconsin and the State of Minnesota in order to represent the Midwest region.

2.2 Historical Movement of Global Climate Policy and that in the United States

Rising concentrations of CO_2 in the atmosphere were first detected in the late 1950s, and observation of atmospheric concentrations of CH_4, N_2O and other gases began in the late 1970s. However, concern about the effects of rising atmospheric concentrations of GHGs remained largely the province of atmospheric scientists and climatologists, until the mid-1980s, when a series of international scientific workshops and conferences began to move the topic onto the agenda of the United Nation's specialized agencies.

The Intergovernmental Panel Convention on Climate Change (IPCC) was established under the auspices of the United Nations Environmental Program (UNEP) and the World Meteorological Organization (WMO) in late 1988, to accumulate available scientific research on climate change and to provide scientific advice to policy-makers. A series of international conferences provided impetus for an international treaty aimed at limiting human impacts on climate. In December 1990, the United Nations (UN) established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (INC). Beginning in 1991; the INC hosted a series of negotiating sessions that culminated in the adoption of emission target by more than 160 countries including the United States. On June 4, 1992, the Framework Convention on Climate Change (FCCC) was signed at the "Earth Summit" in Rio de Janeiro, Brazil. [2]

2.2.1 Framework Convention to the Kyoto Protocol

The Framework Convention divided its signatories into two groups: the countries listed in Annex-I to the Protocol and all others. The United States is listed as one of Annex-I countries. The Convention requires all parties to undertake policies and measures to limit emissions of GHGs and to provide national inventories of emissions of GHGs. Annex-I parties are further required to take actions with aimed of returning to their 1990 level of emissions of CO_2, CH_4 and N_2O.

The signatories agreed subsequently that Annex-I party should provide annual inventories of GHGs emissions. In April 1993, the US President committed his country to stabilizing U.S. emissions of GHGs at the 1990 level by the year 2000, using an array of voluntary measures. In the following years, however, GHGs emissions in the United States and many other Annex-I countries continued to increase. As a result, the signatory countries continued to meet as the Conference of the Parties took up the question of how to limit emissions in the post 2000 period. Finally, in a conference in 1996, they agreed to encompass binding limits on emissions for the parties in the next meeting and asked for a conference in Kyoto, Japan.

2.2.2 Overview of U.S. Strategy in the Kyoto Negotiations and Beyond

Before the Kyoto Agreement, the Clinton Administration proposed a set of measures to reduce emissions domestically. These are:

i) Corresponding to the first stage of the three stage domestic strategy that the President announced in October 1997, the Administration proposed a five-year, $6.3 billion package of tax incentives and R&D investments to improve energy efficiency. It has commenced a set up a series of consultations with domestic energy intensive sectors, aimed at achieving voluntary agreements on reducing GHGs emissions and submitted a proposal for electricity restructuring that will reduce GHGs emissions.

ii) The second stage included a review of its program and an evaluation of the next steps as the administration prepares for a market-based trading system for GHGs emissions.

iii) In the final stage (2008-2012), emissions reductions would occur through a domestic trading program, integrated with international flexibility mechanisms including international trading of emissions allowances, the Clean Development Mechanism (CDM) and Joint Implementation (JI).

The most fundamental feature of the Kyoto Protocol to the Framework Convention, adopted on December 11, 1997, is a set of quantified GHGs emissions targets for Annex-I countries, which collectively produce about 5 percent less than the 1990 emissions of those countries taken as a group. The target for the US was 7 percent lower than the 1990 emissions level. The conference concluded, "Developing country signatories are not required to have quantified targets". By-passing developing countries from the loop creates a loophole in the Kyoto Protocol. The U.S. government formally signed the Protocol on November 12, 1998; however, the US Senate placed certain conditions in advance on the provisions of a Climate Change Treaty to which it would be prepared to consent. Those conditions were embodied in the Byrd-Hagel Resolution (S. Res.98), a "sense of the Senate" resolution which was passed by a vote of 95 to 0 on July 25, 1997. The summary of the resolution was:

The United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change of 1992, at negotiation in Kyoto in December, or thereafter, which would---
a) Mandate new commitments to limit or reduce greenhouse gas emissions for the Annex-I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period or
b) Would result in serious harm to the economy of the United States

The Protocol has not yet been sent to the Senate. The view of the Executive Branch was expressed by the White House Press Secretary:

Signing does not legally commit the United States to implement the Protocol. The Protocol would become binding only with the advice and consent of the U.S. Senate. President Clinton has made clear the United States regards the Kyoto Protocol as a work in progress and that it will not be submitted for ratification without the meaningful participation of the key developing countries in efforts to address climate change. [3]

Beyond the Kyoto Protocol

Since the signing of the treaty, the signatories have continued to shape the "work in progress" and have met few times but many issues remain unsettled. The important issue dividing Kyoto signatories is signified by the term "supplementary" which says "emission trading, Clean Development Mechanism and or Joint Implementation shall be supplemental to domestic actions for the purpose of meeting quantified emissions limitations and reduction commitments". The European Union takes the position to limit the emission credits through the said approaches. On the other hand, the view of U.S. government is that no such sub-limit was intended and imposing this sub-limit would raise the cost of compliance without providing any environmental benefit.

2.3 Emission Trends in the U.S. and Midwest Region

Since the Industrial Revolution, atmospheric concentrations of the most important GHGs--CO_2, CH_4 and N_2O have raised at an increasing rate. In the United States, the emissions of CO_2 have increased more than 1.75 times since 1960 whereas, in Midwest region, the emission of CO_2 has doubled during that period. In 1998, the gross total CO_2 emission levels were 1589.18 million tons where energy source dominated these emissions trends.

Moreover, Midwest region's GHGs emissions as a basket in 1998 were about 17.52 percent higher than emissions in 1990. Since 1990, the Midwest emissions have increased at an annual rate of 2.18 percent, much faster than its average annual population growth rate (0.48 percent). In 1998, CO_2 emissions contributed by type of sources namely Coal Combustion (CL) 35 percent, Petroleum Combustion (PL) 34 percent, Natural Gas burning (NG) 12 percent and Landfills (LF) contributed 19 percent (Figure 2.1). In the same year, CO_2 emissions were dominated, driven by the combustion of fossil fuels to meet the region's energy needs. CH_4 and N_2O made much smaller contributions 0.095 percent and .004 percent respectively. In this year C_2O emission level increased by 12 percent compare to the emission level of 1990 in the Midwest (Figure 2.2). The Midwest region, in 1998, was responsible for 14 percent (Figure 2.3) of the US gross CO_2 emission where coal, petroleum and natural gas

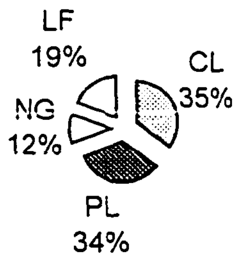

Figure 2.1: Source type contributions to gross total CO_2 emission in Midwest (1998) [a]

a. Data Source: Converted from State Energy Data Report, 1997 and DOE/EIA-0573 (98) Report
CL = Coal, PL = Petroleum, NG = Natural Gas.
LF = Landfill, converted from total waste = population x waste per capita (EPA Workbook, 1998)

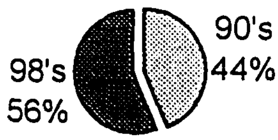

Figure 2.2: Source type contributions to gross total CO_2 emissions in Midwest (1998 over 1990)

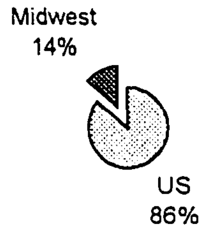

Figure 2.3: Gross total CO_2 emission in Midwest compare to the US (1998)

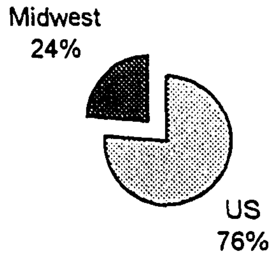

Figure 2.4: CO_2 emission from coal combustion in Midwest compare to the US (1998) [b]

b. Data Sources: Converted from State Energy Data Report. and DOE/EIA-0573 (98) Report were selected as sources of emission. The coal combustion in the Midwest, in 1998, was responsible for 24 percent (Figure 2.4) of the US total gross CO_2 emitted due to coal combustion. This accountability was slightly higher than 1990 emission levels.

2.4 The Concept of Greenhouse Gases

The "greenhouse theory" ---that increases in atmospheric CO_2 will cause the earth to warm --- was first concerned by scientists before the turn of the century (Arrenhius, 1896). This theory is based on the idea that the earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength thermal radiation back into the space. On average, the absorbed solar radiation is balanced by the outgoing thermal radiation emitted into the space. A portion of this thermal radiation is itself absorbed by gases in the atmosphere. By blocking the escape of this radiation, these gases effectively form a thermal blanket around the earth. To rebalance the incoming and outgoing radiations, the earth temperature increases and warms the surface and atmosphere, creating what is known as the "natural GHGs effects".

Although the earth atmosphere consists of oxygen and nitrogen, neither of these gases plays a significant role in the GHGs effect because both are essentially transparent to thermal radiation. Changes in atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land and the oceans (IPCC, 1996). Holding everything else constant, increases in GHGs concentrations in the atmosphere would produce positive radiate forcing and cause climate change. Under the UNFCCC, the definition of climate change is:

A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere which is in addition to natural climate variability observed over comparable time periods.

Clarifying the climate change, IPCC (1996) concluded that:

Human activities are changing the atmosphere concentrations and distributions of GHG. These changes can produce a radioactive forcing by changing either the reflection or absorption of solar radiation or the emission and absorption of terrestrial radiation.

There are two ways in which mankind can influence the atmospheric concentrations of GHGs: by increasing the strength of GHGs source and by decreasing the strength of GHGs sink. Man-made sources are the easiest to quantify that warrants scientific inquiry and policy analysis on the issue.

2.5 Gases Studied in this Section

In this section, I will attempt to identify gases that are included in our definition of GHGs. I begin this by incorporating, a set of mathematical structures, and various forms of identifications of GHGs that are contributed by different agencies or groups in the popular and scientific literature. Then, I will approach to limits in the number of GHGs that will be captured and estimate for estimating historical emission trends in the Midwest states.

US EPA (inventory report, 1998) identified the GHGs as

$\{CO_2, CH_4, N_2O, NO_3, O_3, H\} \in GHGs$

Taking the global warming potentials into account, US EPA has defined

$GPW = f\ (O_3, GHGs)$, where

$\{CO, SO_2, NO_2, NO_3\} \in O_3$ and

{CFCs, HCFCs} $\in$ H

In 1996, the IPCC identified GHGs as

GPW $= f$(GHGs), where

{CO_2, CH_4, N_2O, HCF_s} $\in$ GHGs

In the same report, CO_2 was chosen by the IPCC as a reference gas to measure the radiate forcing impacts of various GHGs. Therefore,

GPW $= f(CO_2)$

To address climate change risks better and to build on the existing treaties, in 1997, Kyoto Protocol identified GHGs as follows

GPW $= f$(GHGs) where

{CO_2, CH_4, N_2O, CFC_s} $\in$ GHGs

We know, the definition of GWP is the ratio of global warming or radiative forcing (both direct and indirect) from one kilogram of a GHG to one kilogram of CO_2 over a set period of time (Lashof and Tirpak, 1990).

Incorporating the definition of GWP and the identified GHGs from the above, I can rewrite the mathematical structure of GHGs production as follows

{CO_2, CH_4, N_2O, H_2O, O_3, CFCs, HCFCs and H} $\in$ GHGs

It is widely accepted in the literature that water vapor, although it is a significant contributor to global warming, occurs in such great abundance as a result of naturally-occurring physical, chemical and biological processes, and is regarded as an uncontrollable GHG and is not normally accounted to measure GWP.

Therefore, {CO_2, CH_4, N_2O, O_3, CFCs, HCFCs and H} $\in$ GHGs, the mathematical structure of GHGs prevails.

Recent emission related studies have ratified that O_3 is a secondary pollutant resulting from complex chain of photochemical reactions between (primarily) non-methane volatile organic compounds, CO and NO_x, in presence of sunlight and heat. Its effects are highly variable and extremely difficult to quantify and therefore, O_3 is excluded in my identification of GHGs.

Therefore the equation, $\{CO_2, CH_4, N_2O$ CFCs, HCFCs and $H\} \in$ GHGs prevails.

Finally, taking into account policy-makers' recent contributions, we know that fluorocarbons and halocarbons, although believed to have significant GWPs and almost entirely of anthropogenic origin, are being phased out as a result of an international agreement reached under the Montreal Protocol on Substances that deplete the O_3 Layer and therefore, I have excluded these gases from my treatment of GHGs. Therefore the equation $\{CO_2, CH_4,$ and $N_2O\} \in$ GHGs prevails.

This mathematical structure suggests that CO_2, CH_4 and N_2O are the three primary GHGs that should be incorporated in this study. CO_2, CH_4 and N_2O are emitted continuously and removed from the atmosphere by natural processes. Anthropogenic activities, however, can cause additional quantities of these and other GHGs to be emitted or sequestered [4], there-by changing their global atmospheric concentrations. Natural activities, such as respiration by plants or animals, and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes except when directly or indirectly perturbed out of equilibrium by atmospheric activities generally do not alter average atmospheric GHGs concentrations over timeframe of decades. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems.

The gases emitted from landfills, primarily, CO_2 and CH_4 are the results of the decomposition of organic materials in an anaerobic environment.[5] These gases are emitted directly in to the atmosphere. However, in some landfills the gas is recovered and either burnt or used as an energy source. When landfill gas is burnt, the CH_4 portion of the gas is converted to CO_2. Since the CO_2 from landfills comes mainly from organic materials, that absorb a similar amount of carbon during the growing cycle, the net effect of CO_2 emissions from landfills can be assumed equal to zero. [6] Since the data related to landfill emissions were unavailable for each state in this region, therefore, the landfill source was included for emission level estimations where the data information were available and it was mentioned in the respective section if it was otherwise.

N_2O is produced naturally in soils by microbial processes. Use of commercial nitrogenous fertilizers provides additional nitrogen source and increases emissions of N_2O from soil. The nitrogenous fertilizer as well as landfill sources were integrated in estimating N_2O emission levels.

2.6 Sources, Types and Quantification of GHGs

The purpose of this Chapter is to identify the primary sources, types and quantities of GHGs emissions in the Midwestern states since 1960. Only these GHGs emissions that are physically located within the borders of each state in this region are considered. Emissions generated in other regions to help meet Midwest region needs for energy and materials are not included. Similarly, emissions due to energy and materials, produced in this region but consumed elsewhere will not be subtracted. More precisely, activities by the citizens of this region result in GHGs emissions are traced, then scrutinized as required in my emission estimation and summarized in Table 2.1. Matrix of activities along with the GHGs considered in this chapter is shown in Table 2.1

The emission estimations provide base data for subsequent chapters as well as providing information for decision-makers that are considering what actions to take to curtail emission magnitudes, especially, CO_2 emissions where coal combustion dominates the trends significantly.

2.6.1 Carbon Dioxide (CO_2)

Most Midwest anthropogenically produced CO_2 emissions result from energy consumption. Most commercial energy is produced through the combustion of fossil fuels, such as Coal, Petroleum and Natural Gas. Some non-fossil fuel energy processes, notably cement production and some energy process' such as biomass burning can also produce CO_2 in this region but their levels are insignificant comparing to gross emission levels emitted from fuel combustion. Energy sources in Midwest, in 1990, contributed 81 percent to gross total CO_2 emissions in the region in which Coal, Petroleum and Natural Gas contributed 46 percent, 40 percent and 14 percent respectively (Figure 2.5). The contributions of Natural Gas remained constant in 1998 but Petroleum contributed slightly more than 1990 and Coal contributed slightly less over 1990 (Figure 2.6). This was due to the increase in demand for energy as a result of increasing population, which was related to increase in the number of jobs in the Midwest. Per capita electricity usage

Sources	CO_2	CH_4	N_2O
Energy Related			
- Coal	**x**		
- Petroleum	**x**		
- Natural Gas	**x**		
- Biomass Fuel Combustion	x		
- Coal Mining		x	
Materials Production Related			
- Production Process	x		
- Landfills	**x**	**x**	**x**
- Forest Products	x		
Agricultural Related			
- Domestic Animals		x	
- Animal Manure		x	
- Fertilizer Use			**x**
- Agriculture Burning		x	
Land Use Related			
- Wetlands		x	

Table 2.1: Matrix of Sources and GHGs [c]

c. Corresponding bold marked sources are incorporated in my emission estimation

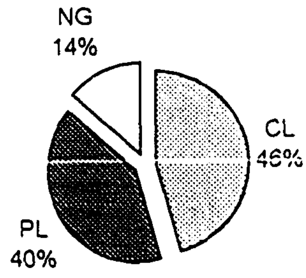

Figure 2.5: CO_2 emission from energy sources in Midwest (1990) [d]
d. Data Source: Converted from State Data Energy Report, CL = Coal, PL = Petroleum, NG = Natural Gas

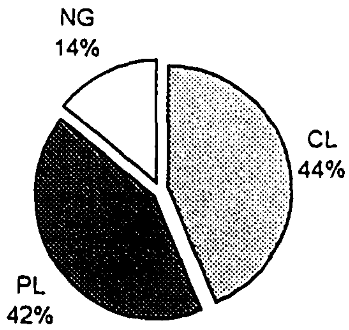

Figure 2.6: CO_2 emission from energy sources in Midwest (1998) [e]
e. Data Source: Converted from State Data Energy Report, 1997 and DOE/EIA-0573 (98)

also increases due to the increase of time saving options facilitated by technology improvements. The total CO_2 emission levels, in 1998, in Midwest were 1589.175 million tons.

2.6.2 Methane (CH_4)

Gases from landfills, consisting primarily of CH_4 and CO_2, are produced as a result of the decomposition of organic waste in an anaerobic environment. The principal source of CH_4 in Midwest was each state's Municipal Solid Waste (MSW). In 1997, the Midwest anthropogenically based CH_4 emissions totaled ,1507.63 thousand tons, a decline of about 2.64 percent from the 1996 levels and 228.788 thousand tons less compare to1990 levels. The decline can be attributed to an increase in CH_4 recovery for energy use in order to meet the federal act. A diminishing portion of MSW (Figure 2.7) was the results of regulatory activities and technology improvement that had positive influences on recycling and compost programs. Moreover, increasing amounts of CH_4 are being captured and used as an energy resource or burnt to control odor or emissions of other pollutants. These developments have reduced waste management emissions. The trends were upward till 1994 although it had decreasing rate of changes since 1960.

2.6.3 Nitrous Oxide (N_2O)

Most anthropogenically-based N_2O emissions in the Midwest region can be attributed to agricultural and energy sources. In particular, more than 54 percent of the estimated emissions of N_2O were attributable to nitrogen fertilization of agricultural soils.

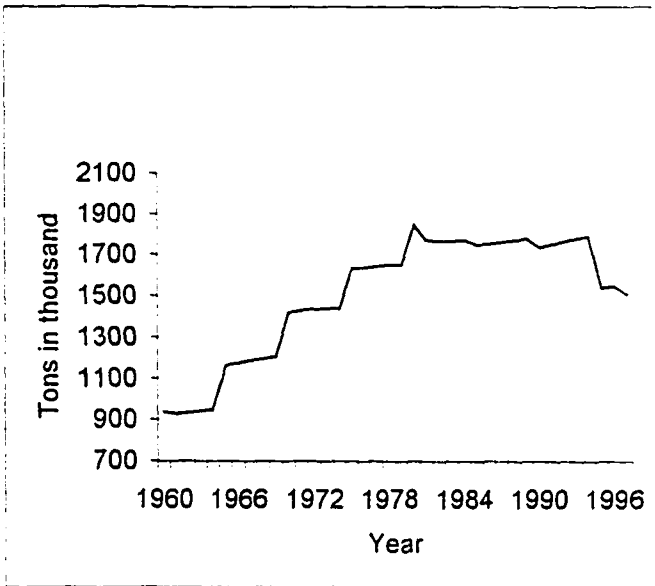

Figure 2.7: CH_4 emission in Midwest (1960 – 1998) [f]

f. Data Source: Converted from total waste = population x per capita waste (EPA Workbook, 1998)

The second largest source of anthropogenic N_2O emissions was energy consumption, which includes mobile source combustion from passenger cars, buses and trucks. The estimated N_2O, excluding Landfill source, emissions in the Midwest region totaled 76.99 thousand tons in 1998, about 1.3 percent less than 1997 but much more increased than 1990. Nearly all the increases from 1990 levels can be attributed to emissions from the nitrogen fertilization of agricultural soils. The trend of N_2O emission from nitrogenous fertilizer was upward till1971. It was the results of using more nitrogenous fertilizer than the recent years. Since 1972, the trend declined and again significantly increased in 1981. The 1990 N_2O emission level was the highest since 1960. Midwest region produced huge quantity of corn and soybean in that year. This region had a bumper crop production in 1990. Therefore, using nitrogenous fertilizer in crop production, might have a linkage to 1990, the highest emission level.

2.7 Emission Estimation

2.7.1 Data Collection

The time series data collected from different sources mainly, Energy Information Administration (EIA), U.S. Department of Agriculture (USDA) - local and federal agencies, for each state for 37 years have been input to a Microsoft Excel -6.0 data file. A computer program used as template was then developed using an PC-SAS package to manage, convert and aggregate the yearly source data into yearly GHGs emissions for each state. These yearly GHGs emissions from each state were then aggregated to yearly Midwest regional GHGs emissions.

2.7.2 Methodologies for Estimating GHG Emissions

Carbon Dioxide (CO_2)

To estimate CO_2 emission from coal, natural gas and petroleum product, the following steps were followed.

1. The total carbon content of the fuel was estimated
2. The net potential carbon emission was calculated
3. The carbon actually oxidized from energy uses was estimated
4. Net carbon emission from energy consumption to total CO_2 emission was converted

Step One

Estimation of Total Carbon Content in Fuels:

Here carbon content represents the total amount of carbon that could be emitted if 100 percent was released into the atmosphere.

$TC_{sit} = (F_{sit} * CCC_{it})$, where

TC_{sit} = Total Carbon Contained in fuel i in pounds (lbs. C)

F_{sit} = Fuel Consumption for fuel i in million Btu

CCC_{it} = Carbon Content Coefficient for fuel i in lbs. C / 1 million Btu.

The CCC are 57.5, 31.9 and 44 for coal, natural gas and petroleum respectively.[7]

Step Two

Estimate Carbon used for non-combustion purposes:

The amount of carbon contained that is used for non-combustion purposes can be determined.

$K = F_{intj} / F_{itj}$, where

n =non-combusted purpose, j = nationwide

K = National level fraction of fuel i used for non combustion purposes

F_{intj} = Fuel i used for non combustion purposes in nationwide in million Btu

$F_{it\,j}$= Amount of fuel i consumed nationwide in year t in million Btu

F_{sit} = Amount of fuel i consumed in state s for the specified sector in year t

in million Btu

Carbon Combusted

$NCC_{sit} = \{TC_{sit} - (K * TC_{sit})\} / 2000$, where

NCC_{sit} = Net Carbon Contained that are combusted for fuel i in short tons

Step Three

Estimate Carbon Actually Oxidized: [8]

$TCO_{sit} = NCC_{sit} * f$, where

TCO_{sit} = Total Carbon Oxidized in tons (in short ton)

f = Fraction oxidized for solids and liquids is 0.99 and for NG is 0.995

Step Four

Estimate CO_2 Emission level

$E_{sit} = TCO_{sit} * M_i$

$TE_{sit} = \Sigma E_{sit}$

$GTE_{sit} = TE_{sit}$

$GTE_{CO2\,MW\,t} = \Sigma\, GTE_{st}$ where

E_{sit} = CO_2 Emission from fuel i in state s in year t

TE_{sit} = Total CO_2 emission from fuel i in state s in year t in tons

GTE_{sit} = Grand total CO_2 emission in state s from different sources in year t in tons

$GTE_{CO2\,MW\,t}$ = Grand total CO_2 emission in the Midwest states in year t in tons

M_i = Molecular weight ratio.

The molecular weight ratio for CO_2 is 3.6667, calculated as follows: the total molecular weight of CO_2 is 44 grams. Of the 44 grams of CO_2, the molecular weight of carbon is 12 grams. Hence, for every gram of carbon that is burnt, 3.6667 grams of CO_2 are produced. Without loss of generality, I can take the constant 3.6667 to estimate short tons of CO_2 per short ton of carbon. Although the type and quality of coal used in generating electricity, or other uses where coal is combusted, vary from one place to another, the carbon content and thus the CO_2 emission levels vary but not in a significant way. Therefore, I can ignore the influences of type and quality of coal in estimating CO_2 emission levels.

Methane (CH_4)

To estimate emission levels, the following steps were followed

Step One

Estimate Waste in Place at MSW landfills

$W_{st} = P_{st} * R_{st} * M_{st}$, where

W_{st} = Total Waste in state s in year t in tons

P_{st} = Population in state s in year t in million

R_{st} = Per capita waste landfill (pounds/per person/year) (EPA Workbook, 1998)

M_{st} = 30 year multiplier for waste in place (Constant).[9]

Step Two

Estimate CH_4 Generated from Waste Place:

Fraction of W in large vs. Small landfills are exogenous

$W_{small\ st} = W * F_s$

$W_{large\ st} = W * F_l$

$TE_{st} = E_{small\ st} + E_{large\ st}$, where

$W_{small\ st}$ = Waste in small landfills in short tons in year t in state s

$W_{large\ st}$ = Waste in large landfills in short tons in year t in state s

TE_{st} = Total CH_4 emission in short tons in state s in year t

F_s = small landfills fraction

F_l = large landfills fraction

As we know, the CH_4 generation rates in large versus small landfills differ due to a variety of factors such as different waste ages and ease of moisture movement within the landfill. For my estimation, a large landfill is defined as having more than 1.1 million tons of waste in place. Therefore, I use the default values developed by the U.S. EPA in 1998 for the fraction of waste in large versus small landfills.[10]

In case of small landfills

$E_{small\ sD} = e * W_{small\ st}$, where

$E_{small\ sD}$ = CH_4 geneated from W in ft^3 /day

e = coefficient for non-arid = 0.35 of W(in short ton) ()[11]

To convert this result for daily CH_4 emissions in ft^3 to annual CH_4 emissions in tons. I multiplied the result by conversion factor.

$E_{small\ st} = E_{small\ sD} * CF$, where

$E_{small\ st}$ = CH_4 emission from small landfills in state s in year t in short tons

CF = conversion factor = 0.0077 (short tons CH_4 / year) / (ft^3 / day) ()[12]

In case of large landfills

$W_{avg\ st} = W_{large\ st} / N_{st}$

$E_{l\ D} = N_{st}\ (417957 + e_i * W_{avg})$ ()[13]

$E_{large\ st} = E_{l\ D} * CF$

$TE_{CH4\ st} = E_{small\ st} + E_{large\ st}$, where

W_{avg} = Average waste in place in short tons in state s in year t at large landfills

$W_{large\ st}$ = Waste in large landfills in short tons in year t in state s

N_{st} = Number of large landfills in state s in year t

$E_{l\ D}$ = CH_4 emission from large landfill in state s in ft^3 / day

$TE_{CH4\ st}$ = Total CH_4 emission from landfill in state s in year t

Adjustment for Oxidation

Not all CH_4 generated from landfills is emitted into the atmosphere. Some CH_4 is oxidized in the top layer of soil over the landfills and thus is not emitted to the atmosphere. The extent of such oxidation is uncertain and depends on the characteristics of the soil and the environment. U.S. EPA assumed in its Workbook, 1998 that 90 percent of total CH_4 on a landfill is oxidized. Therefore, in my estimates, total CH_4 emissions from landfill is:

$TE_{landfill\ st} = TE_{st} * 0.90$, where

$TE_{landfill\ st}$ = CH_4 emissions from landfills in tons in year t in state s

Industrial landfills are not significant in mounting CH_4 emission (U.S EPA Workbook, 1998). Therefore, they have been ignored in my estimates.

CO_2 estimation from Landfill Source

$E_{sit} = W_{st} * 0.40$ tons, (EPA, 1998)

Nitrous Oxide (N_2O)

There are different sources that contribute to emissions of N_2O. Nitrogenous fertilizers are the major source of N_2O. My study will consider nitrogenous fertilizer as a source of N_2O if it is not mentioned otherwise.

Step One

Estimate emission of nitrogen (N) in the form of N_2O

$EN_{sit} = W_{sit} * e_s$, where

EN_{st} = Emission of N from fertilizer i in state s in year t in tons of N_2O -N

W_{sit} = Weight of N fertilizer i consumed in state s in year t in tons

e_s = emission coefficient (low, median and high). Here recommended median

<u>Convert to Units of N_2O</u>

$TE_{N2O\ st} = (EN_{st} * M)$, where

$TE_{N2O\ st}$ = Total N_2O emission

M = Molecular weight = 1.571

The constant 1.571 has been calculated as follows: the total molecular weight of N_2O is 44 grams. Of the 44 grams of N_2O, the molecular weight of N is 14 grams. Hence, for every gram of N that is burned, 1.571 grams of N_2O are produced. Without loss of generality, I can take the constant 1.571 to estimate tons of N_2O per ton of N.

N_2O estimation from Landfill Source

$E_{N2O} = W_{st} * 0.0001$ tons, (EPA Workbook, 1998)

2.8 Emission Trends in Midwest States

In 1998, Midwestern States contributed gross total 1589.18 million tons of CO_2 where by State of Ohio contributed 20 percent, the highest percentage in the region. In contrast, the State of Minnesota (Figure 2.8) contributed 5 percent, the lowest percentage in the region. Energy sources contributed the most of these emission levels.

In the same year, the Midwest region was responsible for 74.13 thousand tons of N_2O whereby Illinois contributed (Figure 2.9) 22 percent, the highest in the region, and the State of Iowa contributed 20 percent and was placed second position in the region.

In case of CH_4 emission in the Midwest region in 1998, the total emission levels were 1507.63 thousand tons whereby the State of Illinois (Figure 2.10) contributed 22 percent and was placed first. In contrast, the State of Ohio was responsible for 20 percent and was placed second in the region.

