ESTIMATION OF EXTERNALITY COSTS OF ELECTRICITY GENERATION FROM COAL: AN OH-MARKAL EXTENSION

DISSERTATION

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By

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ABSTRACT

Anthropogenic green house gas (GHG) emissions, such as those emitted by coal-fired power plants, are reported by the Intergovernmental Panel on Climate Change to be very likely influencing the global climate change. Many states of the US have adopted a renewable electricity portfolio standard to facilitate incorporation of renewable energy sources to mitigate GHG impacts. Ohio's advanced electricity portfolio includes clean coal and renewable sources leaving leeway for continued large dependency on coal. The argument for deployment of coal-fired electricity to a large extent is the lower upfront private cost of electricity. However, ongoing coalmining impacts in Ohio and unregulated Carbon dioxide (CO_2) suggest that the current price structure of Ohio does not reflect the true cost of electricity. This inability of the prevailing cost structure to fully internalize the externalities misleads the decision makers from providing a level playing field for renewable energy sectors which could reduce water pollution, global warming, and potentially create green jobs.

This dissertation identifies the externalities of coal-based electricity generation and evaluates the externalities inadequately addressed by contemporary regulatory framework. Three major areas addressed by this research are evaluation of coalmining impacts on lake recreation; estimation of reclamation costs and revisiting the taxes on

coal mined in Ohio; and the impacts of internalizing the externalities on electricity portfolio of Ohio.

The visitation function model was developed to evaluate two important aspects of coalmining impact. First, the externality associated with coalmining on five of the impacted lakes is estimated as \$18.04 million. Secondly, potential recreational benefits due to improved water quality attributed to reclamation in watersheds of impacted lakes were estimated as \$3.88 to \$5.75 million per year.

Reclamation costs were estimated for existing coalmining problems in Ohio. Estimated reclamation costs is \$ 689.616 million dollars, out of which \$383.807 million is the construction costs and the rest is administrative cost. Federal budget allocated for reclamation until 2021 is \$157.899 dollars. Federal fees and State severance tax obtained from mining coal in Ohio is estimated as \$32.6 and \$5.35 million. This leaves a large deficit of \$512.899 million for reclamation of all abandoned mines.

A federal fee of \$2.68 and \$2.04 per ton of surface and underground mined coal respectively until 2012 followed by \$2.30 and \$20.04 for the period of 2013 -2021 will generate required reclamation funds assuming leverage funds *ceteris paribus*.

Based upon these research results on five of the impacted lakes, Potential Pareto Improvement (PPI) could be demonstrated for continued reclamation of the coalmining problems for Seneca Lake and Wills Creek Lake. Our analysis does not include all the impacted lakes and notably excludes revenue from increased house and land values, aesthetic improvement, recreation on streams, and impacts on wild life. Estimation of

revenue from all these sectors upon reclamation would help determine the PPI of reclamation.

Including these externality costs in OH-MARKAL model indicates a reduction of average annual share of coal-based electricity generation by 0.3 %. More importantly, reduction in CO2 emissions by 15,000 to 574,000 tons/year will be achieved.

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CHAPTER 1

1 INTRODUCTION

1.1 Background

Anthropogenic green house gas (GHG) emissions, such as those emitted by coal-fired power plants, are reported to be very likely influencing the global climate change (IPCC, 2007). In addition to air borne pollutants, water pollution related to coal mining is not insignificant. One way of reducing air and water borne pollution including the anthropogenic GHG emissions from electricity sector is by employing renewable energy. Renewable energy sources such as wind, biomass, solar, and wastes are considered comparatively environment friendly. Deploying renewable energy thus displaces air and water pollution including carbon dioxide (CO_2) emissions associated with electricity generation. Innovations and regulations in coal mining and burning for producing electricity in recent years has contributed in reducing the pollution from coal based electricity generation. However, the urgency for reducing the CO_2 emissions to mitigate global climate change and impacts of coal mining is not adequately addressed by current regulatory framework.

The argument for deployment of coal-fired energy to a large extent is the lower upfront private cost of production per unit of electricity. In Ohio for example, price of electricity from coal is 5.89 cents/kWh for industrial consumers, 8.56 cents/kWh for commercial consumers, and 8.88 cents/kWh for residential consumers (EIA). The question that arises here is whether this price reflects the actual full cost of production of electricity or not. Since several of the Ohio counties do not meet ozone and particulate matter ($PM_{2.5}$) concentration as required by Clean Air Act, and there is no mandatory rule to account for CO_2 damages, it can be hypothesized that the electricity cost of Ohio does not reflect the true cost. Additionally, the legacy of coal mining is impacting society in eastern Ohio, which remains unaccounted in the cost of electricity. This inability of the prevailing cost structure in Ohio to fully internalize the externalities misleads the decision makers from providing level playing field for renewable energy sectors, which could reduce water pollution, global warming, and more importantly create jobs. This research focuses on estimating the externality costs associated with coal power generation in Ohio, the first step in the process. Furthermore, the research investigates impacts of internalizing externality costs on electricity portfolio of Ohio.

1.1.1 Contemporary Regulatory Framework

Specific government policies have contributed in reducing pollution from the energy sector. Renewable portfolio standards (RPS) implementation, for example, has been recognized as an important policy in reducing the emissions from electricity generation by enhancing the use of renewable energy. The RPS policy makes it mandatory for the electricity suppliers to provide a certain amount of electricity from renewable sources. While RPS has been implemented in 24 states of the US, Ohio has just passed an energy bill, SB221 to facilitate clean energy production in the state.

Ohio derived 85.8 percent of its electricity from coal as compared to 0.26 percent from renewable sources (Figure1) in 2007, while the national average is respectively

48.4% and 5.94%. Under SB 221 bill, advanced energy share will increase to 25% by the year 2025, which includes 12.5 % of advanced coal technology and 12.5 % of renewables. Half of the renewables' share can be imported from other states. This will still allow for continued large dependency on coal based electricity generation in Ohio.

Figure 1 Source of Electricity Production in US and Ohio in 2007 (Source: EIA)

The SB 221 bill is formulated considering advanced coal technology with carbon capture and sequestration as environmental impact free option of electricity generation. The advanced coal technology does not take into account the coal mining externalities. It is important to address the coal mining externalities while formulating renewable portfolio standard.

Coal mining externalities are observed as internalized by the Surface Mining Control and Reclamation Act (SMCRA, 1977), however even the reclaimed coal mined lands are impacting rivers and streams costing millions of dollars to society for their clean up. The provisions of the SMCRA regulation and the current status of reclamation of coal mining land will be discussed in Chapter 2.

Understanding of externalities in general and externalities associated with coal based electricity generation in particular at this point will help to narrow down research objectives. Thus, the following section focuses on externalities.

1.1.2 Externalities

Externality is defined as a cost or benefit accrued to an economic activity that is imposed upon a third party without compensation outside of the transaction (Giffin and Steele, 1986). Baumol and Oates (1988) define externality as the unpriced, unintentional, uncompensated extra effect of an economic activity of an agent that affects the other agent directly. For example, emissions from coal power plants cause health hazards to people living downwind from the plants, which is an unintentional bi-product of electricity production activity. The health hazards are not compensated and thus are considered an externality. Externality exists when the cost or benefit from an economic activity in private terms differs from that in social terms.

Externalities associated with electricity generation have two aspects; environmental externalities and non-environmental externalities. Non-environmental externalities are the energy subsidies, assistance to energy sectors for programs, research and development, and funding to administrative agencies. These costs are not reflected in costs of electricity paid by the customers and thus remain as an externality. Environmental externalities are the damages to the environment and ecosystem that are not accounted for by the price of electricity. Non-environmental externalities such as subsidies are provided to fossil and non fossil fuel based electricity generation. In an analysis in Hitzhusen (2009), largest share of energy subsidies is allocated to oil and gas sector $41 billion. Other sectors that receive substantial energy subsidies are nuclear $9billion, coal $8 billion, renewable $8 billion, ethanol $6 billion, and conservation $2 billion. Internalization of the subsidies allocated to different sectors is worthwhile exploring, though as constrained by time and budget remains out of scope of this research. This research focuses on environmental externalities.

1.1.2.1 Environmental Externalities of Electricity Generation

Electricity generation is associated with a number of externalities. Fossil fuel based electricity generation for example stresses the environment while extracting the resources, preparing the fuel into usable form, transporting them to electricity generation facility, construction and demolition of those facilities, and while burning the fuel in the power plants. Similarly, non-fossil fuel electricity generation such as wind and biomass consists of their own sets of environmental stressors. Initially, the planned research was conceptualized as life cycle analysis of each of the feedstocks in the electricity generation sector and the use of this information for estimating the cost effective mix of electricity for Ohio. However, that occurred to be beyond the scope of one dissertation. Therefore, this research effort had to settle on one of the important energy sector of Ohio, coal.

Coal is the most important source of electricity in the US, and the rest of the world, especially in Ohio and thus it is the focus of this research. There is a large reserve of coal, which is comparatively cheaply recovered for use as fuel in Ohio. Ohio’s share of electricity from coal is 1.8 times more than that of the national average. In addition to that, coal is one of the fossil fuels that impacts environment the most by polluting air and water resources. Therefore, this research opted for studying the environmental externalities associated with the coal based electricity generation.

Environmental externalities from coal based electricity production are illustrated in Figure 2. The coal-fired power plant emits pollutants such as Sulfur dioxide (SO_2), GHGs, particulate matter, CO_2, mercury, and volatile organic compounds, which impacts environment and human health, and are not fully accounted for when pricing the electricity.

On the other hand, coal mining is associated with externalities such as drinking water pollution, mine explosions and casualties, respiratory diseases, ecological losses due to mountain top removal, losses of recreation value of lakes and streams, and losses of lakeside housing property due to water pollution.

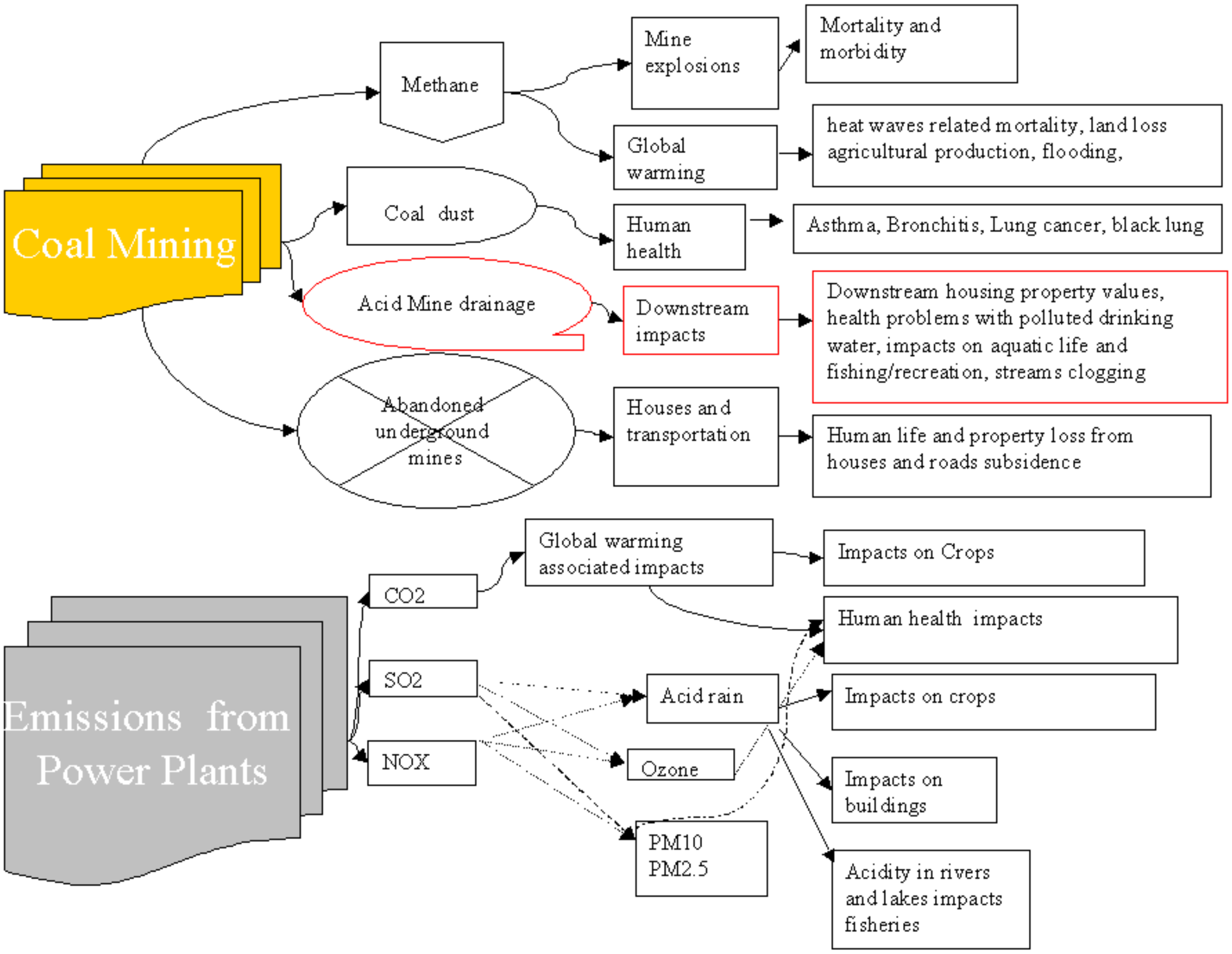

Figure 2 Schematics of Externalities from Coal Based Electricity Generation

The social cost of production of electricity from coal-fired power plants includes the environmental externality costs in addition to the prevailing cost of production (Figure 3). The MPC in Figure 3 denotes the marginal private cost of electricity production from coal, while MSC is the marginal social costs, which includes the externality costs (EC).

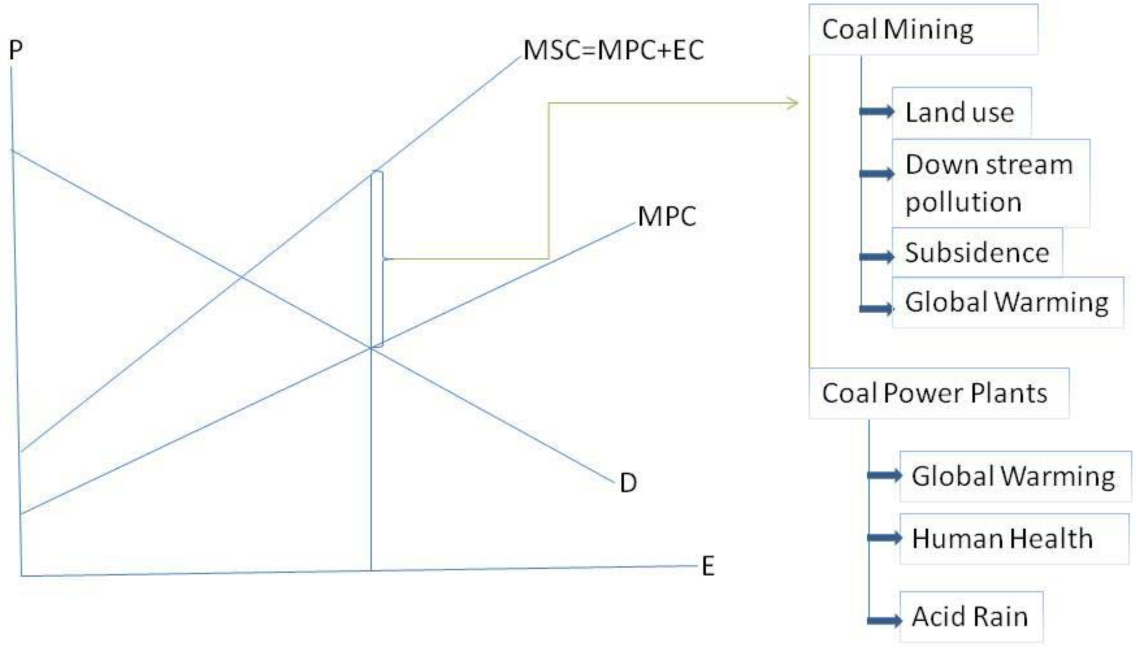

Figure 3 Social Costs versus Private Costs

The comparison of cost of electricity production from coal and other renewable sources on the basis of insufficiently internalized externalities is potentially misleading due to different levels of pollution associated with each source of electricity.

1.1.2.2 Externalities associated with other sources of electricity:

Some of the renewable sources of electricity production in Ohio are biomass co-firing, solar thermal, and wind. According to Shakya (2007), with appropriate policy intervention, Ohio has a potential to introduce 7% from biomass feedstock per year. Ohio is producing 7.2MW per year of electricity from wind in Bowling Green.

Renewable energy sources are associated with different set of externalities. Wind turbines, for example can cause bird mortality, visual disamenity from tall towers, and loss in value of land in proximity to tower area. The humming noise and view obstruction due to the wind turbines can impact the housing property value in the vicinity of wind turbines. Lord (2007) reports that homeowners are asking for 'homeowners protection plan' if wind turbines are to be installed. In case of Ohio, wind speed is higher in Lake Erie region, where the summer coastal homes could potentially be affected due to view obstruction and noise. It should be noted here that the wind energy development in this region will face political lobbying of summer house owners and the wind turbine builders. In addition to that, bird mortality is an issue of concern since the west coast region of Lake Erie is in the flyway for many seasonally migrating birds and is also breeding place for some endangered bird species.

Wind turbines are claimed to cause bird mortality. Based on 12 studies on the effects of wind turbines on birds in California, 2.3 birds per turbine per year or alternatively stated 3.1 birds per MW of electricity are killed by wind turbines (NREL fact sheet). Wind turbines claim 40,000 birds each year in the US (Manville, 2005). However, the author states that bird mortality due to high-rise buildings (97.5 million per annum) and vehicles (57 million per annum) are vastly higher than that from wind turbine towers. Furthermore, positive externality of offshore towers is that they provide reefs for aquatic habitat. Therefore, a vigilant study of both the positive and negative externalities associated with wind energy is required before concluding the net impacts.

Similarly, biomass co-firing is controversial in its environmental impacts. One school of thought suggests that managing biomass judiciously helps reduce soil erosion Jeanty (2006), while reducing carbon dioxide emissions from electricity sector. Blanco-Canqui & Lal (2007) suggests that carbon sequestration will be enhanced by leaving the biomass behind in the fields rather than by harvesting it.

The cost of electricity production estimated after internalizing the externalities for different sources of electricity would provide a more comprehensive basis for economic comparison of the different sources of electricity. Estimation of full social costs of electricity from different sources will thus help in establishing a level playing field in order to compare the different sources of energy, which would be useful for designing an appropriate portfolio of electricity for the State. Due to the limitations discussed earlier, this research will focus on estimating externality costs of coal based electricity generation.

1.1.3 Estimation of externality Costs

Environmental externality costs are estimated through several steps of analysis (Figure 4). A multidisciplinary approach is required often to perform the process successfully.

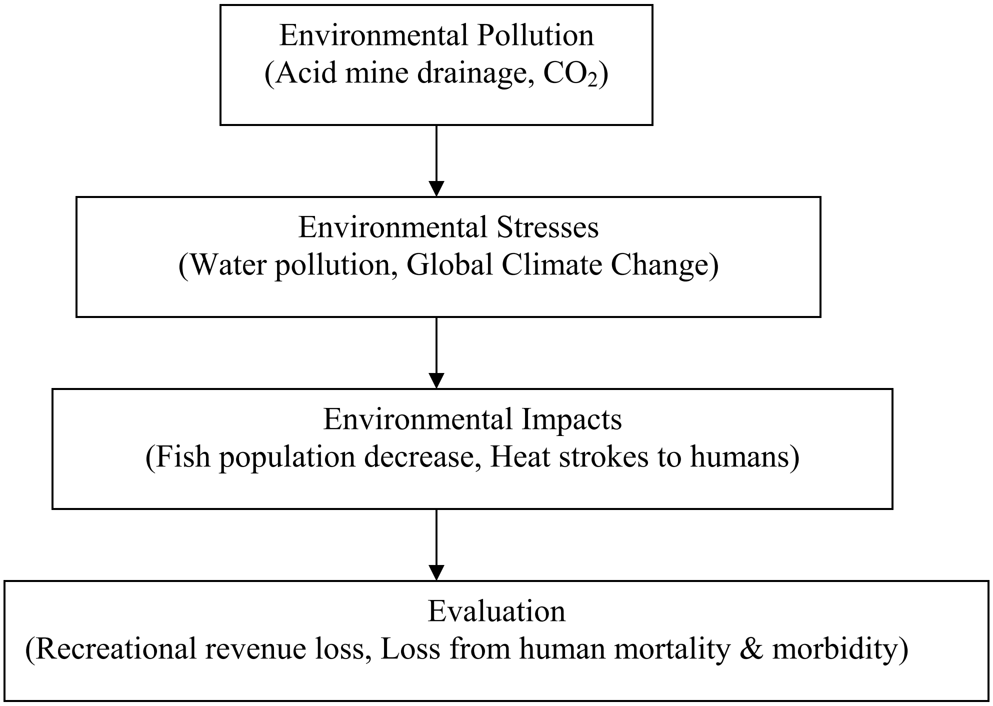

Figure 4 Externality Costs Estimation Flow Chart

Literature on estimation of externalities shows a range of approaches. Some studies are localized and are generalized for a broader scale, bottom up approach, while others estimate the global impacts and then narrow it down for location specific application, a top down approach. Each approach has its own merits and demerits for estimation of externality costs associated with specific type of pollutants. For example, EC associated with CO_2 is estimated using top down approach since its impacts are global.