2.8.1 Emission Trends in the State of Illinois

Illinois is a major agricultural state with approximately 23.4 million acres cultivated. The major crops are corn and soybeans but other crops such as wheat, oats sorghum and potatoes, also are grown. In 1998, approximately 229.125 million tons of

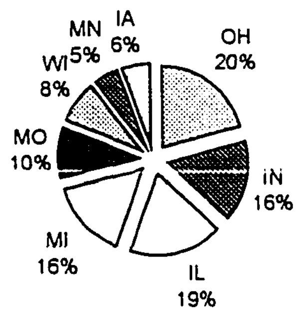

Figure 2.8: State's contributions to CO_2 emission in Midwest (1998)

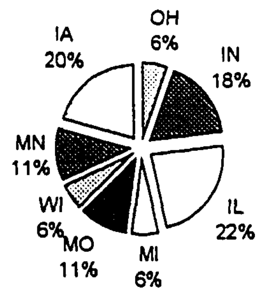

Figure 2.9: State's contributions to N_2O emission in Midwest (1998) [g]

g. Data Source: Converted from Summary Data, 1992, 1998, Tennessee Valley Authority and USDA Statistical Bulletin No. 472

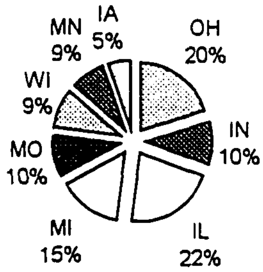

Figure 2.10: State's contributions to CH_4 emission in Midwest (1998) [h]

h. Converted from total waste = population x per capita waste (EPA Workbook, 1998)

CO_2 were emitted from fossil fuel combustion. In contrast to 1997 and 1990 levels, it was higher by 0.85 percent and 14.5 percent respectively. The trends (Figure 2.11) since 1960, were upward till 1978. In 1979, the trend started to decline and continue till 1984. It again started to increase in smaller rate of changes. The main factors that caused these significant changes were energy prices, especially, oil price shocks of 1973 and 1978 and the degree of urbanization. In 1998, fuel combustion accounted 77 percent of gross CO_2 emission where Coal and Petroleum contributed 39 percent and 42 percent respectively (Figure 2.12). In contrast, Natural Gas contributed 19 percent.

In Illinois, sixteen landfills are equipped with gas recovery systems - ten of these collect gases for energy applications. The emissions are reduced by the amount of gas recovery. The net CO_2 emission from landfill in 1997 was 69.39 tons, which was higher than the level contributed by NG. By contrast, in 1997, landfill contributed 325.38 thousand tons of CH_4. These contributions (Figure 2.13) were 11 percent lower than 1990. The current trend is downward as it is in any other states in the region as a result of implementing current CH_4 recovery programs and related MSW regulations in practice.

In 1997, approximately 1739.26 tons of N_2O were emitted from nitrogenous fertilizer in Illinois. Although agriculture in Illinois is a substantial business, N_2O emissions from nitrogenous fertilizer were relatively minor sources of overall GHGs emissions in 1997. In 1997, the emission trends from nitrogenous fertilizer declined by 12.39 percent from 1990 emission levels. The trends (Figure 2.14) declined significantly in 1995 even thought it was upward with smaller rate of change since 1960.

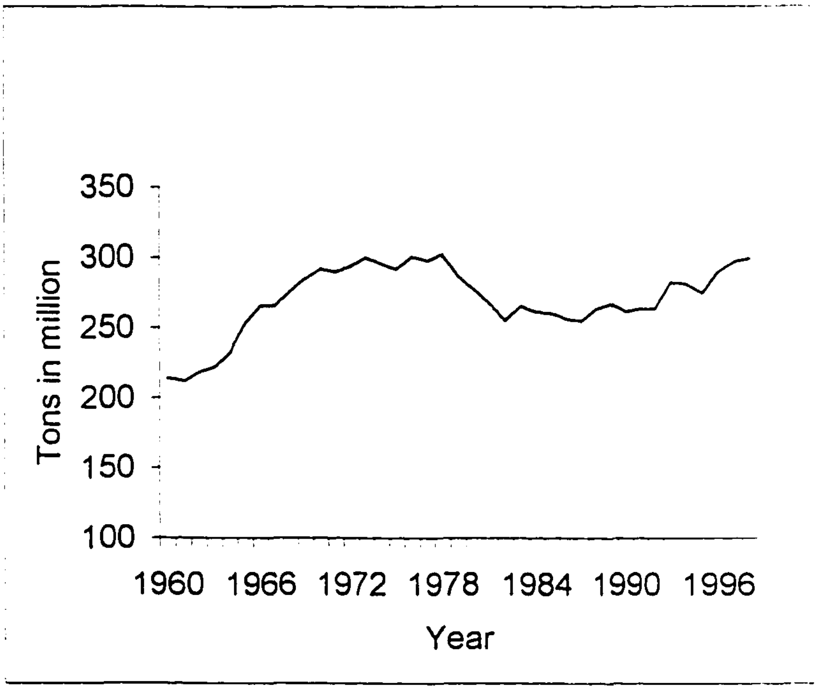

Figure 2.11: CO_2 emission trends in Illinois (1960 – 1998) [i]

i. Converted from State Energy Data Report, 1997 and DOE/EIA-0573 (98)

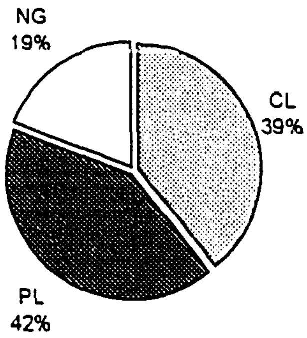

Figure 2.12: CO_2 emission from source type in Illinois (1998) [j]

j. Converted from State Energy Data Report, 1997 and DOE/EIA-0573 (98)

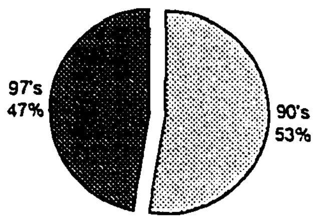

Figure 2.13: CH_4 emission in Illinois (1997 over 1990) [k]

k. Converted from total waste = population x per capita waste (EPA Workbook, 1998)

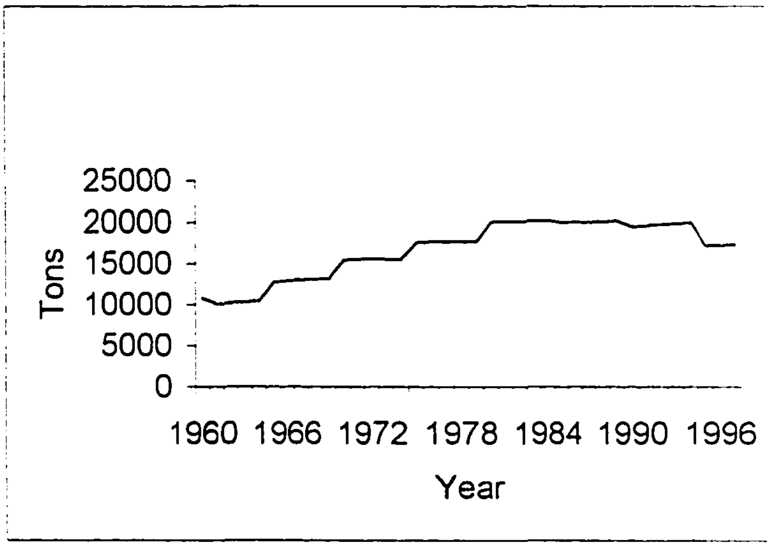

Figure 2.14: N_2O emission from nitrogenous fertilizer in Illinois (1960 – 1998)[1]

1. Data Source: Converted from Summary Data, 1992, 1998 and USDA Statistical Bulletin No. 472

2.8.2 Emission Trends in the State of Indiana

In 1998, the State of Indian emitted a total 223.01 million tons of CO_2 and its *per-capita* emission level was 39.82 tons. This was the highest emission level *per-capita* among the Midwest states. In 1998, CO_2 emission levels were greater by 5.04 *per-capita* than 1990 and it was also the most among the Midwestern States. CO_2 emission trends (Figure 2.15) were upward till 1981 with minor disturbances. In 1982, the emission trends declined significantly. Although CO_2 emissions in Indiana have been growing since 1983, their growth accelerated in the recent years. The 1998 emission level was 14 percent higher than 1990 emission levels. In 1998, energy sources contributed 87 percent (Figure 2.16) to gross total CO_2 where Coal, Petroleum and Natural Gas (Figure 2.17) contributed 60 percent, 30 percent and 10 percent respectively. Several unrelated factors caused the recent trends upward. The *per-capita* energy consumption in this state was higher than any other states in this region. However, the emission level of CH_4, in 1997, was 154.26 thousand tons and was placed it third among Midwest states. During 1960s to 1970s the emission levels were significantly high like it was in any other states. After 1980, CH_4 emission level started to decline and it was followed by the recent years. In 1995, CH_4 emission trends (Figure 2.18) declined significantly and in 1990, the emission trends were lower by 22.86 percent over 1998. In the case of N_2O, the emission levels in 1998 increased by 1.74 percent over 1997 level and 4.63 percent over 1990 emission level. The trends were upward since 1960 (Figure 2.19) with continuos increasing rates and it rapidly increased in 1980 due to increase the application of nitrogenous fertilizer. In 1983, it started to

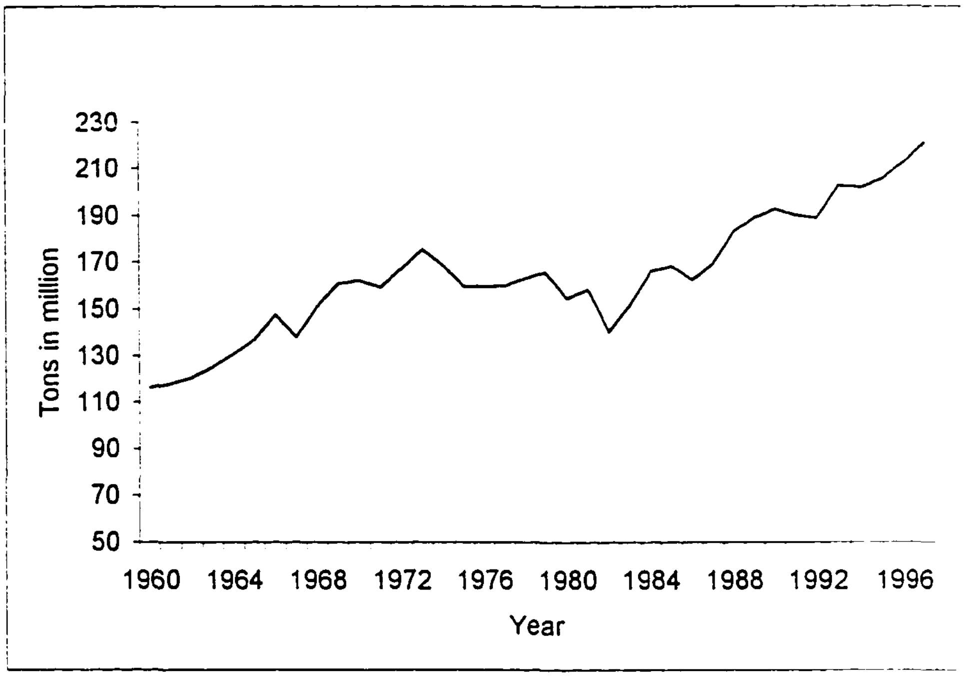

Figure 2.15: CO_2 emission trends in Indiana (1960 – 1998) [m]

m. Converted from State Energy Data Report, 1997 and DOE?EIA-0573 (98) Report

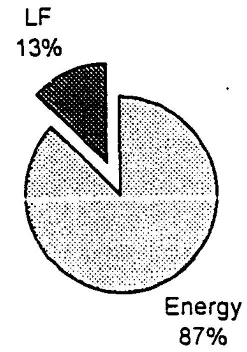

Figure 2.16: CO_2 emission from source type in Indiana (1998) [n]

n. Converted from DOE/EIA-0573 Report and
Total waste = population x per capita waste
LF = Landfill, Energy = CL + PL + NG

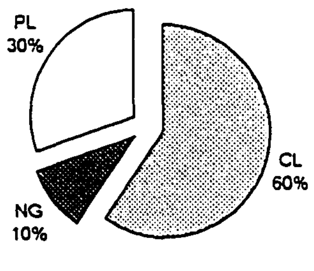

Figure 2.17: CO_2 emission from energy source type in Indiana (1998) [o]

o. Converted from DOE/EIA-0573 (98)
CL= Coal, PL = Petroleum and NG = Natural Gas

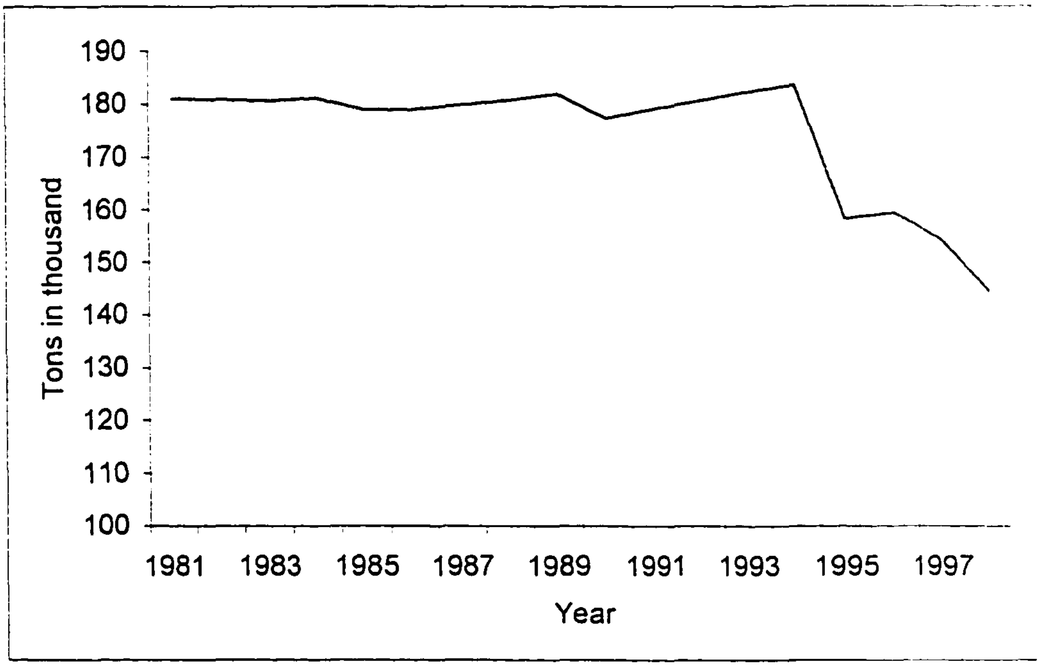

Figure 2.18: CH_4 emission trends in Indiana (1960 – 1998) [p]

p. Converted from total waste = population x per capita waste (EPA Workbook, 1998)

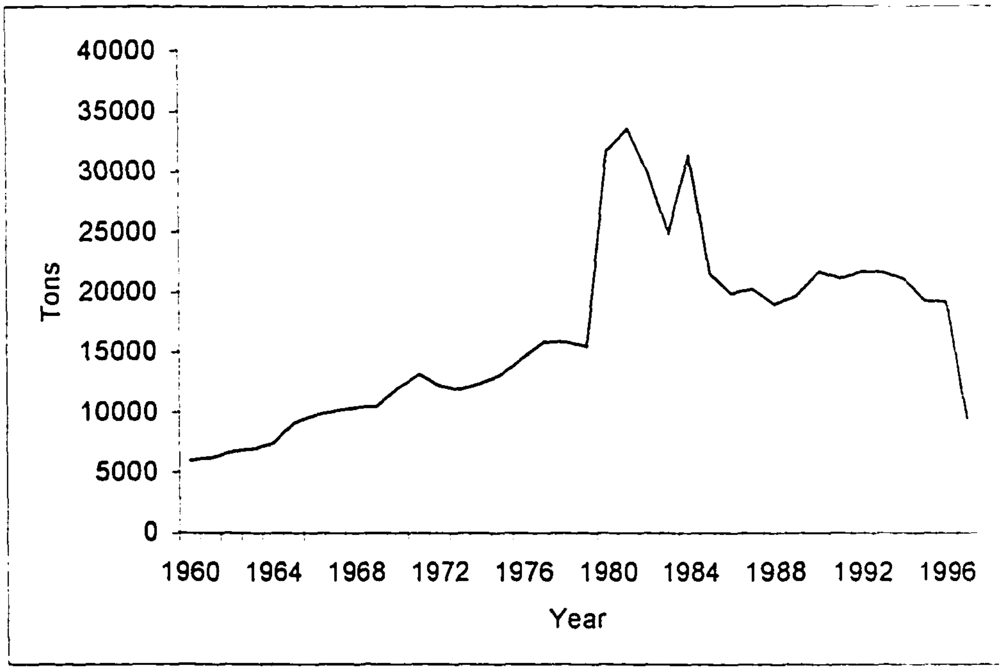

Figure 2.19: N_2O emission trends in Indiana (1960 – 1998) [q]

q. Converted from Summary Data, 1992, Summary Data. 1998. Tennessee Valley Authority and USDA Statistical Bulletin No. 472

decline due to reduce the application of nitrogenous fertilizer required by laws. In 1995, the trends started to decline significantly, and the highest rate of decrease in the recent years.

2.8.3 Emission Trends in the State of Iowa

Iowa is a major agricultural state. It is the third ranking state in value of farm products, exceeded only by much larger California with its irrigation-based agriculture Total 1998 emissions of CO_2 were 89.80 million tons and *per-capita* emission level was 26.35 tons and was placed second based on *per-capita* emission levels in the region. In 1998, the emission levels were greater by 16.63 million tons (28.55 percent). The fossil fuel combustion in 1998 accounted for 89 (Figure 2.20) percent of total CO_2 emission in Iowa. On the other hand, landfill contributed 11 percent to gross CO_2 emissions. The coal contributed 53 percent to the gross energy source emitted CO_2 emissions (Figure 2.21) where petroleum and natural gas contributed 20 percent and 27 percent respectively. The rapid growth of natural gas consumption in Iowa contributed higher CO_2 emission than petroleum contribution, which is exceptional from any other state in this region.

The trend of CH_4 emission from landfill was upward like any other state in Midwest till 1980. Since 1981 (Figure 2.22) it started to decline with a small rate of change. In 1995, the trend declined significantly and the regulations of solid waste management influenced the trend in a negative significantly. Since 1960, the trend of N_2O emission (Figure 2.23) from nitrogenous fertilizer and landfill increased with a significant rate of change but drastically decreased in 1983. The nitrogenous fertilizer

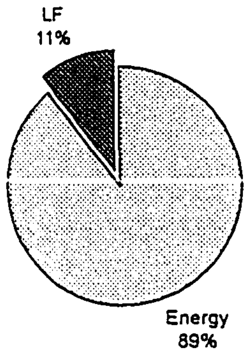

Figure 2.20: CO_2 emission from source type in Iowa (1998) [r]

r. Data Source: DOE/EIA-0573 (98) Report
Energy = CL + PL + NG and LF = Landfill, converted
total waste = population x per capita waste (EPA Workbook)

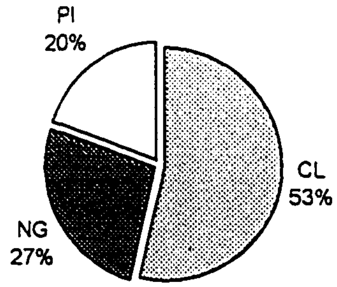

Figure 2.21: CO_2 emission from energy source type in Iowa (1998) [s]

s. Data Source: DOE/EIA-0573 (98) Report
CL = Coal, PL = Petroleum and NG = Natural Gas

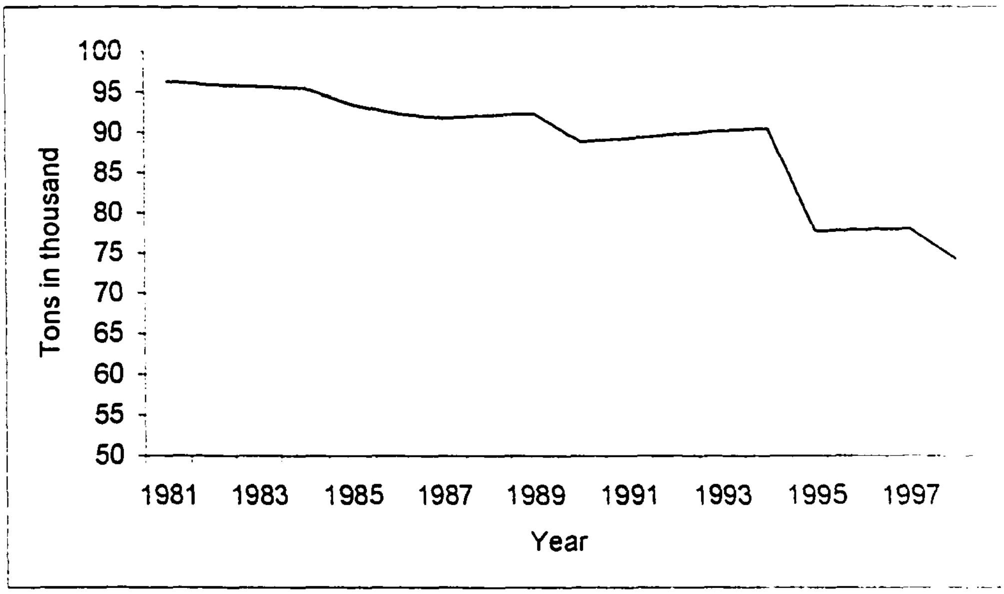

Figure 2.22: CH_4 emission trends in Iowa (1960 – 1998) [t]

t. Converted from total waste = population x per capita waste (EPA Workbook, 1998)

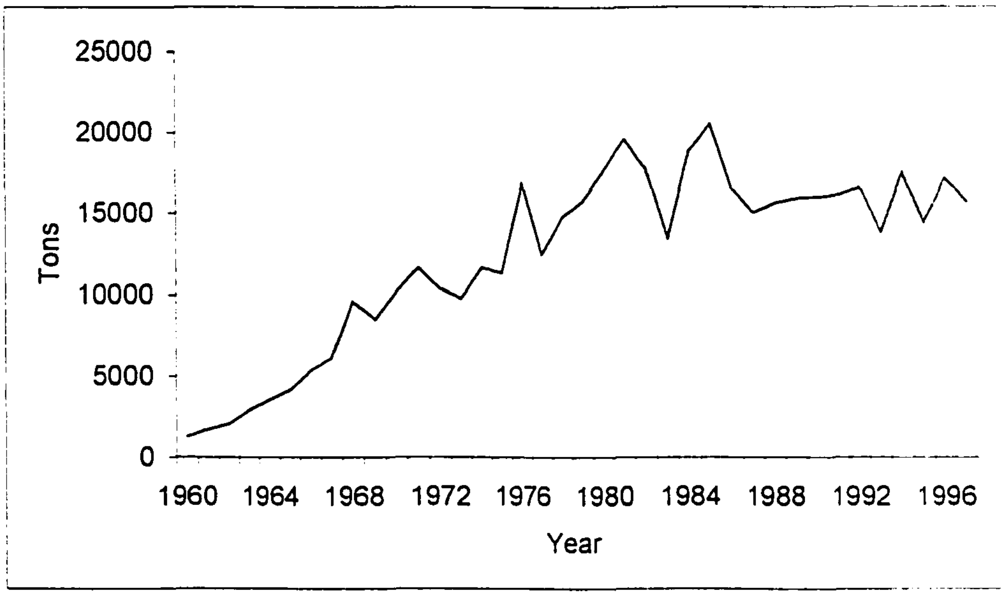

Figure 2.23: N_2O emission trends from fertilizer source in Iowa (1960 – 1998) [u]

u. Converted from Summary Data, 1992, Summary Data, 1998, Tennessee Valley Authority, USDA Statistical Bulletin, No. 472

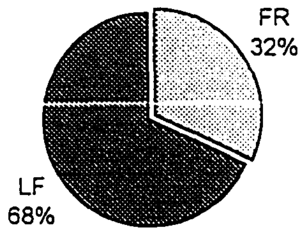

Figure 2.24: N_2O emission from source type in Iowa (1960) [v]

v. Converted from USDA Statistical Bulletin No. 472, LF = Landfill, FR = Fertilizer

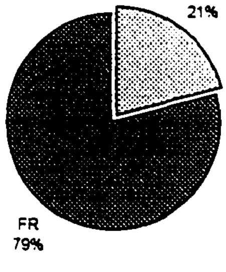

Figure 2.25: N_2O emission from source type in Iowa (1998) [w]

w. Data Source: Converted from Summary Data, 1998 Tennessee Valley authority and Total waste = population x per capita waste (EPA Workbook, 1998).
FR = Fertilizer, LF = Landfill

source contributed significantly to this change. Landfill contributed contributed significantly (Figure 2.24) to the gross total CH_4 emission in Iowa in 1960's and then after, nitrogenous fertilizer source began to dominate the emission trend. In 1998 (Figure 2.25) the nitrogenous fertilizer source was dominated to this upward emission trend.

2.8.4 Emission Trends in the State of Michigan

In 1997, the state of Michigan emitted approximately 246.42 million tons of CO_2 (Figure 2.26) where energy sources contributed 77 percent and landfills contributed 23 percent. In this year, the petroleum source was responsible for approximately 78.0245 million tons, or 41 percent of total CO_2 emissions (Figure 2.27) in Michigan. The combustion of natural gas was accounted for 21 percent. The contributions of coal were 3 percent lower over petroleum's contributions. The trends of CO_2 emission from coal and petroleum sources are exceptional from any other states in the region. The petroleum sources contributed higher CO_2 emissions (Figure 2.27) over coal contributions since early 1960. The petroleum sources are dominating in the recent years too. Michigan is an industry-based state. Industry sector, especially, car industry has dominated to the gross total CO_2 emission in this state.

In Michigan, CH_4 emission level increased significantly (Figure 2.28) since 1960 and continued to rise till 1980. In 1981, the trend first declined and continued to decline, with minor disturbances. The trends (Figure 2.29) of N_2O emissions from landfill and nitrogenous fertilizer were upward till 1980 with minor disturbances. In 1983, it declined significantly. In 1995, the N_2O emissions reduced drastically in

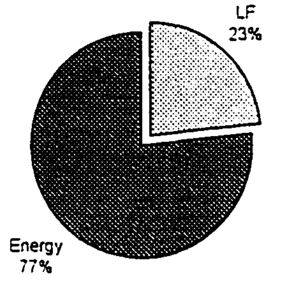

Figure 2.26: CO_2 emission from source type in Michigan (1998) [x]

x. Data Source: Converted from DOE/EIA-0573 (98) and total waste, LF = Landfill and Energy = CL + PL + NG

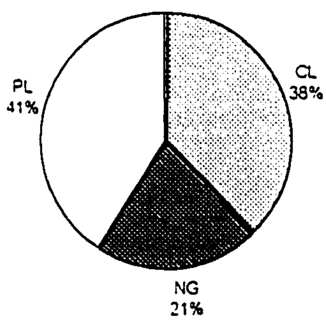

Figure 2.27: CO_2 emission from energy source in Michigan (1998) [y]

y. Data Source: Converted from DOE/EIA -0573 (98) CL = Coal, PL = Petroleum and NG = Natural Gas

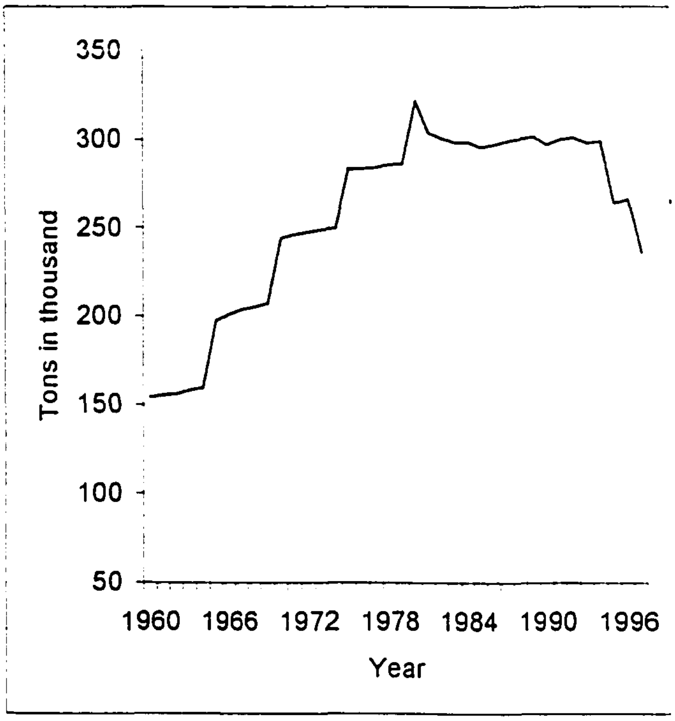

Figure 2.28: CH_4 emission trends in Michigan (1960-1997) [z]

z. Data Source: Converted from total waste = population x per capita waste (EPA Workbook, 1998)

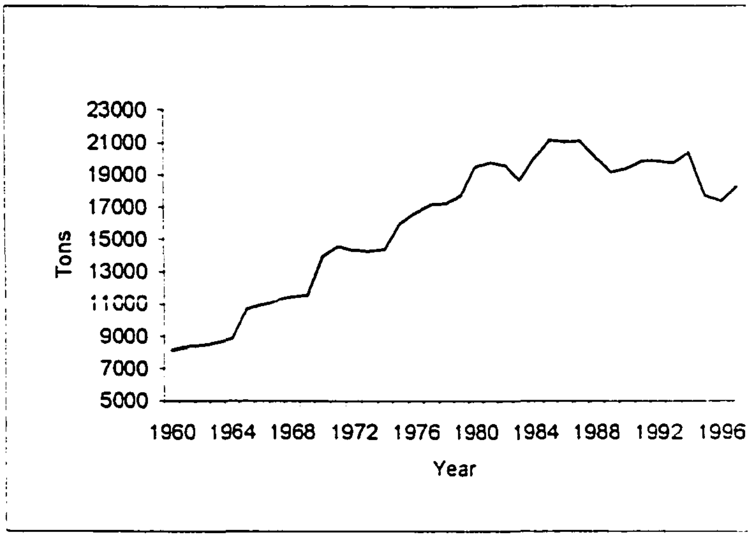

Figure 2.29: N_2O emission trends in Michigan (1960 – 1997) [a1]

a1. Data Source: Converted from Summary Data, 1992, 1998 and USDA Statistical Bulletin No. 472

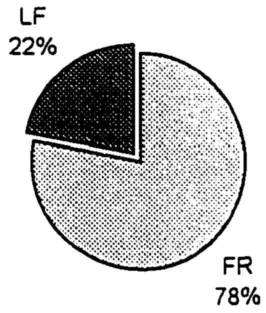

Figure 2.30: N_2O emission from source type in Michigan (1997) [b1]

b1. Data Source: Summary Data 1998, Tennessee Valley Authority and Total waste = population x per capita waste (EPA Workbook, 1998). FR = Fertilizer and LF = landfill

Michigan. The implementation of the regulations related to Solid Waste Management (SWM) that caused this change. In 1997, nitrogenous fertilizer (Figure 2.30) contributed 78 percent to gross total N_2O emissions. In contrast, landfill contributed 22 percent.

2.8.5 Emission Trends in the State of Minnesota

Total 1998 emissions of CO_2 in Minnesota were 75.86 million tons. It was slightly higher than in 1997 and 5.707 million tons more than 1990. The *per-capita* emission in 1998 was 10.76 tons which was the lowest in the Midwest states although its *per-capita* income was the second highest in this region. In 1998, energy sources (Figure 2.31) contributed 64 percent to gross total CO_2 emissions in Minnesota. In contrast, landfills contributed 36 percent in that year. The contributions of landfills in percent in Minnesota were the highest in the region. Energy sources namely coal, petroleum and natural gas contributed 65 percent, 27 percent and 8 percent respectively (Figure 2.32) in the year of 1998. In 1998, the State of Minnesota emitted 128.17 thousand tons of CH_4 from landfill. The trends of CH_4 emissions in Minnesota since 1960 were upward with minor disturbances till 1994. In 1994, the trends first significantly declined and it continued to decline till 1996. The implementation of SWM regulation caused these drastic changes. Since 1997, the trends started to rise with small rate of change. The State of Minnesota in 1998 emitted gross total 14868.55 tons of N_2O into atmosphere. The Nitrogenous fertilizer and landfill contributed 54 percent and 46 percent respectively (Figure 2.33) to the gross total of N_2O in 1998. The emission levels (Figure 2.34) of 1990 were higher by 28.72 percent over 1998. The trends of N_2O emissions in Minnesota (Figure 2.35) from landfill were very much

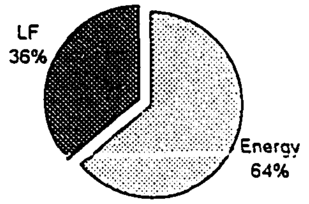

Figure 2.31: CO_2 emission from source type in Minnesota (1998) [c1]

c1. Data Source: Converted from State Energy Data Report, LF = Landfill, converted from total waste

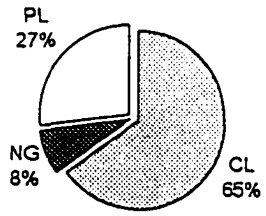

Figure 2.32: CO_2 emission form energy sources in Minnesota (1998) [d1]

d1. Data Source: Converted from State Energy Data Report, CL = Coal, PL = Petroleum, NG = Natural Gas

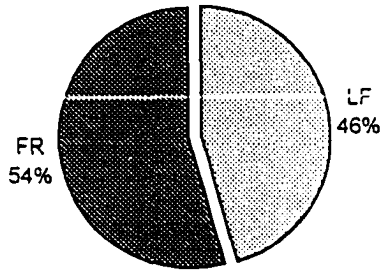

Figure 2.33: N_2O emission from source type in Minnesota (1998) [e1]

e1. Data Source: Converted from Summary Data 1998. Tennessee Valley Authority

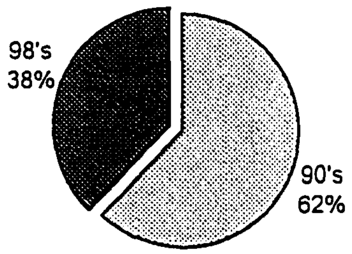

Figure 2.34: N_2O emission from fertilizer in Minnesota (1998 over 1990)

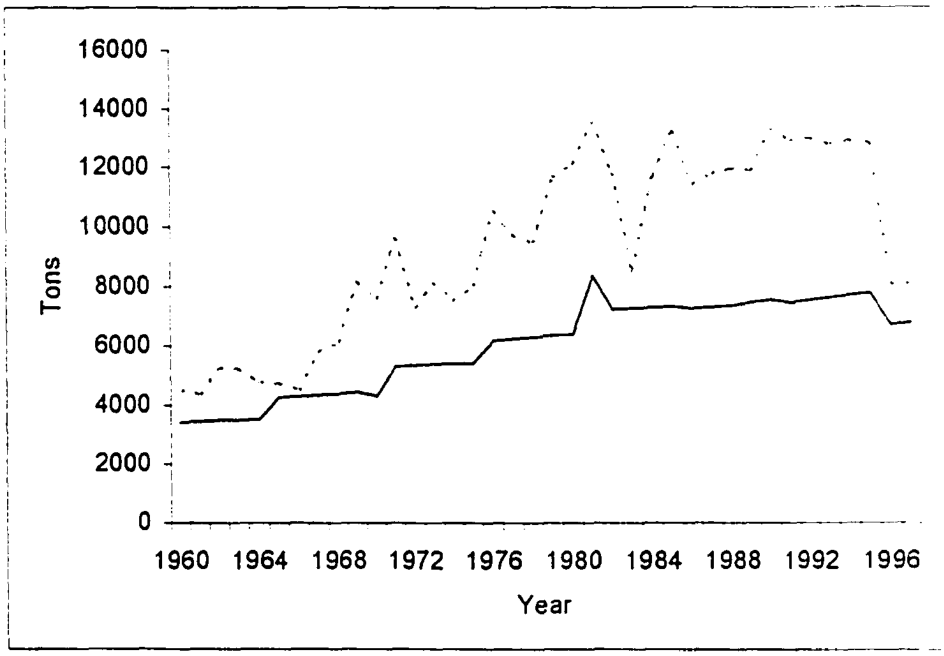

Figure 2.35: Comparison of sources' contributions to N_2O emission trends in Minnesota (1960-1998) [f1]

f1. Dashed line represents FR and solid line represents LF
Data Source: Converted from Summary Data 1992, Summary Data 1998 and USDA Statistical Bulletin No. 472

upward with small rate of change. In contrast, the emission trends from nitrogenous fertilizer (dashed line in Figure 2.35) were upward with significant rates of changes. In 1983, the trends of emission from nitrogenous fertilizer drastically declined. The reduction of nitrogenous fertilizer caused these changes.

2.8.6 Emission Trends in the State of Missouri

The total 1998 emissions of CO_2 in Missouri were 127.58 million tons or 4.93 million tons higher over 1997 emissions. The *per-capita* CO_2 emission levels were 23.62 tons, which were slightly higher than the average *per-capita* emission level in the Midwest. The trends of CO_2 emissions (Figure 2.36) were upward with minor changes since 1960. In 1998, the emission levels were lower by 18.89 percent over 1990. During 1998 (Figure 2.37) landfills contributed 21 percent. In contrast, energy sources contributed 79 percent, which was the highest in Midwest region. The coal, petroleum and natural gas (Figure 2.38) contributed 48 percent, 43 percent and 9 percent respectively to the gross total of CO_2 emission from energy sources.

The trends of CH_4 emission in Missouri were upwards from 1960 till 1980 with minor disturbances. In 1981, the trends (Figure 2.39) declined first and continued to decline with smaller rate of changes till 1993. In 1995, the trends first declined drastically and the emission levels were 145.65 thousand tons.

The trends of N_2O (Figure 2.40) from landfill were significantly higher over emissions from nitrogenous fertilizer till 1995. Since 1996, the trends of emissions from nitrogenous fertilizer over landfill continued to increase till the recent years. This was an exceptional scenario in Midwest region.

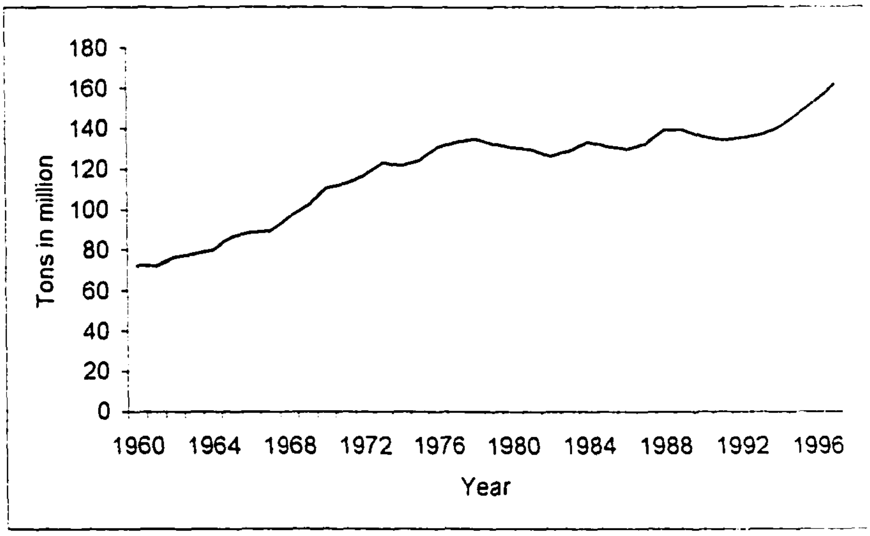

Figure 2.36: CO_2 emission trends in Missouri (1960-1998) [g1]

g1. Data Source: Converted from State Energy Data Report and DOE/EIA-0573 (98)

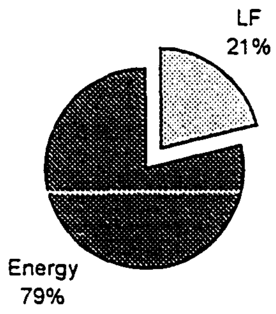

Figure 2.37: CO_2 emission from source type in Missouri (1998) [h1]

h1. LF = Landfill, converted from total waste

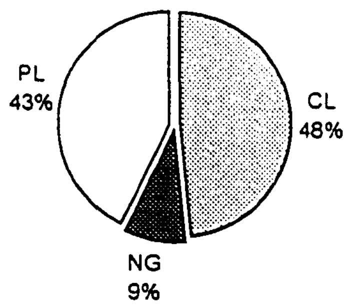

Figure 2.38: CO_2 emission from energy sources in Missouri (1998) [i1]

i1. CL = Coal, PL = Petroleum and NG = Natural Gas

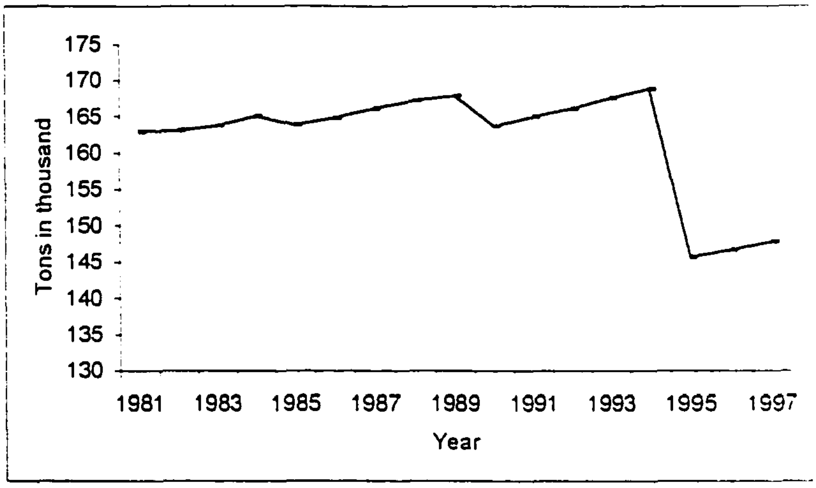

Figure 2.39: CH_4 emission trends in Missouri (1981-1998)[j1]

j1. Data Source: Converted from total waste = population x per capita waste (EPA Workbook, 1998)

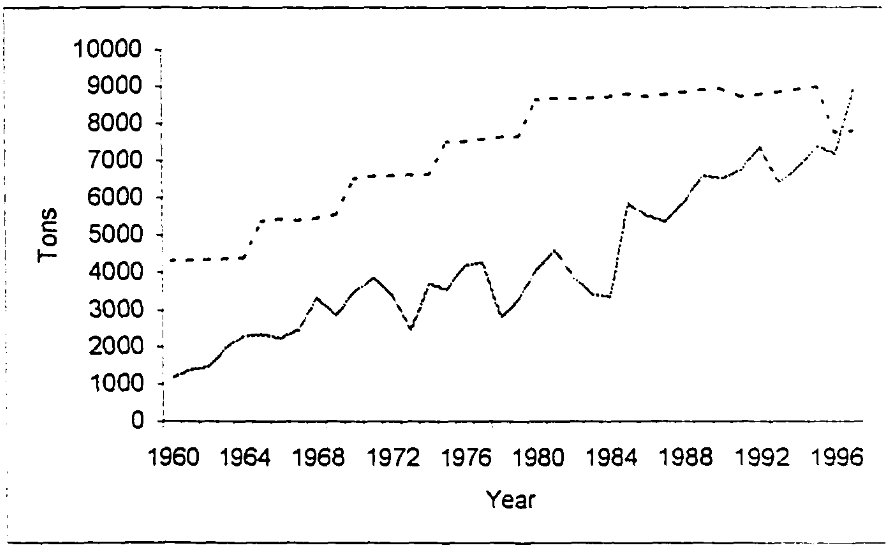

Figure 2.40: Comparison of source's contributions to N_2O emission trends in Missouri (1960 - 1998) [k1]

k1. Dotted line represents LF and solid line represents FR
Data Source: Converted from Summary Data, Tennessee Valley Authority and USDA Statistical Bulletin No. 472

2.8.7 Emission Trends in the State of Ohio

Total emissions of CO_2 in 1998 were 341.1 million tons where energy sources contributed (Figure 2.41) 80 percent, in contrast landfill contributed 20 percent. The 1998 emission levels were 2.99 percent higher over 1997 and 12.79 percent higher over 1990 emission levels. In the same year (Figure 2.42) coal, petroleum and natural gas contributed 51 percent, 31 percent and 14 percent respectively. Although the trends of CO_2 emission from energy sources were upward since 1960 till to the current years, the rate of growth of emissions in the recent years are smaller over 1960's or 1970's emissions. The trends of CH_4 emission from landfill (Figure 2.43) in Ohio were significantly upward till 1980. Since 1981, the trends started to decline with minor variations. In 1995, the emission trends first declined drastically. The 1990 emission trends were 13.95 percent higher over1998 emissions. On the other hand, in 1998, the State of Ohio emitted 20,157.51 tons of N_2O from landfill and nitrogenous fertilizer sources where fertilizer contributed 81 percent. These emission levels were 58.6 percent lower over 1990 emissions. The landfill contributed 19 percent and nitrogenous fertilizer contributed 81 percent in 1998 to gross total N_2O emissions in Ohio (Figure 2.44).

2.8.8 Emission Trends in the State of Wisconsin

In 1998, the State of Wisconsin emitted 132.58 million tons in to the atmosphere. These emission levels were higher by 18.77 million tons over 1990 emission levels. In 1998 (Figure 2.45) energy sources contributed 77 percent and landfill contributed 23 percent. Fossil fuel consumption was the major source of GHGs

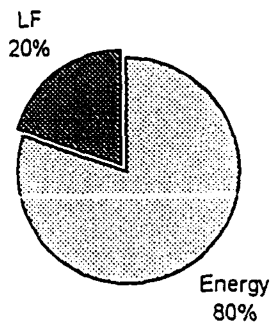

Figure 2.41: CO_2 emission from source type in Ohio (1998) [l1]

l1. Converted from State Energy Data Report and LF = landfill, converted from total waste

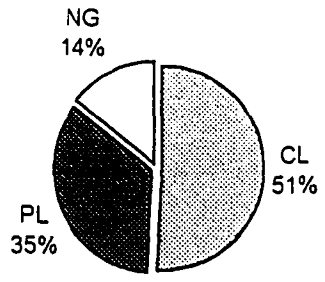

Figure 2.42: CO_2 emission from energy sources in Ohio (1998) [m1]

m1. Converted from State Energy Data Report
CL = Coal, PL = Petroleum and NG = Natural Gas

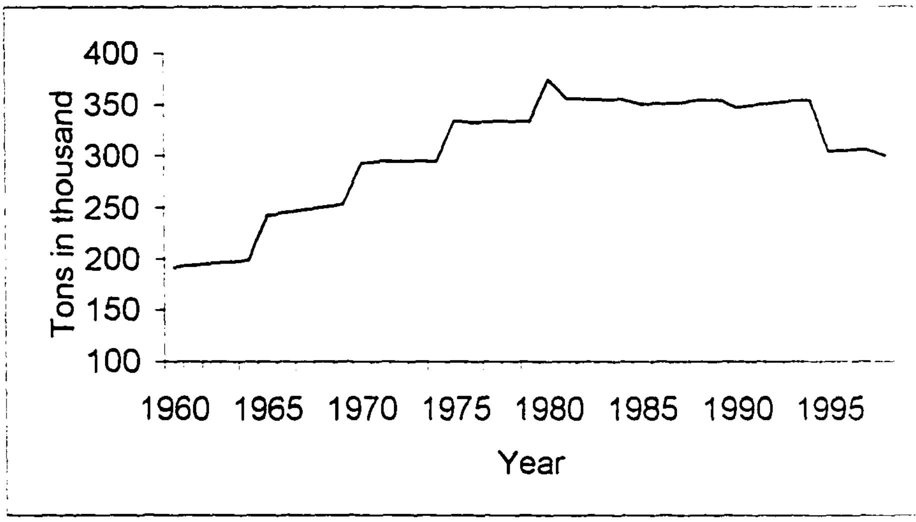

Figure 2.43: CH_4 emission trends in Ohio (1960 - 1998) [n1]

n1. Data Source: Converted from total waste = population x per capita waste (EPA Workbook, 1998)

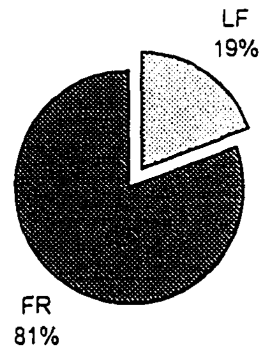

Figure 2.44: N_2O emission from source type in Ohio (1998) [p1]

p1. Data Source: Converted from Summary Data. Tennessee Valley Authority and USDA Statistical Bulletin, No. 472

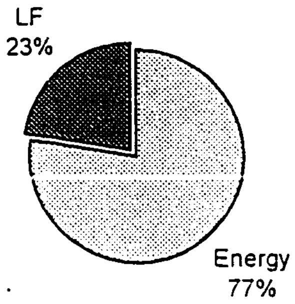

Figure 2.45: CO_2 emission from source type in Wisconsin (1998) [q1]

q1. Data Source: Converted from State Energy Data Report and total waste

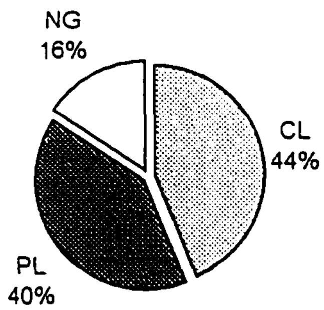

Figure 2.46: CO_2 emission from energy sources in Wisconsin (1998) [r1]

r1. Data Source: Converted from State Energy Data Report and DOE/EIA-0573 (98)

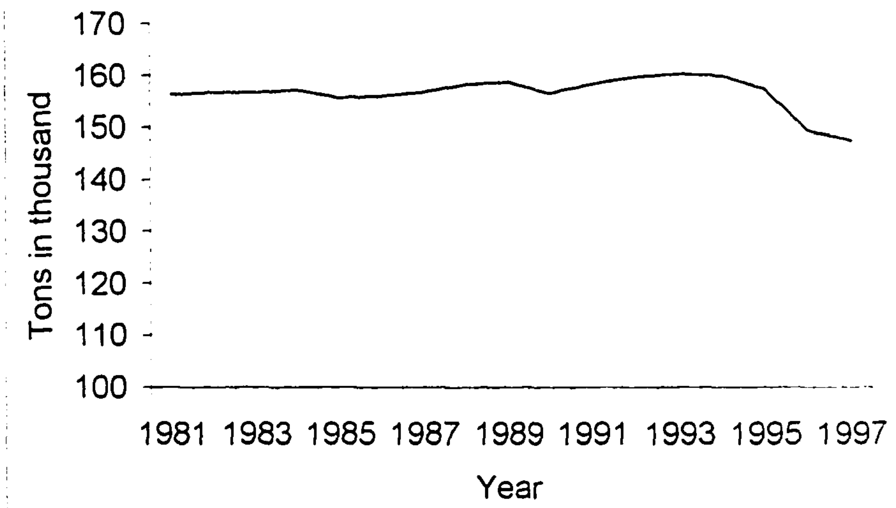

Figure 2.47: CH_4 emission trends in Wisconsin (1981 - 1998) [s1]

s1. Data Source: Converted from total waste = population x per capita waste (EPA Workbook, 1998)

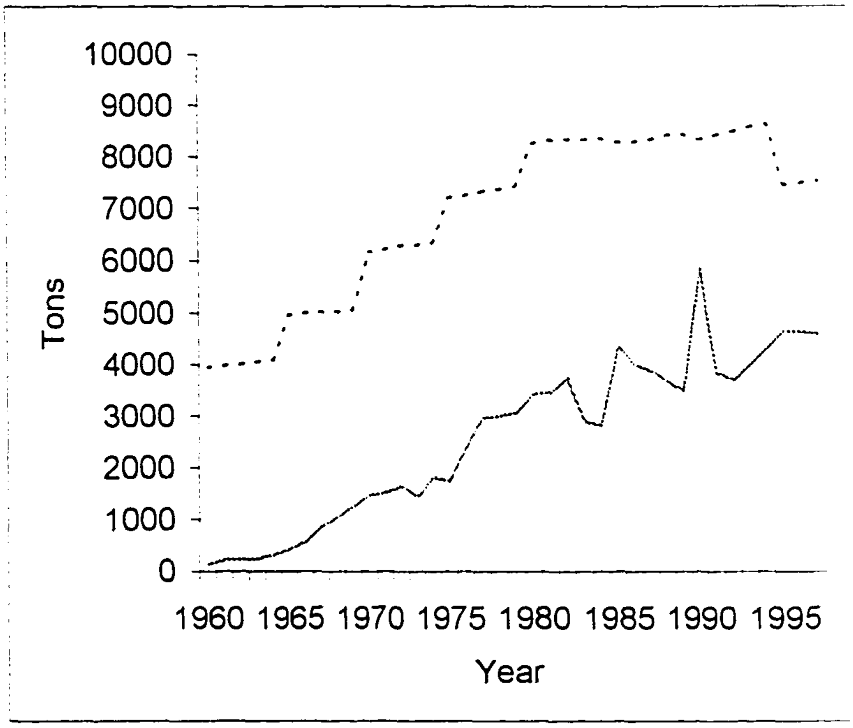

Figure 2.48: N_2O emission form source type in Wisconsin (1960 - 1998) [t1]

t1. Dashed line represents LF and solid line represents FR
Data Source: Summary Data, Tennessee Valley Authority and USDA Statistical Bulletin No. 472
FR = Fertilizer and LF = Landfill, converted from total waste

emission in Wisconsin. In 1998 (Figure 2.46) fossil fuel consumption produced 44 percent, petroleum and natural gas contributed 40 percent and 16 percent respectively.

The trends of CH_4 emission in Wisconsin were very much upward till 1980 with minor disturbances. In 1981, the trends first started to decline (Figure 2.47) with a smaller rate of change. In 1995, the trends declined drastically. These changes were influenced by different regulations related to SWM. The trends of N_2O emissions (Figure 2.48) in Wisconsin were upwards till 1994 with minor disturbances. In 1995, the emission levels increased significantly and nitrogenous fertilizer contributed to these upward trends (Figure 2.48) contributed 63 percent and landfills contributed 27 percent.

2.9 Conclusions

Based on scientific evidence available to date, human activities caused considerable anthropogenic additions to GHGs production, especially CO_2, which have led to an "enhanced GHG effect" often referred to as global warming or climate change.

GHGs identified to date include CO_2, CH_4, N_2O, water vapor, O_3, CFCs and other holo-carbons. This Chapter demonstrated logical arguments in order to limiting number of gases and focused three primary gases namely; CO_2 CH_4 and N_2O with aimed to display Midwest region's historical emissions scenarios of GHGs instead of integrating all six gases.

In 1998, gross total CO_2 emissions were 17.52 percent higher than 1990 over the whole region. The energy sources: namely; Coal, Petroleum and Natural Gas were responsible for the major parts of gross total CO_2 emissions where coal combustion dominated these trends in each state with an exception in Michigan where petroleum dominated the trends. In contrast, landfill, as a source of CO_2 emission, contributed a small percent to total CO_2 emission in that year. The State of Ohio contributed 20 percent of total CO_2 emitted in the region, in 1998, and was placed first. Illinois was the second and Missouri and Wisconsin placed third position. Minnesota contributed 5 percent in that year placed last. However, taking per capita emission into estimation, the State of Indiana was placed first in the region. The historical emission trends were upward with minor disturbances in region as well as in individual state. On the other hand, in 1998, the Midwest region emitted 74.133 thousand tons of N_2O into atmosphere. The State of Illinois contributed 22 percent and placed first, in contrast, State of Indiana contributed 18 percent placed second in the region. Ohio, Michigan and State of Wisconsin contributed 18 percent in total whereby each state contributed 6 percent. The application of nitrogenous fertilizer in agriculture soil was the major source of this emission in the region. Landfill contributed very small portion after 1980. The historical emission trends were more alike in states with exceptions in Illinois and in State of Indiana. These two states, historically dominated N_2O emission in the region.

In 1998, the landfill sources contributed 1507.63 thousand tons of CH_4 in the region whereby the State of Illinois was responsible for 22 percent. The State of Ohio contributed 20 percent and placed second in the region. The historical emission trends were significantly high till 1980, then started to decline since 1981.

CO_2, which was by far the most prominent of GHGs in terms of total emissions from the Midwest region, is a combustion product, especially by the burning of high carbon fossil fuels. The two other primary GHGs, CH_4 and N_2O, are emitted in far lower quantities than CO_2. On the hand, the global warming potentials of these two gases are comparatively higher.

Therefore, the overall contributions to the inventory of these additional gases in atmosphere are significant and warrant effective and efficient climate policy (s) that could assist to curtailing the magnitudes of these gases, especially, CO_2 emissions.

2.10 Notes

No.	Page	
1	7	See Committee on Science, Engineering and Public Policy (U.S.), Policy Implications of Greenhouse Warming-Synthesis Panel, Policy Implications of Greenhouse Warming, National Academy Press, Washington, D.C., 1991 and Summary of the Scientific Assessment of Climate Change, a report prepared for the IPCC by Working Group I, 1990.
2	9	The Framework Convention was adopted by a vote of the conference of the parties on May 9th, while the signatures and ratification of member's states flowed in over a period of years. The treaty entered into force in 1994
3	11	Statement by the Press Secretary, the White House, November 12, 1998 Ref. web site www.whitehouse.gov
4	18	Carbon from CO_2 is sequestered when it is removed from the atmosphere for a long time period. For example, forests sequester carbon in trees.
5	19	CH_4 gas produced by landfills varies by moisture and by size of landfill. Small landfills may produce slightly more emissions per ton of waste. Landfills in non-arid climates are believed to produce more CH_4 per unit of waste in place than do landfills in an arid climate. Midwest states are non-arid states.
6	19	USEPA, Estimation of GHG Emission and Sinks for the United States, 1990. Washington, D.C.: USEPA Draft for public comments, June 21, 1993, p.22
7	26	Carbon content coefficients are sometimes called carbon coefficients. Coal, natural gas and petroleum coefficients are taken from U.S. EPA State Workbook, Methodologies for Estimating Greenhouse Gas Emissions, third edition, 1998
8	27	See EPA Inventory Report, 1995
9	29	In most states, the quantity of waste that is land-filled each year is much larger now than it was 30 years ago. This is due to both increases in population and an increase in annual amount of waste per person. Incorporating all these causal factors, U.S. EPA has estimated 30-Year

No.	Page	
		Multiplier for waste in place and published in State Workbook, Methodologies for Estimating Greenhouse Gas Emissions, Third Edition, 1998. We have incorporated those 30-Year Multipliers as needed in our estimation of CH_4 emissions.
10	29	The fraction of waste landfills at large landfills for the all Midwest states is 81 percent. See U.S. EPA State Workbook, 1998.
11	29	As we know, moisture is an important factor in the production of CH_4 in landfills. Landfills in non-arid climates are believed to produce more CH_4 per unit of waste in place than do landfills in arid climates. As of Department of Commerce, 1988, Midwestern region has rainfall more than 25 inches per year and thus, all Midwest states are classified as non-arid states. In case of each state in Midwest, e = 0.35 W (in short tons) as it was used as a default value in U.S. EPA Workbook, 1998
12	30	CF = [365 (days/yr)*19.2 (g/ft^3) / 453.49 (g/lbs.) * 2000 (lbs./ ton) = .0077 (short tons CH_4 / yr.) /(ft^3 / day)]
13	30	This equation was incorporated from State Workbook, U.S. EPA, 1998

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CHAPTER 3

SHARING EMISSION BURDENS UNDER LIABILITY RULES: THEORY AND APPLICATION

> *When you can measure what you are speaking about and express it in numbers, you know something about it; but when you can not measure it, when you can not express it in numbers, your knowledge is of meager and unsatisfactory kind* --- Lord Kelvin (1889)

3.1 Introduction

The possibility of global warming problems associated with anthropogenic emissions of GHGs, especially CO_2, is one of the most crucial environmental issues in today's world. Midwest states in the United States have to be very concerned about this issue. Since the early 1900's these states have been criticized or blamed by the other states or regions on the issues of emission burden liabilities and mitigation options (Dunlap and Mertig, 1992).

Traditions in both law and economics suggest that making the involved parties liable in certain degrees for all of changes in the costs associate with CO_2 emissions from coal combustion and making harmless will induce policy. These days, much of the current public policy debate concerns the selection of institutional arrangements to handle this problem. They, especially in Europe, often attempt to identify fully liable parties in the organization of production and consumption instead of investigating the party's roles in causing the magnitude of the problem. They often call this the *Polluter Pays Principle* (PPP). The primary example of the PPP in economics is the Pigovian tax on polluters. This approach has been lately attracted considerable attentions among policy-makers in domestic as well as all over the world although later writers have increasingly relegated pollution problems to footnote status, until a recent explosion of interest. Now the pathologies of convexity and single member "markets," the same inherent pathologies that induced earlier neglect, attract the attention of theorists, at the same time as the growth in visibility and magnitude of emission problems attracts practical environmental economists.