Environmental valuation methods such as contingent valuation, hedonic pricing, travel cost, benefit transfer, or delphi panel methods are used for the evaluation of environmental impacts. The first three methods are based on demand for environmental amenities provided by a site. People's willingness to pay (also willingness to accept for that matter in CV method) to enjoy certain environmental characteristics is considered as a proxy for the value of the site. Benefit transfer and Delphi panel methods are based on results of other studies and experts judgment respectively. One or more of these methods are used for evaluation of environmental impacts of pollutants associated with coal based electricity generation.

Previous studies on estimation of coal based electricity generation focused on air borne externalities such as sulfur dioxide, nitrous oxides, and lately carbon dioxide. However, the studies either did not estimate or did not find significant impacts on water. According to EIA (1995), externality costs associated with carbon dioxide, sulfur dioxide, and nitrous oxides vary from 0.1 to 4.16¢/kWh, 0.05 to 3.6¢/kWh, and 0.48 to 2.09 ¢/kWh respectively. In a rigorous study on electricity externalities, Rowe *et al.* (1995) estimated the externality cost associated with nitrogen oxide (NO_X) and SO_2 as 2.04 to 0 .45 mills/kWh and 0.09 to 0.009 mills/kWh respectively for the State of New York. The study accounts for the water borne externality as the impacts of acid deposition into rivers and lakes and hot water circulated to the river system, which ranges from 0.015 mills/kWh to 0.20 mills/kWh. None of these studies included externality costs associated with coal mining in the production of electricity.

Various studies have estimated impacts of coalmines on water quality including those by Randall *et al.* (1978); Hitzhusen *et al.* (1997); Farber and Grinner (2000);

Sommer (2001); and Williamsons *et al.* (2007). Hitzhusen *et al.* (1997) estimated damage per annum to Piedmont Lake, Ohio attributed to upstream strip mining as $250,492 loss in recreation value and $7,754 (1995 dollars) in housing value. Sommer (2001) estimated an increase in annual benefits of $0.12 to $0.22 million for boaters and $2.5 to $5.1 million for fishers respectively with small to large improvement in water quality on Hocking River valley, Ohio. Only one study, Randall (1976) translated the damage value to cost per kWh, which ranged from $0.40 to $9.10 (1976 dollars); a large range is observed in the study on a watershed in Kentucky before the Surface Mining Reclamation Act of 1977 (SMCRA) was implemented. The major focus of this research is on translating coal mining externalities into cost of electricity generation.

Social cost of electricity production from coal in Ohio has not been estimated in spite of the fact that 86% of electricity is derived from coal in Ohio. Neither has the coal mining externalities estimation and its translation to electricity cost been rigorously pursued for the state, in spite of being a predominant coal mining state. This research is thus an attempt to estimate the social costs of electricity production from coal in Ohio, the first step in this process. Thus estimated social costs will be used as an input to the OH-MARKAL model to examine the change in least cost electricity portfolio for Ohio.

1.1.3.1 OH-MARKAL model:

MARKAL model is a linear programming model. This model consists of cost minimization of electricity production from fossil and renewable sources as an objective function subjected to several constraints including those imposed as a result of environmental regulations. OH-MARKAL model estimated the feasibility of incorporating biomass co-firing power plants in order to reduce CO_2 emissions from electric sector in Ohio (Shakya, 2007). According to the research, biomass supply of Ohio on regional level can produce 7% of electricity generation by co-firing and new power plants in cost effective way, which would also be able to reduce CO_2 emissions from electricity sector by 6%. The OH-MARKAL model was expanded in 2009 to examine the cost effective measure of electricity supply in Ohio through 2030 while attaining CO_2 emissions of the state reduced in the year 2030 by 25% and 35% of emissions in 2005 by incorporating renewable sources such as biomass, wind, anaerobic digesters, and solar (Shakya, 2009).

The OH-MARKAL model so far incorporates private costs and some of the social costs of coal based electricity. This research will attempt to extend the model by adding coalmining externality costs into it. The OH-MARKAL model used carbon tax of $25 and $50 per ton of carbon in the model. An extension of this model will be recalibrating the model using social costs of carbon that is estimated under new advancement in climate change knowledge.

Extension of the OH-MARKAL model incorporating the social costs of electricity from coal will provide us the picture of most cost effective electricity portfolio of Ohio and policy interventions required to achieve that.

1.2 Objectives

1.1.1. General Objective: To estimate the social cost of electricity generation from coal in Ohio.

1.1.2. Specific Objectives:

1.1.2.1.Evaluation of coal mines externality

- To estimate the recreational damages from upstream coal mining on lakes of Ohio,
- To develop a visitation model,
- To update the study by Hitzhusen *et al.* (1997) to estimate the damage from coal mines in Muskingum conservancy district,
- To estimate the reclamation costs of the abandoned coal mines,
- To delineate the relationship between reclamation and damages from abandoned coalmines,
- To summarize coal mine damages to streams in Ohio,
- To translate the damage in terms of increase in costs of electricity produced from coal per kWh,

1.1.2.2. Evaluation of air borne externality

- To summarize the externality costs associated with air borne pollutants such as NO_x and SO_2,
- To estimate the externality costs of CO_2 emitted from coal fired power plants in Ohio using benefit transfer method.

1.1.2.3. MARKAL

- To incorporate these shadow costs into a modified version of the OH-MARKAL electric sector math programming model to determine their impact on least cost solutions for energy system in Ohio.

1.3 Organization

Second chapter of this dissertation summarizes a review of literature on estimation of social cost of electricity, pollutants associated with the industry and their damages. Third chapter will focus on the methodology developed to meet each objective. Fourth chapter discusses the estimation and analysis of results. Last chapter concludes the dissertation with summary of findings, policy recommendations, and further research needs.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

This section summarizes literature on various aspects of coal power generation and externalities associated with it. Discussion on the state of the art on environmental externalities of coal power generation in Ohio, the regulations that are enforced in Ohio to mitigate the damages, and current scenarios of mitigation of such externalities will help highlight the need for this research. A review of previous studies and their monetization will be helpful in understanding various methodologies and estimated values of social costs of coal based electricity study-wise, location-wise, and technology-wise. This section will also provide input for crafting methodologies including benefit transfer methods utilized to estimate some of the externalities.

2.2 Environmental Externalities associated with coal power generation in Ohio

Coal power externalities are produced in two stages: coal extraction or mining and coal burning in power plants. Some of the externalities generated during coal mining as well as coal burning have been internalized partially by regulations in the US and Ohio, while others are still imposing social costs, and thus are still externalities of the process. The pollutants from the two foregoing sources differ in their nature of stress to the environment and impact pathways; and enter into cost functions of electricity production in different ways. Thus for convenience in comprehension, they are discussed under two separate sections. Literature on the pollution from each source of pollutants, impact pathways, impact status in Ohio, and evaluation of the respective pollutants are discussed below.

2.1.1. Coal power plants externalities in Ohio

There are 21 investor owned and two city-owned coal fired power plants in Ohio (Table 1). Eight of them are less than 500 MW, five of them are 500-1000 MW and the rest of them have capacity of 1000 to 2500 MW. First Energy Generation Corporation generates more than 5000 MW of electricity in Ohio, followed by 4000 MW by Cincinnati Gas and Electric Company.

Table 1. Coal Fired Power Generating Units in Ohio as of January 1, 2006.

S.N.	County	Company	Plant Name	Nameplate Capacity (Megawatts)
1	Adams	Dayton Power & Light Co	J M Stuart	2440.8
2	Adams	Dayton Power & Light Co	Killen Station	666.4
3	Ashtabula	First Energy Generation Corp	Ashtabula	256
4	Belmont	First Energy Generation Corp	R E Burger	540.8
5	Butler*	Hamilton City of	Hamilton	75.6
6	Clermont	Cincinnati Gas & Electric Co	Walter C Beckjord	1221.3
7	Clermont	Cincinnati Gas & Electric Co	W H Zimmer	1425.6
8	Coshocton	Columbus Southern Power Co	Conesville	1890.8
9	Cuyahoga*	Cleveland City of	Lake Road	160
10	Cuyahoga	First Energy Generation Corp	Lake Shore	256
11	Gallia	Ohio Power Co	General James M Gavin	2600
12	Gallia	Ohio Valley Electric Corp	Kyger Creek	1086
13	Hamilton	Cincinnati Gas & Electric Co	Miami Fort	1378
14	Jefferson	Cardinal Operating Co	Cardinal	1880.4
15	Jefferson	First Energy Generation Corp	W H Sammis	2455.6
16	Lake	First Energy Generation Corp	Eastlake	1257
17	Lorain	Orion Power Holdings Inc	Avon Lake	766
18	Lucas	First Energy Generation Corp	Bay Shore	639.4
19	Montgomery	Dayton Power & Light Co	O H Hutchings	414
20	Pickaway	Columbus Southern Power Co	Picway	106.2
21	Trumbull	Orion Power Holdings Inc	Niles	265.6
22	Washington	American Mun Power-Ohio Inc	Richard Gorsuch	200
23	Washington	Ohio Power Co	Muskingum River	1529.4
Total				23510.9

* not investor owned

Quantity of coal required for producing electricity from each of the above plants depends upon their capacity, heat rate, efficiency, and type of coal used.

Total emissions from burning coal to produce electricity in the power plants of Ohio are given in Figures 5 and 6.

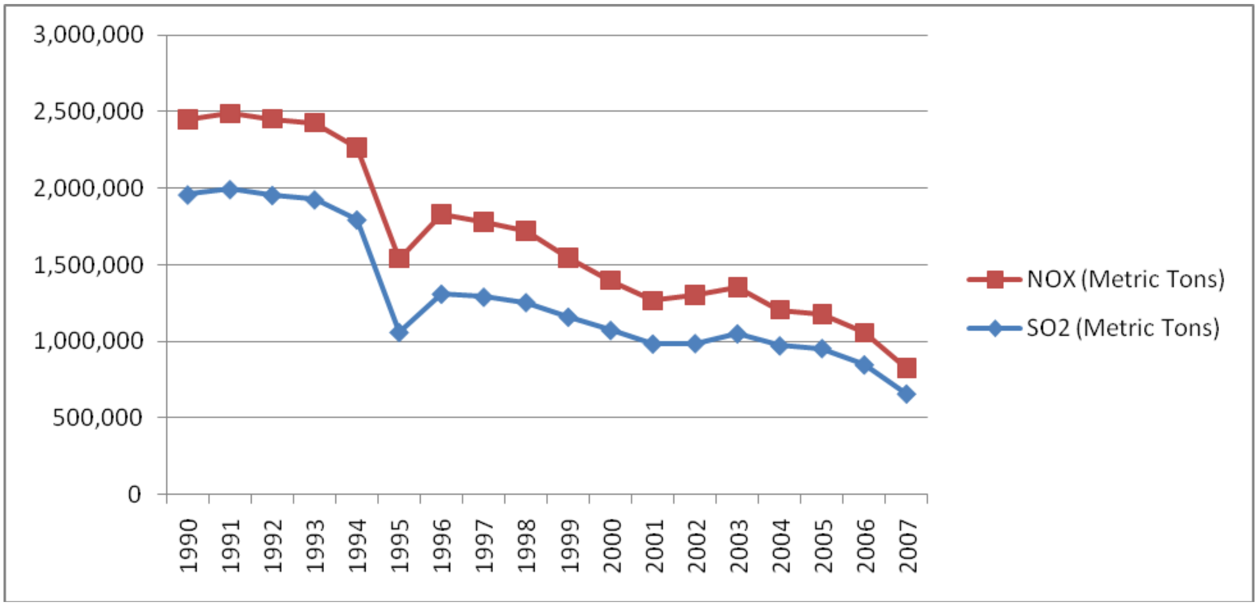

Figure 5 SO_2 and NO_x Emissions of Coal Fired Power Plants in Ohio (Source: EIA)

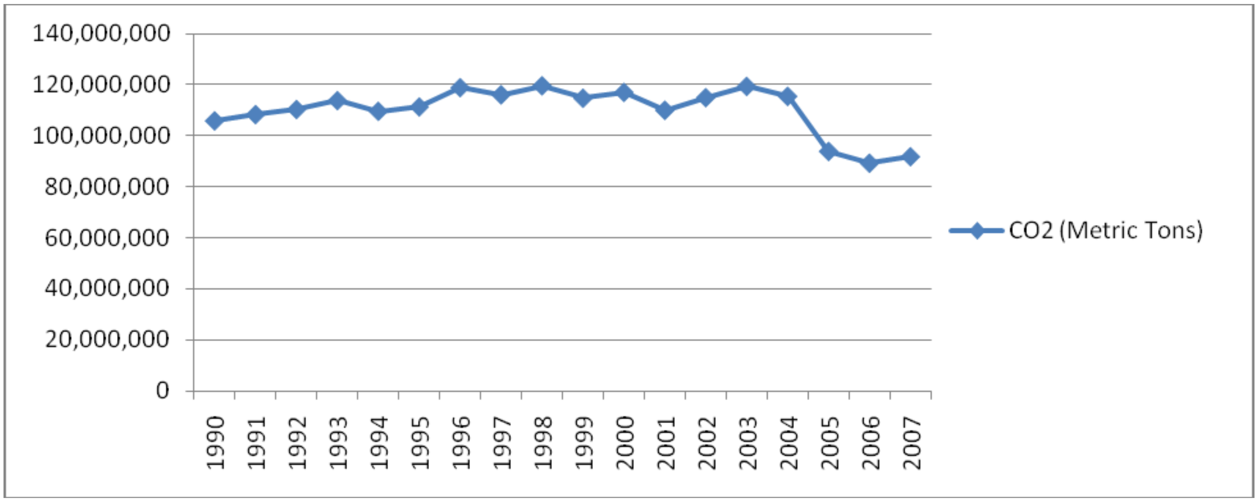

Figure 6 CO_2 Emissions from Coal Fired Power Plants in Ohio (Source: EIA)

In order to mitigate some of the impacts of these pollutants, the government regulates emissions of some of the pollutants discussed in the next section.

2.1.1.1.Regulations

Emission control regulations have come a long way since implementation of the Clean Air Act of 1977 and several amendments following the Act. Under Title I program, power plants constructed or modified between 1971 and 1978 were mandated to meet the NO_X emission standard depending upon the available technology. Amendments of Clean Air Act 1977, designed new standard for the emissions from the power generation units constructed or modified after 1978. Under title II, the emission level of NO_X was made more stringent by lowering the emission level from 0.50lbs of NO_X per million BTU (mmBTU) to 0.45lbs per million BTU by the year 2000. For the older generation units, Title IV of the Clean Air Act mandated a standard for emission of acid producing gasses. The utilities had the options of complying with this regulation by any of the four ways: changing the boiler system, over controlling one among several generation units, applying for extension for compliance or by applying to the EPA for reduction in emission limits after installing the required equipment. First phase of NO_x compliance under Title IV started in 1996 by reducing the emission levels to 0.39 lbs per mmBTU. In 2002, NO_x budget program rules were finalized and from 2004 onwards the program was implemented for the regulated units thereafter. The program aims to reduce 60 to 85% of NO_x emissions as compared to the historical emissions from the regulated units (Ohio EPA)[1]. The Clean Air Interstate Rule (CAIR, 2005) achieves the largest reduction of emissions from coal fired power plants. The rule is expected to reduce the NO_x level to 264,000 tons by 2009 and 274,000 tons by 2015 in Ohio.

In 1995, under the acid rain program, SO_2 allowances were allocated which resulted in a sharp reduction in SO_2 emissions by 2001(Figure 4). Tightening of per unit emissions from 2.5 lbs of SO2/mmBTU of heat output in 1995 to 1.2 lbs SO2/mmBTU in 2000 is reflected in the graph in Figure 4 with a sharp decline of SO_2 emissions in the same year. In 2010, the number of allowances allocated each year will be capped at 8.9million tons. With SO_2 cap in effect and retirement of some of the grandfathered power plants, the level of SO_2 is likely to decline further. According to CAIR, SO_2 emissions are expected to go down to 1,373,000 tons by 2010 and 1,064,000 tons by 2015.

Under title IV, the industries were allowed to emit SO_2 after they purchased allowances to do so. The phase I of the program implemented in 1995 restricted the emission from 223 units at 110 mostly coal burning electric power plants east of the Mississippi river to reduce their emissions. The power plants achieved this largely by use of scrubbing processes using Fluidized Gas Desulfurization (FGD) or by buying the SO_2 emission credits in the market.

Eleven units of power plants in Ohio have installed the SO_2 reduction equipment, 17 have proposed installing SO_2 control devices and two of them are preparing sites for the control. Table 2 shows the plants/units with control measures and status of control. The plants are equipped with one of the three control measures: dry Lime FGD, wet Lime FGD, or flue gas desulfurization.

Table 2. Power Plants in Ohio with Operating SO2 Emission Control Equipment

Plant Name	Equipment	Install Date	SO_2 Reduction (percent)	SO_2 (lbs/mmBtu/yr)
Niles	Wet Limestone	1/1/1954	93	1.16
Niles	Other	1/1/1954	37.5	4.88
Conesville	Wet Lime FGD	5/4/1977	93	0.38
Conesville	Wet Lime FGD	6/3/1978	93	0.4
W H Zimmer	Wet Lime FGD	3/1/1991	93	0.53
Gavin	Wet Lime FGD	12/10/1994	93	0.29
Gavin	Wet Lime FGD	3/4/1995	93	0.31
Hamilton	Dry Lime FGD	5/28/1999	82	0.84
Bay Shore	Dry Lime FGD	1/1/2001	82	0.42
Miami Fort	Wet Limestone	5/15/2007	90	0.89
Killen Station	FGD	7/25/2007	99	1.09

According to the Ohio Air Quality Report, 2005, the concentration level of pollutants such as SO_2 and NO_x, were lower than that required by the Clean Air Act, which are respectively, 0.14 ppm and 0.053 ppm. The SO_2 and NO_x emissions from power plants in Ohio are declining (Figure 4). Therefore, direct impacts of SO_2 and NO_x will be considered largely internalized for this study. However, some of the SO_2 and NO_x externalities still exist and their impacts are still evident in terms of induced effects via Particulate Matter (PM) and Ozone.

Both PM and Ozone are formed from various sources including coal power plants. The PM is the toxic emission that consists of metals like aluminum silicates, elemental or organic carbon, sulfates, and ultra fine particles. The PM forms from the emissions from various sources including burning coal. Similarly, ozone formation depends upon several other factors such as volatile organic compounds, sunlight, and concentration of NO_x, which are not exclusively contributed from coal power plants. Segregating the impacts of PM and Ozone related to coal power plants from the other sources potentially requires a separate study, which is beyond the scope of this research. Therefore, this study will summarize evaluations of externality costs of SO_2 and NO_X and focus primarily on externality costs of coal mining and CO_2 emissions.

2.1.1.2. Summary of previous studies on evaluation of externalities associated with coal power plants

Environmental externalities of electricity generation have been assessed using a range of methodologies since 1982, when Shuman and Cavanah (1982) estimated the externality costs of coal power generation. According to the literature, two broad categories of methods used for estimating environmental externality costs are: damage costs approach and abatement costs approach. Abatement costs approach is based on estimating the costs of mitigating the damages from emissions or controlling the emissions, such as costs of installing and maintaining FGD. Alternatively, damage costs approach includes measuring the costs imposed by a pollutant, for example social costs of global climate change.

Externality costs of coal estimated using abatement costs ranges from 0.06 ¢/kWh to 44.07 ¢/kWh (Shuman and Cavanah, 1982) to 2.17 ¢/kWh to 20.67 ¢/kWh (Cifuentes and Lave, 1993), which shows a large range of estimates. Some other studies show a narrower range such as 4.37 ¢/kWh to 7.74 ¢/kWh as estimated by Chernick and Caverhill (1989) while Bernow and Marron (1990) estimated a similar range of 5.57 ¢/kWh to 12.45 ¢/kWh.

Damage cost estimation of coal is carried out using top down or bottom up approach. Top-down approach derives a value of externality costs of pollutants based upon the damages on large scale such as national value. Externality costs estimated for coal using this approach range from 3.62-8.86 ¢/kWh (Ottinger *et al.*, (1991) for the US. Other studies outside of US show a range of 0.36-0.86¢/kWh for Denmark (Hohmeyer, 1988), 2.67-14.43 ¢/kWh for UK (Pearce et al (1992), and 3.98 ¢/kWh for Netherlands (Faaji *et al.*,1998).

Bottom up damage cost approach begins with quantifying damages from a single source using environmental valuation techniques and deducing value for larger scale. This is the most preferred approach in estimation of externality (Sundquist, 2004). Externality costs estimated using this approach for regions in the US, fall within a range of 0.31 ¢/kWh (Rowe et al., 1995) and 0.11 to 0.48¢/kWh (ORNL and RFF, 1998).

Other studies such as a US fuel cycle study estimated coal externality costs as 0.2 ¢/kWh for the United States and 1.8¢/kWh for the European Community. Both the studies' estimates excluded externalities associated with CO_2.

Roth and Ambs (2004) estimated externality costs from power generation depending upon the technology used for power generation in the US. The study found that the externality costs associated with conventional boiler, Rankine Cycle (coal), was the highest followed by the advanced fluidized bed combustion, and integrated gasification combined cycle. Estimated externality costs ranged from 12.07 ¢/kWh, to 8.21 ¢/kWh, and 6.94 ¢/kWh respectively.