3.2 Objectives

In this study, I examine the relationships between the assignment of liability for abatement costs and the level of CO_2 emitted from power plants, a paradigm of *status quo* using the basic principles of "new" welfare economics where people's willingness to pay are money measures of welfare gains and losses.

An observable of alternative for measuring the intensities of preferences of an individual for one situation versus another is the amount of money the individual is willing to pay or accept to move from one situation to another (Hicks, 1943).

I determine the liability assignment, or share, that maximizes economic welfare where parties, end-user(s) and generating company(s) take part and favor the profit maximization options. To capture the equity aspect of the issue, I construct a weighted social welfare function that reflects the interests of principal groups affected by the liability rules.

The conclusions for this Chapter should exhibit avenues for policy-makers concerning today's global warming issues. It will also be of interest to economists who are concerned about emission markets instead of Pigovian taxes in the real world settings.

3.3 Problem Statement

The emissions from coal combustion create external environmental costs. Economic theory indicates that there would be more efficient allocation of resources and greater cost effectiveness in reducing the magnitude of emission levels if the involved parties were required to pay these costs. In general, to internalize these costs. electricity-generating company could be made to pay either through the assignment and enforcement of full liability or through payment of Pigovian tax. The generating companies then pass these incurred costs on to the end-users by charging a higher rate per kWh of electricity usage or by charging as emission compliance cost. The methods of charging the emission cost may vary from regulated utility era to deregulated utility era. But the goals and ideas remain unchanged.

The basic question addressed in this Chapter is whether these policies maximize social welfare. I examine two reasons why these policies may not produce an allocation of resources that maximizes social welfare. The first reason is that the full liability (transferable) creates an incentive for electricity generation under coal combustion. thereby changing the costs and benefits associated with electricity generation. The second reason is that the assignment of liability affects the distribution of costs and benefits among affected parties. These distribution effects could not change the levels of social welfare even if there were changes in the levels of costs and benefits. It is possible that the assignment of liability for external costs will change both the levels and distribution of benefits and costs. Thus, the optimal assignment of liability to electricity generators may be a share less than full liability for the external costs. Even though there is a substantial literature concerned with liability in the case of externality problems, to date, to my knowledge, no study has been done assigning the liabilities in the case of domestic CO_2 emission burdens.

The conclusion in this Chapter indicate that the assignment of full liability of CO_2 emission costs to electricity generating companies and then pass it on to end-users will not necessarily maximize a standard unweighted social welfare function. The assignment of full liability may also fail to maximize a weighted social welfare function, one in which the benefits and costs associated with the assignment of liability are weighted by who pays and who benefits.

3.4 Strategy of Dissecting Past Work

Three types of literature have been reviewed as the background for this Chapter. (i) State and Federal Statutes relating to smoke nuisance (ii) related legal literature on the doctrines of the tort liability, including strict liability, joint and several liability and common law. (iii) legal and economics literature on the effects of liability rules.

The legal and economics literature has been enlivened by three approaches, first, associated with Pigou (1932) the second with Coase (1965), and the third, associated with controversies over Coasian's neutrality theorem. A detailed discussion and results of this literature appears in section 5 of this Chapter.

3.5 Literature Review

Examining the liability for environmental damages under the scrutiny of law, economics (efficiency and welfare) and ethical grounds, is the thrust in this section to review the literature. The rules of liability are codified in related smoke nuisance statues in different Midwestern states, in municipal ordinance (to my knowledge there is no specific statues for CO_2 emissions at the federal level), and the effects of liability rules on economic efficiency have been examined in both the legal and economics literature. Accordingly, this review begins with an overview of smoke nuisance statutes and then proceeds to an overview of the legal and economic studies that are most relevant to this study.

3.5.1 Legal Institution and Air Pollution

The US legal past can be roughly divided into three eras. From 1800 to 1880 (19th century-I), commonly shared premises concerning the perceived benefits of increased productivity through market processes made strong demands on the legal system. Law responded generously to these pressures by protecting the profit-maximizing conduct of acting parties in the American market and, in general, supporting policies that advanced economic values. [1]

From 1880 to 1930 (20th century-I), rather than passively resigning control to other factors in society, law assumed a more of an active stance. For the first time the legal process began to address some of the long-run social costs that had been generated (and then subordinated) by the 19th century- I emphasis on short-run economic gains. After 1930 the use of law to regulate economic behavior was not only generally accepted, it was expected. Throughout most of the 19th century - I law and its institutions refused to control the smoke nuisance that causes the emissions. In the 20th century - I laws began to force private decision-makers to absorb the external costs of their polluting activities by making those activities more expensive and less attractive (application of Pigovian tax). State legislatures enacted enabling statutes giving municipalities the power to regulate smoke nuisance; [2] cities in turn responded by passing ordinances declaring the emission of *dense smoke* to constitute a public nuisance. [3]

The discussion in this section is premised on two assumptions: (i) before we use law to affect the decisions of acceptable emission levels we must first understand the limitations of legal processes; and (ii) these limitations are best revealed by studying how law has failed or succeeded in the past. The thesis of this section is that a study of the legal history of the 20th century-I reveals a continuing underlying tension affecting the use of the law as a tool for emission control. It is true that the pre 1930 era recorded several positive laws making efforts that developed and communicated the major working principles of today's Air Pollution Control Acts. The 20th century-I law also contained features that thwarted the law's impact on emission problems by their stubborn persistence in the legal process, which continued to limit the law's impacts on today's emission problems.

Social and Economic Appendage

Prior to 1880 the dominant social and economic institution which both affected and implemented men's choices was the market (Laitos, 1975). Positively, as the market sanctioned sustained bargaining among individuals over the use of assets, it fostered the most energetic use of limited capital, manpower and managerial talent. This positive virtue seen in the market reflected a more general idea prevalent in the 19th century - I that economic productivity was the means by which men could live a better life.

Negatively, it was believed that such a broad pattern of bargaining prevented the market outcomes from ever being grossly biased in favor of any particular segment of private interest. This negative virtue reflected an idea that was brought to special definition in our legal institutions, that all forms of power were so open to abuse as to be distrusted and hence a premium should be put on arrangements (of which the market was a prime example) that kept power in a healthy balance (Laitos, 1975). However, by 1880 social and economic arrangements changed drastically due to increased demands for food and shelters caused by increasing numbers of the population and their daily needs, especially in Midwestern states (Dunlap and Mertig, 1992). By the turn of the century, a simple market of many bargaining entrepreneurs had largely disappeared. In its place was the beginning of a new era of big industry, big finance, big cities and an increasing interdependence of activities between them. [4] Urban expansion of the factory system in the 1880's and 1890's in turn caused a degree of air and water pollution that would have seemed improbable fifty years earlier. Nor were there economic incentives to reduce the amounts of pollution produced. The manufacturer, with all his capital tied up in new machinery, was driven to seek a rapid return on his products, generally at low prices in a highly competitive market. They were competing with each other to reduce their overhead costs by using the physical environment (air, water) as a free and convenient receptacle for their factory's waste. Regardless of the fact that such economies were at the expense of diseconomies imposed on the surrounding cities and eventually the manufacturing system certainly seemed to justify the resultant pollution nuisance. [5]

At last policy makers began to acknowledge the existence of social costs. [6] There were no other alternatives. Market forces were alone insufficient to make the individual who wished to use the air or water as a pollution disposal medium consider or bear no costs his action imposed on others. It became clear that the action to prevent nuisance activities would have to come from the public sector in the form of a law and legal process (Laitos, 1975).

The Legal Response to Air Pollution

In the case of air pollution the first legislative bodies to take affirmative action were the common councils of large industrial municipalities in most of the Midwest states.[7] It is not surprising that it was the city and not the state or federal government, which first responded to air pollution. People saw dirty air as a local problem, not a regional or national concern. As a result of the failures of these local laws and in essence to protect air purity, the federal government stepped in with a comprehensive environmental legislative package in the 1970's that was based mainly on traditional approaches (command and control). Nearly all of the major environmental programs administered by the federal government were initiated in that decade.

Statutes Prior to Federal Intervention

Air pollution ordinances, enacted during the late 19th century and the early 20th century, by metropolitan common councils in Midwestern states fell typically into three categories. Most common were the ordinances that were simply declared: emission of dense smoke from smokestack within the city was a public nuisance and made the party who caused this emission liable to fine, usually not exceeding $100. () [8]

The second type of ordinances were more sophisticated laws which placed an affirmative duties on the polluters, requiring them to remove all ashes and to construct furnaces so as to consume the smoke arising from there. The third ordinance was required to prohibit the importation, sale, use or consumption of any coal containing more than 12 percent ash or 2 percent sulfur. [9] It is noticeable that all the ordinances were based on strict liability (SL) but none had an objective to achieve a fixed level of air quality. None had addressed today's emission problem. Another distinctive feature of those ordinances was the lack of provision for an enforcement mechanism. Although the ordinance declared typically that the emission of thick dense smoke was a public nuisance, no public agent was responsible to locate or abate this nuisance. The greatest weakness with these laws was that they were nearly always worded solely in terms of a simple "dense smoke" prohibition that makes the laws ineffective in implementation.

Federal Involvement

Brief history of Clean Air Act

Congress responded initially to the problem of offering encouragement and assistance to States based on the constitutional power given by the American people. In 1955 the Surgeon General was authorized by Congress to utilize scientific studies related to air pollution and finally passed the first air pollution law[10]. The Clean Air Act of 1963, ()[11] authorized federal authorities to expand their research efforts by making grants to state air pollution control agencies and intervening directly to abate interstate pollution in limited circumstances. In 1966, 80 Stat. 954 broadened federal authority to control motor vehicle emissions. The focus shifted somehow to the maintenance Air

Quality and Congress passed a law in 1967, the Air Quality Act 1967, 81 Stat. 485. It indicated mainly the primary responsibilities of States and local governments associated with the pollution control problem. The responses of States, which were relatively disappointing, resulted in the modern Clean Air Act of 1970. [12] This law increased federal authority sharply and responsibility in the continuing efforts to combat air pollution. Based on Statute, Environmental Protection Agency (EPA) was asked to set up "National Ambient Air Quality Standards (NAAQs)" although the law explicitly preserved the principle: "Each State shall have the primary responsibility for assuring air quality within its geographic area by applying any appropriate strategies". The development of this law was that the States were no longer given any choice as to whether they would meet this responsibility. For the first time they were required to ensure air quality of specified standards, and to do so within the specified period of time. A series of amendments were made to implement the original Clean Air Act by Congress in different sessions. In the 1977 Amendment, Congress required all sources to have or to implement a technology-based approach that they employ "reasonable available control technologies (RACT)". Congress also required all new sources to have a process-based technology standard called "lowest achievable emission rate (LAER)". Sources had to "offset" their new pollution by an even greater reduction of old pollution. For more than a decade, the CAA seemed to muddle through in its 1977 configuration. Additionally, local electric plants had started to install tall smokestacks. political questions were raised associated with costs and benefits of environmental improvements. Finally, the Reagan Administration chose to deal with this political question and introduced today's Clean Air Act Amendment (CAAA) of 1990. [13]

Title IV of the CAAA-1990 deals with acid rain control. It had tremendous impact upon electric utilities and consumers of electricity. Although the CAAA excluded today's CO_2 emission problem, CAAA is still a vital force in relation to my study for assigning liabilities for this issue or to internalize the damage costs in practice. In short, the purpose of title IV was to reduce the adverse effects of acid deposition through reduction in annual emissions of SO_2 of 10 million tons from 1980 emission levels. In combination with other provisions of the CAAA the emission of NO_x was to be reduced by approximately 2 million tons from 1980 emission levels. It was the intent of the acid deposition control title to effect such reductions by requiring affected sources to achieve prescribed emission limitations by specified time deadlines. [14] In essence to meet the CAAA-1990 requirements, policy-makers in states acted smartly and adopted different regulations within the state for the greater benefit of the state. Midwest states, especially, Ohio legislators passed laws [15] that introduced *Emission Fees Rider* [16] and under this banner, the SO_2 compliance costs have been collected from the end-users.

Liability Created by Statute

One depending for its existence on the enactment of a statute, and not on the contract of the parties. One which would not exist but for the statute. Here parties are legally responsible to meet the standards assigned by the statute.

Strict Liability

Congress did not define the strict liability under title IV. In order to extend my study I incorporate the different liability rules that are in practice under different environmental laws such as Compensation and Liability Act of 1980 (CERCLA) [17] although it is not related directly to the emission problems but it is related to externality problems that generated from hazardous waste. It was amended by the Super-fund Amendments and Reauthorization Act of 1986 (SARA). CERCLA 's objective is to provide the federal government with the authority and funds to clean up chemical spills and toxic waste sites. Congress did not define the standard of liability under CERCLA, leaving this to the discretion of the courts. Examples of strict liability cases are:

In the state of New York vs. Shore Realty Corporation and United States vs. Conservation Chemical Company. [18] In the State of New York vs. Shore Reality Corporation 759F, the court held that: (1) state's response, costs must be paid by the owner; (2) injunctive relief under CERCLA was not available to the state; (3) based on New York nuisance law, injection could be issued against defendants; and (4) stock holders and officers of the corporation were liable as an operator under CERCLA.

In other cases court ruled that past off-site generators of hazardous waste were among those potentially liable for clean up costs, and that such generators would be held to a standard of strict liability subject to affirmative defenses listed in the statute.

Joint and Several Liability

Congress did not define the standard of joint and several liabilities under CERCLA, leaving this to the decision of the courts. Examples of joint and several liability cases are United States vs. Chemical Dyne Corporation and United States vs. A and F Materials Company. [19] In both cases the court ruled that (1) the intent of Congress was to impose joint and several liabilities under CERCLA; (2) Congress intended under CERCLA to create a standard of liability and to rely on courts to determine this liability under a common law.

Other Sources of Liability

Apart from these liabilities imposed by Statute, anyone in the hazardous waste management business must recognize that there are established common law theories that can form the basis for recovery by plaintiffs in respect of personal injury and property damage. The following are few of common law theories for which there is a substantial body of existing site law upon which lawsuits could be and, in fact, are being based.

Negligence

Negligence can be defined as conduct that falls below the standard established by law for the protection of others against unreasonable risk of harm. The law has long recognized that if a person discharges pollutants negligently and as a result, someone else suffers or property damaged a cause of action may be maintained for the damages caused as a result.

Trespass

Trespass involves interference with a person's possessory interest in land. Most states recognize that any one who pollutes the environment so as to cause physical damage to other's property is liable for the resulting damages in a trespass action.

Nuisance

A private nuisance is an unreasonable interference with another's use and enjoyment of his or her land, or related personal or property interest. A public nuisance is one that involves interference with a general public right. A civil cause of action may be maintained on either type of nuisance.

Strict Product Liability

There is a growing trend to hold parties strictly liable for the consequences of their actions involving toxic materials. Strict environmental liability is related in concept to strict product liability. Just as a manufacturer may be held strictly liable for injuries caused by a defensive product, firms, which manage toxic materials similarly may be held strictly liable for those materials that escape and cause injury.

Most recently, additional theories of toxic tort liability have been advanced with the aim of easing the plaintiff's burdens. These doctrines include those of alternative liability and enterprise liability.

Alternative Liability

Alternative liability may be applied in situations where two or more defendants acted in a way that may have caused injury to a plaintiff, but it is not always possible to tell which of their actions in fact was the cause. Today, this theory is being applied in the environmental damage context.

Enterprise Liability

Enterprise liability addresses the situation where an industry wide practice may be harmful. If it can be established that an entire group breached its obligation to the plaintiff, as a result of which he was injured and though no fault of his own he is unable to identify which member or members of the group actually caused the injury, the entire group may be jointly and severally liable. This enterprise group could include the contract who designed or constructed a waste site or who participated in a waste site clean-up action.

General Statutes After 1970's

The Clean Air Act of 1970, as amended, [20] required industry, after an initial planning period by the states, to control emissions of certain designated air pollutant by installing expensive, energy intensive air pollution control equipment. It also requires the control of certain toxic air pollutants.

Clean Air Act Amendment of 1990

Under this amendment, the owner or operator of any power plant, subject to the requirements of CAA acid rain provisions, that emits SO_2 or NO_x for any calendar year in excess of that units emissions limitation requirement or, in the case of SO_2, the allowances the owner or operator holds for the use of that unit for that calendar year, is liable for the payment of an excess emission penalty. It required the companies to reduce their annual SO_2 emission beginning January 1, 1995. The addition of Title V of CAAA (SO_2 permits) [21] culminated in the strict law of Title IV to negligence law.

Power plants have the opportunity to meet the emission levels by trading or banking the SO_2 emission permits beside technology improvements. On December 19, 1996, the U.S. EPA issued final Title IV NO_x regulations. These regulations established the NO_x emission limits that were assigned to meet by January 1, 2000. In order to meet the NO_x regulations, many Companies have begun capital project of combustion control modifications. During the Fall of 1998, the U.S. EPA issued several final regulations that required further reductions in NO_x emission from the Midwest power plants. The U.S. EPA justified these further NO_x emission reduction requirements as being necessary to solve O_3 non-attainment problems in the Eastern and Northeastern states. A number of affected Midwest states and electric utilities initiated legal actions in efforts to overturn these regulations. However, this regulation was not over turned [22] and companies in Midwest states are now required to reduce NO_x emissions further to levels somewhat below 0.15 pounds per million British thermal unit (mBtu) of coal combustion, during the five month O_3 season (May through September) each year starting May 1, 2003.

On the question of regulating CO_2 emissions from electric generation under CAAA of 1990, EPA has claimed its authority and defined an air pollutant as "any physical, chemical, biological substance or matter that is emitted into the ambient air". After almost two years of debate over the issue, United States House Members concluded [23] in a recent letter to EPA that "we are more convinced than ever that the CAAA does not authorize EPA to regulate CO_2".

3.5.2 Economic Judgment of Liability Rules

Economic studies concerned with efficient emission control have traditionally devoted most of their attention to analyzing the effects of legal or regulatory policy instruments, such as effluent taxes or pollution standards (Buchanan and Tullock, 1965; Baumol and Oates, 1971; Hochman and Zilberman, 1987). With the exception of a relatively small number of articles (Lands and Posner, 1980; Opaluch, 1984; White and Wittman, 1979; Sullivan, 1986; and Fox, 1991), the role of the court system in general, and liability rules in particular, have not received analytical attention in the economic literature in proportion to their importance in resource allocation.

An early attempt to analyze the economic aspects of multiple tort feasters was the study by Lands and Posner (1980). The focus of their argument was the distinction between what the publication calls simultaneous and successive joint torts. They developed a theoretical framework of liability for simultaneous joint torts of both joint and alternative care types. Their study showed that in the joint care case (where efficiency requires both parties to take care) the common law rule of "no contribution" is efficient, and in the alternative case (where efficiency requires one but not both parties to take care) the common law rule of indemnity is efficient. In the special case where the costs of taking care are the same for the both parties, the common law rule would be inefficient.

Opaluch (1984) examined the use of liability rules in controlling toxic substance accidents, reviewing strict liability with particular emphasis on its role in toxic pollution events. He demonstrated the success or failure of liability rules, for providing economic incentive for pollution controls, by means of a simple conceptual model. He concluded that several difficulties with court rules lead to less than complete financial responsibility for damages from pollution accidents.

White and Wittman (1979) broadened the analysis of pollution control measures by considering the implications both for efficient abatement between a fixed polluter and pollutee (short run efficiency) and for the incentives they set up for creation of an efficient spatial location pattern (long run efficiency). They analyzed theoretically the role of liability rules and pollution taxes as alternative policies to correct the pollution problem in case of hazardous waste. They developed a conceptual framework:

X denotes smoke from a single polluter who damages a single pollutee, Y. D denotes the amount of pollution damage to Y expressed in dollars. D depends on the dollar amount of an input, x, used by X in damage prevention and the dollar amount of an input, y, used by Y for protection. The more x and y are used, the less the damage that occurs. Each unit of input is assumed to have diminishing returns in reducing damage. and land uses are assumed fixed at their locations. In the long run, most of land uses are fixed at their current locations. Thus, in some cases, spatial separation is a more efficient means of reducing pollution than on site abatement. They assumed that all polluters are in perfect competitive industries and that the prices of their outputs are exogenously determined in national or regional markets. They then defined an amount W_i as the maximum that the i^{th} land users could pay for an unpolluted site which is otherwise identical to the polluted site near the polluter's facility. Finally, they asserted that there are two basic factors defining a liability rule (LR). The first is the decision rule (court rules) that determines when the polluter is liable to the pollutee for damages.

and the second is the rule that sets the dollar amount to be paid. Then they considered several liability rules based on these two factors. They considered first several liability rules under which the polluter, if found liable, must pay the actual dollar amount of damages incurred by polluter. The seminal article argued that liability for actual damages (LAD) is a common standard in nuisance cases. However, the polluter may either be strictly liable (SL) or liability may be based on a variety of negligence standards.

To summarize this mathematically the rule is

LAD / SL = D (x, y), where the polluter is liable wherever damage occurs, regardless of whether or not he or she acted to reduce pollution.

Another polluter rule makes the polluter liable for damages only if negligent (N), where negligence is defined as failure to meet a specified level of due care. They assumed that X is liable for the actual damage incurred by Y if the level of X's pollution abatement input, x, is below the socially optimal level, x^*. X is not liable otherwise.

LAD/N = D(x,y), if $x < x^*$; or LAD / N = 0 otherwise.

The article viewed negligence as an economic concept; that is, the polluter is negligent if he or she uses less than the socially optimal amount of his own pollution abatement input. In the second part of that article, they proposed another liability rule that makes the polluter liable for the optimal cost (LOC) of pollution abatement by pollutee, plus remaining damages (R). LOC / SL = D [x; R (x)] + R (x). Here X's liability does not depend on actual damage, but it depends on optimal damage and prevention costs, given x.

White and Wittman (1979) pointed out that rules based on optimal rather than actual behavior, are relatively unfamiliar in economics but, are common in various areas of the law where they are known as the doctrine of avoidable consequences or mitigation of damages. The negligence version of LOC the paper argued can be expressed as:

LOC/N = D[x, R(x)] + R(x), if $x < x^*$, or LOC/N = 0 otherwise.

Establishing the short run efficiency properties of the liability rule (LR) given a fixed polluter and a fixed pollutee, White and Wittman (1979) assumed that each party treated the other's current level of pollution abatement input as fixed. They found that the result of the LAD / SL rule was not short run efficient because the pollutee has no incentive to prevent damage by using input y. However, the LAD / N does lead to the short run efficiency.

Turning to the optimal cost approach: liability rule under strict liability (LOC/SL), the polluter minimizes his or her total private costs, which are now equal to the sum of the cost of his abatement input, plus the optimal amount of abatement input by Y plus residual damages to Y. Thus, X internalizes all costs and the polluter's cost minimization point is the same as society's. Therefore, the polluter will choose x^* and pollutee will choose y^*.

To examine the long run efficiency of LR under LAD/ N case, they assumed that the polluter was the fixed land user and that two pollutees were bidding for a site nearby. The i^{th} land user's willingness to pay for polluted land is $W_i - [D_i(x_i^*, y_i^*) + y_i^*]$. This statement simply says that land rent must decrease by an amount equal to the private cost of pollution to the pollutee, efficiently abated, in order for the i^{th} land user to be able to produce at zero profit, at the polluted site.

Since the LAD / N rule is only short-run efficient, any arbitrarily involved parties have incentives to abate pollution efficiently. White and Wittman (1979) stated:

"Therefore, land owner rents the land to the highest bidder. The land market thus capitalizes the private cost of pollution into the price of the polluted land, as well as the value of other specific attributes, to the highest bidder". The authors then raised the question, "Is this an efficient result in the long run?" The answer was "not necessarily"

Their claim that the LR for negligence leads to correct action in the long run results in some cases but not others as because the land market capitalizes the private cost of pollution to the pollutee but not the social costs for pollution (SCP). Thus the land owner has an incentive to choose these land uses for which the polluter's cost of abatement is inefficiently high and the pollutee's cost is inefficiently low.

For LOC/N, the paper showed that a willingness to pay (WTP) by the i^{th} pollutee for the polluted site as W_i - $[D_I\{x_i*, R(x_i*)\} + R_i(x_i*)]$. Since $R_i(x_i*) = y_i*$, it is apparent that WTP is the same under LOC/N as under the LAD/N. They then concluded that neither rule consistently leads to efficient results in the long run.

For LOC/SL in the long run, the article reported slightly different. Here WTP by the i^{th} pollutee for the polluted site becomes W_i - $[D_i(x_i*, y_i*) + y_i*] + D^i[x^i*, R(x^i*)] +$ $R^i(x^i*)$. It can be noted here that the pollutee's WTP falls by an amount equal to private cost of pollution efficiently abated but rises by the amount of damage payment expected from the polluter.

Therefore, under strict liability (SL) with polluter's location fixed, they concluded that: there is no tendency for more pollution sensitive land users to be outbid for polluted sites by less pollution sensitive users. This suggests that SL, such as LOC/SL, in general has less favorable results for the long run pollution control that negligence rule such as LOC/N or LAD/N (White and Wittman, 1979).

The final study related with liability rules reviewed is of Sullivan (1986). The goal of that paper was the assignment of responsibility for the cleanup of unsafe hazardous waste disposal sites. The author, in his paper, explored the efficiency effects of different liability rules. Sullivan argued about the EPA policy that is designed to assign full liability to waste generators. He found the assignment is somewhat inefficient and that it has encouraged the illegal waste disposal on the part of the waste generator. This full liability required a subsidy to the generator out of tax revenue. He also found that this assignment produced some welfare costs of taxation and as a consequence it increased the proportion of costs assignment to the waste generator.

3.5.3 Economics Literature on Externality

Laws and regulations are not the sole means to improve liability for environmental damage. Economists have long advocated different approaches to frame this *Liability Rule*. In this section I will review the literature that has been created by two controversies, one associated with Pigou and the other with Coase. I begin with the first.

Controversy over Pigouvian Tradition

The British economist, Alfred Marshall (1920), first gave the name "external economies" to knowledge that benefited a firm but was generated outside it, and "internal economies" to the improved organization developing inside a firm a larger scale. After significant controversy, Arthur C. Pigou (1932) first made a seminal suggestion on external diseconomy. His dominant economic argument was the adoption of a system of unit taxes or subsidies to control pollution, where tax on a particular activity is equal to the marginal social damage, (i.e., the difference between its marginal social cost and marginal private cost). The producer of the externality should be fined or taxed and the fine or tax would continue until the externality disappeared completely. Although Pigou's early formulation was left in an odd position, since the theory had been found deficient, Pigou's policy solution to the externality problem has remained widely accepted. The Pigovian solution remained unchallenged until 1960 when Ronald Coase (1965) published his watershed article attacking what he called the Pigovian "oral tradition". Coase (1965) began by undermining the symmetry of uncompensated dis-services:

The question is commonly thought of as one in which A inflicts harm to B and what has to be decided is: How should we restrain A? But this is wrong. We are dealing with a problem of reciprocal nature. To avoid harm on B would inflict harm on A (Coase, 1965)

He argued that the solution between a polluter and pollutee was entirely symmetric. Forcing abatement would harm the polluter, whereas on the other hand, allowing pollution would hurt the pollutee (receiver). Coase suggested that this argument has both positive and normative implications. Firstly, the positive implication is that given rights to pollutee and no approaches to negotiation, as a paradigm of negligence liability, at least one of the parties involved will have an incentive to change the magnitude of emission regardless of the existing liability rules. If an industry has legal rights (zero liability) to emit unlimited smoke in air and the pollutees are inconvenienced then the pollutee has an incentive to offer the industry owner an inducement to encourage them to reduce the emission level. If law specifies an emission level (standard level) which the pollutee permits, then the industry owner has an incentive to offer compensation to induce the pollutee's to accept additional smoke. It can assume that industry emits smoke only under laissez-fair conditions because the reduction of emissions raises the cost so that complete emission reduction would drive the industry out of business. Under each liability rule each party has an incentive to induce a change in emission levels.

The normative implication is: neither party has a monopoly in causing harm and. therefore, adherence to moral principle does not mean that the industry should be required to cease its offensive emission or for that matter the industry should cease their complaint. Basically this theorem says:

With a clear definition of property rights and encouragement to bargain, a Pareto optimum would be reached without government interference of Pigovian taxes. Furthermore, with cost-less market transactions, the decision of courts concerning liability for damage would be without effect on the allocation of resources (Coase, 1960).

Following this argument, Stigler (1966) cast the Coase theorem in a more general form:

Under perfect competition and any assignments of property rights, market transactions between a firm, producing, a nuisance and one, consuming, it will bring about the same composition of output as would have been determined by a single firm engaged in both activities.

Davis and Whinston (1962) made the distinction between separable and non-separable cost functions and pressed on with their attack. They pointed out the practical difficulties of the government in estimating damage curves in a separable case and the game theoretic indeterminacy of the non-separable case. Finally, they attempted to save Pigovian tradition by suggesting merging inter-acting firms and admitting the existence of costs due to this merger. Calabresi (1968), in his seminal article, accepted Coase's conclusion but raised a question about its validity in a long run situation. Nutter (1968) came forward with a confused empirical study to counter Calabresi's strong arguments and concluded " Coase theorem applies to long run as well as short run allocation resources." Since then, Calabresi's claims have prevailed. In 1968, he concluded:

Even if transactions brought about the same short run allocation, liability rules would affect the relative wealth of the two joint cost causing activities, and in the long run this would affect the relative number of firms and hence the relative effect of the activities.

Controversy over Coasian Doctrine

Coase finished his attack on Pigou by turning one of Pigou's own examples against him. If a railway was forced to compensate farmers for fires caused by the railroad, farmers would be indifferent between planting crops next to the railroad and collecting compensation or taking the more socially appealing action of moving some of the crops away from the railroad. Thus, according to Coase, not only is the Pigovian solution unnecessary and ill defined in terms of equity, but also sometimes it is non-optimal. The last point seems to be self-damaging for Coase, since Pigovian compensation is equal in Coase's bargaining, under the specialization of price taking behavior of both parties. However, I may anticipate a result of my model in the coal combustion externality problem (this will be discussed in the later section) and conclude that Pigovian compensation should be paid on the basis of damage, after defensive strategies are taken by parties, involved in electricity generation and usage activities.

The Coasian analysis of externality was enshrined rapidly in the economic literature. It concentrated mainly on a case study where both parties were producers.[24] Davis and Whinston (1965) extended a case study where both parties were consumers and found the results parallel to Coase's analysis including the findings of neutrality of liability rules.