Another aspect of analyzing externality costs of coal power generation is the costs associated with an individual pollutant. Komey and Krause (1997) summarized studies that estimated damage per pound of pollutants emitted from power plants including Public Utility Commissions; EPRI (1987); Hohmeyer (1988), Chernick and Caverhill (1989), Schilberg et al (1989), and Pace University. According to the studies, environmental damage of SO_2 ranges from \$0.48 (EPRI) to \$2.03 (Pace University) per pound, damage of NO_X ranges from \$0.07(EPRI) to \$3.40(NV PSC), that for CO_2 ranges from \$0.0015(NY PSC) to \$0.042 (Chernick and Caverhill, 1989), and for particulates \$0.23 (Hohmeyer, 1988) to >\$2.63 (Chernick and Caverhill, 1989) per lbs of pollutants. In a study done in Germany, externality costs associated with SO_2 were estimated as \$2.73 to \$3.77, while for NO_X the range was \$1.55 to \$2.45, and for PM it ranged from \$5.91 to \$7.91 per pound of pollutants (Krewitt, 1999). The study also shows the damages to EU-15 by SO_2, NO_X, and PM_{10} as \$4.45, \$2.77, and \$9.23 per pound of pollutants respectively. According to Kammen and Pacca (2004), externality costs associated with SO_2 range from \$0.004 to \$4.06 per lbs while that of NO_X ranges from \$ 0.05 to \$1.66 per pound of pollutants (2003 Dollars).

Externality costs from pollutants emitted from coal power plants differ spatially between rural, metropolitan fringe, and urban areas (Banzhaf et al. 1997). The authors' estimates show that impact per ton of pollutants increases when moving from rural to urban areas. Externality costs of NO_X range from 0.3 ¢/lbs in rural to 8.04¢/lbs for urban area; while for SO_2 the values range from 0.4¢ in rural to 8.09¢/lbs in urban area. Particulate matter (PM) particularly shows a large spread in the estimates spatially ranging from 85 ¢/lbs for rural to 275¢/lbs for the urban areas.

Other studies estimated externality cost of each pollutant per kWh. Estimated costs by some state public utility commissions (PUCs) for SO_2 varies from 0.05-0.36

¢/kWh, while that for NO_X varies from 0.48-2.09¢/kWh (Table 3). Similarly, CO_2 externality costs ranged from 0.1-2.5¢/kWh. Overall air-borne externality costs excluding mercury range from 0.9-4.79 ¢/kWh.

Table 3. Externality Values
(¢/kWh used by state agencies, adapted from EIA/ Renewable Energy Annual, 1995)

States	**SO_2**	**NO_x**	**CO_2**	**PM_{10}**	**Total**
California	0.36	2.01	0.94	0.02	3.33
Massachusetts	0.30	2.09	2.4		4.79
Minnesota	0.05	0.48	1.36		1.89
Nevada	0.14	1.65	2.5	0.03	4.32
New York	0.25	0.55	0.10		0.9
Oregon		0.44	4.16		4.6
Wisconsin		1.10	1.5		2.6

Several recent studies focused on the externality costs associated with CO_2 in light of advancing scientific evidence on global climate change. Social cost of CO_2 (SCC) is estimated using a range of methodologies. Extern-E estimated damage costs of CO_2 as \$5-\$180 per ton. The IPCC second assessment report (1996) estimated damages of \$5-\$125 per ton of carbon. Based upon 10 studies summarized by Burtraw (2002), ancillary benefits from reduction of 1 ton of carbon range from \$2 to \$86 (1996 US dollar). Pearce (2003) suggests that the marginal social costs of CO_2 ranges from \$8 to \$16 per ton, while equity weighing with the income elasticity of unity increases the price from \$8 to \$40 per ton. Tol (2005) concluded from 103 estimates from 28 studies on marginal damage costs of CO_2 that the costs range from \$42.67 to \$165.33 per ton of carbon assuming a social discount rate of 4-5%. The authors also concluded that it is unlikely for the costs to rise above $133.33 per ton of carbon. In his updated study, Tol (2007) estimated a mean $23/ton of carbon using 211 estimates from 47 studies from 1992-2006.

There have been a few studies that estimated externalities associated with Ozone and PM. These two pollutants even in small concentrations are capable of causing health damages and thus the damages estimated were in terms of ppb of pollutants.

Damages caused by Ozone and PM in Ohio were examined by ABT associates, 1999. Ozone related respiratory hospital admissions were 2.8 thousand, cardiovascular hospital admissions were 0.8 thousand, total respiratory ER visits were 8.4thousand, asthma ER visits were 870, minor symptoms were 4.7 million, shortness of breath were 19,000 and asthma attacks were 0.35 million. Higher ozone level reduces yield of wheat, potato, rice, rye, oats, tobacco, and barley (Krewitt *et al.* 1999). The impact of ozone exposure in terms of annual cost of crop loss of corn, soybean, and wheat in Ohio in 1997 was estimated to be from $83.07M to $154.4M (ABT associates, 1999). Rowe et al (1995) found that the economic loss was $2,597,848 for the state of New York. Their estimation is based upon the change in yield with 1 ppb change in ozone level for 5 commercial crops of the state.

According to Burnett, Dales, and Krewski (2004), an increase of $PM_{2.5}$ by 10μg/m is associated with 6% increase in risk of mortality related to cardiovascular diseases (CVD) and 4% increase in mortality risk due to all mortality causes including CVD. Also, ABT associates estimated that $PM_{2.5}$ claimed 1900 deaths, 1200 hospital admissions, 37000 asthma attacks, 1100 chronic bronchitis, 313000 work loss days and 1.6 million days of minor restricted activity in the state of Ohio.

The foregoing studies evaluated the damages associated with one or more of the power plant emissions such as SO_2, NO_X, CO_2, particulates, VOCs, mercury, lead, solid wastes. Externality costs studies show that the externality costs associated with coal power plants are not trivial. These studies estimated the externality costs using different approaches, including one or more pollutants, and for power plants in different locations. Impacts of each of these pollutants depend upon the stack height, wind speed, wind directions, population and demographics, and socioeconomic condition of the impact zone of each power plant. Generalization from these studies is difficult. Therefore, from this review of literature it is safe to state that externality costs of coal power plants in Ohio are not trivial given that the electricity price in Ohio ranges from 5.89¢/kWh to 8.88 ¢/kWh and the external costs estimations ranged from .11¢/kWh to 22.67 ¢/kWh. Any internalization of the externality costs might facilitate the incorporation of more renewable energy options into electric power generation in Ohio.

According to Waxman-Markey's proposed US Climate and Energy Bill called as American Clean Energy and Security Act, ACES, H.R. 2454, emissions cuts will begin in 2012 with 3% cut in emission level below that of 2005. The CO_2 emissions of US in 2005 were 7206 million metric tons. This will be followed by 17% cut by 2020, 42% cut by 2030 and more than 80 % cut by 2050. Additionally, a permit to emit 1 ton of CO_2 or its equivalent would be $11-15 in 2012, $22-28 in 2025 (2005dollars). The US senate is still debating upon the bill. Depending upon the limitations imposed by the bill, it can be expected to address at least some of the emissions issues related to coal fired power plants.

2.1.2. Coal mine externalities

The legacy of 200 years of coalmining in Ohio has degraded land and water resources imposing a large social cost to Ohioans. Coal mining started in Ohio as early as 1808 A.D., and has been mined in 32 counties. Currently, coal is mined in 16 counties in eastern Ohio. Belmont County produces the highest quantity of coal followed by Harrison, Jefferson, Perry, Athens, Tuscarawas, Guernsey, Muskingum, Meiggs, and Noble counties (Crowell, 1995). According to Ohio Air Quality development Authority (OAQDA) the top five coal producers in 2004 were Belmont, Harrison, Athens, Tuscarawas, and Vinton Counties. Carroll, Columbiana, Coshocton Jackson, Jefferson, Mahoning, Muskingum, Noble, Perry, Stark and Washington counties are the other counties actively producing coal in the state. Surface mines produce 39% of total production from 94 mines while 7 underground mines produce 61% of coal produced in the state in 2008 (OAQDA, 2008).

The impacts of coalmining are manifold, which makes their social cost estimation a complicated process. The major impacts associated with surface coal mining are air pollution from methane and dust particles produced during mining, surface and ground water pollution via acid mine drainage (AMD), aesthetics, habitat fragmentation of wildlife, and land use issues. Deep shaft mining externalities are AMD, risks to humans from mine explosions and mine collapse, and threats of diseases such as asthma, bronchitis, lung cancer, and black lungs of the mineworkers. There is likelihood of explosions due to methane gas accumulation and other mine accidents, which results in several human causalities each year. Methane also has the highest potential per unit of volume for global warming. In addition to that, deep shaft mining poses threats to houses and transportation routes near the mined land from mine subsidence.

Abandoned mines, surface and deep shaft mined land, pose problems in different ways (Table 4) and are prioritized according to the extent of damage they pose to a society.

Table 4. Problem Types Imposed by AML and Priority Problems (Source: ODNR)

Problem type	Priority
Clogged Streams (CS)	1. An AML problem category meeting the conditions under Section 403(a)(1) [coal], or 411(c)(1) [non-coal] of SMCRA concerning the protection of public health, safety, general welfare, and property from extreme danger of adverse effects of mining practices or a condition that could reasonably be expected to cause substantial physical harm to persons or property, and to which persons or improvements on real property are currently exposed. 2. An AML problem category meeting the conditions under Section 403(a)(2) [coal] or 411(c)(2) [non-coal] of SMCRA concerning the protection of public health, safety and general welfare from adverse effects of mining practices or a condition that is threatening people but is not an extreme danger.
Clogged Stream Lands (CSL)	
Dangerous High walls (DH)	
Dangerous Impoundments (DI)	
Dangerous Piles & Embankments (DPE)	
Dangerous Slides (DS)	
Gases: Hazardous/Explosive (GHE)	
Hazardous Equipment & Facilities (HEF)	
Hazardous Water Body (HWB)	
Industrial/Residential Waste (IRW)	
Portal (P)	
Polluted Water: Agriculture & Industrial (PWAI)	
Polluted Water: Human Consumption (PWHC)	
Subsidence (S)	
Surface Burning (SB)	
Underground Mine Fire (UMF)	
Vertical Opening (VO)	
Bench (B)	3. An AML problem category meeting the conditions under Section 403(a)(3) [coal] or 411(c)(3) [non-coal] of SMCRA concerning the restoration of land and water resources and the environment previously degraded by adverse effects of mining practices or a condition that is causing degradation of soil, water, woodland, fish, wildlife, recreational resources, or agricultural productivity.
Industrial/Residential Waste(IRW)	
Equipment/Facilities(EF)	
Gob (GOB)	
High wall (HW)	
Haul Road (HR)	
Mine Openings (MO)	
Other	
Pits (PIT)	
Spoil Area (SA)	
Slurry (SL)	
Slump (SP)	
Water (W)	

Magnitude of the problems in Ohio is illustrated in Table 5.

Table 5. Occurrence of AML problems in Ohio.

Priority	Problem Type	Quantity	Units
1 and 2	CS	141.8	miles
	CSL	13,104.50	acres
	DH	64,705.30	feet
	DI	3	count
	DPE	76.1	acres
	DS	134.3	acres
	HEF	29.00	count
	HWB	36.00	count
	IRW	2.00	acres
	P	57.00	counts
	PWHC	31.00	counts
	S	183.60	acres
	VO	22.00	count
3	BE	93.00	acres
	DP	2.00	acres
	EF	13.00	count
	GO	656.50	acres
	H	29,915.00	feet
	O	20.00	others
	PI	363.00	acres
	SA	21,215.40	acres
	SP	17.00	acres
	WA	4,051.00	gallons/minutes

Analysis of AML that could potentially impact downstream water shows that 36,000 units of abandoned mined land require reclamation (Table 6 and 7). This does not include the land areas with dangerous high walls, dangerous slides, gasses and hazardous explosives, portals, vertical openings, mine openings etc. Columbiana County has the largest share of unreclaimed abandoned mined land followed by Jefferson. Meanwhile, Tuscarawas County in the Muskingum Watershed Conservancy District, has the highest unreclaimed mined land acreage. Muskingum River Basin Report, 2006 estimated $187 million for reclamation of AMD impact alone (MRB report, 2006).

Table 6. Reclamation progress (Source: ODNR)

S.N.	Type of problem	Unfunded (Units)	Funded (Units)	Completed (Units)
Priority 1	CS	35.5	0	4.1
	CSL	957	0	1671.5
	DPE	1	0	25
Priority 2	CS	105	0	40.1
	CSL	12472.5	13	5253
	DPE	75.1	0	115.7
Priority 3	GOB	656.5	0	225.8
	BE	93		2.0
	Pits	363	3	38.5
	Spoil Acres	21664	75	828.5
	Slump Area	17	0	3

Table 7. Abandoned Reclamation Area According to Problem Type (Source: ODNR)

Priority	Problem type	Surface (Units)	Underground (Units)	Both (Units)	**Total** (Units)
Priority 1	CS	34.1	0	1.3	**35.4**
	CSL	957	0	0	**957**
	DI	1	1	0	**2**
	DPE	1	0	0	**1**
Priority 2	CS	99.3	1.2	5.7	**106.2**
	CSL	11985	111.2	376	**12472.4**
	DI	1	0	0	**1**
	DPE	0	60	15.1	**75.1**
Priority 3	BE	80	10	3	**93**
	GOB	112	322.5	218	**652.5**
	Pits	260	0	63	**323**
	Spoil Acres	16947	1535	2961	**21442.6**
	Slump Area	0	11	5.5	**16.5**

2.1.2.1. Reclamation Regulations: In order to reduce the losses attributed to coal mining, both federal and state governments have reclamation programs for mines abandoned before 1977 and regulation to prevent pollution from mines after 1977. Under Surface Mining Reclamation Act of 1977 (SMCRA), mining companies are mandated to prevent surface and ground water contamination. Mining companies are also required to return the land to the original state before mining by reclaiming the mined land according to the Act. Besides the control through regulations, several government programs are underway under the Ohio Department of Natural Resources (ODNR), Ohio Environmental Protection Agency (OEPA), and local watershed conservation groups for the cleaning up of the AMD affected lakes, rivers and streams. The Appalachian clean stream initiative (ASCI) established in 1994 has brought the government and local watershed groups together in cleanup efforts of these AMD affected streams. After implementation of all these regulations and programs for a number of years, Hitzhusen *et al.*, (1997) found that strip mining is still affecting lake recreation and property value downstream of strip-mined land in the Muskingum Conservancy District.

Abandoned coalmines abandoned before implementation of SMCRA are undergoing reclamation. Reclamation programs are funded by the taxes levied on outputs of coalmines. The taxes paid by current mining companies enter into the cost function of coal based electric producers. Thus, at least some of the legacy of abandoned coalmines has been internalized into the current cost of electricity. The mining companies are required to pay a tax of 35¢ per ton of surface mined coal and 15¢ per ton of underground mined coal to the federal government before mining (ODNR). In addition to that there is 6¢ per ton of state coal severance tax in Ohio, out of which 2¢ per ton of state coal is allocated for reclamation. The fund collected by the State and Federal government is used for reclamation of land abandoned before 1972 (state fund) and 1977 (federal fund). Reclamation costs range from $1,000 to $61,000 per acre of abandoned land. Based on previous reclamation of abandoned mines, the average cost ranged from $1,174 per acre of surface mined pits to $17,288 per acre of dangerous piles and embankment area. Clogged streams under priority 1 and 2 were most costly to reclaim per unit. Currently 5.5 thousand acres of land and 1.4 miles of stream restoration programs are ongoing under joint effort of government and local watershed groups (ODNR). However, the fund is insufficient for reclamation of abandoned mines. Government is lagging behind by 135,650 acres of abandoned mine reclamation, which has been estimated to cost 205 million dollars for reclamation (ODNR, 2008). The government is unable to cover the reclamation costs from the present and future tax revenues generated from the severance tax and federal fees paid by current coal mining companies.

2.1.2.2.Studies on evaluation of coal mine impacts:

Coalmines externalities are estimated by previous studies using travel cost method, hedonic pricing method, and contingent valuation method. Acid mine damages were first evaluated by Randall *et al.* (1978) for the North Fork Watershed of Kentucky. The authors estimated the environmental damages from surface mining in terms of water treatment costs, recreation restoration costs, flooding damage, damage to land and buildings, and damage to the aesthetics of the area. Employing valuation techniques such as actual expenditure/ market price of output, benefit transfers and contingent valuation techniques, the authors found that surface mining caused environmental damage worth

$3.556 million to $58.995 million (1976 dollars). The translated value in terms of costs per ton of coal mining ranged from $0.40 to $9.10.

Hitzhusen *et al*. (1997) estimated damage per annum to Piedmont Lake, Ohio attributed to upstream strip mining as $250,492 loss in recreation value and $7,754 (1995 dollars) per annum loss in housing value. The authors employed travel cost method and hedonic pricing methods to estimate the recreational losses and losses to lakeside housing properties due to upstream strip mining respectively. A two step travel cost method estimated by the authors consists of first estimating trip demand curve based on individual observations from the survey and then estimating a representative household's demand curve. This is followed by calculation of consumer surplus for each individual from the coefficients obtained from first step and observations on number of visitors acquired from US Army Corps of Engineers (US ACE). The damage from strip-mining was estimated as the difference in consumer surplus from an unaffected lake Leesville and affected lake Piedmont. In order to estimate the losses to the housing properties near the lakes, the authors utilized hedonic pricing method to estimate marginal implicit price associated with distance from house to the impacted portion of the lake and converted that to loss in annual rental equivalent.

Farber and Grinner (2000) limited their estimation to the marginal valuations for improvements of AMD affected water of Lovalhanna Creek and Conemaugh River in the Lower Alleghany Watershed in Western Pennsylvania. Conjoint analysis was used to estimate both the user and non-user groups' willingness to pay (WTP). The user groups' per household WTP varied from $23.09 to $125.25(1996 dollars) per year for 5 years, while the non-user group was willing to pay \$1.39 to \$54.26. The estimations for the nonuser groups were not significant statistically.

Sommer (2001) studied downstream impacts of coal mining in Hocking River Valley, Ohio. Estimated damage, which was estimated as an increase in the annual benefit with improvement in water quality were respectively \$0.12 to \$0.22 million for boaters and \$2.5 to \$5.1 million for fishers with small to large improvement in water quality.

The most recent study on acid mine drainage valuation is by Williamsons *et al* (2007). The authors used Hedonic pricing model and GIS for the analysis. They found that the WTP for restoration of housing properties at ¼ mile buffer of AMD affected Cheat river watershed in West Virginia was \$1.7 million. This hedonic analysis is based on the data on housing market transactions between 1985 and 2005.

The foregoing studies were primary studies involving surveys in cases of estimating recreational damages. These studies are performed for a streams and rivers except for the Hitzhusen et al (1997) study, which studied impact on one of the impacted lakes of Ohio. The Piedmont Lake is not necessarily a representative lake in Ohio. Therefore, using only this study for benefit transfer in order to determine recreational damages of upstream mining to a number of lakes in eastern Ohio would not be appropriate. There could be two other potential methods. First method would be to pursue contingent valuation methods for some of the representative lakes in Ohio and generalize the results. Second method would be to develop recreation demand model that takes into account the mine impacts. Due to lack of funds, and difficulty in generalizing results, the second method was adopted even though the resulting benefit estimates are likely to be lower bound.

Lake Chemistry: In order to capture the coalmine specific impacts on lakes, lake chemistry was reviewed. According to the water quality analysis of lake conditions of Ohio by Ohio EPA in 1996, three out of 446 public lakes assessed were impaired by acid mine drainage (Davic, Eicher, and DeShon, 1996), another assessment will be completed by 2010. The affected lakes according to the 1996 report are Friendship Park lake, Essington lake, and Lake Hope. The lakes were designated as AMD affected on the basis of the following chemical analysis standard of the water quality of the lakes: PH<6.5, TDS>1500mg/l, Mn>4.0mg/l, Fe>10.0mg/l, and SO4>960mg/l. Davic and DeShon, (1989) discuss how the extent of effects were classified. If less than 25% of the lake's shoreline was affected, then the lakes were considered as lakes in full use for designated purpose. Designated purpose according to the 1996 report signifies four uses: public drinking water supply, aquatic life, recreation and fish contamination. If the impacts were observed in 25% to 50 % the lakeshore, then they were considered as threatened use. The Lakes were considered impaired if more than 50% of the lakeshore was affected. According to the EPA 1996 report, the lakes which were impacted by acid mine drainage in more than 50% of their shorelines were considered as impacted lakes. Friendship Park Lake is reported to be in full use for recreation despite its AMD impairedness, while Lake Hope is reported to be in partial use for recreation. Lake Essington was not assessed for recreation use.

The report also provides the lake condition index (LCI) (details in Appendix A). LCI ranges from 10 to 100, and according to the report, LCI of 21.5 or less implies 0 probability of impacts while >30.8 implies 100% probability of impaired use of 1 of the designated uses. LCI between 21.5 and 30.8 means full use attainment for some of the designated use and some with partial use attainment.

Coalmines impacts include sedimentation, increase in metals concentration including heavy metals such as copper, lead, and mercury, aesthetics, and secondary impacts such as lower Index of Biotic Integrity (IBI), and decreased volume of the lake. Thus, an index incorporating all the water quality parameters representing the impacts from abandoned mines needs to be derived to more comprehensively explain the abandoned mine impacts.

In this analysis recreational use is the topic for study. The following physical, chemical, and biological parameters are measured/evaluated in order to determine the recreational use status of a lake. A lake is defined as a fishable lake based on indices such as IBI, fish tissue contamination, acid mine drainage and sediment contamination. While *Fecal coliform* bacterial contamination, nuisance growth of macrophytes, aesthetics, volume loss due to sedimentation, and sediment contamination are considered to determine the swimmability of a lake. On the other hand, whether aquatic lives are safe in a lake and whether the lake water is eligible for human consumption is determined by non-priority pollutants, priority organics, priority metals, nutrients, index of biotic integrity, and acid mine drainage. Among these factors, abandoned coalmines contribute to the following water quality parameters directly related to the recreational use of a lake: IBI, fish tissue contamination, acid mine drainage, sediment contamination, aesthetics, volume loss due to sedimentation, and priority metals. Deriving an index for the impacts of abandoned mines would ideally involve computing a LCI for each lake using the water quality parameters directly affected by abandoned mines. However, it is difficult to distinguish the impacts from abandoned mines from the other sources of pollutants.

Rikard and Kunkle (1990) distinguished the coal mine impacts from other sources of impacts by examining 11 water quality parameters of water samples collected from three coal mined basins and two unmined basins, every 4-5 weeks for four years. Among the water quality parameters examined by authors such as pH, specific conductivity[1], dissolved oxygen, alkalinity, acidity, hardness, chloride, iron, manganese, sulfate, and turbidity, the authors found dissolved sulfate as a prime indicator for detecting coal mining impacts followed by the specific conductivity of water. Sulfate concentrations in the mined watershed exceeded $10 \mathrm{mgL}^{-1}$ 95% of the time and exceeded $50 \mathrm{mgL}^{-1}$ 75% of the time, while it remained less than $10 \mathrm{mgL}^{-1}$ in unmined basins in their experiment. On the other hand specific conductivity was found almost always above $60 \mu\mathrm{mhos\ cm}^{-1}$ and often above $300\ \mu\mathrm{mhos\ cm}^{-1}$ in mined watersheds, while it was found always less than $60\ \mu\mathrm{mhos\ cm}^{-1}$ in unmined watersheds.

A significant negative relation was found between Integrated Biotic Index (IBI) and specific conductance (USGS, 2006). Rogowski (2006) found a significant negative relationship between specific conductance and the mean length of fish. Thus, it is reasonable to use specific conductance as a variable to explain AMD impact on visitation for fishing. Sulfate level and specific conductivity were found highly correlated in previous studies. Sulfate produces strong smell, which affects swimming activity. Therefore, in order to establish a relationship between impacts of mining to the recreation, sulfate and/or specific conductivity of lake water will be used in this research.

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[1] Specific conductivity is the measure of mobile ions present in a solution. Increased quantity of ions such as Iron, Sulphate, Cadmium, Arsenic, contributed from coal mines, increases the conductivity of the water.

2.1.2.3.Studies on value per recreation visit

Some important studies that estimated value per trip are U.S. Water Resources Council, (1964,1973,1979,1983); Bergstrom and Cordell (1991); Walsh, Johnson, and McKean (1992); Bhat et al. (1998); Rosenberger and Loomis (2001); and Sommer and Sohngen (2002). The studies estimated value per trip per each recreational activity based on observations for single site, multiple sites in one locale, region, or throughout the nation.

Bergstrom and Cordell (1991) estimated travel demand equations for 37 land based and water based recreational activities using data from Public Recreation Visitors Study (PARVS) and other secondary sources. Walsh, Johnson, and McKean(1992) transferred benefit from studies reviewed by Sorg and Loomis (1984) and 184 other studies from 1968 through 1988 to estimate value per trip of recreation activities . Bhat *et al.* (1998) estimated value per trip for 10 eco-regions in the US. Ecoregions were classified based upon the interaction between vegetation and physiography, vegetation and soils, and physiography and soils in the region. Each ecoregion consists of large ecosystem with a number of smaller ecosystems within it. Ohio falls under Northeast and Great Lakes ecoregion. The authors used individual travel cost method to estimate the visitation as follows:

TRIPS = f (INC, TC, SUBST, NON);

where, INC is the income level, TC is the travel cost, SUBST is the price of logical substitute, and NON is a dummy to classify local from non local activity. The authors calculated consumer surplus per day by dividing consumer surplus per trip by average activity days per trip. The authors used individual travel costs method to estimate the demand function and then estimated trip value at 90% confidence level. The trip-value per day for motor boating and fishing were respectively $9.85 and $25.70.

Rosenberger and Loomis (2001) used 760 estimates from 163 studies in order to derive average consumer values per activity day per person of 21 recreation activities for 5 regions and national average. Five regions, northeast, southeast, intermountain, pacific coast and Alaska were categorized based upon Forest Service Regions and Northeast covers all northern part of US east of Rockies mountains. The authors employed benefit transfer methods such as point transfer, average value transfer, demand function transfer, and metaanalysis. The results of this study relevant for the recreational activities assessed by our research are swimming, boating and fishing. Using 12 estimates from 9 studies that evaluated value per swimming trip including three studies in northeast region (Kalter and Gosse, 1969; Ribaudo and Epp, 1984; and Silberman and Klock, 1989), value for swimming activity in NE region was obtained as $14.44 (1996 dollars). Similarly, value for fishing was estimated using 122 values from 39 studies as $37.01(1996 dollars). For boating, the authors used 14 estimates from 9 studies and estimated per day value of $29.95(1996 dollars).

In addition to the benefits from increased visitation numbers due to improved water quality in the lakes, the increase in value per trip due to improved water quality needs to be incorporated in benefits from lakes. Per trip per person benefits from improvement in dissolved oxygen level and water quality in Lakes of Wisconsin, US were $4.83 for the boaters, $1.08 for fishers, and $6.66 for the swimmers (Parsons and Kealy, 1992). Jeong and Sohngen (2005) estimated increase in value per fishing trip from

$13 ($8-$20) to $20($12-$30) and $30 ($18-$45) with improvement in water quality from poor to good and excellent, respectively in Ohio. In Hocking River Valley study by Sommer and Sohngen (2004), per trip value for fishing increase from poor to good and excellent water quality were $4.79 and $4.99, respectively.

Abovementioned studies on increase in value per trip due to water quality improvement will be used to estimate the value for the water quality improvement for lakes in Ohio.

2.1.2.4. Impact on the Rivers/ Streams in Ohio:

Ninety-two river and streams segments are impacted by abandoned surface and deep shaft coalmining in Ohio. According to OEPA report, AMD impacts were observed in 1300 stream miles in 42 of the river segments. Forty-three other segments were impacted by sedimentation, or chemical pollution from surface mines. Mine tailings impacts were observed in four rivers and three rivers segments were impacted by subsurface mines impacts. In total, 69 rivers (see Appendix B) are impacted by coalmines in eastern Ohio in their different segments, of which 36 are exclusively impacted by AMD and 26 are impacted by runoff from surface mines.

Evaluation of the damage to these streams from the respective abandoned surface mines along with the damages to lakes in Ohio would allow us to estimate the total damage of the abandoned surface mines in eastern Ohio. One way of estimating the damages to each stream is by evaluating the loss in recreational value of the streams or willingness to pay for the improved water quality by the recreational users.

Sommer (2001) estimated the impacts of AMD on Hocking River. Hocking River provides recreational services such as boating and fishing. The river is impacted by AMD beginning at 48.89 river miles from its headwater and ending at 34.93 lower river miles

(OEPA, 2000). The author used travel cost method to estimate the value of boating and fishing on the river and the value of improvement in water quality. Annual benefit from the Hocking River Valley with the then water quality condition was estimated to be $1.45 million in the study. The study calculated the increase in the annual benefit with small improvement in water quality to be $123, 448 for boaters and $2.5 million for fishers, while a large water quality improvement will result in an increased annual benefit of $220,444 for boaters and $5.1 million for fishers. The values were based on a per-trip benefit of $11.69 for boaters and $12.54 for fishers.

In order to estimate damage for each of the impacted rivers/ streams, first of all the impacted rivers/streams need to be categorized into those providing water based recreational services and those not supporting recreation. It is also important to analyze the rivers/streams that contribute to the rivers/streams supporting swimming, boating, and/or fishing. If we can find data on number of annual visits for the water based recreational activities to each stream or river a benefit transfer method can be developed to estimate a lower bound AMD damage to each river/stream. However, primary data collection and analysis on recreation visits and willingness to pay for improved water quality for each impacted river/stream is beyond the scope of this dissertation.

Sommer (2001) shows that the impact on recreational service of Hocking River is large. It is likely that the magnitude of damage to 68 rivers exceeds the damages to lakes in Eastern Ohio estimated by this research. Inability to assess the damages to the streams will probably limit our estimation to less than half of the total recreation damage from abandoned coalmines. Thus, the output of this research will be a lower bound estimate for the recreation damage from abandoned mines.

2.3 MARKAL model

MARKAL is a mathematical model of energy systems developed by Energy Technology Systems Analysis Program (ETSAP) that provides a technology-rich basis for estimating energy dynamics over a multiple period horizon (Loulou, Goldstein, and Noble, 2004). The MARKAL model is based on Reference Energy System (RES) that works by transforming paths of primary energy resources such as coal to electricity via series of technologies (see schematics in Figure 7). RES consists of four types of technologies; resources technologies, process technologies, conversion technologies, and demand technologies. Primary energy resources such as coal, natural gas, biomass feedstock etc. constitute the resources technology. Process technology comprises fuel refining and transportation technologies. Components such as power plants associated with conversion of these processed resources to electricity are the conversion technology component. Energy demand for residential, commercial, industrial, and transportation constitute the demand technology components.

MARKAL model is based on an assumption that in an energy economy, producers maximize their profits and consumers maximize their utilities in a perfectly competitive market for energy carriers. The objective function of the model is maximization of total social surplus or minimization of net total costs of an energy system over a period of time under given constraints.

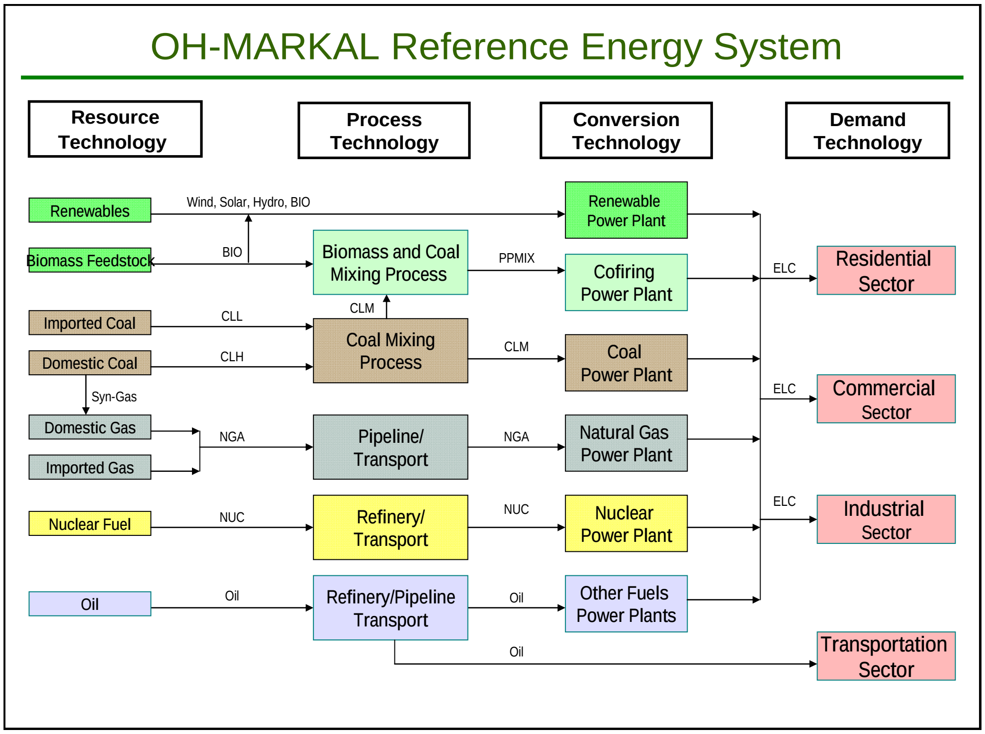

Figure 7 OH-MARKAL Reference Energy System (adapted from Shakya, 2007)

MARKAL has been a popular method to compute the costs of internalizing the externalities by energy policy researchers around the world. Rafaj and Kypreos (2007) used multiregional bottom-up partial equilibrium MARKAL model to internalize the externalities from power generation sector such as environmental and health damages from SO_2 and NO_X, climate change and other burdens. Their study shows that the electricity production system would shift towards natural gas combined cycle, nuclear power and renewables if these externalities were to be fully internalized. Barreto, Rafaj and Kypreos (2004) analyzed the effect of incorporating marginal abatement costs for mitigation of non-CO_2 GHGs in enhancing the degree of flexibility of climate change mitigation strategies using MARKAL model. MARKAL model has provisions for satisfying several other constraints in an energy system.

Shakya (2007) developed OH-MARKAL model to study the incorporation of biomass co-firing power plants into the electricity portfolio of Ohio in order to reduce the CO_2 emissions of the state.

2.3.1 OH-MARKAL model

Shakya (2007) examines electricity sector of Ohio for 30 years with base year 2002 using OH-MARKAL model. The analysis considers variations along 3 seasons (summer, winter, and intermediate) and 2 diurnal variations (day and night) making a modeling framework in 6 time slices. The objective function is the minimization of the total costs of the energy system discounted over the modeling time horizon. The total cost includes the following components: annualized investments in technologies, fixed and variable annual operation and maintenance costs of technologies, cost of exogenous energy and material imports and domestic resource production (mining), revenue from exogenous energy and material exports, fuel and material delivery costs, net economic loss resulting from reduced end-use demands, taxes and subsidies associated with energy sources, technologies, and emissions.

$$NPV = \sum_{r=1}^{R} \sum_{t=1}^{t=NPER} (1+d)^{NYRS.(1+t)} .ANNCOST(r,t).(1+(1+d)^{-1}+(1+d)^{-2}+......+(1+d)^{(1-NYRS)}$$

where,

NPV is the net present value of the total cost for all regions.

ANNCOST (r, t) is the annual cost in region *r* for period *t.*

d is the general discount rate.

NPER is the number of periods in the planning horizon.

NYRS is the number of years in each period *t.*

R is the number of regions.

The *ANNCOST(r,t)* is expressed as follows:

$$
\begin{aligned}
&\mathit{ANNCOST}(r,t) = \\
&\Sigma k\ \{\mathit{Annualized\_Invcost}(r, t, k) *\mathit{INV}(r, t, k)+\mathit{Fixom}(r, t, k) *\mathit{CAP}(r, t, k)\\
&+ \mathit{Varom}(r, t, k)*\Sigma\ s,s\ \mathit{ACT}(r, t, k, s)\\
&+ \Sigma c\ [\mathit{Delivcost}(r,t, k, c)*\mathit{Input}(r,t,k,c)*\ \Sigma s\ \mathit{ACT}(r,t,k,s)]\ \}\\
&+ \Sigma c,s\ \{\ \mathit{Miningcost}(r,t,c,l)*\mathit{Mining}(r,t,c,t)+ \mathit{Tradecost}(r,t,c)*\ \mathit{TRADE}(r,t,c,s,i/e)\\
&+ \mathit{Importprice}(r,t,c,l)*\mathit{Import}(r,t,c,l)- \mathit{Exportprice}(r,t,c,l)*\mathit{Export}(r,t,c,l)\ \}\\
&+ \Sigma c\ \{\mathit{Tax}\ (r,t,p)\ *\ \mathit{ENV}(r,t,p)\}
\end{aligned}
$$

where,

Annualized_Invcost(r, t, k) is the annual equivalent of the lump sum unit investment cost, obtained by replacing this lump sum by a stream of equal annual payments over the life of the equipment in such a way that the present value of the stream is exactly equal to the lump sum unit investment cost for technology *k*, in period *t*.

Fixom(r, t, k), Varom(r, t, k), are unit costs of fixed and operational maintenance of technology *k*, in region *r* and period *t*.

Delivcost(r, t, k, c) is the delivery cost per unit of commodity *c* to technology *k,* in region *r* and period *t*.

Input(r, t, k, c) is the amount of commodity *c* required to operate one unit of technology *k,* in region *r* and period *t*.

Miningcost(r, t, c, l) is the cost of mining commodity *c* at price level *l,* in region *r* and period *t*.

Tradecost(r, t, c) is the unit transport or transaction cost for commodity *c* exported or imported by region *r* in period *t*.

Importprice (r, t, c, l) is the (exogenous) import price of commodity *c,* in region *r* and period *t*; this price is used only for exogenous trade.[1]

Export price (r, t, c, l) is the (exogenous) export price of commodity *c,* in region *r* and period *t*; this price is used only for exogenous trade, see below.

Tax(r, t, p) is the tax on emission *p,* in region *r* and period *t*.

Env(r, t, p) is the emissions of pollutant *p,* in region *r* and period *t*.

The author included the following constraints in OH-MARKAL model. First, the capacity of power plants should be able to meet the demands in each region and time period explained in the model. Second constraint is on capacity transfer. Total capacity of a period is sum of capacity generated by investment in current period and that residual from investments in previous periods. Third constraint limits the supply from each technology to remain within the capacity of each plant. Another constraint deals with the balance of electricity and heat produced. This constraint requires that the quantity of electricity imported and produced should be equal to the quantity of electricity exported, consumed, and lost in transmission. The next constraint describes the peak reserve required in the system. The capacity installed should exceed the quantity of electricity required in a region for that time period in order to supply at the time of peak. Another constraint is electricity base load constraint. This constraint differentiates the base load capacity plants such as coal and nuclear plants from others. This differentiation is required because the base load plants require longer time period for changing the quantity of electricity produced. In addition to these, the author includes environmental externality constraints in the form of emission tax/ cap for CO_2 to examine the potential for biomass energy entry into the electricity market of Ohio.

The taxes imposed in the model were static tax of \$20 and \$50 per ton of CO_2 starting 2010. The carbon cap imposed were 25% and 35% below 2005 emission levels in 2030. The model results showed that under such policy intervention, the power industry of Ohio could be diversified using as much as 7% of biomass co-firing electricity generation.

In addition to these constraints, the model is based upon several assumptions about the electricity industry in Ohio.

The SO_2 and NO_X emissions from power plants will be reduced to 98% and 90% beginning 2012. This will be achieved by installation of FGD equipment for SO_2 emissions control and selective catalytic reduction equipment for NO_X emission control by 2012 in new and existing power plants in Ohio. The older power plants, in which it would be cost ineffective to install such equipment, are assumed to retire by 2012.

Efficiency of power plants is assumed to increase to 60% by 2020 from 40% at the beginning of the model period. Another assumption is that Ohio uses 40% of domestic coal and 60% of imported coal for electricity generation. Additionally, demand for electricity is assumed to reduce by 22.5% because of energy efficiency programs during 2009-2025.

OH-MARKAL data set and analyses are managed by software program, ANSWER. The program manages a number of 'Excel' worksheets. Information is categorized into two groups of Excel sheets, namely declaration worksheets and data sheets. In declaration worksheets, information on technologies are defined. Data associated with them are in data sheets. The OH-MARKAL declaration sheets consist of technologies, commodities, and constraints worksheets. Data sheets consists of demand data; technical data on new and existing power plants and renewable options; price of fuels such as domestic and imported coal, natural gas, biomass etc.; data on emissions coefficients for CO_2, NO_X, SO_2, and Mercury (Hg); data on fuel mixing technology and supply of fuels, such as high and low sulfur coal, biomass etc.

An extension of the OH-MARKAL model, 2009 shows that with 25% cap, the share of biomass would be 7.87 %, and that of wind and anaerobic digesters would be 2.06% and 0.4 % respectively. Similarly, share of biomass, wind, and anaerobic sources will be 7.45%, 4.45%, and 0.4% respectively, if the CO_2 cap is 35%. Under this scenario, solar will also be cost effective option and will make up 0.16% of electricity generation of Ohio. The author states further that with 25% and 35% cap in $CO_{2,}$ the price per kWh will increase to 9.92 c/kWh and 13.53 c/kWh respectively in 2026.

The OH-MARKAL model will be modified to incorporate externalities associated with coal based electricity generaiton, which is discussed in methodology section. The results will show the extent to which these shadow priced external costs will impact emissions and change the mix of coal versus renewable energy based electricity production in Ohio.

CHAPTER 3

3 METHODOLOGY

3.1 Introduction

This section discusses the methodology to answer a major unanswered subset of the research questions put forth in this dissertation. Major hypothesis of this research is whether the internalization of externalities associated with coal electric power would significantly change the cost of electricity generation from coal. Additional research question is whether and how this change in cost structure might impact the electricity portfolio of Ohio. In order to meet these objectives, this research proposed to evaluate the social costs of electricity from coal. As observed in literature review section, social costs of coal based electricity generation have been studied since 1982, however the studies have primarily emphasized impacts of coal burning in power plants while externalities related to coal mining remains neglected. Some studies have quantified the damages from coal mining but have failed to connect it to electricity sector.

Discussions of methods to identify downstream impacts of coal mining include identification of impacted lakes; a visitation function to evaluate the downstream damages of the coal mines; and monetizing the downstream damages using benefit transfer methods. This is followed by description of estimation of reclamation costs of the impacting mines and a method developed to translate the damages to damage per ton of coal. Finally, extension of OH-MARKAL to incorporate these externalities to assess the impacts of internalizing externality costs on the electricity portfolio of Ohio will be discussed.

3.2 Evaluation of impacts of coal mines

Coalmine impacts embrace downstream impacts to lakes and rivers, land use impacts, aesthetic damages, impacts on wild life, health impacts to residents and workers, and underground coal mine causalities. This research develops methodology to assess downstream recreation impacts of coal mining, while for the estimation of the other impacts it depends upon results from other studies.