In 1966, a group with three subgroups first attacked Coase's results. The first group claimed that the zero transaction cost assumptions were unrealistic and such solutions unworkable. In this group, Kneese (1966) pointed out the vulnerable aspects of Coasian's doctrine as includes a two-party world. Olson (1964) argued that large groups behave fundamentally differently than small ones. Some or all members of a small group may have individual incentives to bear the costs of the bargaining themselves, since the benefits of negotiation may be vary concentrated. However, for a larger group the benefits of a negotiated settlement become more extended out, and the benefits to any particular individual may be less than the costs of bargaining for him, if he takes an active part in negotiation. It may be to the advantage of each affected member of the group to become a free rider on the others' efforts.

The second group accepted Coase's static perfect competition assumptions for the sake of argument, but negated Coase's neutrality of liability rules. In this group, Dolbear (1967), Randall (1971, 1972) and Mishan (1971) made varying degrees of progress towards normative analyses of Coasian neutrality doctrine. Dolbear (1967) first claimed that Coasian's analysis was not fitted for allocation of property rights and that income can affect allocation of products. Dolbear's point, while a general one, is most obvious when the two parties are two consumers. Dolbear's findings are as follows:

The amount of externality that will tend to emerge depends on the extent of legal responsibility. The distribution of the " gains from the trade" should also have an effect on the degree of externality. It is not simply related to regulated externality with only government tax schemes. Some of the current standard tax proposals will not generate results that always satisfy the requirements for Pareto optimality. It is not in general possible to impose a per unit tax which simultaneously compensates (exactly) for the damages and still achieve a Pareto optimum. With information deficiencies and no legal restrictions on pollution (smoke), a government authority set up to offer bribes for the reduction of pollution may be unable to make improvements in the Pareto sense.

Mishan (1971) and Randall (1971, 1972) have used two different acting party cases (producer and consumer) instead of homogeneously acting parties (producers or consumers) that were used by Dolbear under the same static perfect competition assumptions. Randall (1971, 1972) was able to demolish Coase's claims in his seminal thesis. He finished his attack on Coase's doctrine, of the allocative neutrality of liability rules in one of his seminal articles in 1972 and theoretically approached to assign a liability based on Pareto efficiency. He concluded:

Allocative neutrality with respect to liability rules can be accepted only in situations where all of the involved parties are producers, the use of capital is a free good and no transaction costs incurred in the process. In cases other than these, in every significant externality problem, an full liability (L^f) or some intermediate position will result in a market solution specifying a higher degree of abatement.

He then went on and raised the question:

Are market solutions based on a full or intermediate liability rule preferable to solutions forced by systems of fines and subsidies or standards?

His answer was:

The market solutions in many cases will achieve a substantial abatement if the liability rules were changed to L^f *or something approaching to it.*

He added more:

A full liability law would result in a greater degree of abatement of external diseconomies than zero or intermediate liability laws.

In this Chapter, I will examine the relationships between the assignment of liability empirically and the magnitude of abatement of CO_2 emission from a power plant, under the subject matter of "law and economics" and in essence, a sense of ethics and classical liberal maxim act here as catalyst. To my knowledge, it is the first assigning liability in the case of domestic CO_2 emission problems. My approach uses a three party case where power generating companies burn coal for generating electricity, based on end-user's demand and emits CO_2 including other effluent gases. The second party is the electricity customers (end-users). The last party involved is society including next generation, which faces the harm. Currently, most academic and other institutional literatures concerned with the issues concentrate on externality, versus welfare analysis, instead of assigning liability rules for environmental damage. Recent developments concerning the issue, such as the Kyoto Protocol ratify my claims. Overcoming the shortcomings of the availability of literature on liability concerning effluent gas emissions, I have incorporated a few recent studies that have been developed on assigning liability for CO_2 emission problems internationally instead of only as domestic emission problems. The mechanics of choosing our domain daunts the very recent claim that "liability is not a suitable instrument for dealing with pollution of widespread character" by the European Community (EC-2000). [25]

Based on this opportunity, I will first start to incorporate Calabresi's arguments based on law and economics. Calabresi (1968) observed Coase's attack and concluded: "transaction valued at money, and since for transactions, the taxation, liability rules or structural rules also do not cost less". The calculus of the costs incurred to implement rules is integral to the effectiveness of these rules. Observing this phenomena, I believe, as Buchanan (1962) claimed: "externalities are either reduced or eliminated by the shift of an activity from market to political organization".

The Coasian neutrality has been shown to have intrinsic problems of its own. The third stage of attack on the Coasian position was to attack its ethically neutral foundation. To the Coasian, it makes no sense to separate polluter and pollutee since the situation is reciprocal: if A harms B, then to prevent A from harming B is to harm A. Underlying the idea of neutrality, allocation is the idea of ethical neutrality. The only criterion is the total social product under different arrangements. I start with the ethical question of inequality just alluded to. The ethics of marginal distribution of income has been defended on the grounds of merit, as well on the ground of efficiency allocation. In connection with liability rules, we first need to acknowledge that one of the primary characteristics of humans, as a species, is our ability to modify the environment to meet our needs. For example, *usage energy* allows us to modify a variety of environments and increases our productivity and personal comfort. Unfortunately, overuse of energy may also be our undoing and that may demand for a higher volume of electricity generation.

Buchanan (1954) claimed: *those who work hard and contribute more should receive more. Besides having efficiency allocations, the tax system is consistent with this merit* *principle*. This statement presses as again to introduce Pigovian tax with a kind of liability rules instead of strict liability rule on our emission problem, although it has been controversial. Baumol and Oates (1971), in waste hazard emission problems, observed two reasons why: (i) the social damage of pollution was difficult to measure and (ii) although efficient taxes should correspond to an optimal situation, available data are related not only to the neighborhood of the economy's initial position. They reviewed the nature of these difficulties and then proposed a substitute solution to the externality problem. This alternative, which they called the environmental pricing and standards procedure, sets an arbitrary standard of environmental quality and then imposes taxes to attain this standard. Although their solution is not necessarily Pareto-efficient, it achieves the desired limits on pollution, given the level of outputs, at a minimum cost to the economy. Their approach decreases the information required for decision-making by adjusting the tax per pollution unit, by increasing or decreasing it, whenever the actual level of pollution is above or below the predetermined. Hochman and Zilberman (1978) argued that the effects of adjusting taxes are not conclusive and depend on the specific forms of the distributions. For instance, one would expect that an increase in the tax rate always result in a reduction of the average pollution. Recently, the European Community Commission concluded: [26]

The most appropriate option would be a framework directive providing for strict liability for damage caused by EC-regulated dangerous activities, with defenses, covering both traditional and environmental damage, and fault-based liability for damage to biodiversity caused by non-dangerous activities.

They added new rules to improve the implementation of key environmental principles, i.e. the polluter pays, by assigning environmental liability instead of strict liability, polluter pays principles (PPP). The Commission invited the European parliament, the Council, the Economic and Social Committee and the Committee of the Region as well as interested parties to discuss and comment on their white paper. They claimed that "this approach can provide the most effective means of implementing the environmental principles of the EC treaty, in particular the PPP".

3.6 Theoretical Models

The development of an analytical framework for investigating the efficiency and equity trade-off of liability rules for CO_2 emission burden from power-generating companies require two major steps. They are (1) modeling end-user (consumer) and generating company (producer) behavior for curtailing the magnitudes of emission levels, and (2) quantification of this behavioral model. This section contains both a geometric

and mathematical model of the emission from power plant. I begin to incorporate my model into underpinning the following assumptions and definitions that are assumed in practice.

i) Power plants operate under an assumed federal law (hypothesized statute) that requires curtailing the magnitude of CO_2 emissions for dating the 1990 emission levels as it is required by the United States to meet the Kyoto Protocol target; ii) Defining Markets.

Permissible Emissions

Electric companies are currently operated in a regulated market. As of FERC rule 888 requirements, the operation mechanism will shift to a comparative retail service market in January 1, 2001. Under regulated scenario, I assume the effluent fees are announced and it is taken into account in electric service rate-making process and it raises electricity prices per kWh. On the other hand, if the industry is operated under a competitive retail service market, I assume that the generating company reduces the emission levels until the marginal cost of compliance equals the affluent fees. No alternate is allowed in either market in order to meeting the emission target under our hypothesized statutes. This approach can be again in two folds. *Command without Control* where the tax rate of emission is announced and the system solves for the volume of emission. *Command and Control* where emission target and tax rates are announced and system solves for the volume of emission level after meeting emission target levels. Allowing emission permits market, the company may face incentive to generate electricity under coal combustion in order to meet our hypothesized emission law. Here, the company pays fees where it fails to meet the standard level.

Unauthorized Emission

Under the umbrella of assumed emission law, I assume CO_2 emission treatment, storage in soil or dump into ocean or any other activities not our hypothesized law approved is unauthorized. Penalties for violation include fines and imprisonment. Electric utility market is a paradigm in my study.

3.6.1 Geometric Model

The model for this analysis deems a power plant that emits CO_2, as a negative externality from its electricity generation process. The generating company has opportunity to choose various ways to generate electricity such as electricity under coal combustion, electricity under nuclear power plant, electricity under oil, etc. or a combination of fuels. For the purpose of this research I assume total electricity is generated under coal combustion (such as AEP). Under hypothesized statute, the generating company has opportunity to choose two scenarios of electricity generation, namely "permissible emission scenario" and "unauthorized emission scenario".

Under a hypothesized statute, public policy determines the price of electricity per kWh directly. But the price of electricity per kWh in market two depends indirectly on the enforcement policy. More enforcement will increase the expected cost of electricity generation, decreasing the volume of electricity generation under coal combustion and induce electricity generation under nuclear power plant or other options that result a

lower emission level in order to ensure uninterrupted market demand. The policy generates efficiency gains by decreasing the environmental costs incurred from burning less coal.

Electricity Market under Permissible Emission Scenario

I consider first the determination of the quantity of electricity generation under coal combustion in this market. Let me call this market, "market-one". Market-one is illustrated by figure 3.1. Let C_p represents the marginal private cost (including rate of return in case of regulated market) of total electricity generation, C_s is the marginal social cost of electricity generation and E (D) is the demand for electricity. Point X is the market equilibrium if only marginal private cost (MPC) of electricity generation is covered by the company and passes it on to end-users in terms of electricity price per mWh. The equilibrium price and volume are then P_2 and D_2, respectively. But if the full marginal externality cost is covered by the end-users (consumers) along with the marginal production costs, then market equilibrium occurs at point K with equilibrium price P_1 and volume D_1. An intermediate situation can also arise in the market as shown in Figure 3.1. It is possible that the end-users will pay all of the marginal private costs of electricity but only a fraction of marginal externality cost. This possibility is represented by the C_n schedule shown in Figure 3.1. The market equilibrium occurs now at point G with an equilibrium price of P and equilibrium volume of D. It is assumed in the remaining discussion that point X represents the initial equilibrium and that point G describes the equilibrium point of electricity generation in market one created by policy. Three different groups are represented (Figure 3.1): (1) electricity users (end-users or consumers), (2) electricity generating company (producers) and (3) individuals (excluded or included the above two) adversely impacted by the marginal externality costs resulted from electricity generation under coal combustion - pollutees or victims. Each of these groups is examined in detail in the following paragraphs.

Consider first the impact on the end-user with a demand for electricity. Increasing market price from P_2 to P means that end-user experience a loss in consumer surplus equal to the area P_2PG X. The generators in contrast now provide D units of electricity under coal and charge a price of P. This results in a revenue transfer from consumers to producers equal to the area P_2PGL. But these generators experience a reduction of electricity generation under coal fired provided in market one equal to the distance D_2D. This, in turn, implies a loss in producers' surplus equal to area -BPG + AP_2X. The third impact is concerned with externality costs. If the total electricity generation under coal fired is equal to D_2 the associated level of externality cost is equal to the area CNXA. But if the level of electricity generation under coal combustion is D then the associated level of externality cost is CFYA. A net impact on external cost of reducing the volume of electricity generation under coal fired from D_2 to D is equal to the area FYXN.

Electric Market under Unlawful Emission Scenario

Let me call this market, "market-two" (Figure 3.2). It is assumed that generating companies have demand for both markets for electricity generation under coal combustion. This implies, moreover, that these generating companies receive benefits from having access to market-two. The demand for market-two is assumed to depend on two factors: the policy cost of market-two and policy cost of market-one paid by the company, C_s - C_n. the policy cost of market-two is assumed to be determined by governmental enforcement programs. Such costs are exogenously determined in this analysis. The policy cost of market-one is determined in market-one, as indicated.

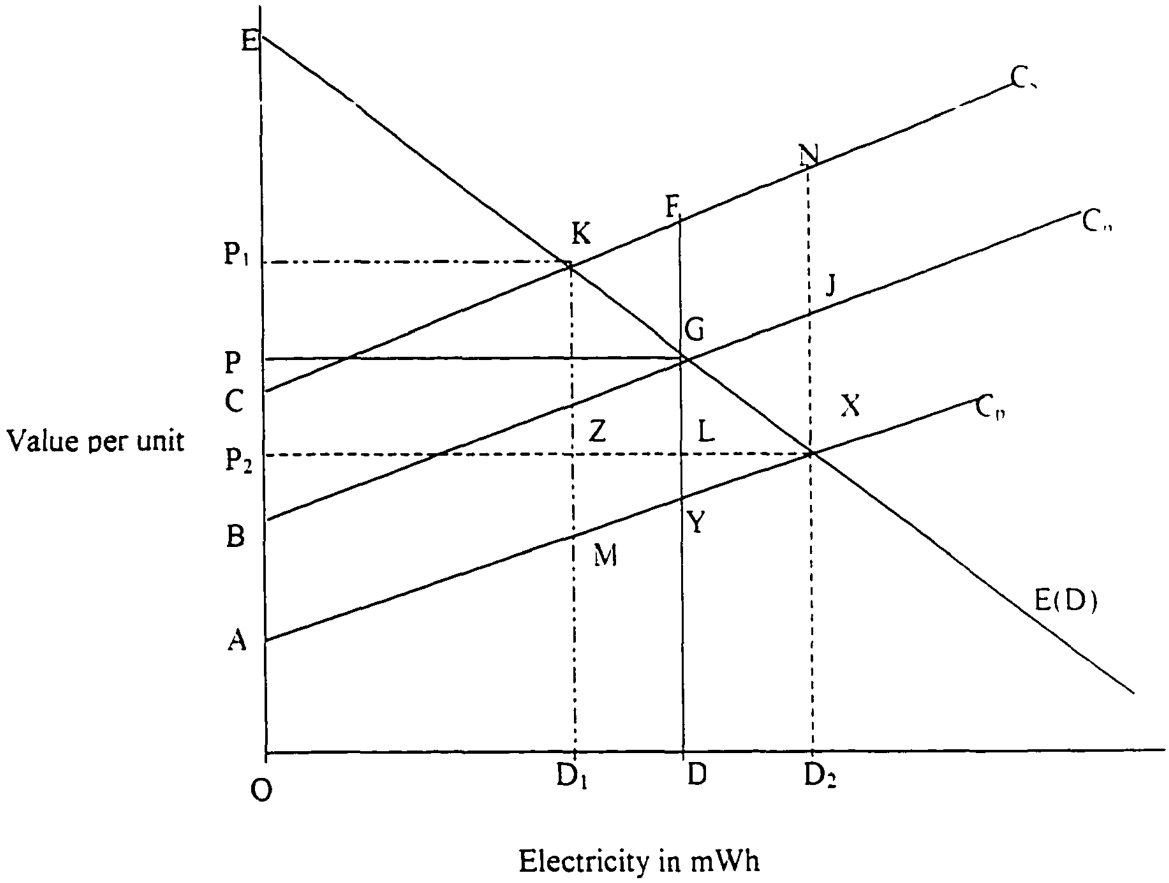

Figure 3.1: Electricity Market-one

Increasing the policy cost of electricity generation under coal combustion in market one paid by the company causes the demand for electricity generation in market-two to shift to the right. That is, electricity generations in market-one and electricity generation in market-two are related as substitutes.

The consequences of changes the demand of electricity generation under coal fired in market-two are shown in Figure 3.2. P_I, the policy cost of electricity generation per mWh is assumed to be constant in this market. Increasing the cost of electricity generation in market-one to generating company means that the demand of electricity generation in market-two increases from I' to I". When demand of electricity generation under coal fired in market-two is I (C'_n, P_I), the total benefit for the consumer is equal to the area OI'MP'$_I$, while the total cost in market two is equal to area OI'MP$_I$. This implies a net benefit equal to P_IMP'$_I$. But if demand is I (C''_n, P_I), then total benefit is OI"NP"$_I$ and total cost is OI"NP$_I$. This implies a net benefit equal of P_INP"$_I$. Thus increasing the demand in market-two from I' to I" implies that the generating company receives a net benefit equal to the area (P_INP"$_I$ - P_IMP'$_I$), which ultimately goes to end-users. Activities in market two also imply the possibility of environmental damage associated with marginal externality costs as well. Discussion and measurement of their costs are based on Figure 3.3. The marginal externality cost of electricity generation under coal combustion in market-two consists of two components. The first is the quantity of

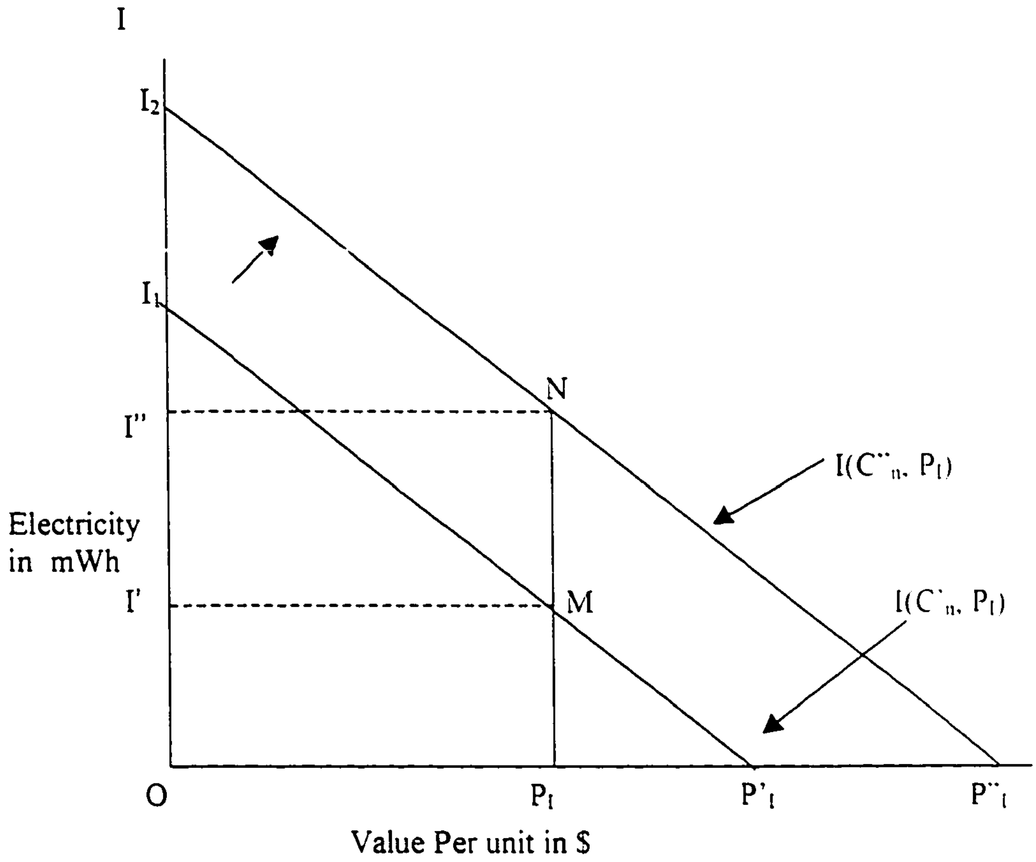

Figure 3.2: Electricity Market-two

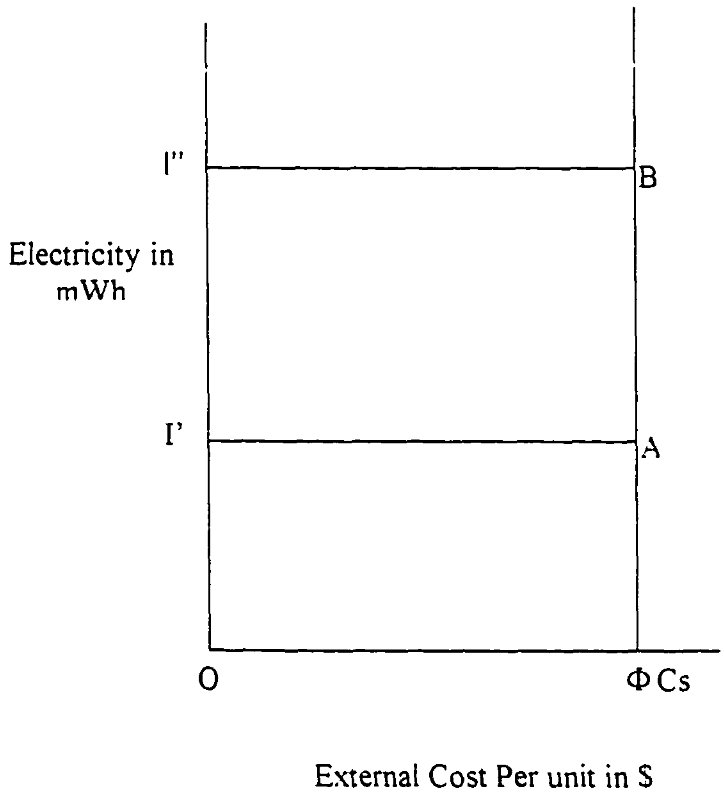

Figure 3.3:External Costs

electricity generation under coal combustion allowing the levels of emission. In Figure3.3, there are two sizes: I' associated with P_2 and I'' associated with P (Figure 3.1).

The second component is the cost of the resources required to make the external effect results of CO_2 emission harmless to third parties affected by market-two. These costs are assumed to be a single value per unit; that is, the per unit cost is assumed to be ΦC_s, where Φ measures electricity cost in market two as a fraction of electricity cost in market one; Φ can be greater than one. The $\Phi < 1$ situation indicates that the market-two is cost effective and it becomes appealing to generating company otherwise it becomes disincentive. The exact relationship between ΦC_s and P_1 is not known on *a prior* basis. Moreover, whether the bargaining outcome under market-one or market-two leads to lower emissions or higher welfare depends crucially on the model parameters. The welfare loss associated with total electricity generation under coal combustion, on an extra units occurring because of the price rise from P_2 to P in market-one, is shown by the area I'I''AB (Figure 3.3). This area is an accurate measures of minimum welfare losses, provided the third parties in market-one value a cleaner environment as highly as the cost of cleanup.

3.6.2 Mathematical Model

I will begin this section by identifying the following terms:

S_1: Net welfare effects to electricity end-users or electricity consumers.

S_2: Net welfare effects to generating company who produces electricity under coal combustion.

S_3: Net welfare effects to all pollutees -- victims of emission -- future generation

Let us calculate each group's net effect separately. Following Figure 3.1 and Figure 3.2, the net welfare effects for end-users can be stated as follows:

$$S_1 = -P_2PGX + P'_IMNP''_I \qquad (3.1)$$

Note that P_2PGX has a negative sign representing a loss in consumers' surplus. Areas appearing in the right hand side of the expression (3.1) are defined as follows:

From Figure 3.1

$$P_2PGX = P_2PGL + GLX \qquad (3.2)$$

and

$$GLX = G\,DD_2X - L\,DD_2X \qquad (3.3)$$

$$P_2PGL = E(D) * D - P_2D \qquad (3.4)$$

$$GLX = [\int_D^{D2} E(d)dD - P_2(D_2 - D)] \qquad (3.5)$$

Substituting equations (3.4) and (3.5) into equation (3.2) yields:

$$P_2PGX = [E(D) * D - P_2 D] + [\int_D^{D2} E(D)dD - P_2(D_2 - D)] \qquad (3.6)$$

From Figure 3.2

Benefit from market-two

$$P'_IMNP''_I = P_I\,N\,P''_I - P_I\,M\,P'_I \qquad (3.7)$$

Where

$$P_I\,N\,P''_I = \int_{PI}^{P'I} I(C''n, PI)dPI \qquad (3.8)$$

and

$$P_I\,MP'_I = \int_{PI}^{P''I} I(C'n, PI)dPI \qquad (3.9)$$

Substituting expressions (3.8) and (3.9) into expression (3.7) yields:

$$P_I \, MNP''_I = \int_{PI}^{P'I} I(C''n, PI)dPI - \int_{PI}^{P^*I} I(C'n, PI)dPI \qquad (3.10)$$

We can now substitute expression (3.6) and (3.10) into expression (3.1) to obtain the following:

$$S_1 = [E(D) * D - P_2D] + [\int_{D}^{D_2} E(D)dD - P_2(D_2 - D)] +$$

$$\int_{PI}^{P'I} I(C''n, PI)dPI - \int_{PI}^{P^*I} I(C'n, PI)dPI \qquad (3.11)$$

To calculate S_2, note that the initial equilibrium in market-one, prior to any policy action is P_2 and D_2 (Figure 3.1). The area P_2XA, therefore, shows the initial producer's surplus.

Next let me assume that some share instead of full liability is imposed on the end-users. Alternatively, let us assume that generating company shares the liability. This amount is shown by the difference between lines C_n and C_p (Figure 3.1). New equilibrium in market-one is reached at point G. It means that the equilibrium point in market-one is now given at point G. Thus, after the policy action the market price is P and equilibrium total electricity generation under coal fired is D. The producers' surplus in this case is the area PGB (Figure 3.1).

The net welfare effects for electricity generating company can be defined as the net change in the producers' surplus that occurs when a generating company shares of the social cost for electricity generation under coal is imposed on the end-users. Thus we can state the change in producers' surplus resulting from an increase in the share from zero to C_p - C_n can be stated as:

$S_2 = - BPG + AP_2X.$ (3.12)

The right hand side of expression (3.12) can be written as follows:

$BPG = OPGD - OBGD$ (3.13)

and

$AP_2X = AP_2LY + LYX$ (3.14)

Note that,

$AP_2LY = OP_2LD - OAYD$ (3.15)

$LYX = LDD_2X - DYXD_2$ (3.16)

Substituting expression (3.13) to (3.16) into expression (3.12) yields:

$S_2 = - OPGD + OBGD + OP_2LD - OAYD + LYX$ (3.17)

Let me define the schedules for C_p and C_n (Figure 3.1) as $C_p(D)$ and $C_n(D)$ respectively. Using these functions, we can convert the geometric areas of expression (3.17) as follows:

$$S_2 = - C_n(D)D + \int_0^D Cn(D)dD + P_2D + P_2(D_2 - D) - \int_D^{D2} Cp(D)dD \quad (3.18)$$

Following from Figure 3.1 and Figure 3.3, the net welfare effects for victims of CO_2 emission from generating company under coal combustion can be stated as follows:

$S_3 = FNXY - I'I''AB$ (3.19)

The areas in the right hand side of expression (3.19) can be further defined as follows:

From Figure 3.1

$$FNXY = \int_D^{D2} [Cs(D) - Cp(D)]dD; \quad (3.20)$$

From Figure 3.2 and 3.3

$I'I''AB = \Phi C_s [I(C''_n, P_I) - I(C'_n, P_I)]$ (3.21)

Where ΦCs represents the externality cost per unit of electricity generation under coal fired in market two. $[I(C''_n P_I) - I(C'_n, P_I)]$ represents the change in demand of electricity generation under coal fired in market two for a fixed unit price of electricity (P_I).

Substituting expressions (3.20) to (3.21) in expression (3.19) yields:

$$S_3 = \int_{D}^{D2} [Cs(D) - Cp(D)]dD + \Phi C_s[I(C''_n, P_I) - I(C'_n, P_I)] \qquad (3.22)$$

Social Welfare Weights

The determination of CO_2 emission policy (i.e. liability rules program) involves implicit weighting of welfare gains and losses by end-users, generating company and victims of the CO_2 emission. Thus, one may hypothesize that the emission policy-makers have a social welfare function that includes social welfare weights for the three groups of individuals involved. This social welfare function can be written as follows:

$$W = \omega_1 S_1 + \omega_2 S_2 + \omega_3 S_3 \qquad (3.23)$$

Where ω_1, ω_2, ω_3 are weights for end-users, generators and victims of CO_2 emission due to coal combustion respectively; and S_1, S_2 and S_3 are respective net welfare effects of the policy.