Downstream impacts from coalmines are categorized as the recreational damage and other damages to simplify estimation. Other damages include drinking and agricultural water pollution. Recreational damages associated with poor water quality impacts primarily some activities such as fishing, skiing, sailing, canoeing, motor-boating, swimming, kayaking. Other activities such as tourism, hiking, and picnicking will also be impacted. These in turn impact the local supplier of goods and services associated with such recreational activities. In addition to that, poor water quality impacts the value of the housing properties in the vicinity and may reduce revenue from commercial buildings.

Recreational damages are estimated by developing a visitation function for inland lakes in Ohio. MacGregor (1988) used a visitation model for estimating the loss from lake sedimentation. Details on the model development follow shortly. Since the damage evaluated represents a subset of the whole problem, the estimated damage value is a lower bound estimate. The estimated damage is compared with an updated damage estimate from Hitzhusen *et al.* (1977) study.

First, the lakes potentially damaged from mining activities and abandoned mines in their respective watershed were identified using GIS analysis. Then information on chemical conditions of the impacted lakes was gathered. A visitation function was developed to estimate impacts of coal mining on demands for recreation at the impacted lakes.

3.2.1 GIS analysis of Coal mines impacts in Ohio

GIS analysis allows identifying the spatial distribution of coal mining area. Maps were generated for ongoing coal mining area, reclaimed coal mines, and unreclaimed abandoned underground and surface coalmines located in eastern Ohio (Study site in Figure 8). Data on historic and current coal mining in eastern Ohio from ODNR were used to map the coal mine impacted area (Figure 9). A Digital Elevation Model (DEM) (USGS, 2009a), watershed map (NRCS, 2009), map for the streams and map for the lakes (USGS, 2009b) were downloaded for the study area. A DEM (Figure 10) provides a view of the spatial variation of elevation at 30 m spatial resolution. Slope (Figure 11) and flow accumulation (Figure 13) maps were derived from the DEM using the spatial analyst function of ArcGIS 9.3 (ESRI, Redlands, CA). Spatial analysis was used to identify the lakes and streams impacted by coalmines.

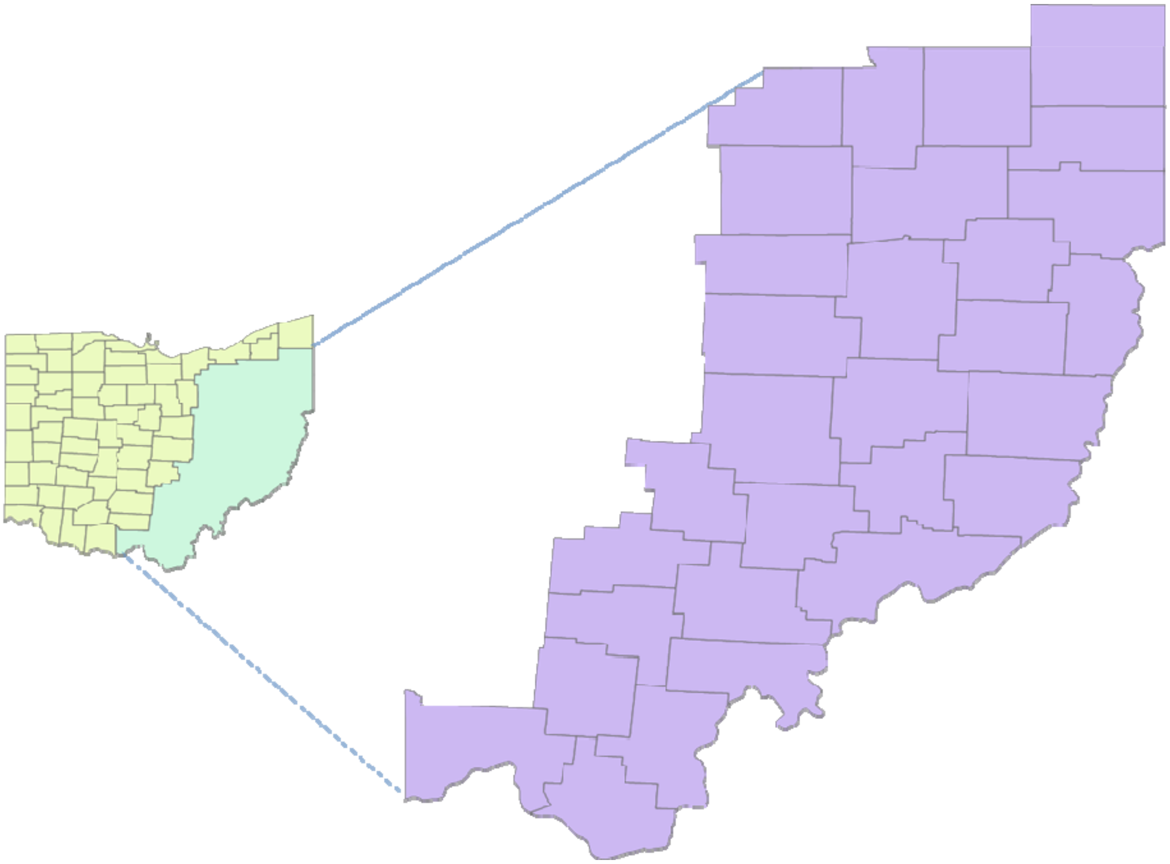

Figure 8 Location of Study Area in the State of Ohio.

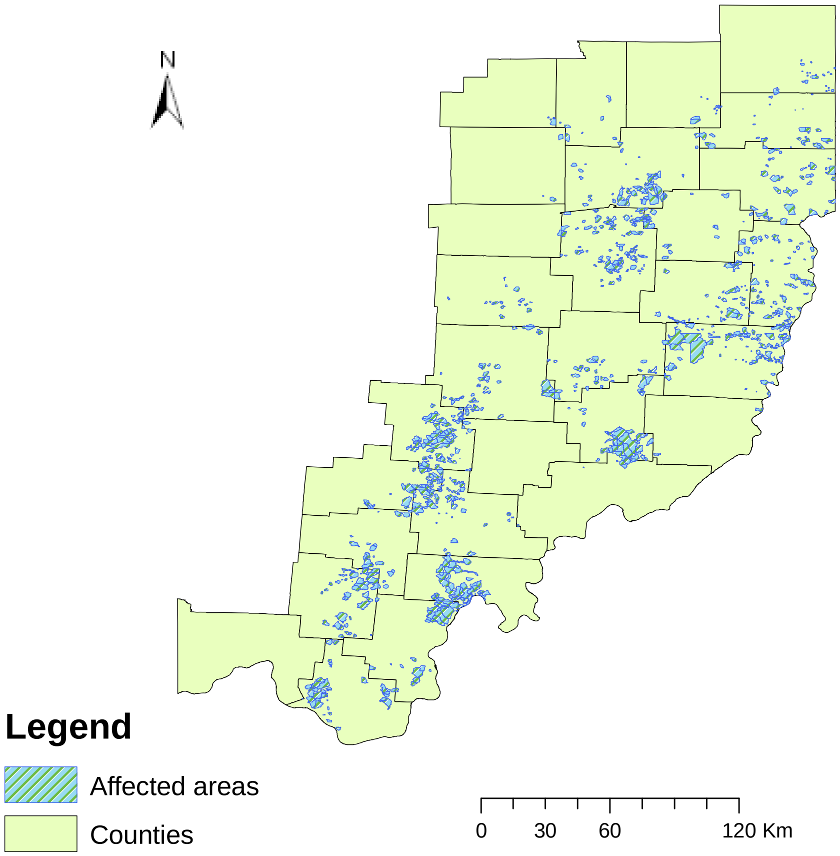

Figure 9 Abandoned Coal mining area in eastern Ohio.

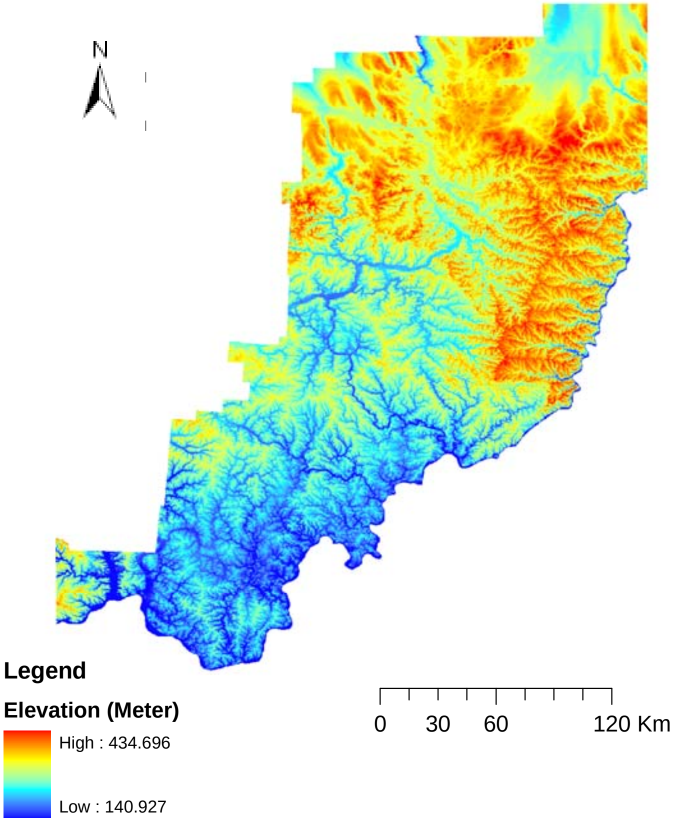

Figure 10 Digital elevation map of coal mine impacted area of Ohio.

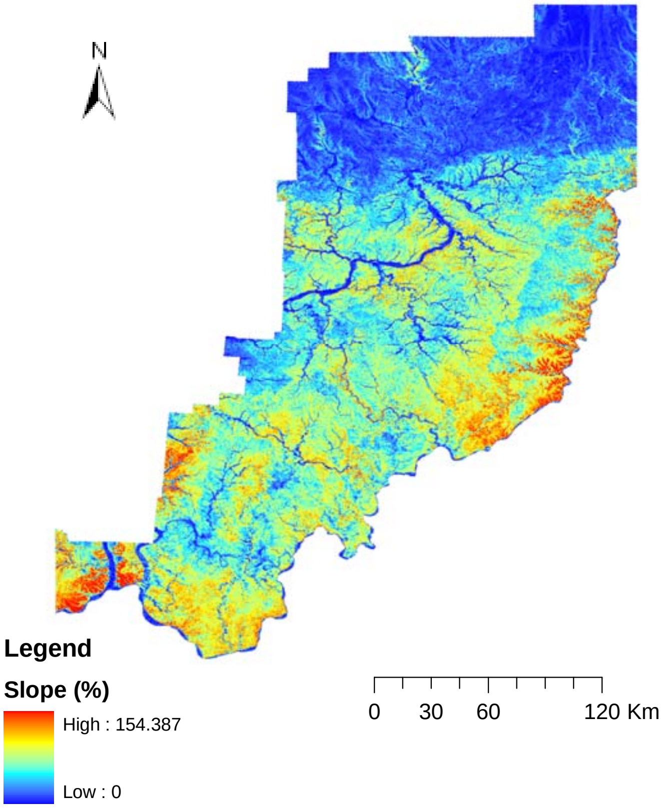

Figure 11 Spatial variation in slope of the coal mine impacted region of Ohio.

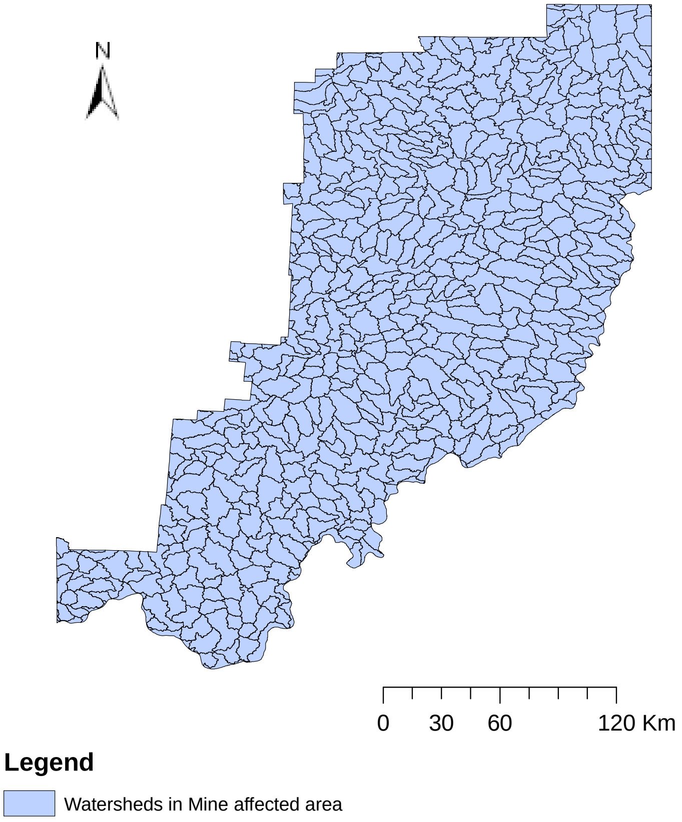

Figure 12 Watershed delineated in the affected area

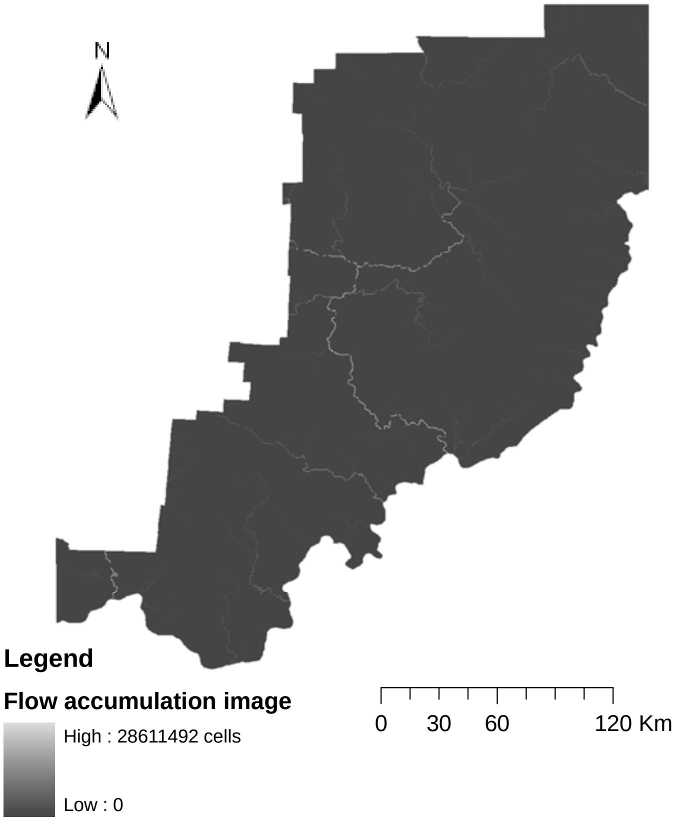

Figure 13 Flow accumulation in the study area.

Figure 14 illustrates the spatial distribution of lakes and mines in affected counties of Ohio.

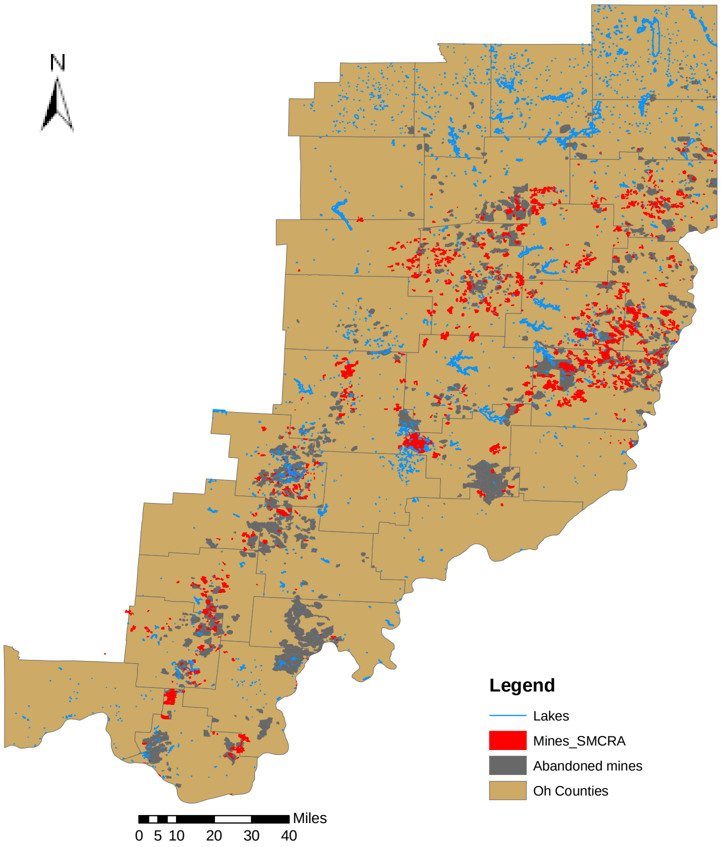

Figure 14 Lakes and coal mined area in eastern Ohio

Using these maps, the watersheds affected by coal mining were identified. Watershed map, slope map, flow accumulation map, land use map, map of unreclaimed mines, map of reclaimed mines under SMCRA were overlaid on map of lakes (Figure 14). Spatial analyses helped to estimate variables required to estimate runoff to the lakes from the mines. Distance between the affecting mines and the lakes, slope of the path, and land cover in between them were estimated. Rainfall data for the watershed was obtained from the weather station in the nearest vicinity. Rainfall data during summer months for 5 years were collected and mean rainfall was used for runoff calculation. Using the aforementioned data and average rainfall measured at a weather station in proximity, the runoff volume contributed by each mine was estimated. Details on runoff estimation are listed in Appendix C. Lakes, with unreclaimed coal mines in its watershed, receiving mines runoff were identified as the impacted lakes.

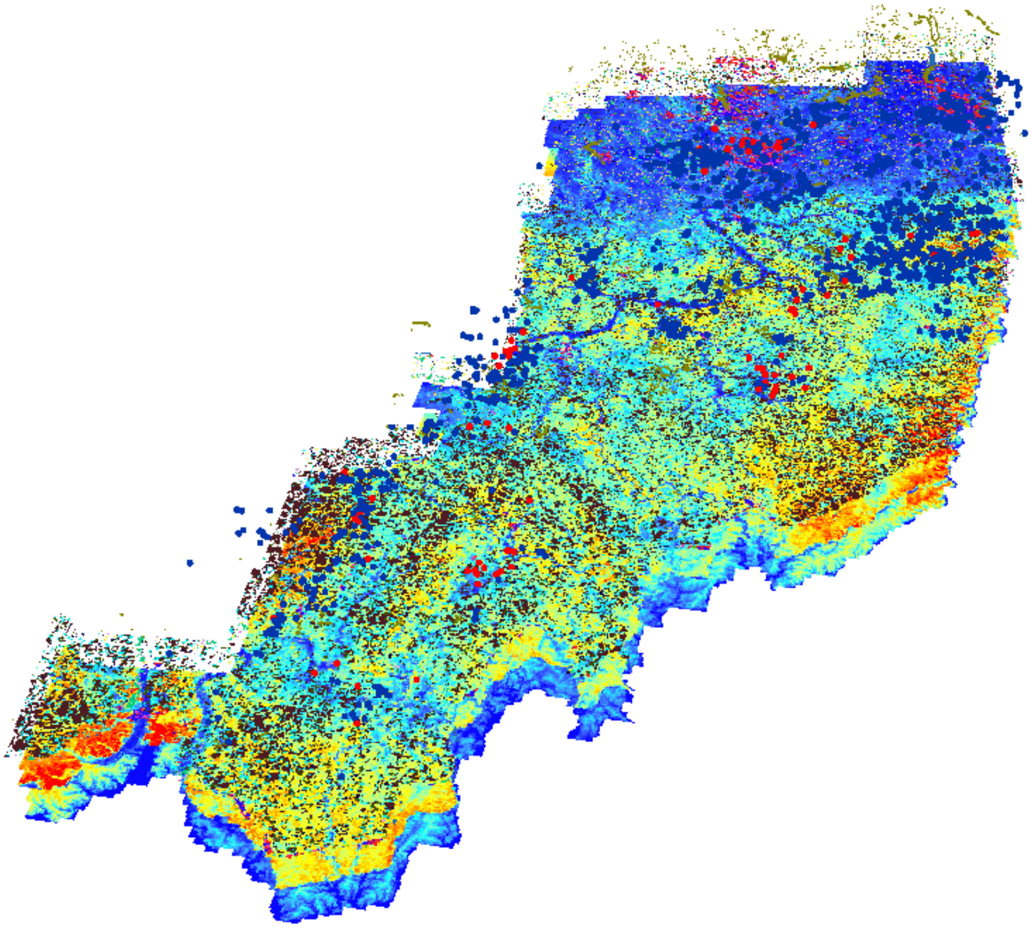

Figure 15 Representation of overlaid maps of Lakes, mines, slope, watershed, and land use.

Unreclaimed mines contributing their respective runoff to lakes were documented (Table 8).

Table 8 Unreclaimed coal mine units in watershed of respective lakes.

S.N.	Lakes	Unreclaimed coal mines (Units)
		72
		800
		103
1	Seneca	83
		1
2	Piedmont	1
3	Clendening	5
4	Atwood	100
5	Mohawk	1
6	Berlin	12
7	Meander Creek	38
8	Evans	274
		23
9	Pines	25
10	Belmont	3
		50
11	Wills creek	15
12	Dow Lake	50
		470
13	Lake Snowden	67

According to the GIS analysis, 12 lakes were identified as receiving the runoff from the abandoned mines (Table 9).

Table 9 Lakes Found Impacted by Coal Mines from GIS Analysis

AML (Surface) impacted lakes	AML (Underground) impacted lakes
Atwood Lake	Wills Creek reservoirs
Evans Lake	Tappan Lake
Piedmont Lake	Wolf Run Lake
Senecaville Lake	Dow Lake
Lake Snowden	Lake Rupert
Jackson Lake	
Lake Vesuvius	
Lake Rupert	

3.2.2 Chemistry of coal mine impacted lakes

Based on the literature review on chemical conditions of coal mine impacted lakes, SO_4, and SC of lakes are appropriate measures for identifying coal mine impacts. Lakes identified as coal mine impacted show higher level of SO_4 than unimpacted ones according to the data on SO_4 obtained from USACE for the lakes from 1980 to 2008 (Table 10, Figure 15). Leesville lake, a coal mine unimpacted lake is observed to have a lower SO_4 level of 26 mg/l, while Piedmont Lake has the highest SO_4 level of 840 mg/l.

Table 10 Sulfate levels in lakes of Eastern Ohio

S.N.	Lakes	SC (µ mho/s)	SO_4 (mg/l)
1	Alum Creek	562	75
2	Atwood	377	48.5
3	Beach City	672	114
4	Berlin	319	63
5	Charles Mill	606	80
6	Clendenin	1363	703
7	Deer Creek	594	32
8	Delaware	596	55
9	Dillion	609	66
10	Kokosing	577	41
11	Leesville	245	26
12	Michael Kirwan	336	46
13	Mosquito Creek	240	35
14	Paint Creek	602	30
15	Piedmont	1670	840
16	Pleasant Hill	497	33
17	Senecaville	456	45
18	Tappan	1668	714
19	Wills Creek	1443	611
20	Wolf Run	255	NA

Relationship between SO_4 and SC shows their high correlation (Figure 16). Thus these two measures will be used separately in the visitation function. The trend in SO4 levels in the impacted lakes was plotted to analyze the sulfate levels in the impacted lakes over time. Interpolation was used to estimate the SO_4 level for the data points with missing variable. The graph (Figure 16) shows that SO4 level in the lakes is not declining with the minimum reclamation of coal mines carried out in the respective watersheds of the Lakes.

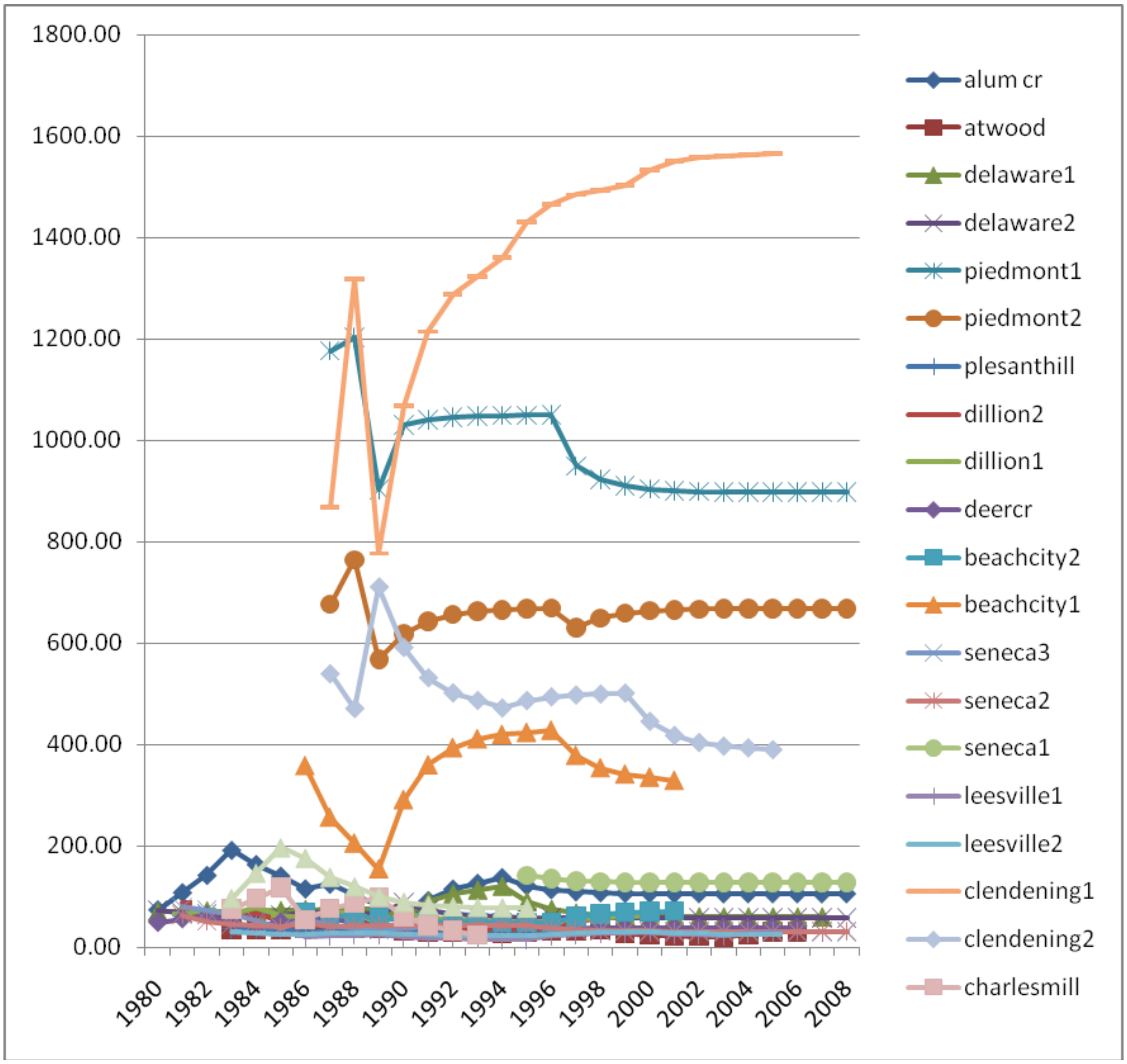

Figure 16 Sulfate Level in Lakes in Eastern Ohio from 1980 to 2008

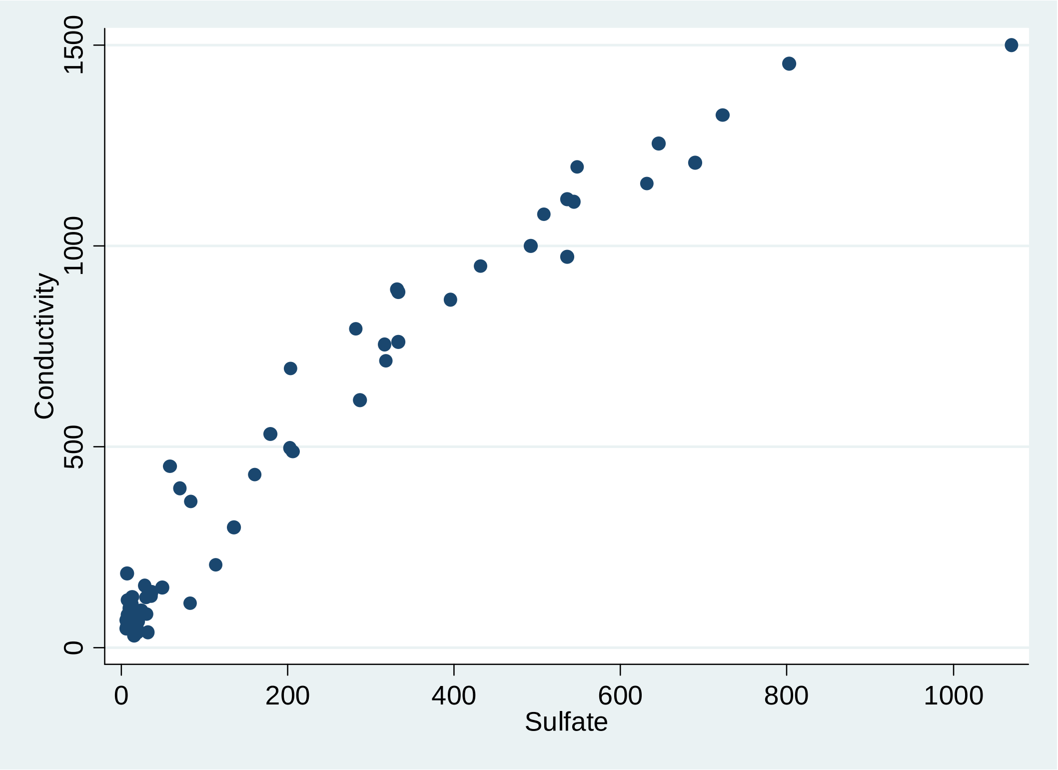

Figure 17 Relationship between SO_4 and SC

3.2.3 Developing visitation function

Recreational visitation to a lake depends upon factors associated with the amenities of the lake, characteristics of population living in the vicinity of the lake, and substitutes or complementary recreational opportunities in the proximity of the lake. Reduced form of a visitation model is:

$V = f\{L_c, W_q, D_c, S_c\}$

where, V_i is the recreational visitations, *Lc* is the Lake characteristics, *Dc* is the demographic characteristics, and *Sc* is the substitutes or complimentary sites to the lakes.

Lake characteristics include surface area of lake, depth, age, and horse power (HP) allowed for boating in the lake. Larger lakes, lakes where higher HP boats are allowed, or deeper lakes attract more visitors for recreation. In the mean time, since costs associated with recreational activity or the travel cost is a deciding factor in recreational demand of an individual, proximity to a lake from city/ies is another determining factor of recreation. It is assumed here that the farther a lake is from an interstate highway, the higher the travel cost. In other words, proximity to major highway increases the probability of visitation at a lake.

Better water quality principally increases recreational visitation to a lake. Physical, chemical, and biological water quality measures such as IBI, LCI, color, turbidity, chemical indices, pH, alkalinity, oxygen indices, coliform count, have been used in previous studies to evaluate the water quality impacts on water based recreation demand. In this research, since we focus on defining the recreation demand affected by coalmines in particular, we follow Rikard and Kunkle (1989) and propose to use SO_4 and SC as water quality metrics for studying coal mine impacts.

In contrast to some water quality measures such as turbidity level of water; SO_4 or SC level is not visible in water. A question could be raised here, how visitors relate to the chemical condition of the lakes such as SC and SO_4 level? According to USEPA, (2002), IBI is negatively correlated with SO_4. The study also found that zinc and sodium are neagatively correlated with SO_4. Rogowski (2006) reported a significant negative relationship between SC and the mean length of fish. Another study by United States Geological Survey (USGS, 2006) found a significant negative relationship between IBI and SC. USEPA (2009) found that SC between 150 and 500 µmhos/cm could support good mixed fisheries. In light of these correlates, SC and SO_4 are used as water quality parameters in this research to explain visitation to a lake.

Population in the vicinity is another major factor that determines the number of recreation visits to a lake. The higher the population around the lake, the larger will be the recreational visits. Income on the other hand, directly relates to the recreational budgets of families. Thus, the average annual family income and population were also included in the model to explain recreational visits to a lake.

The visitation function is

$$V_i = \beta_1 + \beta_2 A_i + \beta_3 HP_i + \beta_4 Y_i + \beta_5 S_i + \beta_6 DH + \beta_7 I_i + \beta_8 SC + \varepsilon$$

$$V_i = \beta_1 + \beta_2 A_i + \beta_3 HP_i + \beta_4 Y_i + \beta_5 S_i + \beta_6 DH + \beta_7 I_i + \beta_8 SO_4 + \varepsilon$$

where, *Vi* is the vector of water based recreation visits: swimming, boating/skiing, fishing, and total water based recreation, *Ai* is the surface area of lake in acres and *Si* is the sum of surface acreage of substitute lake/s within 20 miles and 30 miles radius of a lake. The *HP* denotes the horsepower allowed in a lake. The *DH* is the distance from lake to highway in miles, *SC* is the specific conductivity of the lake in µmho/cm, and SO_4 is the dissolved sulfate level in the lake in mg/l, *Yi* is the income of the recreation visitors and *Ii* is the population within 20 miles and 30 miles radius of a lake.

As compared to Leesville Lake, a clean lake in the region, the other impacted lakes have comparatively high sulfate level. So had there been no upstream coal mining, the sulfate level in the impacted lakes would be expected to be similar to the sulfate level in Leesville Lake. The impact of differential sulfate level in a lake as compared to Leesville Lake on number of recreational visits to the lake is thus considered as the proxy for the externalities to the lake associated with upstream coal mining.

3.2.4 Monetizing the damage estimated using visitation function

Recreational damage value is estimated considering two aspects: first reduction in number of visits related to coal mining impacts, and second change in value per visit due to coal mining impacts on water quality. Damage value is estimated as the proxy for potential increase in revenue by improving the water quality. In other words, potential increase in revenue associated with increase in visitation by improving water quality would be one aspect of the assessment. Another aspect of assessment would be increased value per trip attributed to water quality improvement. In order to compute the increase in recreational value due to water quality improvement, the following two steps are involved. First, value per trip for each water based recreation activity needs to be estimated. Second, increase in value per trip for those activities due to improvement in water quality from poor to good or excellent needs to be estimated.

3.2.5 Value per trip

Recreational trip provides utility to a consumer, which is defined as the value per recreational trip. Value per trip estimated by surveying visitors to respective lakes studied would provide the first best scenario for benefit assessment. However, this research does not have the time or resources for primary data collection. Therefore, benefit transfer methods and metrics will be used to estimate value per recreational trip.

Benefit transfer method provides better estimates if the study site and policy site possess similar characteristics. Studies in eastern Ohio will thus be most relevant in estimating value per trip. Sommer (2001) estimated per day trip value for boating and fishing in hocking river valley as \$11.69 and \$13.35 respectively. Similarly, Bhat *et al.*

(1998) day use value is based on a public area recreation visitors study and customer surveys in ecological region that includes the reservoirs in Ohio under USACE. However, the authors have not evaluated per day value of swimming activity. Per day value estimated by Rosenberger and Loomis (2001) provides the best value since the authors' estimates are based on large number of estimates and sound methodology such as metaanalysis. The estimates are for various regions. The Northeast region, which signifies the region east of Mississippi, can be considered better than national averages found in the literature. Value for swimming estimated by Rosenberger and Loomis (2001) using metaanalysis is $14.44. The lakes studied are in less populated area as compared to the northeast region studied. Population in Ohio is 1/5 of the population in the northeast of Mississippi. Ohio's population in 2006 was 11.65 million and per capita income US $5,760.

The value of swimming is adjusted for population, income and perimeters of lake. These day use values for each recreation activity will be updated for the year 2006 before being utilized to evaluate swimming in lakes in Ohio (Table 11).

Table 11 Recreational Values used for Estimation of CS from other Lakes

Activity	Per day trip value (Dollars in study year)	Per day trip value (2006 dollars)	Authors
Motor boating	9.85	12.14	Bhat *et al.* (1998)
Boating	11.69	13.35	Sommer (2001)
Fishing	12.54	14.33	Sommer (2001)
Swimming	14.44	18.39	Rosenberger and Loomis (2001)

3.2.6 Value per trip and water quality improvement

Benefit transfer method will be used for determining increase in value per trip. Results from previous studies on increase in value per trip due to water quality improvement will be used to estimate the increase in value per recreational trip to lakes in Ohio.

Sommer (2001) estimated an increase in per trip value for fishing at $4.79 and $4.99 corresponding to water quality improvement in Hocking River valley from poor to good and excellent quality respectively. Jeong and Sohngen (2005) estimated increase in value per fishing trip in Ohio from $13 ($8-$20) to $20 ($12-$30) and $30 ($18-$45) with improvement in water quality from poor to good and excellent quality respectively for streams in Ohio.

Per trip per person benefits from improvement in dissolved oxygen level and water quality in Lakes of Wisconsin, US were $4.83 for the boaters, $1.08 for fishers, and $6.66 for the swimmers (Parsons and Kealy, 1992).

Since Sommer (2001) study was done in eastern Ohio and water quality deterioration is attributed to coal mine impacts, direct benefit transfer is proposed whenever possible for estimating increase in value per fishing trip to the policy sites (lakes studied in this research). The closest option for estimating increase in value per trip is Parsons and Kealy (1992) since the study was done in a Midwest state and is a closer value than national average (Table 12). In addition to that, the author estimated incremental value per trip associated with improvement in water quality unlike other studies.

Table 12 Increase in value per trip (Parsons and Kelley)

Activity	Incremental value per trip (2006 dollars)
Fishing	4.79
Swimming	6.66
Boating	4.83

Next, the procedure for estimating increase in recreational value of lakes upon improving water quality will be discussed. Economic surplus from each lake and damage from abandoned mine drainage was estimated as;

$$ES_i = VN_i * VV_i$$

where, VN_i is the visitation for an activity; VV_i is the day use value per visitation Total benefits from improving water quality of the lakes was estimated as

$$Total\ Benefit = \sum_{i=1}^{n} \{(VN_i * VV_i) - (VN_{is} * VV_{is})\}$$

where, VV_i and VV_{is} are the values per trip per activity under improved and status quo water quality condition in lake *i*. VN_{is} and VN_{is} are number of visitors under improved and status quo water quality condition. Improved condition is measured as the reduction in sulfate level in lakes. Benefits are estimated based upon the assumed three levels of sulfate reduction achieved by means of reclamation of AMLs.

3.3 Translation of recreational loss to loss per ton of coal

Damages to the aforementioned lakes are contributed by historic and current coal mining operations. Both the abandoned mines and mines reclaimed under SMCRA (1977) are the sources of pollution to these lakes. Coalmines mined under SMCRA (1977) are reclaimed and do not have major impacts on water bodies in most cases. However in some cases, where it is impossible to contain the pollutants due to topography of mining area, pollution is an ongoing problem. Such pollution problems that begin after the bonds for mining are released back to the mining companies after seven years becomes the responsibility of the government and not of the mining companies. Thus, even the coal mining operations after implementation of SMCRA, cause continuous impacts over a long time horizon. Such damages continue until full reclamation of the problematic mined land is attained; however magnitude of damage is expected to reduce with increasing reclamation.

3.3.1.1 Reclamation costs estimation:

Reclamation costs for the unfunded abandoned mined land will be estimated using the costs of reclamation for the reclaimed abandoned mines as baseline estimates (Table 13) and current reclamation costs. Current reclamation costs per acre of abandoned mines will be obtained from ODNR and coalmine reclamation studies in Ohio and neighboring states.

Table 13 Costs for Reclamation of Problems Caused by Abandoned Mined Land (2009 Dollars)

S.N.	Type of problem	Unfunded	Average costs $/acre	Completed costs/acre	
Priority 1				minimum	maximum
	CS	35.5	325,890.70	75,086.00	761,906.00
	CSL	957	10,047.38	2,016.00	40,526.00
	DPE	1	17,288.00	6,700.00	27,412.00
Priority 2	CS	105	156,323.00	7,401.00	1,900,000.00
	CSL	12472.5	11,204.00	2,056.35	61,011.00
	DPE	75.1	11,365.00	1,060.00	18,834.00
Priority 3	GOB	656.5	12,697.00	2,721.00	46,352.00
	BE	93	2220.5	2220.5	2220.5
	Pits	363	1,174.29	1,000.00	2,220.00
	Spoil Acres	21664	5,221.00	1,000.00	38,795.00
	Slump Area	17	50,000.00	50,000.00	50,000.00

Given the high costs for reclamation and ongoing budget constraints under the current economy, it might take at least 10 to 15 years for reclamation of the abandoned mines. With the Public law 109-432 signed into law in 2006, severance tax on coal is extended for Ohio until 2021 (ODNR, MRM division 2007).

Net present value of total costs of reclaiming abandoned mines depends upon the time period within which the mines are reclaimed. According to ODNR MRM annual report, 4.9 million dollars was granted in 2007 and 7.9 million dollars in 2008. This is expected to increase to 20.1 million dollars in 2014. Between 2008 and 2017, 144.7 million dollars will be received for non emergency abandoned mine land work in Ohio.

If the proposed federal budget cut for mine reclamation is implemented, it could take much longer. Until reclamation of all the problematic mines is achieved, the mining companies are bound to keep paying taxes for the reclamation of abandoned mines.

Reclamation costs will be estimated assuming that abandoned mines will be reclaimed by 2021. According to the information from ODNR, Ohio will receive budget for reclamation up to 2021. If there is a federal budget cut for reclamation of abandoned mines, reclamation will be postponed.

The priority for reclamation depends upon several factors including the most pressing health and safety issues as well as political considerations. Abandoned mines with health and safety issues are categorized under priority 1 and 2. Therefore, abandoned mines under these categories will be given higher weight in determining the need for immediate reclamation followed by priority 3.

From ODNR annual reports 2005 and 2007, a baseline for reclamation of different types of AML areas can be determined (Table 14).