Optimal Liability Share

The ultimate goal of this exercise is to determine, first the optimal liability share for end-users where the optimal liability share, λ, is defined as the portion $C_s(D) - C_p(D)$ which, if paid by the liable party (s), will maximize the value of expression (3.23). This determination has two steps. Firstly, an expression for the optimal quantity of electricity generation under coal combustion D is established. Second, the optimal D is substituted into the expression

$[E(D) - C_p(D)] \div [C_s(D) - C_p(D)]$

to determine the optimal liability share for end-user. The calculation of the optimal electricity generation under coal fired begins with the substitution of expression (3.11), (3.18) and (3.22) into expression (3.23). This substitution yields:

$$W = -\omega_1[\{E(D) * D - P_2D\} + \{\int_D^{D_2} E(D)dD - P_2(D_2 - D)\}]$$

$$+ \omega_1 [\int_{PI}^{P'I} I(C''n, PI)dPI - \int_{PI}^{P'I} I(C'n, PI)dPI]$$

$$+ \omega_2[- C_n(D)D + \int_0^D Cn(D)dD + P''D - \int_0^D Cp(D)dD$$

$$+ P''(D_2 - D) - \int_D^{D_2} Cp(D)dD]$$

$$+ \omega_3 [\int_D^{D_2} \{Cs(D) - Cp(D)\}dD - \Phi C_s \{I(C''_n, P_I) - I(C'_n, P_I)\}] \qquad (3.24)$$

Expression (3.24) is the desired social welfare function for the problem outlined in this chapter in section (3.1.4). I postulate that the total electricity generation under coal combustion, D, is determined so as to maximize expression (3.23). The first derivative of expression (3.24) is

$$\frac{\partial W}{\partial D} = -\omega_1[\{\frac{dE(D)}{dD} * D + E(D) - P_2\} + \{-E(D) + P_2\}]$$

$$+ \omega_1 [\int_{PI}^{P'I} \frac{\partial I}{\partial C''n}(C''n, PI)\frac{\partial C''n}{\partial D} dP_I - \int_{PI}^{P'I} \frac{\partial I}{\partial C'n}('n, U_I) \frac{\partial C'n}{\partial D} dP_I]$$

$$+ \omega_2[- \frac{dCnD}{dD} * D - C_n(D) + C_n(D) + P_2 - C_p(D) - P'' + C_p(D)]$$

$$+ \omega_3[-\{C_s(D)-C_p(D)\} - \Phi \frac{dCs(D)}{dD} \{I[C''_n(D), P_I) - I(C'_n(D_2), P_I]\}$$

$$\Phi C_s(D)\{ \frac{\partial I}{\partial C''n}(C''_n(D),U'I)\frac{\partial C''n}{\partial D} - \frac{\partial I}{\partial C'n}(C'n(D),P_I) \frac{\partial C'n}{\partial D} \}] \qquad (3.25)$$

Simplifying expression (3.25) yields:

$$\frac{\partial W}{\partial D} = -\omega_1 [\frac{dE(D)}{dD} * D] + \omega_1 [\int_{PI}^{P'I} \frac{\partial I}{\partial C''}(C''_n, P_I)\frac{\partial C''n}{\partial D} dP_I$$

$$- \int_{PI}^{P'I} \frac{\partial I}{\partial C'n}(C'_n, P_I)\frac{\partial C'n}{\partial D} dP_I] - \omega_2[\frac{dCn(D)}{dD} * D] + \omega_3 [- \{C_s(D) - C_p(D)\}$$

$$- \Phi\frac{dCs(D)}{dD} \{I(C''_n(D), P_I) - I(C'_n(D), P_I)\} - \Phi C_s(D)\{ \frac{\partial I}{\partial C''n}(C''_n(D)\frac{\partial C''n}{\partial D}$$

$$- \frac{\partial I}{\partial C'}(C'_n(D), U'_I)\frac{\partial C'}{\partial D} \}] \qquad (3.26)$$

Solving expression (3.26) for the optimal total electricity generation under coal combustion yields:

$$\omega 1 \; [\int_{PI}^{P'I} \frac{\partial I}{\partial C''n}(C''_n,P_I)\frac{\partial C''n}{\partial D} - \int_{PI}^{P'I} \frac{\partial I}{\partial C'n}(C'_n,P_I)\frac{\partial C'n}{\partial D} dP_I \qquad (3.27)$$

$$+\omega 3 \{-[C_s(D) - C_p(D)] - \Phi \frac{dCs(D)}{dD} [I[C''_n(D),P_I)$$

$$- I(C'_n(D),P_I)] - \Phi C_s(D)[\frac{\partial I}{\partial C''n}(C''_n(D),P_I)\frac{\partial C''n}{\partial D}$$

$$D = \text{-------------------------------} \frac{-\frac{\partial I}{\partial C'n}(C'n(D), PI\frac{\partial C'n}{\partial D}}{\omega 1\frac{dE(D)}{dD} + \omega 2\frac{dCn(D)}{dD}}$$

To make the model simple, I work with linear versions of the demand and cost functions.

That is:

$E(D) = E - \delta D$ (3.28)

$C_p = A + \alpha D$ (3.29)

$C_s = C + \gamma D$ (3.30)

Subtracting expression (3.29) from (3.28) and rearranging the terms, yields:

$E(D) - C_p = (E - A) - (\delta + \alpha)D$ (3.31)

Subtracting expression (3.29) from (3.30) yields:

$C_s - C_p = C + \gamma D - A - \alpha D = C - A$ When $\alpha = \gamma$ (3.32)

The liability share, λ, that maximizes social welfare is determined by noting that the following holds:

From Figure 3.1

$$\lambda = \frac{E(D) - Cp(D)}{Cs(D) - Cp(D)} \qquad (3.33)$$

Substituting expressions (3.31) and (3.32) into expressions (3.33) and remaining terms, yields:

$$\omega 1 \left[\int_{P_I}^{P'_I} \frac{\partial I}{\partial C''n}(C''_n, P_I)\frac{\partial C''n}{\partial D} dP_I - \int_{P_I}^{P'_I} \frac{\partial I}{\partial C'n}(C'_n, P_I)\frac{\partial C'n}{\partial D} dP_I \right]$$

$$+ \omega 3 \{ -[C_s(D) - C_p(D)] - \Phi \frac{dCs(D)}{dD}[I(C''_n(D), P_I)$$

$$-I(C''_n(D), P_I) - \Phi C_s(D)[\frac{\partial I}{\partial C''n}(C''_n(D), U_I)\frac{\partial C''n}{\partial D}$$

$$\lambda = [\frac{E-A}{C-A}] - [\frac{\delta-\alpha}{C-A}] \quad * \frac{-\frac{\partial I}{\partial C'n}(C'n(D), PI\frac{\partial C'n}{\partial D}}{\omega 1\frac{dE(D)}{dD} + \omega 2\frac{dCn(D)}{dD}} \qquad (3.34)$$

The second-order condition for maximization is:

$$\omega_1 \frac{dE(D)}{dD} - \omega_2 \frac{dCn(D)}{dD} < 0 \qquad (3.35)$$

Model Parameterization

It is clear from the expression (3.34) that the optimal liability share depends on the value of a number of parameters. Values for each parameter is determined by a search of the literature on emission issues vs. power plants, operated under coal combustion and public policy relates to externality problems.

Sensitivity Analysis

It is expected that a range of plausible parameter values will be found in related literature. Thus, it is necessary to make a thorough sensitivity analysis to determine the plausible range of values for λ. This analysis is reported in the following section. for non-marginal changes in λ. The effect of increasing or decreasing key parameters on marginal changes in λ can be determined by inspecting equation (3.34). The results of this inspection are summarized as follows (Table 3.1).

Most of the effects on λ of larger values for the parameters (Table 3.1) are straightforward. The exceptions are $\frac{\partial I}{\partial Cn}$, P_I and ω_3.

The larger $\frac{\partial I}{\partial Cn}$, the larger the size demanded of electricity generation under coal fired.

The larger I is, the larger the consumer's surplus from electricity generation under coal combustion (the term multiplied by ω_1 in the numerator of equation 3.34) and the larger external cost of electricity generation under coal combustion (the term multiplied by ω_3 in the numerator of equation 3.34).

Parameter	Effects on λ
E	▲
∂	▼
A	▲
α	▲
C	▼
$\partial I / \partial Cn$	?
P_I	?
Φ	▼
ω_1	?
ω_2	▲
ω_3	?

Table 3.1: Effect of Parameters Increases on λ

The larger values for consumer's surplus in market two increases λ; larger values for external costs in market two reduce λ. Therefore, the net effect on λ is ambiguous, *a priori*. Larger values for P_I have just the opposite effects of larger values for $\partial I / \partial Cn$: they reduce the consumer's surplus from electricity generation under coal combustion and reduce the external costs from market two. Smaller values for consumer's surplus in market two reduce λ; smaller values for external costs in market two increases λ. The net effect on λ is once gain ambiguous. If ω_3 increases, it increases the external costs in both markets. Neither is desirable. However, the avoidance of the higher external costs in market one requires an increase in λ, and the avoidance of higher external costs in market two requires a lower λ. Whether the optimal λ should rise or fall can not be determined, *a priori*.

3.7 The Market for Electricity

In this section, I summarize the limited information available on electric utility markets where electricity is generated under coal combustion subject to the Clean Air Act (CAA). In this study, a SO_2 permit market is utilized to facilitate a company meeting its SO_2 emission standard costs effectively. The Clean Air Act (CAA) or Clean Air Act Amendment (CAAA) does not regulate CO_2 emission issues. Therefore, generating units have accesses in market to minimize generation costs under these laws though the practices produce a huge volume of CO_2 emissions that contribute to global warming.

Since my study is limited to the Midwest region, I have the option to choose any state in my model paradigm and relate the results to other states within the region to explore the entire Midwest power plant's CO_2 emission scenarios.

3.7.1 Ohio Electricity Market

Ohio is the fourth largest coal-burning state in United States and is the largest coal burning state in the Midwest region. Moreover, it is the largest user of bituminous coal (ODOD, 1992). Therefore, Ohio electricity production scenarios are a key paradigm in my model to reflect Midwest electricity production scenarios. In 1999, Ohio electricity generation in the forth quarter was 36.92 million mWh and 87.49 percent of this amount was generated through coal combustion, 9.97 percent by nuclear power plant and 2.54 percent by natural gas or oil fired respectively.

In 1999, five investor-owned unit electric utilities, one consumer-owned utility and one non-profit trade organization served the electricity needs of Ohio ratepayers (Ohio Electricity Statistics, 1998). The investor owned utilities are:

1. American Electric Power Service Corporation (AEP)
2. First Energy Corporation (FE)
3. CINergy Corporation (CIN)
4. Allegheny Power Company (AP)
5. Dayton Power and Light Company (DP&L)

The Buckeye Power Inc. (BP) is a consumer owned company and the American Municipal Power-Ohio, Inc (AMP-Ohio) is a nonprofit trade organization. Ohio Valley Electric Company (OVEC) supplies electric power to only one retail customer i.e. United States Government's gaseous diffusion plant at Piketon. The AEP-Ohio is the parent holding company of Columbus Southern Power Company (CSP) and the Ohio Power Company (OP). On the other hand, FE is the parent company of the Cleveland Illuminating Company (CEI), the Toledo Edison Company (TE) and the Ohio Edison (OE). The Cincinnati Gas & Electric Company (CG&E) is the operating company in Ohio. The ratios of AEP-Ohio electricity generation (Table 3.2), through coal combustion from 1994 to1999 were between 93 percent and 100 percent. Since the

AEP-Ohio is the largest generating company in Ohio and almost coal-based system. I have chosen AEP-Ohio, as my paradigm of a coal based electricity-generating system in order to incorporate the available information in my model.

The State of Ohio passed a law in 1999 "Ohio Electric Restructuring Act of 1999" to provide, in part, some customer choice of energy supply. To reach this goal, the relevant rule-making processes are underway and the comparative retail electric service may begin in early 2001.

Year	Electricity Generation under Coal in mWh	Net Electricity Generation in mWh	% of Electricity Generation under Coal
1994	55465365	56373132	98.39
1995	56956488	56956488	100
1996	56283264	60283264	93.36
1997	60697588	60697588	100
1998	61931170	61931168	100
1999	54908135	54359054	99

Table 3.2: AEP-Ohio's Electricity Generation
Data Sources: AEP Long-term Forecasting Report – 2000

AEP-Ohio is the largest of the investor-owned public utility holding companies engaged in the generating electricity in Ohio. It has other energy holdings in the US, the United Kingdom, China and Australia. The AEP-Ohio generated 42.992 gWh out of a total of 126.94 gWh electricity in Ohio in 1998 (AEP-1999) and in1999, it was 41.944 gWh out of 136.928 gWh.[27] Like few other companies, the AEP provides services to residential, commercial, municipal and other sector customers and charges different rates for different group of customers in different sectors.

In 1999, AEP-Ohio generated total 54,908,135 mWh electricity in which 99 percent of total electricity generation in Ohio was under coal combustion (AEP, 1999). Electricity usage charges per mWh in 1999 to residential, commercial and industrial were $ 88.4266, $85.2312 and $ 43.8495 respectively (AEP, 1999). In contrast, for electricity generated under the combination of nuclear power plants, steam and oil (AP) the estimated usage charge per mWh was $118.8921 and the estimated fixed cost was $83.6911 (AP, 1999).

3.7.2 Compliance Environmental Regulation

All electricity generating companies in the United States are subject to regulation concerning effects on air and water quality, hazardous and solid waste disposal and other environmental matters, by various federal, states and local authorities as mentioned in section 5.1 of this chapter. Each company has its own strategies to comply with these environmental regulations.

My study summarizes AEP-Ohio's various strategies aimed to meet the environmental regulations in this section as follows.

Highlights

The AEP system first developed an environmental management system in 1971 to meet its compliance obligations. It has designed its environmental management system to assure compliance with Statute, regulations, permits, limits and license conditions. The AEP system environmental organization has grown in size and has been refocused, as the company continues to improve the environmental performance of technologies and programs used in the generation and distribution of electric energy, in order to achieve environmental leadership. Its goal is "to seek the most effective ways of protecting and enhancing the environment while providing reliable electricity at a competitive cost." (AEP Performance Report 1997-98). AEP meets current emissions standards for SO_2 by the use of scrubbers, the burning of low sulfur coal and by participating in permit markets.

Annually, AEP produces over 6 million tons of coal combustion products (CCPs) that must be managed either by being disposed of in a regulated landfill or used for a beneficial purpose. AEP indicated in its performance report that nearly 28 percent of CCPs was used beneficially in 1997. In 1998, nearly 26 percent was used beneficially. The performance report - 1997-98 also indicated that AEP's efforts reduced NO_x emission effectively at many Phase II units well in advance of regulatory deadlines, but additional NO_x reductions are still occurring in the remaining uncontrolled units as they are gradually brought into compliance with phase-II requirements. The rates of NO_x emissions of coal burned were 3.77 and 3.52 tons per gWh in 1997 and 1998, respectively. On the other hand, the SO_2 emission rates were 8.08 and 8.49 tons per gWh for 1997 and 1998 respectively. The increases in SO_2 emissions were due to increased generation from coal, adjustments of coal sources resulting from low market prices for higher sulfur coal and SO_2 allowances.

In its performance report, AEP expressed its interests concerning the Climate Challenge Program to reduce, avoid or sequester CO_2 emissions voluntarily for two basic reasons:

(1) a desire to avoid mandatory, costly and restrictive command and control regulations; and (2) a genuine belief that a voluntary program could succeed in meeting the President's commitment to reduce domestic GHGs emissions to their 1990 level by the year 2000. The company's goal of sequestering and avoiding CO_2 emission that caused a total of 9.55 million tons in the year 2000 through many activities in its facilities and on AEP land holdings and through other activities which are supported financially by the company. Based on preliminary results for 1998, these programs have resulted in a cumulative total of approximately 18 million tons of CO_2 that has either not produced or sequestered for the years 1991 through 1998. In 1999, AEP-Ohio emitted 38.680 million tons of CO_2 into atmosphere.

In 1998, AEP introduced a new service called "Datapult" in its communication events to help commercial and industrial customers via the Intranet, for managing and decreasing their energy use to reduce environmental impact. AEP manages 30,000 acres of land for the public to use in recreational and leisure activities and to enhance habitats wherever possible. Also to safe guard the environment and comply with environmental laws and regulations, in 1997 and 1998, AEP spent approximately $321 million on CO_2 emission reduction facilities and technologies. During these years it received three notices of violations for federal laws and four notices of violation for state laws. The company paid $ 7000.00 in penalties.

3.7.3 AEP Environmental Management and Technologies

Technology and research, which protects the environment, are an integral part of AEP's environmental management system. From the engineering and design of pollution control and abatement systems, that meet or exceed the permit limits or regulatory standards, through to research on advanced clean coal technologies, AEP strives to minimize the environmental impact of their company operations.

Pollution Control Technologies

AEP uses approximately 75 individual technologies that assist it to meet the environmental regulations. These systems range from alarms that alert operators that adjustments need to be made to keep emissions within permit limits, to electrostatic precipitators that remove up to 99.8 percent of fine particulate fly ash before it leaves the stack. Other examples of reduction systems include scrubbers to remove SO_2 from flue gas, combustion control systems to reduce NO_x emission, continuous emissions monitors to measure compliance. AEP has installed a demonstration selective non-catalytic reduction (SNCR) system on a 600 megawatt generating plant in Ohio show SNCR's ability to reduce NO_x emissions in large, coal-fired generating units with cost effective options.

Environmental Research

AEP is a member of the Electric Power Research Institute (EPRI) and it funds EPRI's Climate Change Research Program that has helped inform national and international policy debates on environmental issues and has generated support for mechanisms such as emission trading and joint implementation between nations.

3.7.4 AEP Release Effluent Gases into Air

To meet the requirements of Title IV of CAAA of 1990 concerning SO_2 and NO_x reduction, AEP's compliance program includes the installation of scrubbers, fuel switching to lower sulfur coal and participation in the SO_2 permit market. The Phase I of SO_2 reduction program began in January 1995. Phase-II of the Title IV program began in the early of 2000. All of AEP's coal-fired units will be regulated under Phase-II. As AEP mentioned in its Environmental Performance Report 1997-1998, the additional SO_2 emission reductions will be achieved through upgrades to existing pollution reduction equipment and by switching to lower sulfur coal at a few units. In 1995, the magnitude of SO_2 emission declined significantly. This significant change was the reflective of the first year of Phase I (1995) and the start up of the SO_2 scrubbers on Gavin power plants in Ohio. In 1996, the emission level again increased and it has been increasing since then.

Increases in emissions since that year have been due to increased generation from coal units, adjustments of coal sources resulting from low market prices for higher sulfur coal, and SO_2 allowances.

3.7.5 Environmental Expenditures

Between 1996 and 1998, AEP spent approximately $ 4.8 billion (in actual dollars) in constructing, operating and maintaining environmental emission control facilities.[28]

In 1997 and 1998, AEP spent approximately $ 321 million. The AEP strives to reach its corporate environmental impacts in its business leadership goal by considering environmental impacts in its business strategy, particularly as the electric utility industry prepares to be restructured. Costs incurred by the company have been offset by avoided costs, tax credits and revenues generated from customers based on per kWh electricity used as a contribution to compliance Title IV. The Performance Report-1997-98 also indicated that the company continually seeks to reduce its environmental costs in other ways as well. AEP received approximately $11 million each year from sales of timber, coal combustion products such as fly ash and scrap materials. It also received $13 million in state tax credits each year for investing in the Gavin scrubbers and other compliance facilities associated with burning coal. The AEP's environmental expenditures may increase in future years due to meeting the recent NO_x emission standard required by the U.S. EPA.

3.7.6 Credit for Voluntary Reduction

The Energy Policy Act 1992, Section 1605(b) [29] requires U.S. electric utilities and other manufacturers to record the results of voluntary measures taken by the companies to reduce, avoid, or sequester GHG emissions in essence to mitigate potential environmental impacts. One hundred eighty seven US companies and other organizations reported to the Energy Information Administration (EIA) that, during 1998, they had undertaken 1.507 projects that achieved GHG emission reductions and carbon sequestration equivalent to 212 million metric tons of CO_2, or by about 3.2 percent of total U.S. emissions for the year (EIA, 1998). Public interest in the Voluntary Reporting Program has continued to increase, in part because of growing awareness of climate change issues inspired by the signing of the Kyoto Protocol, and in part because of public interest in the concept of credit for early reductions. In 1997, the White House announced that it favored offering "credit for early reductions" as a means to limit future U.S. GHG emissions (EIA, 1999).

On July 27, 2000, a group of U.S. Senators led by Senator Sam Brownback introduced a bill entitled: *Carbon Sequestration Investment Credit.* [30] The short title is *Investment Tax Credit*. Under this bill, the eligible projects can receive funding at a rate of $ 2.50 per verified ton of carbon stored or sequestered - up to 50 percent of the total project cost. The minimum length of these projects must be 30 years and the Implementing Panel can only approve $ 200 million tax credits each year. Mr. Brownback has mentioned that this act will encourage investment in projects for developing nations, which soak up the CO_2 accumulation in the atmosphere produced by the burning of fossil fuels. It is clear that the senator Brownback has introduced this bill to lay the groundwork for its passage in the next Congress. The Senate floor has forwarded the bill to the Finance Committee for budget approval. Senator Brownback's bill once again signals that enough is known about the science and potential impacts of global warming to know it is a problem that must be dealt with.

3.8 The Model Applied to CO_2 Emission from Electric Utilities

In this section, I have used the limited information that is available, most of which was summarized in Chapter II and in section 3.7 of this Chapter, to construct quantitative models of my assumed markets related to CO_2 emissions from electric utility. I begin with benchmark case based on a combination of data that was available in the literature and assumed parameters for the demand supply and external cost functions. Using a procedure for determining changes in economic welfare, I have calculated the optimal λ, then assumed different values for these parameters and calculated a series of additional values for λ. I found that λ varied widely over the assumed range of values. The implications of these findings for theory, policy and future research are outlined in section 3.9 of this Chapter.

The Benchmark Case

The model underlying the benchmark case was the same as the one depicted in Figures 3.1 to 3.3. Here I have assigned values to the parameters of the linear functions. Most of the parameter's values were cited in section 3.7 of this Chapter. The model can be specified as a system of 6 equations:

(1) $E(D) = E - \delta D$

(2) $C_p = A + \alpha D$

(3) $C_s = C + \alpha D$

(4) $I = K - g(dD) - \beta P_I$

(5) $P_I = P''_I$

(6) $\Phi C_s = \Phi \overline{Cs}$

E(D) is the demand for total electricity generation under coal combustion. Here each unit of electricity demand estimates how much the end-user is willing to pay for an additional unit of electricity usage. C_p and C_s are marginal private costs and marginal social costs respectively for electricity generation under coal combustion in market one. Here the marginal social cost is equivalent to the sum of the marginal private cost as well as external costs in market one. I is the demand for electricity generation in market- two. P_I is the price of electricity per kWh and ΦC_s is the per unit value of the external cost in market-two. Solution of the model also requires the assignment of welfare weighting to the gains or loss experienced by the end-users, the generating company and the pollutees. In terms of the model developed in section 3.6 of this Chapter, I have assigned values for ω_1, ω_2 and ω_3 in Table 3.3. Table 3.3 contains values of parameters that are cited in section 3.7 of this Chapter for this benchmark case. The prices of electricity are cited from Ohio Utility Rate Survey, August 2, 2000 prepared by the PUCO. The costs of electricity generation are cited from Acid Rain Compliance Report, April 29, 1992, Case No. 92-790-EL-ECP and then upgraded based on rate of inflation.

Parameter	Value
E	\$118.8921 per mWh
δ	- 0.0000008258
A	\$19.5606 per mWh
α	0.000016378
C	\$ 83.6911 per mWh
g	1/5 *
β	-1.1825517 million
P_I	\$ 40 mWh *
ΦC_s	\$ 200 *
ω_1	1.0
ω_2	1.0
ω_3	1.0

Table 3.3 Parameters for the Benchmark Case (AEP-Ohio-1999, Electricity average prices) [a]

a. * marked values are assumed

The parameters (Table 3.3) are consistent with the initial price and quantity in market-one and with assumed values for the elasticity of demand and supply for electricity generation under coal combustion. The initial price and quantity in market-one was $72.5024 per mWh [31] and 54,908,135 mWh [32] respectively. These values are based on 1999 average retail prices of residential, commercial and industrial customers that are collected from AEP-Ohio's Long-term Forecast Report, 2000, submitted to Market Monitoring Division at the PUCO.

To obtain the economic welfare lost by end-users, due to a given increase in the price of electricity, my study employs the demand curve for electricity for end-users in aggregate. For this purpose, it is not necessary to know the shape of the demand curve over the whole range of possible consumption. It is enough to know how the quantity of electricity demanded, in aggregate, responds to price in a relatively narrow region near current levels of consumption. A number of studies on residential elasticity and commercial and industrial elasticity demands have been made using either cross-section or pooled data. Some of recent studies include those AEP's Acid Rain Compliance Report, 1992 to the PUCO [33]. In the report, the long-run residential price response or elasticity, which was estimated in empirical analyses of AEP data, to lie in the range -0.4 to -0.5 for the customers of the Ohio Power and Columbus Southern Power Companies. Long-run price responses for the commercial and industrial customers' range were -0.9 to -1.2. An average price response of -0.75 for end-users has been chosen to incorporate in my benchmark case study. This means that if the price of electricity rises 10 percent, the quantity of electricity demanded by end-users in the long run will decline by 7.5 percent. For residential customers it will decline by 4 to 5 percent and for commercial and industrial customers it will decline by 9 to 12 percent. Since the externality cost associated with CO_2 emission is excluded from generating cost per mWh of electricity generation, I have assumed that the response of electricity generation through coal combustion is elastic. In emission burden liability estimation, I have assumed the supply elasticity of electricity generated through coal is 2.0. This means that if the price of electricity rises 10 percent, the quantity of electricity generation under coal combustion will increase by 20 percent and, in this case, the electricity transmission grids in the United States facilitates the generating company to transmitting the excess electricity to other states, after meeting local demands. In other words, the response of electricity generation under coal fired systems are fairly responsive. Here cross price elasticity of demand (CPED) for electricity generation under coal-fired system in market-two is assumed to be 1.0. This means that if the cost of electricity generation through coal combustion in market-one rises by 10 percent then the demand for electricity generation through coal combustion in market-two rises by 10 percent.

The cost of the resources to make the external costs cause no harm to the third party is assumed initially to be \$200.00, in other words ΦC_s = \$200. The value for g is assumed to be 0.20, which indicates that the one fifth of total electricity generation under coal takes place in market-two in my imaginary world. In other words, electricity generation under coal combustion, in market-two, is one-fifth of the electricity generation under coal combustion in market-one.

Given these values, and CO_2 emission tax \$2.5 per ton [34] market-one is in equilibrium at

P = $ 74.2074 per mWh [35] and demand for electricity generation under coal fired is D = 54,120,712 mWh. Market-two is in equilibrium, initially I = 10,824,142.4 mWh and P_I = $ 40 per mWh.

The first step in the determination of the optimal λ is to compute the hypothetical equilibrium when full liability ($\lambda = 1$) is imposed on electricity generating companies that they pass on to customer in full as electric retail prices. This is the level of total electricity generation under coal-fired system in market one where E (D) = C_s. Given the above parameters, this equilibrium occurs at 2,044,017.92 mWh. The simultaneous equilibrium in market-two occurs at I = 593,378.402 mWh.

Given these starting points, the technique for determining the optimum λ is to specify smaller or larger values for λ and then to calculate their net effect on economic welfare. In order to calculate the optimal λ, the parameter values have been inserted into a SAS data file. A computer program was then developed using the PC-SAS package and run to manage and to calculate the optimal λ. To see the optimal λ in one shot, it was necessary to create logical arguments in the program. In order to examine the direction of optimal λ, smaller and larger values of λ were tried as long as W is positive. Optimal λ was found when W reached to zero. In other words, an optimal liability combination was the one that minimized the sum of welfare losses in my hypothetical three markets.

As λ is reduced, full liability is shifted to a lower liability, over the range between 1 and 0, the quantity of electricity generation other than coal fired systems in market-one increased and the quantity of unauthorized activities caused CO_2 emission in market-two tends to be decreased. Thus, the economic welfare increased due to increases in the sum of consumer and producer surpluses and to reductions in the deadweight loss in market-one. On the other hand, it reduces external costs in market-two (EC_I). Along the same line, however, economic welfare would fall due to increased external costs in market-one (EC_L) and to loss of consumer's surplus in the market-two (CS_I). With ΦC_S = \$200, P_I = \$40 and other given parameters values as reported as case 1 in table 3.4, the optimal $\lambda = 0.92024$. The corresponding data are shown in Table 3.5.

At $\lambda = -1$, the generating company would face all the liability, so the net gain in CS_L plus PS_L is maximized, and consumers would continue to reap gains. It would be necessary, however, to subsidize producers because the price of per mWh of electricity in market-one would be less than the marginal private cost (C_p). In this case, in the absence of subsidies, investing capital in other businesses becomes incentives to the generating company. On the other hand, the subsidy required for producers is a loss to the taxpayers that exceeds the gain to the consumer. Neither scenario satisfies the Pareto optimality condition.

Again, at $\lambda = 1$, the generating company faces the liability and passes it on to customer in full so that the net gain in PS_L is maximized and generating company would continue to reap financial gains. It would become an incentive to the generating company to produce excess electricity under coal combustion and transfer the excess supply to customers in other states where competitive markets prevail and production is facilitated by electricity transmission grids. On one hand, this would create an extra emission burden for the end-users in the state where the company's plants are sited.

Currently, this scenario is in practice in electric utility market in the Midwest, especially in the State of Ohio.

In any situation, because the optimal λ can be negative i.e. only the generating company faces the liability; if the reduction in EC_I is large enough and policy-makers prefer to prevent the illegal operation related to emission issues. If there are no net gains from lowering λ, then it is necessary to check if λ should be raised above 1. With $\lambda > 1$, the demand for electricity becomes sensitive. End-users, especially, the commercial and industrial customers may switch to other competitive price energy source such as natural gas. Electricity generating company may reap the economic gains. Application of this procedure in the benchmark case produces an optimal λ of 1.23 reported as case 5 in Table 3.4. The basic data for this case are in Table 3.9.

In this case, the assumed value of ΦCs is very large. To implement $\lambda = 1.23$, it would be necessary to pay a huge subsidy or tax break in some fashion to end-users that may create budget deficit. On the other hand, in absence of subsidy, the policy maneuver may stand against policy-makers.

Case	ED_I	ES_I	CPED	ΦCs	P_I	ω_3	Optimal λ
1	-.75	2	1	200	40	1	0.92024
2	-.75	2	1	100	40	1	0.95
3	-.75	2	1	200	80	1	0.88
4	-.75	2	1	200	40	2	0.8
5	-.75	2	1	500	40	1	1.23

Table 3.4: Alternative Cases
Data Sources: Tables 3.5 – 3.9, pp. 145 - 149

Other Cases

In an ideal world, the benchmark case would be constructed upon econometric estimates of the parameters of the demand, supply and external cost functions and the optimal estimated λ would be close to the true λ. Unfortunately, there are insufficient data, especially for the market two case to support such estimates. Alternatively, there are good reasons at this stage to question some of the values assigned to these parameters in the benchmark case. Thus, I calculated the optimal λ for few more cases, characterized by different sets of parameter values. The summarized computer output with different parameter values is in Tables 3.5 to 3.9. Since the optimal λ in the benchmark case depends on heavily upon ΦCs, it is necessary to look at ΦCs carefully. There might be different ways to look at the ΦC_s. I chose a measure that deals with people's willingness to pay to accept emission or to get rid of them. In this scenario, willingness to pay for emissions is equal to the apparent risk of damage (natural environment) times the value that people place on this damage.

It is entirely possible that the risks associated with CO_2 emission are quite small. To allow for this possibility, I constructed two cases, where ΦCs = \$200 and ΦCs = \$100. As expected the optimal λ rose in these cases. $\lambda = 0.920244$ when ΦCs = \$ 200 and $\lambda = 0.95$ when ΦCs = \$100. The new optimal $\lambda = 0.95$ is reported as case 2 in Table 3.4. The corresponding data are in Table 3.7.