Table 14 Reclamation Completed per Year (Source: ODNR annual reports)

Problem type	2005	2007
Dangerous high walls (ft)	1700	2200
Land slides (acres)	3	3
Mine openings (counts)	3	25
Strip mine land (acres)	9.2	
Mine subsidence (acres)	3	
Dangerous impoundments (counts)	2	1
Clogged stream (miles)	500	
Clogged stream land (acres)		6
Coal refuge and spoil (acres)	43.5	61.4

3.3.1.2 Combining reclamation and damage to the lakes:

How does reclamation of abandoned mines translate into reduction in sulfate loading? All the abandoned and current mines (mines after implementation of SMCRA) in the watershed of these impacted lakes were identified using GIS. Data on area of abandoned coalmines and latest mines (1994-2002) in the watershed of each lake were collected. Latest mines posing problems were identified with the help of ODNR.

Sulfate contribution from the abandoned and ongoing mines per year needs to be delineated. A large share of sulfate loaded into a lake from coalmines flows out of lake through outflow. The lake biota assimilates some part of the remaining sulfate and some part leaches into ground water. The remainder of the sulfate accumulates in the lake. Brigham and Gnilka (1977) estimated 13.35% of the sulfate loaded to Lake Shelbyville was retained in the lake. The USACE data on sulfate level over the years in lakes in eastern Ohio shows an average retention of 31.98%. Inflow and outflow of sulfate in mine-impacted lakes are shown in Figure 18.

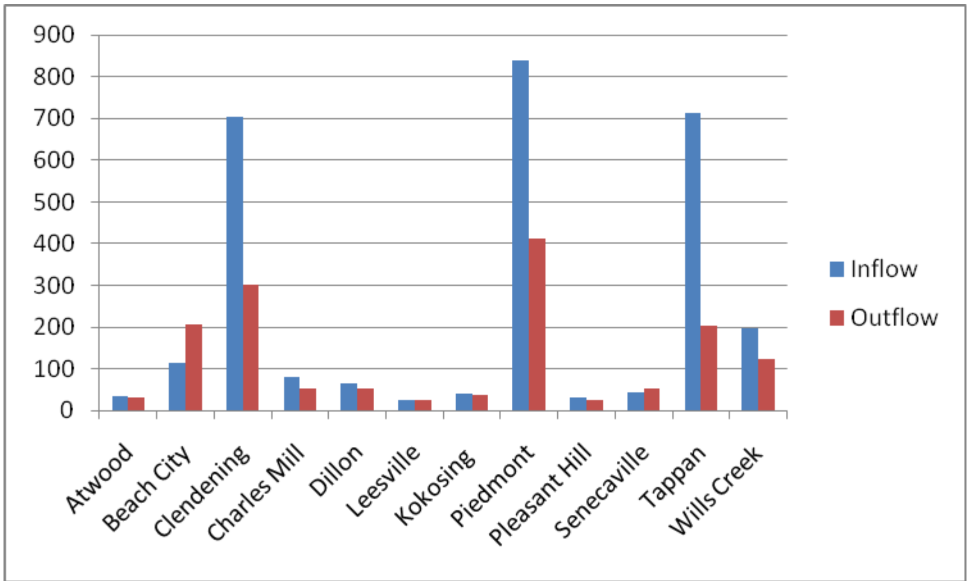

Figure 18 Inflows and Outflows of Sulfate Level

Hren, Wilson, and Helsel (1984) evaluated the effects of coal mining and reclamation on water quality in Ohio. The authors collected observations from 779 sites from June 1975 through September 1982, in 25 eastern counties of Ohio. The sites included abandoned coal mine sites, reclaimed coal mine lands, and mixed areas in the basins. If 50% or more land of a basin was reclaimed or abandoned mines, they fell respectively under reclaimed or abandoned category. A basin was considered unmined if 100% of its land was unmined. Several statistical measures were used to analyze whether the water quality downstream from these basins differ significantly from those of unmined sites. Water quality parameters used were specific conductance, sulfate, acidity, alkalinity, sulfate, total iron, dissolved iron, and total manganese. The authors concluded that the sites with coal mining and reclaimed lands showed higher levels of sulfate and specific conductance than the unmined sites. However, their experiment could not establish a statistically significant difference between sulfate levels in sites having reclaimed and abandoned mines. One of the reasons for such insignificance could be because reclamation in Ohio started in 1972, while the authors started observations as early as 1975. Improper or incomplete reclamation effort might have resulted in low sulfur reduction. However, this information is not able to exclude the possibility that reclamation does not have a measurable impact on sulfate levels downstream. If reclamation does not contribute in sulfate reduction, sulfate accumulated in the lakes has to be treated using water treatments processes such as The Hogen Process, which is very expensive to implement and has not been implemented in lakes in eastern and southeastern Ohio.

Table 15 Summary of SC and SO_4 Levels in Different Basins of Eastern Ohio

Site type	Water Quality	No of Obs.	Max	Min	Mean	Std. Dev.	Median
Abandoned	SC	55	3850	380	1961	752	2000
	SO_4	56	2300	83	1103	484	995
Reclaimed	SC	41	4500	200	2058	995	1900
	SO_4	45	2500	31	1023	564	940
Unmined	SC	179	3500	90	457	348	400
	SO_4	179	1000	12	69	107	42

Langland (USGS) developed a model to estimate the sulfate loading and trends in a watershed in Pennsylvania (Sams III and Beer, 2000). Developing a similar model would be the first best option to estimate sulfate contribution from mines in Ohio and its relationship with reclamation, however that is beyond the scope of this dissertation. Therefore, a sensitivity analysis pertaining to sulfate reduction as a result of different levels of reclamation based upon the study by Hren, Wilson, and Helsel (1984) will be pursued.

Hren, Wilson, and Helsel (1984) estimated that the difference between the abandoned mines (unreclaimed) and reclaimed mines contribution on SO_4 level was 7.25% in 7 years time period. Assuming reclamation will undergo from 2010 through 2021, the best assumption for reduction in sulfate level is 15% for the lakes. A sensitivity analysis was done for the 6.5% reduction and 35% reduction in SO_4 levels in the lakes.

Table 16 Sulfate reduction levels in respective lakes

S.N.	Lakes	SO4	6.5% reduction	15% reduction	35% reduction
1	Alum Creek	75	70.1	63.8	48.8
2	Atwood	48.5	45.3	41.2	31.5
3	Beach City	114	106.6	96.9	74.1
4	Berlin	63	58.9	53.6	41.0
5	Charles Mill	80	74.8	68.0	52.0
6	Clendenin	703	657.3	597.6	457.0
7	Delaware	55	51.4	46.8	35.8
8	Dillion	66	61.7	56.1	42.9
9	Piedmont	840	785.4	714.0	546.0
10	Tappan	714	667.6	606.9	464.1
11	Seneca	45	42.1	38.3	29.3
12	Wills Creek	611	571.3	519.4	397.2

Increased revenue from the lakes due to reduction in sulfates to various levels will be estimated. This monetization of benefit stream accrued to reclamation of mines will help in examining whether the revenue could at least help support or offset the reclamation costs.

3.3.2 Reclamation cost and externality cost of coal

Current tax structure on coal mined in Ohio was revisited using estimated reclamation costs, monies that could be generated, and support or offset from reclamation benefits. Revenue generated from the federal and state taxes on the projected quantities of coal produced within the time frame designated for completing reclamation, namely until 2021, will be estimated. Quantity of coal produced from the coalmines per year in a county over that period of time will be collected from EIA. As a part of cost benefit analysis, the estimated revenue will be compared with the estimated budget required for reclamation plus the low bound estimated recreation benefits from the mines during the period. The result will be used to investigate whether the revenue generated from tax per ton of coal is enough to complete the reclamation of abandoned mines and to what extent these costs can be offset by the reduced pollution associated with coal mining and AMD.

3.4 OH-MARKAL adaptation

Cost effective electricity portfolio of Ohio under business as usual case as well as under defined policy implementation over a period of time can be examined using the OH-MARKAL model. Policy factors are introduced into the model and the results are compared to the base case scenario to analyze the impacts of the policy.

In this research, the externality costs estimated are incorporated and analyzed under several scenarios. First, the business as usual scenario will be analyzed with and without incorporating the externalities. Second analysis involves implementation of Advanced Electricity Portfolio Standard (AEPS) with and without incorporating the externality costs. The AEPS of Ohio mandates 25% of total electricity to be supplied from renewables and advanced coal by 2025. The policy allows that half of the 12.5% of renewables can be imported from out of the state. In addition to AEPS, Ohio senate bill 221 proposed to improve energy efficiency (EE), which will reduce demand for electricity by 22.5% by 2025. An analysis of the achievement of EE will be done. Final analysis will be devoted for analysis of EE and AEPS together with and without incorporation of externality costs.

3.4.1 Incorporating Coal Mining Externality

The externality costs per ton of coal will be converted into costs per BTU and will be introduced into OH-MARKAL as shadow prices for coal to examine changes in the electricity portfolio of Ohio.

$C_{MBTU} = C_{TON}/20.693$

C_{MBTU} is the costs per million BTU, C_{TON} is the costs per ton of coal, and one ton of coal is assumed to provide 20,169,000BTU energy (EIA).

The externality costs per BTU will be added to the projected price of coal in the existing OH-MARKAL model to analyze its impacts on electricity portfolio of Ohio.

3.4.2 Incorporating CO_2 externality

Earlier version of OH-MARKAL model treats a static tax of $25 and $50 per ton of CO_2 in the model. In another scenario analysis it imposes cap on CO_2 at 25% and 35% of 2005 level by 2030. According to Waxman-Markey's proposed US climate Bill 2009, emissions cuts will begin in 2012 with 3% cut in emission level below that of 2005 followed by 17% cut by 2020, and 42% cut by 2030. Additionally the bill suggests that a permit to emit 1 ton of CO_2 or its equivalent would be $11-15 in 2012, $22-28 in 2025 (2005dollars).

The emissions cap and permit prices proposed by US climate bill will be incorporated in the OH-MARKAL model to examine impact on electricity portfolio of Ohio.

3.5 Potential Pareto Improvement

In order to discuss how the potential benefits from reclamation could offset or support reclamation, efficiency and distribution concepts in resource allocation need to be introduced. Economic efficiency is the state where the resources are allocated such that no individual can be made better off without making another person worse off. This is also called as Pareto efficient or optimal allocation. Italian Economist Vilfredo Pareto introduced these concepts of income distribution and economic efficiency. Pareto Improvement (PI) is the stage when in given resource allocation condition, reallocation of resources can make some individuals/group better off without making any other individual worse off. Kaldor-Hicks principle of hypothetical compensation is the basis of benefit cost analysis (Hanley and Spash, 1998). Modern welfare economics examines whether there is potential for compensating the losers but does not require the actual compensation to take place. Potential for compensation arises if the benefits outweigh the costs of a project/program. This approach also assumes at least initially constant marginal utility of money income and hypothetical compensation through costless transfers. This is called Potential Pareto Improvement (PPI).

For PPI analysis, the benefit stream attributed to reclamation will be compared to the reclamation costs estimation, current monies allocated for reclamation and reclamation budget deficit. The Net Present Value (NPV) of the estimated benefit stream will be calculated. The benefit stream from lake-based recreation due to reclamation is assumed to continue for another 20 years after completing reclamation in 2021. The benefit streams are assumed to be from 2021 through 2040.

The NPV of the reclamation costs will be estimated. Reclamation costs will increase each year with the increase in costs of heavy equipments and labor. At the same time, the present value of the costs in future needs to be discounted. Therefore, real interest rate is calculated and used for computing the NPV of reclamation costs.

$$i_r = \frac{i_n - r}{1 + r}$$

where, i_r is the real interest rate, i_n is the nominal interest rate, and r is the rate of inflation.

$$NPV = \frac{RC}{(1+i_r)^n}$$

where, *RC* is the reclamation cost, and *n* is the number of years for discounting.

Comparison of NPV of the benefits and costs will be used to analyze whether the recommended policy is a PPI. In other words, this analysis provides information about whether the policy will improve the overall social welfare.

Another aspect of this problem is the distribution issue. This problem embraces the issues of demand for the resources and services, income and wealth distribution. In this research, characteristics of the population in study area including their demand for various resources such as recreation and electricity, and their income and wealth will be analyzed. This might help to investigate if any policy adjustments need to be made in order to mitigate the impacts to the lower income and/or wealth position population.

CHAPTER 4

4 DATA ANALYSIS AND RESULTS

4.1 Study area

Coal electric power plants of the state of Ohio and coal mining area of eastern and southeastern Ohio are the focus areas of this study.

4.2 Sampling frame

Twenty-two public lakes under USACE and ODNR in eastern Ohio were studied (Table 17). Twenty-three power plants in Ohio shown in Table 1 were studied for the air borne externalities associated with them.

Table 17 Studied Public Lakes in Central and Eastern Ohio

1	Atwood	12	Piedmont
2	Beach City	13	Pleasant Hill
3	Berlin	14	Senecaville
4	Burr Oak	15	Tappan
5	Charles mill	16	Wills Creek
6	Clendening	17	Leesville
7	Dillion	18	Wolf run
8	Kokosing	19	Alum creek
9	Michael Kirwan	20	Deer creek
10	Mohawk Dam	21	Delaware
11	Mosquito creek	22	Paint creek

4.3 Data Collection

The annual visitation for water based recreational activities such as boating, water skiing, swimming and fishing for the year 2006 was retrieved from USACE website. The USACE created a visitation estimation and reporting system (VERS) to record visitation data. The visitation data were collected for individual activities. Since water based recreation activities such as boating and swimming are not mutually exclusive activities, boaters can also swim in the same visit. This leads to potential problem of double counting in total number of visitors. In order to address this problem, 15% of the total boaters and swimmers population to each of the lake were assumed to participate in both the recreational activities.

Information on characteristics of lakes that govern the boating and fishing activities such as HP and water surface area were obtained from USACE website and ODNR websites. Distances from lake to highway, a proxy for travel cost were estimated using MapQuest. Data on population and income were obtained from the census database in tract level. The median household incomes at 20 and 30 miles buffer zone of the lakes were used. Dummy variables for substitute or complimentary recreation site/s at 25 miles distance from the Lake were determined using GIS. Data on specific conductivity (SC) of the lake water and sulfate were obtained from USACE office/s.

4.4 Estimation and Results

4.4.1 Visitation function estimation

Several regressions were run to evaluate the impact of upstream coal mining on water based recreation on lakes. Variables were transformed to fit the regression and best fitted double log regression results were used for explaining visitation. Regressions were run using total area of lakes in the vicinity, income, and population within 20 miles and 30 miles radius distances from target lakes for all the water based recreational activities. Regressions were also run using SC and were not found statistically significant, thus the results are not discussed in this text.

Coefficients signs confirm to theory (Table 18). For example, larger surface area of lakes enhances the total water based recreation visitations to a lake significantly. On the contrary, the farther the lake is from an interstate highway, the higher the travel time and fuel cost. Thus the variable, distance to highway is negatively correlated with the visitation. However, the variable was not found significant in all cases. This could be because most of the sample lakes were from eastern Ohio, in and around Muskingum Watershed Conservancy District; thus less variability within this variable might have resulted in its insignificance. Similarly, the variables income and substitute lakes have correct signs, demonstrating that higher family income means more budget available for recreation; while substitute lakes in the vicinity lowers the visitation to the target lake. However, the regression analysis could not consistently demonstrate them as statistically significant. The models show that the independent variables explain 46 to 64.4 percent of the variation in the dependent variable.

Table 18 Regression Analysis Results

Variables	Total	Fishing	Swimming	Boating
Area	1.112***	0.837***	0.85	0.792
Dist_Hwy	-0.261	-0.226	-0.129	-0.302
Income	1.768	0.83	2.711	-0.992
Subst_Lk	-0.057	-0.038	0.221*	0.087
HP		_	_	0.294
Wat_Qlty	-0.434***	-0.424***	-0.683*	-0.083
Constant	-12.229	-0.953	-23.696	15.099
R2	0.644	0.475	0.46	0.547

Note * denotes statistical significance at *20, **10 and ***5 percent level.

The SO_4 level in water, which is the measure of upstream coal mining impacts was found significant in the case of total water based recreation visits, swimming, and fishing, while the variable was not found significant in case of boating. This could be because boating is a non-water contact recreation activity except for water skiing, which constitutes a small proportion of total boating activity. According to the analysis, the sulfate level in the water does not significantly impact boating.

According to the regression analysis, coal mining related loss in number of visitors for water based recreation ranged from 49,000 to 128,000 per lake per year in case of fishing, while that for swimming were 9,000 to 49,000 (Table 19). Anglers were found most impacted. Boating was found the least impacted; nevertheless a decrease in visitation of 3,000 to 12,000 was estimated.

Table 19 Annual Losses in Number of Visits to Five of the Impacted Lakes

Lakes	**Number of visitation reduced due to coal mining**			
	Fishing	**Swimming**	**Boating**	**Total**
Piedmont Lake	128,526	49,603	9,727	**187,856**
Senecaville Lake	53,200	28,452	8,635	**90,286**
Wills Creek Lake*	49,617	9,114	3,622	**62,353**
Tappan Lake	176,074	26,141	12,749	**214,963**
Clendenin Lake	97,157	50,488	7,845	**155,490**
Total	**504,574**	**163,797**	**42,578**	**710,949**

*Current swimming visitation zero.

A discussion on translating this decreased number of visits to loss in recreational revenue will follow.

4.4.1.1 Evaluation of externality

Recreational damage to impacted lake due to SO_4 level higher than that of comparable unimpacted lake is considered as the externality cost of coal mining. Leesville Lake in the region is the unimpacted lake. Therefore, damages attributed to the difference in SO_4 level between an impacted lake and Leesville Lake is considered as the recreational damage from coal mining. Estimated total water based recreation benefit from improving the water quality condition in five of the coalmine impacted lakes ranged from $1.8million to $3.6 million with a total of $ 18.04 million per year (Table 20).

This is a lower bound proxy estimate for recreational damage from coal mining in a part of eastern Ohio. There are other designated coalmine impacted lakes for which there were no visitation and water quality data available. Damages to those lakes are not included in this research. In addition to that there are several river and stream segments impacted by coal mining, which are not included in this research. Evaluation of damages to all the impacted lakes and streams segments will increase the total recreational damage attributed to coal mining.

Table 20 Recreational Damages to Impacted Lakes (2006 $ per annum)

Lakes	Fishing	Boating	Swimming	Total
Piedmont	2,639,678.51	314,698.47	1,276,631.72	**4,231,008.70**
Seneca	1,976,628.75	988,851.63	1,125,448.96	**4,090,929.34**
Tappan	3,639,289.37	422,194.60	235,385.98	**4,296,869.95**
Wills Creek	1,032,635.37	124,246.53	677,611.85	**1,834,493.75**
Clendenin	2,022,864.43	262,779.62	1,304,115.49	**3,589,759.54**
Total	**11,311,096.43**	**2,112,770.85**	**4,619,194.01**	**18,043,061.28**

4.4.2 Reclamation Costs Estimation

Reclamation costs were estimated using the database on AML obtained from ODNR. The reclamation costs estimate from ODNR does not include the AMD reclamation costs. The AMLs were categorized according to the type of AML problems and priorities assigned to them. Reclamation costs were estimated for each AML problem type based on the per unit (number, acreage, feet, or miles) reclamation costs deduced from the database using the following formula.

$$RC = \sum_{i} CU_i * U * I$$

where RC is the reclamation cost; CU is the per unit reclamation cost deduced from database; U is the unit of AML (acres, numbers, feet, miles); and I is the inflation factor to convert dollars to 2009 dollars.

Per unit reclamation costs were estimated in different ways. If an AML is part reclaimed and part unreclaimed; reclamation costs were estimated based upon per unit cost of reclamation for the completed unit. In case of the AML without reference per unit reclamation cost, reclamation costs for adjacent units with similar type of AML problems were used. In other cases, average per unit cost of reclamation for a type of AML problem in a county was used as reference per unit cost for estimating costs of reclamation for other unreclaimed mines. For some types of AML problems, all units were unreclaimed. In such AML problems, costs estimated by ODNR were used. Based upon the year of reclamation, the reclamation cost was then translated to 2009 dollars.

Since it takes years to complete reclamation of AMLs, reclamation costs estimated for the year 2009 were spread over several years. Office of Surface Mining Reclamation and Enforcement (OSMRE), ODNR has budget allocation for AML reclamation until 2021. Therefore an assumption is made that that the government's reclamation effort will continue until 2021. Another assumption made was that the AMLs under priority-1 and 2 are given first priority to be reclaimed since they have public safety issues, followed by priority-3, which embraces environmental issues. Cost distribution is presented in Table 21. Priority-3 problem area controlling environmental issues shares 35.56% of the total reclamation costs.

The reclamation costs in AML database include only the construction cost. The whole procedure of reclamation involves surveying the sites, reclamation planning by engineers, and other overhead costs. Generally about 50 percent of the AML fund goes to construction and the rest to administrative and overhead costs. According to ODNR, 48.7% of the fund will be allocated for construction in 2011.

Table 21 Estimated Reclamation Costs for AML in Ohio

Unit (million dollars, 2009)

Year	Construction Costs		Administrative Costs		Construction and administrative Costs		
	Priority 1 & 2	**Priority 3**	**Priority 1 & 2**	**Priority 3**	**Priority 1 & 2**	**Priority 3**	**Total**
2010	18.262	5.995	17.546	5.760	35.809	11.755	**47.563**
2011	21.212	8.462	18.069	7.208	39.281	15.670	**54.952**
2012	29.499	16.300	25.028	13.829	54.526	30.129	**84.656**
2013	29.061	18.587	24.360	15.580	53.421	34.168	**87.589**
2014	27.645	15.693	22.619	12.840	50.264	28.533	**78.796**
2015	24.503	10.481	19.646	8.404	44.149	18.884	**63.033**
2016	21.723	12.788	16.671	9.814	38.394	22.601	**60.996**
2017	27.081	12.759	20.167	9.502	47.248	22.261	**69.509**
2018	33.130	16.136	23.938	11.659	57.068	27.795	**84.863**
2019	3.688	6.068	2.585	4.253	6.272	10.320	**16.593**
2020	3.534	5.241	2.403	3.564	5.937	8.805	**14.742**
2021	3.612	4.627	2.382	3.051	5.994	7.677	**13.671**
2022	3.681	4.038	2.353	2.581	6.034	6.619	**12.654**
Total	**246.632**	**137.175**	**197.766**	**108.044**	**444.398**	**245.219**	**689.616**

The amount required for reclamation will increase each year with increases in fuel, labor, and equipment costs. The costs need to be adjusted for inflation during the period of reclamation. Then estimated reclamation cost is compared with the revenue generated from coal mining.