The next parameter that I can examine is P_I. If the CO_2 emission were regulated and if the necessary data were available, then, the P_I could be estimated as follows

P_I = p (prosecution) x p(conviction if prosecuted) x present value of expected fine, if convicted plus cost to generate electricity per mWh under coal combustion. Here p represents probability. As the CO_2 emissions are not currently regulated, I assumed P_I values for two different cases. In case 3, that is reported in Table 3.4 of this chapter, I combined P_I = \$80 with a value of Φ Cs = \$200. This produced, corresponding data are in Table 3.7, a value for λ of 0.88, compared with λ = 0.92024 when P_I = \$40 and Φ Cs = \$200. In other words, raising P_I from \$40 to \$ 80 (100 percent increase) that means a strict emission regulation has a little impact on λ. First of all, implementation of strict regulation requires higher monitoring costs. Secondly, as electricity is a necessary good, it may cause an unstable political maneuver, which is undesirable.

λ	ΔCS (-)	ΔPS	ΔEC $\omega_3=1$	W	ΔCS_L (-)	CS_I (P_I = $40)	ΔEC_L (ΦC_s =$200)	ΔEC_I (ΦC_s=$ 200)
.1	6736.2	493.09	61.23	-6181.9	6771.1	34.89	106.5	45.27
.2	6565.8	986.18	122.46	-5457.2	6635.6	69.77	213.0	90.54
.3	6463.2	1479.2	183.75	-4800.3	6567.9	104.66	319.56	135.81
.4	6360.7	1972.3	245	-4143.4	6500.2	139.5	426.1	181.1
.5	6258.1	2465.4	306.26	-3486.4	6432.5	174.4	532.6	226.34
.6	6155.5	2958.5	367.52	-2829.5	6364.8	209.3	639.12	271.6
.7	6052.9	3451.6	428.71	-2172.6	6297.1	244.21	745.6	316.89
.8	5951.6	3944.7	489.94	-1516.9	6230.7	279.1	852.1	362.16
.9	5915.4	4437	551.27	-927.15	6229.4	313.98	958.7	407.43
.91	5845.1	4486.3	557.34	-801.5	6161.7	316.56	969.3	411.96
.92	5772.9	4535.6	563.45	-673.9	6093.9	320.96	979.9	416.45
.9202	5095.8	4536.5	559.4	0	5416.8	321	980.2	420.8
.93	4412.8	4584.9	569.29	741.4	4739.7	326.9	990.3	421.01
.94	3734.7	4634.2	575.47	1474.9	4062.6	327.9	1001	425.53
.95	3055.0	4684.3	581.83	2211.1	3385.5	330.47	1011.9	430.07
.96	2374.4	4733.6	587.44	2946.6	2708.4	333.96	1022	434.56
.97	1693.8	4782.9	593.88	3682.9	2031.3	337.43	1033	439.12
.98	1013.3	4810.8	600.15	4397.7	1354.2	340.9	1043.8	443.65
.99	329.2	4930.9	612.5	5214.2	677.1	347.87	1065.2	452.7

Table 3.5: Basic data corresponding to Case 1 as reported in Table 3.4
Data Sources: Computer output (Basic data in thousand dollars)

λ	ΔCS (-)	ΔPS	ΔEC $\omega_3 = 1$	W	ΔCS_L (-)	CS_I (P_I = $40)	ΔEC_L (ΦC, =$100)	ΔEC_I (ΦC, =$100)
.1	6736.2	493.09	-168.99	-6412.1	6771.1	34.89	79.89	248.88
.2	6565.8	986.18	-362.07	-5941.7	6635.6	69.77	135.7	497.77
.3	6463.2	1479.2	-586.87	-5570.9	6567.9	104.66	159.78	746.65
.4	6360.7	1972.3	-755.86	-5144.3	6500.2	139.5	239.67	995.53
.5	6258.1	2465.4	-924.85	-4717.5	6432.5	174.4	319.56	1244.4
.6	6155.5	2958.5	-1093.84	-4290.8	6364.8	209.3	399.45	1493.3
.7	6052.9	3451.6	-1262.84	-3864.1	6297.1	244.21	479.34	1742.2
.8	5951.6	3944.7	-1431.83	-3438.7	6230.7	279.1	559.23	1991.1
.9	5915.4	4437	-1600.8	-3079.2	6229.4	313.98	639.12	2239.9
.91	5845.1	4486.3	-1545.83	-2904.6	6161.7	316.56	719.01	2264.8
.92	5772.9	4535.6	-1562.8	-2800	6093.9	320.96	726.91	2289.7
.93	4412.8	4584.9	-1611.62	-1439.5	4739.7	326.9	742.99	2354.6
.94	3734.7	4634.2	-1622.04	-722.54	4062.6	327.9	750.98	2373.1
.95	3055.0	4684.3	-1629.3	0	3385.5	330.47	758.97	2388.3
.96	2374.4	4733.6	-1632.3	726.89	2708.4	333.96	766.96	2399.3
.97	1693.8	4782.9	-1639.2	1449.86	2031.3	337.43	774.93	2414.2
.98	1013.3	4810.8	-1656.11	2141.39	1354.2	340.9	782.94	2439.1
.99	329.2	4930.9	-1689.91	2911.79	677.1	347.87	798.92	2488.8

Table 3.6: Basic data corresponding to Case 2 as reported in Table 3.4
Data Sources: Computer output (Basic data in thousand dollars)

λ	ΔCS (-)	ΔPS	ΔEC $\omega_3 = 1$	W	ΔCS_L (-)	CS_I (P_I = \$80)	ΔEC_L (ΦC_s =\$200)	ΔEC_I (ΦC_s =\$200) (-)
1	6745.0	493.09	189.8	-6062.1	6771.1	26.09	106.5	83.31
.2	6583.4	986.18	377.59	-5219.7	6635.6	69.77	213.0	164.59
.3	6489.6	1479.2	566.45	-4443.9	6567.9	104.66	319.56	246.89
.4	6395.8	1972.3	755.29	-3668.3	6500.2	139.5	426.1	329.19
.5	6302.1	2465.4	944.09	-2892.6	6432.5	174.4	532.6	411.49
.6	6208.3	2958.5	1132.91	-2116.9	6364.8	209.3	639.12	493.79
.7	6114.5	3451.6	1321.69	-1341.1	6297.1	244.21	745.6	576.09
.8	6021.9	3944.7	1510.48	-566.8	6230.7	279.1	852.1	658.38
.82	6012.3	4043.3	1548.3	-420.63	6229.4	313.98	873.46	674.84
.88	5990.1	4339.2	1650.92	0	6161.7	316.56	937.38	713.54
.89	5990.3	4388.5	1680.48	78.79	6093.9	320.96	948.03	732.45
.9	5994.6	4437	1699.38	141.78	5416.8	321	958.7	740.68
.91	5924.3	4486.3	1718.22	280.24	4739.7	326.9	969.3	748.92
.92	5853.9	4535.6	1736.96	418.69	4062.6	327.9	979.9	757.06
.93	4497.1	4584.9	1755.67	1843.51	3385.5	330.47	990.3	765.37
.94	3817.4	4634.2	1774.6	2591.45	2708.4	333.96	1001	773.6
.95	3137.6	4684.3	1793.73	3340.39	2031.3	337.43	1011.9	781.83
.99	416.2	4930.9	1888.18	6402.88	1354.2	340.9	1065.2	822.98

Table 3.7: Basic data corresponding to Case 3 as reported in Table 3.4
Data Sources: Computer output (Basic data in thousand dollars)

λ	ΔCS (-)	ΔPS	ΔEC $\omega_3 = 2$	W (ω_3=2)	ΔCS_L (-)	CS_I (P_I = $40)	ΔEC_L (ΦC_s =$200)	ΔEC_I (ΦC_s =$200)
.1	4632.4	383.41	122.46	-4126.6	4658.52	26.09	106.5	45.27
.2	4513.1	766.81	244.98	-3501.3	4565.29	52.18	213.0	90.54
.3	4440.6	1150.2	367.5	-2922.7	4518.72	78.27	319.56	135.81
.4	4367.8	1533.6	490.04	-2344.1	4472.14	104.36	426.1	181.1
.5	4295.1	1917.0	612.5	-1765.6	4425.56	130.45	532.6	226.34
.6	4222.4	2300.4	735	-1187	4378.98	156.54	639.12	271.6
.7	4149.8	2683.8	857.42	-608.5	4332.4	182.63	745.6	316.89
.8	4078.1	3098.2	979.88	0	4286.82	208.72	852.1	362.16
.81	4074.5	3105.6	992.24	23.32	4285.83	211.33	862.81	366.69
.82	4069.7	3143.9	1004.5	78.73	4283.63	213.94	873.46	371.21
.88	4049.6	3373.9	1078	402.4	4279.15	229.59	937.38	398.38
.89	4044.7	3412.3	1090.26	457.88	4276.88	232.2	948.03	402.9
.9	4040.3	3450.7	1102.54	512.9	4275.09	234.8	958.7	407.43
.94	2549.8	3604	1150.9	2205.1	2795.07	245.25	1001	425.53
.95	2081.4	3642.4	1163.66	2724.65	2329.22	247.86	1011.9	430.07
.96	1612.9	3680.7	1174.82	3242.59	1863.38	250.46	1022	434.56
.97	1144.5	3719	1187.76	3762.33	1397.53	253.07	1033	439.12
.98	676.01	3757.4	1200.3	4281.66	931.69	255.68	1043.8	443.65
.99	204.95	3834.1	1225	4854.1	465.85	260.9	1065.2	452.7

Table 3.8: Basic data corresponding to Case 4 as reported in Table 3.4
Data Sources: Computer output (Basic data in thousand dollars)

λ	ΔCS (-)	ΔPS	ΔEC $\omega_3 = 1$	W	ΔCS_L (-)	CS_I (P_I = $ 40)	ΔEC_L (ΦC_s =$500)	ΔEC_I (ΦC_s= $500)
.1	6745.0	383.41	-459.14	-6820.7	6771.1	26.09	399.45	858.59
.2	6583.4	766.81	-1040.55	-6857.2	6635.6	52.18	678.5	1719.1
.3	6489.6	1150.22	-17779.68	-7119.1	6567.9	78.27	798.9	2578.6
.4	6395.8	1533.62	-2239.75	-7101.9	6500.2	104.36	1198.4	3438.1
.5	6302.1	1917.03	-2699.83	-7084.9	6432.5	130.45	1597.8	4297.6
.6	6208.3	2300.43	-3159.9	-7067.7	6364.8	156.54	1997.3	5157.15
.7	6114.5	2683.84	-3619.98	-7050.6	6297.1	182.63	2396.7	6016.7
.8	6021.9	3098.22	-4080.05	-7003.8	6230.7	208.72	2796.2	6876.2
.9	5994.6	3450.65	-4540.13	7084.1	6179.4	234.8	3195.6	7735.7
.94	3817.4	3604.01	-4324.64	-4537.9	4062.6	245.25	3754.9	8079.5
.95	3137.6	3642.35	-4370.64	-3865.9	3385.5	247.86	3794.9	8165.5
.96	2457.9	3680.69	-4416.64	-3193.9	2708.4	250.46	3834.8	8251.4
.97	1778.2	3719.03	-4462.74	-2521.9	2031.3	253.07	3874.7	833.74
.98	1098.5	3757.37	-4508.65	-1849.8	1354.2	255.68	3914.7	8423.4
.99	861.02	3834.05	-4331.37	-1358.3	1121.9	260.9	3994.6	8325.9
1	516.71	4980.71	-4717.12	-253.12	780.25	263.54	4034.9	8752.07
1.1	517.53	5976.85	-5576.54	-117.22	833.78	316.25	4841.9	10418.4
1.23	519.1	6126.27	-5607.17	0	843.25	324.15	4964.9	10572.2
1.24	521.31	6176.08	-5644.84	9.93	848.09	326.78	503.25	10658.1
1.25	525.5	6225.89	-5646.34	5214.2	854.93	329.43	5097.6	10743.9

Table 3.9: Basic data corresponding to Case 5 as reported in Table 3.4
Data Sources: Computer output (Basic data in thousand dollars)

In this case study, so far, I have put the same weight on parties involved regardless of who gained or lost from the outcomes of the policy. But the history of social policy suggests, however, that policy-makers may want to attach a higher weight to the gains and losses of lower-income individuals than to gains and losses of higher-income individuals. Examining this phenomenon, I developed case 4, in which ΦCs = \$200 and $\omega_3 = 2$. In this case 4 in this Chapter, the liability dropped by 0.12024.

3.9 Lessons for Economic Theory, Public Policy and Future Research

In this section, I outline the mainstream implications of the findings of this Chapter. The results suggest a critique of mainstream views in both economic theory and public policy that *party (s) in question, that is, the generating company(s) and the end-user(s) should be liable for the externality dilemma.* In other words, *they should share the emissions burdens that they create as results of their own acts.* They also provide some insight on domestic CO_2 emission issues for which policy-makers are seeking feasible options. In the power plant case, the pivotal theme is that the generating company (s) produce electricity as a product in a cost-effective manner so as to achieve their business goals under regulatory mission -- ensure reliable and safety utility services in a reasonable price. On the other hand, consumers make use of electricity, for ensuring a comfortable life style as well as for having fun, for leisure in life and other time saving activities. Here both parties are rational or tend to be rational and attempt to maximize their budgets. With the shed of classical liberal maxim, here party(s) have freedom to pursue its interest in so far as it tends to reduce the freedom or the welfare of others. Taking all these features in to account, it warrants a rule or a set of rules that place both consumer and producer as responsible for internalizing CO_2 emission cost. Finally, the results of this Chapter may shed some lights that should provide priority on research agendas.

3.9.1 Economic Theory

Since there is no law yet that directly regulates CO_2 emissions, taking SO_2 emission regulation as a paradigm, we can see that full liability of external cost is in place where both consumers and producers are involved, especially in the case of electric utilities. The generating company meets the emission standard in different fashions under the CAA and passes on the incurred costs to the end-users, in terms of compliance cost or emission fees (*Emissions Fee Rider*). The company produces excess electricity under coal combustion and transfers it to competitive markets only after meeting local demands. As a result this transferable full liability law creates an extra emission burdens for the local end-users and it becomes appealing to the generating company. The feature of this law reflects the view that the application of full liability, in a two-party case where consumers and producers are involved, does not follow efficiency principle (s) in resource allocation.

The conclusions from this Chapter suggest that the application of full liability to one party in externality issues where both producers and consumers are involved may satisfy neither, Pareto efficiency nor Prareto improvement condition (s) in resource allocation, nor fairness in the distribution of external costs. However, it results in a greater degree of abatement of CO_2 emission magnitudes than any intermediate liability rules. According to the model of this study, the potential inefficiency of our assumed CO_2 regulation and Pigovian taxes are implied for all cases, where optimal liability is less than 1, but approaches it when the weights assigned to gains or losses of pollutees, $\omega_3 = 1$.

3.9.2 Public Policy

Public policy toward environmental issues is constantly evolving. Currently, one of the goals is to alleviate domestic CO_2 emission levels and in essence to reduce the damages and finally implementing the Kyoto Protocol target. The debate over the issue is likely to center on electric utility CO_2 emission levels and on determining the appropriate allocation of liability for this external cost and the equity aspects among parties. The findings may suggest some lessons for the policy makers when they deal with these issues.

One clear implication of the model is that any policy that raises the cost of CO_2 emission standard levels (here 1990 emission level) is likely to induce market-two where generating company faces penalty (s) under the law. If it does, then the optimal liability in market-one is likely to be less than the full liability prescribed by our hypothesized law. Alternately, the cost in market-two should be in any evaluation of a policy that raises the cost of electricity generation under coal fired in market-one.

The results of this study also suggest that the authorities will have to be careful when devising policies to reduce CO_2 emission levels from electric utilities, which may affect end-users of significantly of residential customers that are predominantly middle income families. If the action chosen, for example, a regulation of full liability for external cost and this is passed on to end-users, this will increase the CO_2 emission compliance cost for the whole nation and will induce effects on market-two that may adversely affect the environment as well as these communities. It was noted above that there is currently a policy debate regarding the appropriate levels or extent of CO_2 emissions. Regarding this, Congress may assign different emission standards to different states in order to meet the nation's emission target. This action will tend to produce higher values for external cost in a state where current CO_2 emission levels are higher compared to the nation's emission standard (1990 emission level) than that in a state where CO_2 emission levels are below the nation's emission standard. Some may interpret this as a high value for ΦC_s in the state where emission levels are higher and argue that it suggests a relatively low value for the optimal liability share. This is not the appropriate response, however, because the optimal liability share should be based on an estimate of ΦC_s, that reflects people's willingness to pay for reducing emission levels and it may be quite different from the costs imposed in other states where emission levels are lower than the nation's emission target. It may induce marketing of CO_2 emission permits and facilitate a competitive price in the United States, so that the liability dogma of sharing emissions becomes appealing to the generating company(s). Moreover, in domestic permit market case, it preserves currency flow to other countries in ways that meet the Kyoto Protocol requirements.

3.9.3 Future Research

Ultimately the usefulness of this model in policy debates rests on empirical estimates of the demand and supply functions for electricity generation under coal combustion, the external costs associated with CO_2 emission and the appropriate welfare weights for the gains and losses of affected parties. The results of this Chapter indicate that the optimal liability share is most sensitive to the values attached to external costs and welfare weights. Additional research should begin with these parameters. The optimal liability share seems to be relatively insensitive to the basic elasticity of the model. Perhaps this is because if elasticity were used in a restricted way; namely as a means of calculating the cross price elasticity of demand (CPED). the shift parameter, of functions that were assumed to be linear. Econometric estimation of the demand and supply functions may indicate that the relevant functions are not linear. and that the optimal liability share is more sensitive to the relevant elasticity.

This study has treated the change in CS_I as a benefit from a higher λ. Some may consider that since operation in market-two is a criminal activity, gains from it should not count as a part of benefits of a higher λ. Future research can confirm this or reject this.

In the case of attaching weights to the gains and losses of victims (third party). future research may begin by examining the allocations of external costs on people from different races and educational backgrounds.

Finally, if CO_2 emissions become regulated and, enough information becomes available, then the application of this model in a case where demand and supply functions are non-linear in any externality issue where involved parties are dichotomy in act and homogeneous in goal (consumer and produce) should warrant further future research.

3.10 Notes

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1	81	The nineteenth century I view of the economy, embodied in the law of property, contract and torts was predicted on the faith in short term. market directed productivity. In this era, the entrepreneur also believed that law should provide mechanisms for mobilizing scarce capital and for developing resources on private interests toward the goal of maximizing growth in exchange values. See the use of Law in Four "Colonial States of the American Union, 1954 Wis. L. Rev. 577, 583. The early 19th century concerns for economic considerations manifested itself in a wide variety of constitutional, common law and statutory forms. For example, popular pressures for reapportionment were often linked to economic policy questions; when under represented districts in the South failed to get their full share of state expenditures this impelled them to seek constitutional reform. F. Green Constitutional Development in the South Atlantic States, 1776-1860. The common law doctrine of caveat emptor refused to imply warranties, promoting instead a rapid interchange of commodities free from the threat of subsequent litigation. See McFarland V. Newman, 9 Watts 55 (PA, 1839). And state legislatures pressed for the mobilization of scarce capital to construct the canals, turnpikes and other bulk transport facilities that would provide revenue and open market. See R. Shaw, Erie Water: a History if the Erie Canal, 1792-1854 (1966).
2	82	See, e.g. Ohio Rev. St. S 1692a [1890]: " ...in all cities of the second grade of the first class, such cities shall have the power to regulate and compel the consumption of smoke emitted by burning of coal..."
3	82	See, e.g. Detroit, Mich., Rev. Ordinance ch. 67 [1890], stating in part: "The emission from any chimney or smokestack within the city of dense smoke...shall be deemed a public nuisance."
4	83	The transformation of an agriculturally-based rural society characteristic of 19th century I to the urban industrial economy of the post 1880 era was one of the most significant changes in US nations history. In 1860 the United States, especially Midwestern region, was a second rate industrial region in country, lagging far behind England, France and Germany. But by 1890 the United States had stepped into the first place, its manufacturing productivity had multiplied ten times over, and the value of manufactured goods almost equaled the combined production of all three of the former leaders. Indeed, the 20th century I generation introduced changes of such order that they made a new nations to explain adequately the reasons for these changes is beyond the scope and

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purpose of study. It is certain, though, that law, government and la were significant causative and supportive factors in the growth and expansion of the American economy. Through out the last third of the 19th century men who were not only responsive to the wishes of business; but also eager to further the interests of mass markets and mass production largely controlled government. Lawmakers used prevailing "laissez faire" philosophy to justify the virtual absence of effective restraints on the business community. When government intervened it was to extend loans. grant and subsidies and franchises, hand over public resources and protect home industries from foreign competitors. No economic faction in the nation offered effective competition for the attention and favor of state legislators. Moreover, unlike European businessmen, Americans had no heritage of canon law and feudal custom with which to contend, no royal prerogatives or aristocratic privileges barred James J. Hill (railroads, P. P. Morgan banking). For a detailed see Jan G. Laitos (1975)

5 83 The costs of pollution are traditionally attributable to at least three kinds of institutional influences economic, social and legal.

Economic Causes: Because the present value of future goods and income usually lower than the anticipated future value, individual tend to satisfy immediate demands without taking into account the fact that the resource may have to be foregone in the future. This is especially true for self-renewable goods (such as air) in a market place where prices are fluctuating. Moved by desire to maximize income upon an initial investment and pressed by competitive struggle, entrepreneurs tend to employ resource-exhaustive methods of production to cut out of pocket costs. This emphasis on short-term profit also has the consequences of discouraging scientific research into pollution control. Since such research is not expected to generate income for the entrepreneur, it is unlikely to be given much attention. See K. Kapp. The social cost of Private Enterprise 94 (1950).
The incidence of pollution costs is likewise the result of limitations of the market mechanism. In traditional market system prices balance of demand and supply pressures. But since the pricing system usually fails to put a charge on emitting CO_2 into air (externality), the resource factor is under-priced. When the selling price does not reflect the full cost to society of all inputs and services, more of the resource is used in production. See Goldman. Why Do polluters Pollute?, in Controlling Pollution: The Economic of Cleaner America 12-13 (M. Goldman ed. 1967).

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Social Causes: When people create an ordered society, certain partners of behavior emerge which tend to deplete resources and pollute the environment. Consider the phenomenon of "free riding". When a given service is provided for all citizens, such that the benefit received by one does not diminish the benefit available to others. But since no individual can be excluded from the benefit even if he fails to share the cost, there is no incentive for the individual to pay the price for the service. As no remedial action will take place without its price is paid. The free-rider principle explains why there has never been a groundswell of privately initiated pollution abatement actions. See Goetz, Public v. Private Goods, in Economics of Air and Water Pollution. 22-28 (W. Walker ed. 1969); Hardin, The tragedy of the Commons, 162 Science 1243 (1968).

Legal Causes: When the United States was a debtor nation with the shortage of labor and dependent upon foreign investments and overseas trade, laws responded to these facts of scarcity by furthering exploitation of natural resources. Later, when a common desire to foster industry in the 20th century I placed a premium on the free disposal of waste into the environment, law reflected and encouraged this trend. With little social and economic pressure towards resource conservation, remedial laws which had the effect of diminishing profits by imposing anti pollution costs on the polluters. See J. Hurst Law and Economic Growth: The Legal History of the Lumber Industry in Wisconsin 1836-1915 (1964). There were (and still are) institutional limitations on existing legal agencies that made these bodies ill suited to the needs of pollution management. The judiciary found itself confronting structural limits when it attempted to resolve polycentric pollution problem rather than adjudicate narrowly defined controversies. The legislature functioned best as a political assessment body and worst as a technological assessment body; it generally fully comprehended the benefits which ensued from a resource exhaustive policy, which it understated the potential risks and costs. Even the basic structural units of an organized society, such as states, counties and cities found their basic governmental powers insufficient to control the pecuniary mobile and diffuse problems of inter-jurisdictional pollution. See Zimmerman, Political Boundaries and Air Pollution Control, 46 Urban L. 173 (1968).

6 83 Social costs are direct or indirect losses to the community, which result from private activities but for which private parties are not held accountable. Air pollution is a good example of a social cost. It produces harmful effects on one or more persons and originates in the actions of other people or firms who have no transactional relation with most of those injured.

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7	84	See No. 130 [1890], Ohio Laws 166, supra note 4. Some state legislation went further and prohibited the use of highly polluting "soft" coal. See Law of Apr. 16, 1895, ch. 322, Laws of New York (1895).
8	84	See, Detroit, Mich., Rev. Ordinances, Ch. 37: "Any owner... who shall cause smoke to be emitted from such structure...shall be liable to a fine on not less than $10 or more that $100." See also New York Sanitary Code, $ 181 (cited in People vs. New York Edision, 159 App. Div. 786, 144 N.Y. S. 707 (1913)); Chicago Ordinance $ 10 1903 (cited in Glucose Refining Co. vs. Chicago, 138 Fed. 209 C.C.N.D., Ill. 1905).
9	85	See St. Louis MO. Ordinances 41804, see. 5340 (cited in Ballentine vs Nester, 350 MO.58.164 S.W.2d 378 (1942)).
10	85	{PL 86-493, 74 Stat. 162.}
11	85	{77 Stat. 392}
12	86	CAA of 1970, PL. 91-604, 84 Stat.
13	86	CAAA of 1990, 104 Stat. 2399, The title of main law is PL 101-549
14	87	See Title IV

<u>Title IV</u>

In contrast with the previous laws, the title IV deals with requirements and EPA's rule making activities to implement the Statute. Briefly, the general requirements of this regulation are as follows:

i) A 10 million tons of SO_2 reduction from 1980 levels, primarily from electric utilities. Caps annual SO_2 emissions at approximately 8.9 million tons by the year of 2000.

ii) Reductions are met through an innovative market based system. Affected sources are allocated allowances based on required emission reductions and past energy use. Sources must hold allowances equal to their level of emissions or face a $200.00 excess ton penalty and a requirement to offset excess tons in future years. Any penalties levied under the excess emission penalty provisions of the CAA acid rain title do not diminish the liability of the units owner or operator for a fine, penalty or assessment against the unit for the same violation under any other section of the CAA.

iii) On the date that a coal fired utility unit becomes an affected unit which must meet the SO_2 reduction requirements, such as power plant also becomes an affected unit for the purposes of the NO_x emission

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		limitations which will be established by the EPA.
15	87	On December 22, 1992, Governor George V. Voinovich, Ohio signed into law Substitute Senate Bill No. 359 of the 119the General Assembly, which was passed on December 17, 1992. The bill enacted into law Section 3745.11 of Ohio Revised Code. For the purpose of defraying the costs of administering and enforcing the laws of this State relating to the prevention, control and abatement of air pollution, Section 3745.111 levies in fiscal years 1993 and 1994 a fee of eight dollars per ton on the emission of each of the air contaminants, particulate, SO_2, NO_x and organic compounds. In addition the bill amends Section 4905.31. Revised Code. The amended provision permits an electric light company to recover the emissions fees levied in Substitute Senate Bill No. 359 pursuant to a variable rate schedule which provides for the recovery of the emissions fee by applying a uniform percentage increase to the base rate charged each customer of the electric light company during the period that the variable rate is in effect.
16	87	Pursuant to Section 4905.31(B)(2) and (B)(3) of the Ohio Revised Code, monthly bills, excluding fuel and any other rider adjustment, of all retail customers shall be increased by 0.00% until the emissions fee levied pursuant to 3745.111, Revised Code, is recovered. At such time, this rider shall be terminated.
17	88	State of New York v. Shore Reality Corporation, 759 F2d 1032 (2nd Cir. 1985); United States v. Chemical Dyne, 572F. Supp. 802 (S.D. Ohio 1983).
18	88	United States v. A and Materials Company, 578F. Supp. 1249 (S.D.Ill. 1984, United States v. Chemical Dynes 572F. Supp. 802 (S.D. Ohio 1983)
19	88	See notes 18
20	91	Title V of CAAA of 1990
21	91	Title V of CAAA (SO_2 issues)
22	92	In 1998, Congressman DeLay challenged the veracity of an EPA document entitled: "Electricity Restructuring and the Environment: What Authority Does EPA Have and What Does it Need", which stated EPA has the authority under the CAA to establish pollution requirements for CO_2. In response, EPA General Counsel Jonathan Z. Cannon asserted in

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		a memorandum to EPA Administrator that, under the CAA, EPA has the authority to regulate CO_2, as it is an air pollutant and radioactive substance, therefore, it can be regulated. House members leaded by David McIntosh and Ken Calvert in a letter to EPA recently rejected the claims and asserted "EPA cannot regulated CO_2 under the CAA".
23	92	See, for a discussion of Coase, Mishan, E.J., "Reflections on Recent Developments in the concept of External Effects," Canadian Journal of Economics, February 1965, p. 29-32. on p. 29 Mishan appears to accept the Coase neutrality theorem. His later papers are much less favorable to the theorem.
24	102	See Dolbear, 1967, *"On the Theory of Optimum Externality*, p. 90-91
25	104	Commission of the European Communities, recently invited the European Parliament, the Council, the Economic and Social Committee and Committee of the Regions as well ass interested parties to discussion and comment on the "White Paper On Environmental Liability" developed by the Commission, Brussels, February 9, 2000.
26	106	See White Paper on *Environmental Liability*, Brussels, 9 February (2000), COM (2000) 66 final
27	128	To address the global climate problem, the FCCC, the first international agreement was made in June of 1992 under the umbrella of UN. The treaty encouraged industrial countries to reduce their GHGs emissions to their 1990 levels in a specified period. The US government has agreed and signed this treaty.
28	133	Permit market is one of the options to mitigate the emission trends. Under imaginary emission law, the CO_2 emission taxes can be substituted by an obligation to acquire CO_2 emission permits on the market in order to have the right to emit CO_2 in to the atmosphere. In other words, emission permit could be used as a good in a market.
29	133	AEP Long term Forecasting report, 2000, submitted to Public Utilities Commission of Ohio, OPCo: Case No. 00-201-EL-FOR and CSP: Case No. 00-202-EL-FOR
30	133	Section 1605, Energy Policy Act of 1992 (42 U.S.C. 13385).
31	137	See AEP Long Term Forecasting Report - 2000, submitted to Public Utilities Commission of Ohio. Also see Ohio Utility Rate Survey.

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		August 2, 2000, prepared by Public Utilities Commission of Ohio. http://www.puc.state.oh.us/OHIO UTIL/INDEX.HTML
32	137	From Table 3.2
33	138	See direct testimony in support of the AEP system Acid Rain Compliance Report, April 29, 1992, Case No. 92-790-EL-ECP. See direct testimony of Mark F. Morss on behalf of Ohio Power Company, April 29, 1992.
34	139	On July 27, 2000, U.S. Senator Sam Brownback along with few more Senators held a Capital Hill news conference announcing the introduction *of International Carbon Sequestration Incentive Act*. Mr Brownback has cast the International Carbon Sequestration Act as a win win for both the environment and hard working small business and state interests. Under this bill, eligible projects can receive funding at a rate of $2.50 per verified ton of carbon stored or sequestered - up to 50 percent of the total project cost. The minimum length of these projects is 30 years and Implementing Panel can only approve $200 million in tax credits each year. In conference, Senator Brownback added, "the aim of this proposal is to encourage investment in projects that soak up CO_2 accumulating in the atmosphere from the burning of fossil fuels". See for details in S.20982, 2000.
35	139	See notes 31 and 34 for details. It is assumed that under the hypothesized law the emission tax is $2.5 per ton of CO_2 or other GHG gas equivalent to CO_2. Taking this value into account, the tax is equal to $1.705 per mWh of electricity. Therefore, the new equilibrium price P = $74.2074

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CHAPTER 4

A SYSTEM APPROACH TO EMISSION REDUCTION OPTIONS UNDER LABILITY RULES

It is paradox to say that in our most theoretical moods we may be nearest to our most practical applications -- A.N. Whitehead
(Quoted by Michael P. Vogel (1998), p.21

4.1 Introduction

Although not currently regulated under any national-level policies, the upward trends of greenhouse gases (GHGs), especially, CO_2 emissions have raised concerns about the potential threat of global climate change. As a result of this urgency, 158 countries reached an historical agreement on curtailing all GHGs in December 1997, in Kyoto, Japan. While the United Nations Framework Convention on Climate Change (UNFCCC) signed at the Earth Summit in June 1992, the Annex-I countries were committed in their aim to stabilize emissions of CO_2 and other GHGs at their 1990 levels in a specified time period. In 1997, in Kyoto Conference, this commitment became legally binding for a group of six greenhouse gases and timetables were laid out for these countries (the industrialized countries) to reduce their emissions of GHGs on average by 5.2 percent below 1990 levels by the year 2008-2012. Under this agreement, Kyoto Protocol, each country is free to choose their preferred policies and measures best suited to their economic circumstances, the community concerns and other national criteria. The quotas are defined as groups covering the six gases CO_2, CH_4, N_2O, HFC_s, PFC_s and SF_6.

The United States was required to reduce its CO_2 emissions by 7 percent (UNFCCC, 1997a). The electric utility sector has been responsible for most CO_2 emission trends in this country since the early 1800's and Midwestern States have been blamed.

Relevant to the issue, CO_2 emissions, instead of all these six gases, were chosen to develop models which would provide directions for future studies aimed at developing computable decision support and planning tools for regulators (government agency) as well as for electricity generating companies (stakeholders).

4.2 Organization of the Study

The main theme of this chapter is to develop mathematical models aimed, where empirical data are available, to develop computable decision support and planning tools for regulators (government agency) and electricity generating companies (stakeholders) under the emission liability dogma that was discussed and developed in Chapter 3 of the dissertation.

The Kyoto Protocol placed no restrictions on the use of domestic policy instruments and it allows developed countries to participate in international emission trading. Whatever form of international agreement is adopted, in this chapter, first, I propose to incorporate government's possible choices of domestic climate policy in the forms of models for the international commitment period under the Kyoto Protocol.

Secondly, I will attempt to incorporate generating companies' possible choices under the assumed emission law mentioned in Chapter 3. There is a complex array of alternative approaches that could be adopted by involved parties to curtail the magnitude of CO_2 emissions. The application of different options depends on government's emission policy, parties' emission mitigation strategies and parties' budgets to comply with the emission standards.

4.3 Emission Mitigation Options

Two main forms of economic instruments can be seen in the relevant literatures and categorized for US domestic policy development. One is the use of a taxation regime based on CO_2 emission taxes and the other is a CO_2 emission permit regime. A combination of these two policies could also be used. The economic instruments, from the popular and scientific literature, can be categorized as needed to incorporate the following factors (options) in mathematical models:

1. Tax Options
   a. Command and Control
   b. Command without Control
2. Technology Improvement
3. Taking part in Permit Market
   a. Current Market
   b. Future Contract
4. Emission Reduction Project
   A. Domestic

a. Voluntary Agreement

b. Reforestation

B. International

a. Clean Development Mechanism (CDM)

b. Joint Implementation (JI)

C. Incentive to curtailing the demand of products that cause emission

a. Cash Back Bonus [1]

4.3.1 The Basic Model of Taxation Regimes

The model presented in this section presupposes that we are studying a state with both electricity generating companies (private sector) and regulators (public sector) where generating companies act as the source of CO_2 emission caused by electricity generation using coal combustion.

Under this scenario, the government acts in the international permit market while generating company cuts off from international permit market. The company pays emission taxes to the government if it exceeds the domestic emission ceilings. The company is enabled to participate in the domestic permit market. The generating company passes on the emission costs to the end-users as required by the liability rules. This approach might be an inducement to Annex-II countries in a sense that the climate challenge could turn in to a *hot air* business opportunity.

The Model

The theoretical structure for emission control set out in this section is similar to that used by Steuer (1978), Ware *et. al* (1971), Field *et. al* (1980) and others for modeling forest management.

This study demonstrates a complementary use of Linear Programming (LP) and Goal programming (GP) to investigate the trade-off among decision criterions. The procedure could easily be extended to trade-off among multiple objectives. I shall begin by reviewing LP and its extension from single to multiple decision criteria. GP, which is a variation of LP, is presented as a solution technique for multiple criteria problems. I propose a procedure for applying LP and GP jointly to capitalize on the advantages of each technique. A case study of CO_2 emission allocation scheduling will be used in this procedure where ever the related data are available.

Linear Programming in Presence of Multiple Criteria

Standard Formulation:

In the standard case, Linear Programming (LP) is a form of mathematical programming of a particular simple technique that involves a single, linear objective function and a set of linear inequality or equality constraints. Symbolically, the standard LP problem is usually stated as follows

$$\text{Minimize } Z = \mathbf{C}\,\mathbf{x}$$

$$\text{Subject to } \mathbf{Ax} \geq \mathbf{b}$$

$$\mathbf{x} \geq 0$$

Where;

Z is an appropriate real valued decision criterion. **x** is vector of n decision or activity variables x_j. C is a vector of n specified constants c_j (costs). **A** is an m-by n matrix of technical coefficients a_{ij} and **b** is a vector of available resource amounts or production requirements b_i. It also is common practice to refer to X as the strategy vector and to denote the set of feasible values for these variables by Ω, where

$$\Omega = \{\mathbf{x} \mid \mathbf{Ax} \geq \mathbf{b} \text{ and } \mathbf{x} \geq 0\}$$

in these terms the LP problem is compactly stated as

$$\min \; Z = \mathbf{C}\,\mathbf{x}$$

$$\mathbf{x} \,\varepsilon\, \Omega$$

Where ε implies that **x** is an element of the set Ω.

Multiple criteria-

The LP has proven to be very useful despite the obvious practical limitations of the linear structure. There are many managerial situations where linearity assumptions might prevail, or at least approximately hold, but where conventional LP is not appropriate because the decision-makers are unwilling or unable to specify a single criteria for the evaluation of feasible strategies. It has been suggested for such multiple criterions or multiple objective case, that a standard LP be generalized to vector optimization in the form

$$\text{Min } \mathbf{z} = \mathbf{Cx}$$

$$\mathbf{x} \,\varepsilon\, \Omega$$

Where **z** is a vector of p decision criteria and **C** is now a p by n matrix of specified weights. Z_k represents the value of the k^{th} objective functions evaluated at x.

The same constraint structure is assumed to be operating for all objective functions and thus the set Ω is the same as before.

Except for the trivial case where there exists a unique strategy $\mathbf{x}^* \varepsilon \Omega$ such that all of the Z_k are simultaneously maximized, the nature of the vector optimization problem is considerably different from the single criterion case. In the vector optimization case, I shall not seek a single optimizing strategy vector $\mathbf{x}^*$ from Ω but rather I attempt to partition Ω into disjoint subsets $\Omega 1$ and Ω_2 where $\bar{\mathbf{x}} \varepsilon \Omega_1$ implies that

$$\bar{\mathbf{Z}} = \mathbf{C}\ \bar{\mathbf{x}} \geq \mathbf{Cx} = \mathbf{Z}$$

for any $\mathbf{x} \varepsilon \Omega_2$ (here the relational operator $\geq$ means simply that $\bar{\mathbf{Z}}_k \geq \mathbf{Z}_k$; k= 1, 2, . . . , p but that strict inequality (>) holds for at least one of the Z_k. This partition of Ω is exhaustive, that is, the union of Ω_1 and Ω_2 equals Ω. Strategies $x \varepsilon \Omega_1$ are referred to as non-inferior or efficient strategies. Such strategies are Pareto optimal in the sense that it is not possible to increase any of the Z_k over Ω without causing a decrease in at least one of the other criterion variables. Strategies $\mathbf{x} \varepsilon \Omega_2$ are conversely termed inferior.

Solution procedure:

A number of procedures will be developed to generate Ω_1, the set of non-inferior strategies for the linear multiple- criteria problem. These procedures include generalized simplex methods, various special LP formulations and trade off evaluation methods. However, merely generating a set of non inferior strategy does not necessarily indicate any single optimum decision where multiple criteria are involved. A single preferred strategy must be selected from this set, and this can be accomplished by only some weight considerations of the decision criteria, however, this weight might be implicit or subjective.

Cohon and Marks (1975) identified three classes of solution techniques for multiple criteria problems. They are;

1) those which generate Ω_1 without preference information, then select the preferred strategy

2) those which rely on prior articulation of preferences and select the preferred strategy directly

3)the iterative techniques which rely on progressive articulation of preferences.

They noted the computational difficulties of solving large problems using techniques of the first and the last groups. They further criticized the iterative methods for failing to reflect trade-off between objectives explicitly.

I have selected GP for this study because I believe that I have overcome those shortcomings by using a more restrictive use of the procedure, by linking it to LP and by performing sensitivity analyses.

GP Model Formulation

Standard Form:

GP in its simplest form is a special case of LP aimed at minimizing the departures from specified goals or targets, subject to usual constraints on resources and operations. The technique was developed by Charnes and Cooper (1961) and was first applied to a forestry example by Field (1973). To approach a multiple criteria LP problem as a goal program, the target level must be defined for each of the p criterion variables. These specified target levels may be denoted as g_k and their associated weights as w_k. A weighted difference criterion, L may then be defined as

$$L = \sum_{k=1}^{p} w_k \, |g_k - z_k|$$

and minimized over Ω. For purposes of analysis L is linearized by defining the under and over achievement variables d_k^- and d_k^+ as

$$d_k^- = g_k - z_k \text{ if } g_k > z_k$$

$$d_k^- = 0 \text{ if } g_k \leq z_k$$

$$d_k^+ = 0 \text{ if } g_k \geq z_k$$

$$d_k^+ = z_k - g_k \text{ if } g_k < z_k$$

The GP objective function can now be written as

$$L = \sum_{k=1}^{p} w_k \, (d_k^- + d_k^+)$$

Which linearizes L and gives equal weight to departures above and below the target levels for each value of k. This form of the objective function admits generalization for differential weighting of the departures e.g.

$$L = \sum_{k=1}^{p} w_k^- d_k^- + \sum w_k^+ d_k^+$$

where the w_k^- and w_k^+ are specified or parametrically ranged constants. If the criterion functions z_k are, as has been previously assumed linear functions of the decision variables **x**, the minimization of L over Ω can be accomplished by appending the set of linear equalities

$$g_k = c'_k \mathbf{x} + d_k^- - d_k^+$$

where c'_k is the k^{th} row of the p- by - n matrix C which relates the goals to the decision variables. A is taken as the original constraint set. The linear, cardinality weighted goal program may then be expressed as

$$\min L = \mathbf{W}^{-\prime}\mathbf{d}^- + \mathbf{W}^{+\prime}\mathbf{d}^+$$

subject to .

$$\mathbf{Ax} \geq \mathbf{b}$$

$$\mathbf{Cx} + \mathbf{d}^- - \mathbf{d}^+ = \mathbf{g}$$

$$\mathbf{x}, \mathbf{d}^-, \mathbf{d}^+ \geq 0$$

where $\mathbf{w}^-$, $\mathbf{w}^+$ are vectors of p weights, $\mathbf{d}^-$, $\mathbf{d}^+$ are vectors of p under and over achievements and g is the vector of target levels for the p decision criteria. This formulation permits different weighting for under and over achievements from the same goal as well as for different signs on those weights. Such an approach might apply to unusual cases in which rewards are given for departures in one direction while penalties are assessed in the other. Here constraint, $\mathbf{d}^{-\prime}\mathbf{d}^+ = 0$, guarantees that for each goal, no more than one departure variable should enter the solution.

The formulation also permits the size of the penalty or rewards to depend upon the deviation from the goal and the size of penalty or reward.

Preemptive GP---

A more general form of GP involves a preemptive, ordinal weighting of goals that places particular objectives or decision criteria into priority classes. Criteria are used in defining the departures precisely as above. The sum of the weighted departures that occur at a given priority level is then minimized subject to operational constraints.

It is also a subject to the constraint that no strategy $\mathbf{x}^*$ is feasible if it causes an increase in the sum of the departures for any criteria ranked at a higher priority levels. Conceptually, the preemptive procedure results in a series of cardinal weighted goal programs, one for each priority level where each program depends on the solutions to those preceding it.

Generally, both cardinal weighted and preemptive GP are used to find a preferred strategy directly. In this case a preferred strategy is defined as that strategy which minimizes the sum of weighted departure from the goals. In addition, cardinal weighted GP, like ordinary GP, can be used in identifying Ω_1 by parametrically by varying the weightings. Preemptive GP, on the other hand, can not be used in this way since solutions to such programs are likely to be inferior (that is solutions from set Ω_2). If the decision maker's true preference structure, in multiple criteria problems decisions can be expressed by preemptive ranking, a situation that seems to be rare in practice, then priority procedures can be used to find the preferred solutions. Such a preference structure necessarily implies that satisfying the level of higher ranked goals becomes a binding constraint on the lower ranked goals, an implication that does not seem to be very sound without a considerable analysis of the associated trade-off between objectives. Consequently, I can dismiss the use of preemptive GP and recommend exclusively the application of cardinal weighted GP, referred to hereafter simply as GP.

4.3.2 The Basic Model of a Permit Regime

In this scenario, the private firms have access to participating in international as well as in domestic permit markets where the CO_2 emission taxes are substituted by an obligation to acquire permits on the open market in order to have the right to emit CO_2 into the atmosphere. The failure to meet the emission standards requires the firms to pay a penalty. This approach might be an inducement to the Annex-I countries in a sense that it could offer cost-effective ways to curtailing the emission trends and compliance emission standard.

The Modeling Approach for Improved Planning

Decisions of all types are made with the hope and expectation of favorable outcomes. In an effort to improve the likelihood that good decisions with quality outcomes, are made, emphasis must be placed on the decision process (Chechile & Carlisle 1991). The literature on human decision-making suggests that people "have difficulty articulating a well-defined, comprehensive strategies (Dworman *et al.* 1996). A model can alleviate such shortcomings by providing an analytical framework and quantifiable results cost- effectively for planning and improved decision making.

Algebraic Formulation

The decision or planning evaluation module (EM) consists of three categories of equations. The first category is the expression of mass balance in the system. The second and third categories involve the conversion of these mass flows to costs data. The term cost implies the dollar costs to comply with the emission target (second category of equations). The model calculations for both costs are derived from the algebraic formulation presented in this section and this mathematical representation governs the model's operations. The following equations assumed to estimate CO_2

emission levels and the alternative costs of implementing the choice options to meet the emission standards and to evaluate the consequences of a given operational decision.

CO_2 Emission Level Estimation

The total emission level is estimated by the following equation

$TE = F_t * CCC_t * K * f / 2000$

$E = TE - T_{1990}$

Where TE = Total CO_2 emission by the company in the given year in tons

Costs to Choose the Options

The total cost for system approach, in dollars per year, can be calculated from equations

$$\overline{C} = \overline{C}_T + \overline{C}_C + \overline{C}_O \qquad 4.1$$

$$C = \sum Cg \; ; \; \forall g = t, i, p, r \qquad 4.2$$

Where $\overline{C}$ is a four component column vector of total costs in dollars per year for each of the four options defined to meet the emission target: Tax option (t), Technology improvement (i), Permit option (p), Emission reduction project (r).

$\overline{C}$ is composed of elements C_g and can be written as

$$\overline{C} = \begin{bmatrix} Ct \\ Ci \\ Cp \\ Cr \end{bmatrix}$$

where C_t is the total cost for tax option in dollars per year. At this point, the emission mitigation categories can be divided into these four options and the calculations for each option are separate but parallel. C_i is the total cost incurred in dollars per year for technology improvement (capital cost), C_p is the total cost incurred in dollars per year for permit option, C_r is the total cost incurred in dollars per year for emission reduction project (CDM and JI).

The first term in equation 4.1, $\bar{C}_T$, is again a four component column vector of transaction costs that incurred by each of the four defined options in dollars per year and it can be written as $\bar{C}_T = \begin{bmatrix} CTt \\ CTi \\ CTp \\ CTr \end{bmatrix} = \begin{bmatrix} CTt \\ CTi \\ CTp \\ CTr \end{bmatrix}$

where C_{Tt} is the cost to incorporate tax option in dollars per year and others follow similarly. C_{Tp} and C_{Tr} both equal zero when generating company acts as the source of CO_2 emission and meet the emission target by paying taxes and by adopting new technology.

The middle term in equation 4.1, $\bar{C}_C$, is a four component column vector of the cash outlay (cost) incurred by each of the options in dollars per year, and it can be written as

$$\bar{C}_C = \begin{bmatrix} Cct \\ Cci \\ Ccp \\ Ccr \end{bmatrix}$$

Where C_{Ct} is the capital cost for the tax option in dollars per year and the others follow similarly.

The last term in equation 4.1., $\overline{Co}$, is a four component column vector of other costs excluding transaction cost and capital cost incurred in dollars per year and it can be written as

$$\overline{Co} = \begin{bmatrix} Cot \\ Coi \\ Cop \\ Cor \end{bmatrix}$$

Where C_{Ot} represents all other costs excluding transaction costs and cash layout in dollars per year and others follow similarly.

Once $\overline{C}$ has been calculated from equation 4.1, then the total cost for the generating company to meet the emission target in dollars per year, C, can be estimated by summing the elements of $\overline{C}$ according to 4.2

Model Design

The algebraic formulation introduced in this section provides accountability for the final decisions made by decision-makers. There are key design features of the model that can make it a desirable tool for use in planning. These features include utility of the model, flexibility and customization, *what if?* analysis capability, graphical and tabular output for straightforward interpretation. For customary model tools, a Genetic Algorithm (GA)[2] will be employed to create alternative system designs in the development module. The fact that emission policy alternatives can be expressed in a similar fashion to gene structure is the justification for the use of GA methodology for developing policy alternatives. The program can be developed in Visual Basic Access, which would be easier and more convenient than Fortran or C++.

Mathematical Formulation

The core of the GA is the fitness function. From this function, the search for solutions is directed towards some subset of the most acceptable solutions from the entire solution space. The GA for Multiple Attributes Decision System (MADS) [3] maximizes fitness by maximizing the difference between company emission mitigation budgets and the costs of a policy alternative [4]. Of course, this is not the only fitness function that could be used for permit regime to reduce the emission level and it is easy to see how even the same fitness evaluator could be used for another types of systems by simply replacing the budget for emission compliance with the budget for that other system. In this case the function is linear one that sums the cost of each options included in a particular solution. The fitness function is given in the following equation

$\text{Max } F_j = b - \sum x_s y_s - \sum \mu_i t_i$

Where:

F_j = Fitness of a particular string j; j = 1, 2, ...l

l = population size

b = budget for emission compliance management activities in dollars per year

y_s = cost for substring s in dollars per year; s = 1, 2, ...m

μ_i = penalty i in dollars per year i = 1, 2, ..e

$x_s = \begin{cases} 1 \\ 0 \end{cases}$ sub-string s included in configuration j; otherwise 0

$t_i = \begin{cases} 1 \\ 0 \end{cases}$ constraint i is violated in configuration j; otherwise 0

In order to evaluate the fitness of a particular solution, the general constraints for any cost effective emission mitigation option configuration must be considered. The key constraint in this case is that the company cannot sell permits (but it can buy them) if it exceeds the 1990 emission level. Essentially, this means that the function of each company must be considered to ensure that the cash flow is one way and it is in a logical fashion. To accommodate this trait, the available options will be grouped into bundles of feasible options - this is a type of screening that can be used here to reduce the scope of this type of problems. These are termed sub-strings in this model and, in program, GA will treat each sub-string as a single variable. A programmer will be required to define

a prior the sub-strings for the purpose of simplifying the coding before running the GA. Additional constraints on emission compliance include the following:

1. The cost of the configuration in dollars per year must be less than or equal to the budget allocated for emission compliance.

   $\sum x_s y_s \leq b$

2. Decision-makers must find the policies to be realistic from both an acceptability and implementability perspective.

   $\sum x_s \omega_s \geq W$, where

   w = minimum allowable sum of preference weightings; $0 \leq \omega_s \leq 1$

3. The total volume of emissions must be less than or equal to the emission target levels.

   $\sum E_{sk} \leq E_k$, where

E_{sk} = Volume of CO_2 emission via sub-string s

E_k = Emission target

Algorithm Development

The basic framework for this GA will be used to drive from manual simulations that will be conducted to show the application of GA to policy planning. The budget in the actual MADS GA and the cost of a particular policy alternative, will be the driving factor in the genetic search. Here, decision-maker preferences will also be included. In this case, prior to actual computer coding and implementation of the GA, parameter attributes and values must be assigned.

4.4 Conclusions and Future Research

The Kyoto Protocol must be the starting point for the choice of a nation's domestic climate policy instruments. It is so far uncertain whether the requisite number of parties, especially the US Senate, will ratify the Protocol to enable the Protocol to enter into force.

The first section in this Chapter demonstrated that the US government should place an environmental tax on CO_2 emissions on top of the fiscal tax and these taxes may not be necessarily equal to the permit price on the international market since the US government's goal is to generate revenue. In addition, the environmental tax may fluctuate in accordance with the international permit price to ensure cost-effectiveness. This approach might be an inducement to Annex-II countries. However, it is debatable whether such system is practical and suitable. On the other hand, the permit regimes decrease the possibilities to shutdown a firm. It also induces both a cost-effective division of domestic abatement efforts and a cost-effective allocation of abatement internationally. It might be an inducement to Annex-I countries.

Thus, the Chapter attempted to develop mathematical models with various options, which were incorporated in the aims of finding a cost-effective division of domestic abatement efforts. Upon receiving needed information, future research can be directed to developing computable models using these mathematical models. Secondly, it has been cited in the popular literature that the provision of emission mitigation options in the Kyoto Protocol may encourage the generating companies to turn the climate problem in to a strategy of *hot air* business opportunity. Future research could be directed to investigate the gains of *hot air* business.

4.5 Notes

No.	Page	
1	169	*Cash Back Bonus* is a new approach to internalize the emission costs among involved parties where parties are dichotomy in acts but homogeneous in case of goals. It provides incentive to curtailing the demand of the products that causes emission. (Rahman, 2000).
2	180	The Genetic Algorithm (GA) is a global search technique derived from Darwinian *survival of the fittest* theory. That is, it simulates the natural process of evaluation to direct search of a problem's solution space toward more acceptable or *highly fit* solutions (Holland, 1962). The GA solution can be represented as population members. Iteration of the algorithm can be equated to an emission strategy where new solutions, similar to offspring in nature will be created. Over time, the most fit individuals (solutions) reproduce and increase in number while the less fit individuals eventually die off. In nature, the chromosome, and the genes that comprise it, exists to distinguish individuals in a population. Over time, it is assumed that individuals processing more desirable traits will increase in the population. GA simulates this process.
3	181	The model named Multiple Attribute Decision System (MADS), is composed of two modules - an evaluation module and a policy development module (Rubenstein, 1997)
4	181	The difference between the budget and the cost of a solution is termed *pre-fitness*. Fitness then refers to pre-fitness minus any penalties exacted for a particular alternative.

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CHAPTER 5

SUMMARY AND FUTURE RESEARCH

Environment to each must be
all there is, that isn't me —
R. Buckminster Fuller
(Quoted from Michael P. Vogel)

5.1 Summary

Section one in my dissertation summarized the Midwest region's emission scenario that accumulated from various sources namely; coal, petroleum, natural gas, landfills and nitrogenous fertilizer in each state in the region. This Section demonstrated how to limit the number of gases instead of choosing all six gases to represent GHG in logical ways where the applications of set theory assisted in deduction of logical arguments, which are available in the scientific and popular literatures. CO_2, CH_4 and N_2O gases were considered from the six GHGs namely; CO_2, CH_4, N_2O, O_3, CFC, and water vapor, so as to represent the GHGs emissions trends in the Midwest as well as in each state in the region. Secondly, it developed computable models designed to estimate emission trends from selected sources.

The study concluded that the gross total of CO_2 emissions in 1998, in the region, were 17.52 percent greater than in 1990. The three selected sources, coal petroleum and natural gas contributed a major portion to the total emissions and coal combustion dominated the emissions in each state with the exception of Michigan where petroleum dominated the trends. By contrast, landfills contributed only a small portion to the total CO_2 production in the region as well as in each state. The State of Ohio contributed 20 percent of the total CO_2 emitted in the region, in 1998, and placed in first position for such emission. Illinois was the second and Missouri and Wisconsin was placed in the third position. Minnesota, which contributed only 5 percent in that year, was placed the in lowest position. Historically, emission trends were upward with minor disturbances in region as well as in different states.

On the other hand, the Midwest region emitted a total of 74.133 thousand tons of N_2O in 1998 so that nitrogenous fertilizer gases dominated the emission trends. The State of Illinois contributed 22 percent of these and placed first. In contrast, Ohio, Michigan and the State of Wisconsin contributed together 18 percent of the emissions where each state contributed 6 percent. The State of Indian contributed 18 percent and was placed second in the region. The patterns of trends were very similar with minor disturbances during the time span of the study.

Landfills contributed 1507.63 thousand tons of CH_4 in 1998 in the Midwest region where as the State of Illinois was responsible for 22 percent. The State of Ohio contributed 18 percent and was placed second in the region. The historical emission trends were significantly higher during the period 1960 to 1980 over the period 1981 to on. They started to decline from 1981 to on in the region as well as in each state. Regulations related to Solid Waste Management probably influenced these changes. Section two addressed the externality issues in two party cases where one party was the consumer and other was the producer of emissions. Electricity generating companies generate electricity using coal combustion that injects effluent gases into atmosphere. The emission of CO_2 from coal combustion was used as a paradigm of GHGs. Traditionally, to internalize the external environmental costs, generating companies could be made, under imaginary emission related laws, to pay either through the assignment and enforcement of full liability or through Pigovian tax. Then the generating company(s) pass the costs incurred on to the end-users, by charging a higher rate per kWh of electricity used. This Section, first questioned whether these policies maximize social welfare and then developed computable models, using the basic principles of "new" welfare economics, where people's willingness to pay are money measures of welfare gains and losses, assigning CO_2 emissions liabilities. The conclusions of this Section were that the assignment of full liability of external environmental costs would not necessarily maximize a standard unweighted social welfare function. Moreover, this Section concluded that the assignment of full liability failed to maximize a weighted social welfare function, in which the costs and benefits associated with the assignment of liability are weighted by who pays and who benefits.

Finally, this Section outlined the mainstream implications of the conclusions in both economic theory and public policy that *party(s) should be liable for the externality. That is to say, party(s) in question, the electric company(s) and the end-user(s), should share the emission burdens that they create as results of their own acts*. In the power generating company case, relying on the milieu, *both parties are rational and attempt to maximize their budgets*, it warranted a law or a set of laws that could make both generating company(s) and end-user(s) accountable, in order to internalize CO_2 emission costs.

Section three of this dissertation dealt with simple theoretical models related to decision supports and planning tools for regulators, stakeholders and for individuals under emission burdens sharing dogma in order to reach optimal goals of the respective party. In the first part of this Section, the government attempted to maximize taxes on CO_2 emissions in order to comply with the Kyoto Protocol and continued to use taxes to regulate domestic emissions. Given the existence of a well behaving international permit market, the government might prefer to place environmental tax on CO_2 emissions, on top of a fiscal tax where the environmental tax should be equal to the permit price on the international market. In addition, it was demonstrated that the environmental should encourage the government to adjust the level of fiscal tax. Here the environmental must fluctuate in accordance with permit price in international market to ensure cost-effectiveness. However, it is debatable whether such a system is practical and suitable.

The second part of this Section looked at the establishment of a domestic market for tradable permit whereby domestic permit market becomes an integrated part of international permit market and it increased the possibilities of achieving a cost-effective distribution domestic abatement and import of permits. At the same time, the danger of weakening the market's efficiency through market powers was reduced. In this scenario, the domestic government was required to create the CO_2 emission permit market by establishing emission law stating that companies must acquire permits corresponding to their CO_2 emission in order to phase out the excess emission levels.

5.2 Future Research

The usefulness of the model in emission policy debate lies on subsequent empirical assessment of the demand and supply functions for electricity generation under coal combustion, the damages due to emission, and the welfare weight that influences political opinions. Since the optimal liability share is most sensitive to the values attached to external costs and welfare weights, the additional research should begin with these parameters. Secondly, economic estimates of the demand and supply functions may pose nonlinear functions in practice, therefore, these concerns should be addressed in future research.

In the first Chapter, the sources were limited to estimation of the magnitudes of emissions in order to develop simple computable models that could serve as template for all greenhouse gas emissions. Future research can be directed to include all feasible sources in estimating emission trends. In spite of the fact that GHGs may interact or influence each other, which may cause decay or enhance the magnitude of GHGs, especially, CO_2 in the atmosphere, a future research can be directed for emission projection addressing gas's decay or enhance.

The third Chapter demonstrated mathematical models with various options, which were incorporated in the aim of finding a cost-effective division of domestic abatement efforts. Upon receiving needed information, future research can be directed to developing computable models using these mathematical models. Secondly, it has been cited in the popular literature that the provision of emission mitigation options in the Kyoto Protocol may encourage the generating companies to turn the climate problem in to a strategic of *hot air* business opportunity. Future research could be directed to investigate the gains of *hot air* business.

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