4.4.3 Estimation of revenue from coal mining

Revenue from coal mining is estimated using the coal production forecast in Ohio until 2021 and the taxes on coal mined by companies in Ohio. The funding of AML reclamation has three sources: federal monies, state tax monies, and leveraged fund. The federal fees on underground and surface mined coal are 15 and 35 ¢/ton of coal mined respectively for the year 2007 and they are proposed to decline by 10 % every year until 2021. The state severance tax rate is 6 ¢/ton of coal (Source: ODNR website); however the monies are distributed towards several other things including forfeiture sites reclamation. According to ODNR, only the revenue from 2 ¢/ton of coal tax is allocated to AML reclamation. In 2006, Public Law 109-432 was signed into law allowing state severance tax until 2021. Leveraged fund includes the funds from OEPA 319 grants, funds from USCORPs, and MWCD funds. The reliability of leveraged fund sources is low according to ODNR.

The ODNR estimates that federal funding share on AML reclamation will increase while the state and leveraged funds will decrease over the period of time (Table 22).

Table 22 Share of sources of AML funding

Unit: Percentage

Year	Federal	State	Leveraged
2009	82.9	9.8	7.3
2010	86.9	7.5	5.6
2011	87.8	6.9	5.1
	91.4	4.9	3.7

Coal production from surface and underground mining in Ohio was estimated based upon forecasted coal production in Appalachia, obtained from EIA website (Table 23).

Table 23 Coal production forecast in Ohio (million short tons)

Year	SURFACE	UNDERGROUND	TOTAL
2007	6.7830	15.7930	22.5760
2008	6.9931	16.2821	23.2751
2009	6.4284	14.9674	21.3959
2010	6.3777	14.8492	21.2269
2011	6.3589	14.8055	21.1644
2012	6.4747	15.0753	21.5500
2013	6.4215	14.9514	21.3729
2014	6.2835	14.6300	20.9135
2015	6.1339	14.2817	20.4157
2016	6.0190	14.0141	20.0330
2017	5.9949	13.9580	19.9529
2018	5.9010	13.7395	19.6405
2019	5.9767	13.9158	19.8925
2020	5.9872	13.9402	19.9274
2021	5.9629	13.8836	19.8465
2022	5.9545	13.8639	19.8184
2023	5.9390	13.8279	19.7669
2024	5.9191	13.7817	19.7008
2025	5.9217	13.7877	19.7094
2026	5.9481	13.8491	19.7972
2027	5.9135	13.7685	19.6820
2028	5.8160	13.5415	19.3575
2029	5.8199	13.5505	19.3704
2030	5.8585	13.6404	19.4989

Revenue stream for AML reclamation until 2021 is estimated to be $32.6 million from federal tax, $5.35 million from state severance tax and $1.05 million from leveraged sources (Table 24).

Table 24 Source Wise AML Reclamation Funds (2009 $)

		Federal			State			Total
Year	**Surf**	**Undgrnd**	**Total**	**Surf**	**Undgrnd**	**Total**	**Leveraged**	
2009	2.250	2.245	4.495	0.129	0.299	0.428	0.324	5.25
2010	2.009	2.005	4.014	0.128	0.297	0.425	0.225	4.66
2011	1.803	1.799	3.602	0.127	0.296	0.423	0.190	4.22
2012	1.652	1.648	3.301	0.129	0.302	0.431	0.125	3.86
2013	1.475	1.471	2.946	0.128	0.299	0.427	0.078	3.45
2014	1.299	1.296	2.594	0.126	0.293	0.418	0.054	3.07
2015	1.141	1.138	2.279	0.123	0.286	0.408	0.034	2.72
2016	1.008	1.005	2.013	0.120	0.280	0.401	0.018	2.43
2017	0.903	0.901	1.804	0.120	0.279	0.399	0.004	2.21
2018	0.800	0.798	1.599	0.118	0.275	0.393		1.99
2019	0.729	0.728	1.457	0.120	0.278	0.398		1.86
2020	0.658	0.656	1.314	0.120	0.279	0.399		1.71
2021	0.589	0.588	1.178	0.119	0.278	0.397		1.57
Total	**16.32**	**16.28**	**32.60**	**1.61**	**3.74**	**5.35**	**1.05**	**38.99**

Federal budget allocation for Ohio for AML reclamation amounts to $151.5 million over the period of 2010 to 2021. Including state and leveraged fund, Ohio will have $157.9 million in total for AML reclamation. However the estimated total cost of reclamation is $ 670.620 million (2009 dollars). This leaves a large budget deficit of $512.721 million dollars (Table 25).

Table 25 Revenue Generation, Reclamation Costs, and Deficits

Year	Reclamation cost	Total AML funds	Deficit
2010	44.091	12.252	31.839
2011	51.874	13.250	38.624
2012	80.338	19.014	61.325
2013	84.348	19.156	65.192
2014	76.748	17.706	59.042
2015	61.773	14.272	47.501
2016	60.142	14.242	45.900
2017	68.953	16.118	52.834
2018	84.694	22.003	62.691
2019	16.593	2.493	14.100
2020	14.742	2.398	12.344
2021	13.671	2.499	11.173
2022	12.654	2.497	10.157
Total	**670.620**	**157.899**	**512.721**

One way of generating the total funds required for reclamation would be by increasing the state severance tax and federal fees.

$$T_{ig} = \frac{RC}{P_i * S_i * S_g}$$

where,

$$i \begin{cases} \text{Surface mined coal} \\ \text{Underground mined coal} \end{cases} \qquad g \begin{cases} \text{Federal fees} \\ \text{State severance tax} \end{cases}$$

RC is annual reclamation cost, P is annual production of coal, S is share in percentage.

$$\Delta T_{ig} = T_{ig} - t_{ig}$$

where, t_{ig} is current tax.

An increase in tax of 0.2 ¢/ton of underground mined coal to \$1.3 per ton of surface mined coal is required in order to bridge the projected budget deficit for reclamation (Table 26).

Table 26 Proposed Incremental Taxes

(Dollars per ton of coal)

	Federal Fees		State tax	
Year	Surface	Underground	Surface	Underground
2010	1.56	1.49	0.21	0.17
2011	2.05	1.89	0.18	0.16
2012	3.36	3.00	0.27	0.23
2013	3.75	3.33	0.19	0.16
2014	3.60	3.19	0.12	0.10
2015	3.02	2.68	0.04	0.04
2016	3.09	2.73		
2017	3.62	3.18		
2018	4.61	4.02		
2019	0.79	0.74		
2020	0.70	0.65		
2021	0.65	0.61		
2022	0.61	0.57		
2010-2012	2.68	2.43	0.21	0.18
2013-2021	2.30	2.04	0.08	0.07

4.4.4 Benefits from Reclamation:

Reclamation of coal mined land will result in several benefits. Aesthetic benefits, increase in value of housing property, reduction in mine subsidence, decrease in downstream water treatment costs, and rise in land values adjacent to the impacted area are other benefits of reclamation in addition to recreation benefits from lakes and streams. This research focused on only a subset of the benefits from coal mine reclamation, the lake based recreation. According to an earlier study Randall (1978), fish, wildlife and recreational benefits were .46% of the total damages from coal mining. The study found that aesthetic damages constitute 96% of the total damages followed by 3.11% damages attributed to land and buildings, 0.46% to flooding damages, and 0.21% to water treatment.

Lake based recreational benefits attributed to upstream reclamation range from $3.8 million to $ 5.75 million from five of the impacted lakes depending upon the assumptions on level of lake sulfate reduction achieved (Table 27). The rest of the impacted lakes do not have either data on sulfate level or recreation data. Since damages to many of the impacted lakes could not be estimated, the damage estimated here is a conservative estimate of the total recreational damages attributed to coal mining.

Table 27 Recreation Revenue from Increased Reclamation

2009 Dollars

Activity	Lakes	6.5% reduction	15% reduction	35% reduction
Fishing	Piedmont	207,210.16	238,241.90	332,628.00
	Seneca	1,096,791.51	1,260,391.22	1,757,996.06
	Tappan	310,089.91	356,528.88	497,777.64
	Wils creek	95,456.46	109,758.77	153,233.27
	Clendening	174,400.15	200,366.37	279,399.01
		1,883,948.19	**2,165,287.14**	**3,021,033.98**
Boating	Piedmont	142,746.00	146,905.92	158,792.80
	Seneca	856,845.18	881,911.36	953,537.56
	Tappan	197,463.77	203,212.13	219,637.99
	Wils creek	59,625.12	61,380.56	66,396.70
	Clendening	122,883.61	126,484.16	136,806.76
		1,379,563.68	**1,419,894.13**	**1,535,171.81**
Swimming	Piedmont	40,101.51	49,128.53	77,930.36
	Seneca	497,323.13	607,431.82	958,747.53
	Tappan	8,334.07	10,210.10	16,195.82
	Wils creek	26,818.75	32,855.76	52,117.60
	Clendening	46,835.95	57,290.57	90677.2095
		619,413.42	**756,916.78**	**1,195,668.52**
Total	Piedmont	390,057.68	434,276.34	569,351.15
	Seneca	2,450,959.82	2,749,734.40	3,670,281.15
	Tappan	515,887.75	569,951.12	733,611.45
	Wils creek	181,900.33	203,995.09	271,747.56
	Clendening	344,119.71	384,141.10	506,882.98
All Lakes & activities		**3,882,925.29**	**4,342,098.05**	**5,751,874.30**

Net present value (NPV) of the recreational benefit stream was estimated using the following equation.

$$NPV = \frac{RC}{(1+i_r)^n}$$

where RC is the reclamation benefit, i is the discount rate, and n is the number of years of revenue flow.

Discount rate of 7% per annum (discount rate proposed by Office of Management and Budget, Circular No. A-94) is used to estimate the NPV of reclamation benefits. Sulfate level reduced in each impacted lake corresponding to reclamation upstream are assumed as 6.5%, 15%, and 35%. According to Hren, Wilson, and Helsel (1984), the difference between the SO_4 levels in lakes downstream from abandoned mines and reclaimed mines in Ohio was 7.25% in 7 years period. A 12 years reclamation time frame will more likely be achieving a 15% reduction in SO_4 level. A sensitivity analysis assuming 35% and 6.5% corresponding respectively to accelerated and slowed down reclamation were also done. The NPV of reclamation benefits were then calculated assuming that designated percentage of sulfate reduction will be achieved after 12 years of reclamation, by 2021. It was further assumed that the benefit stream will continue until 2040. Benefit stream prior to 2021 are also estimated assuming 3.25% reduction in sulfate level by 2015.

The NPV of the benefit streams ranges from $29.8 to $44.2 million based upon reduction in SO_4 level in the lakes; the most likely result of reducing SO_4 levels by 15%, is expected to provide a recreational benefit of $33.37 million (Table 28). The benefit is the recreational benefit attributed to improvements in six of the impacted lakes and does not include recreational benefits from other impacted lakes and streams. In addition to that, reclamation of those AML land will also enhance land based recreation and other non-use based value. Therefore, this estimation might not be the accurate number but is the best possible result from the foregoing research.

Table 28 Net Present Value of Recreation Benefits (2009 US dollars)

Period	Lakes	6.5% Reduction	15% Reduction	35% Reduction
2012-2021	Clendenin	1,066,130.76	1,190,122.58	1,570,394.02
	Piedmont	1,208,452.99	1,345,448.55	1,763,929.12
	Seneca	7,593,414.65	8,519,059.91	11,371,041.86
	Tappan	1,598,292.05	1,765,787.89	2,272,830.39
	Wills Creek	563,552.54	632,005.18	841,911.77
	Total	**12,029,842.99**	**13,452,424.10**	**17,820,107.15**
	Lakes	**6.5% Reduction**	**15% Reduction**	**35% Reduction**
2012-2040	Clendenin	2,645,340.11	2,952,995.20	3,896,544.84
	Piedmont	2,998,477.59	3,338,398.22	4,376,754.38
	Seneca	18,841,182.73	21,137,942.76	28,214,431.47
	Tappan	3,965,766.91	4,381,366.46	5,639,467.16
	Wills Creek	1,398,316.41	1,568,164.72	2,088,996.09
	Total	**29,849,083.75**	**33,378,867.36**	**44,216,193.94**

4.5 OH-MARKAL Adaptation

Coal externality costs from reclamation of abandoned mines were incorporated into cost of coal for the power plants. Externality cost per ton of coal was translated to cost per BTU (Table 29) using conversion factor of 1 ton of coal = 20,169,000 Btu (Source: EIA).

Table 29 Externality Costs per million BTU of Coal

Year	Surface	Underground
2009	0.09	0.09
2010	0.12	0.11
2011	0.19	0.17
2012	0.20	0.18
2013	0.18	0.16
2014	0.15	0.13
2015	0.15	0.13
2016	0.18	0.16
2017	0.22	0.19
2018	0.04	0.04
2019	0.03	0.03
2020	0.03	0.03
2021	0.03	0.03
2010-2012	0.15	0.13
2013-2021	0.11	0.10

Early peak of 2009 shows cost of coal for power plants as $1.47 per million BTU (EIA). Extended OH-MARKAL model incorporates these externality costs to the EIA forecasted coal prices for electricity sector until 2030 (Table 30).

Table 30 EIA Forecasted Price of Coal

Unit: Dollars per million BTU

Year	Price of Coal
2010	1.89
2011	1.90
2012	1.92
2013	1.92
2014	1.93
2015	1.94
2016	1.93
2017	1.92
2018	1.92
2019	1.92
2020	1.92
2021	1.92
2022	1.93
2023	1.93
2024	1.94
2025	1.96
2026	1.97
2027	1.98
2028	2.00
2029	2.02
2030	2.04

4.5.1 Incorporation of externalities

Cost of coal per BTU after adding the tax was used for analysis in the OH-MARKAL model. Impact of the new cost of coal on share of coal based electricity generation, emissions of GHGs and acid gas were analyzed.

Change in coal use for electric generation under new cost of coal and under several policy scenarios were analyzed. Under business as usual (BAU) case, an average annual reduction of 0.38% is observed in coal use (Table 31). Similarly, if the Advanced Electricity Portfolio Standard (AEPS) is successfully implemented, a reduction of 0.08%

in coal use will be observed. The AEPS diversifies the electricity portfolio introducing other non fossil fuel sources for electricity generation. Since implementation of AEPS reduces the coal use, the incremental reduction in coal use under new social cost of coal is smaller in this case. If in addition to AEPS, Energy Efficiency (EE) is also implemented successfully; average annual reduction in coal use will be 0.16%. Increased EE reduces the demand for electricity in general; therefore marginal reduction in coal use is higher in this case.

Table 31 Change in Coal use with and without New Coal Price (trillion BTU)

Year	BAU	BAU NCP	Change%	EE+AEPS	EE+AEPS+NCP	Change%	AEPS	AEPS+ NCP	Change%
2011	1568.70	1556.50	-0.78	1470.00	1466.20	-0.26	1500.80	1499.30	-0.10
2014	1608.30	1603.10	-0.32	1494.80	1493.20	-0.11	1530.50	1528.40	-0.14
2017	1600.30	1594.70	-0.35	1460.40	1457.80	-0.18	1508.30	1507.30	-0.07
2020	1612.00	1610.90	-0.07	1433.70	1432.30	-0.10	1495.40	1495.40	0.00
2023	1651.20	1651.20	0.00	1440.50	1439.70	-0.06	1505.20	1506.20	0.07
2026	1698.50	1698.50	0.00	1433.50	1431.80	-0.12	1488.80	1488.70	-0.01
2029	1750.50	1750.20	-0.02	1514.30	1513.50	-0.05	1546.20	1545.50	-0.05
Average change			-0.38			-0.16			-0.08

This decreased coal use translates to reduction in greenhouse gasses as well as reduction in acid gasses. When externality costs of coal mining were internalized, CO_2 emissions were reduced by 15,000 to 574,000 tons annually as compared to BAU. Similarly, if APS were successfully adopted and the coal mining externality were internalized 1,000 to 21,000 tons of CO_2 will be reduced per annum. In another scenario, if EE and APS were implemented together with internalization of externality costs of coal mining will help in reducing CO_2 emissions by 8,000 to 39,000 tons of CO_2 per year (Table 32). Internalizing externality considering implementation of EE and APS shows CO_2 emissions by an average of 16.53 million tons a year (Figure 19 and 20).

Table 32 Reduction in CO_2 Emissions with new Coal Price
(Million tons)

Year	BAU	BAU NCP	Emission Reduction	APS	APS+NCP	Emission Reduction	EE+APS	EE+APS +NCP	Emission Reduction
2002	154.63	154.63		149.11	149.11		149.11	149.11	
2005	153.67	153.67		148.37	148.37		148.37	148.37	
2008	160.08	160.01		155.19	155.13		153.90	153.69	
2011	161.20	159.95	-1.246	154.29	154.13	-0.16	151.11	150.72	-0.39
2014	165.42	164.88	-0.538	154.28	154.07	-0.21	153.79	153.63	-0.16
2017	164.77	164.19	-0.574	152.20	152.10	-0.1	150.45	150.19	-0.26
2020	166.11	165.99	-0.119	150.15	150.15	0	147.85	147.70	-0.15
2023	170.16	170.16	0.000	147.56	147.67	0.11	148.59	148.51	-0.08
2026	170.07	170.05	-0.015	138.42	138.41	-0.01	147.93	147.77	-0.16
2029	168.93	168.90	-0.028	143.66	143.59	-0.07	153.10	153.36	0.26
Average Annual Change			-0.360			-0.063			-0.134

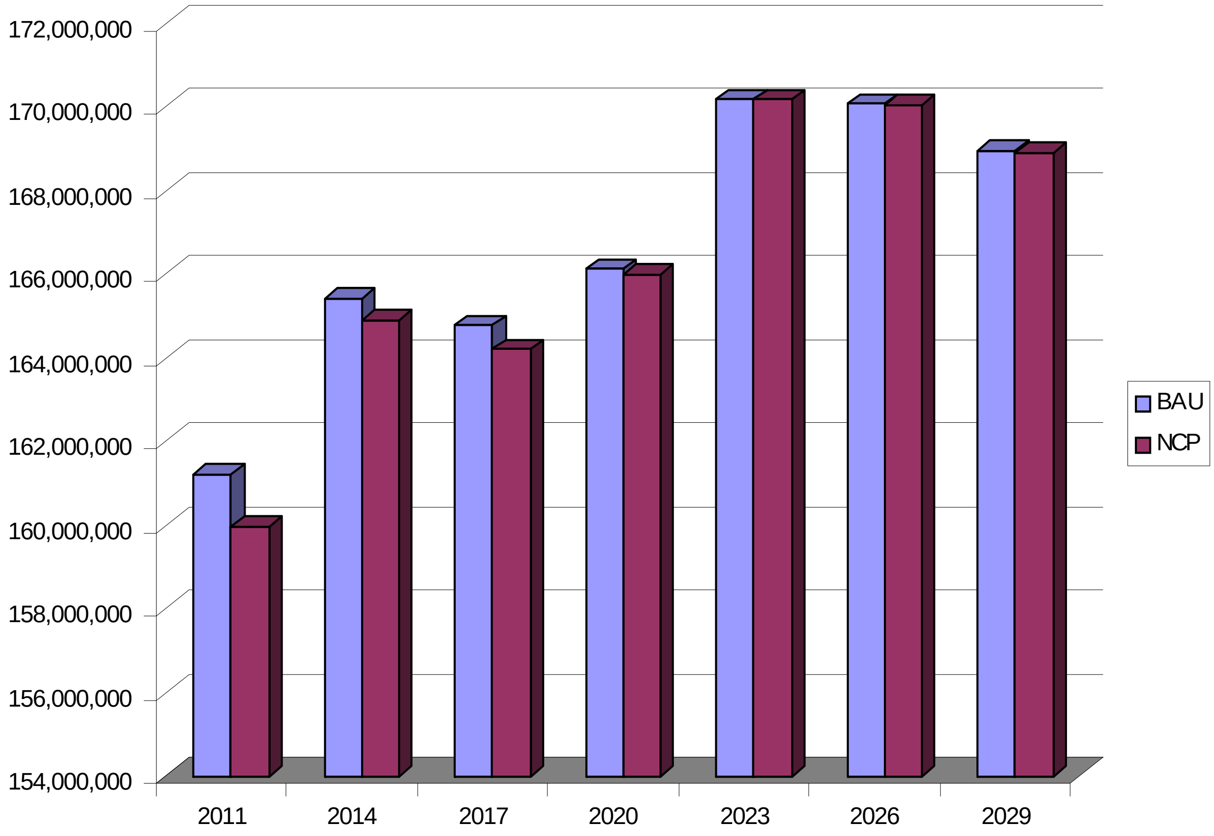

Figure 19 CO_2 emissions under BAU and new coal price situations.

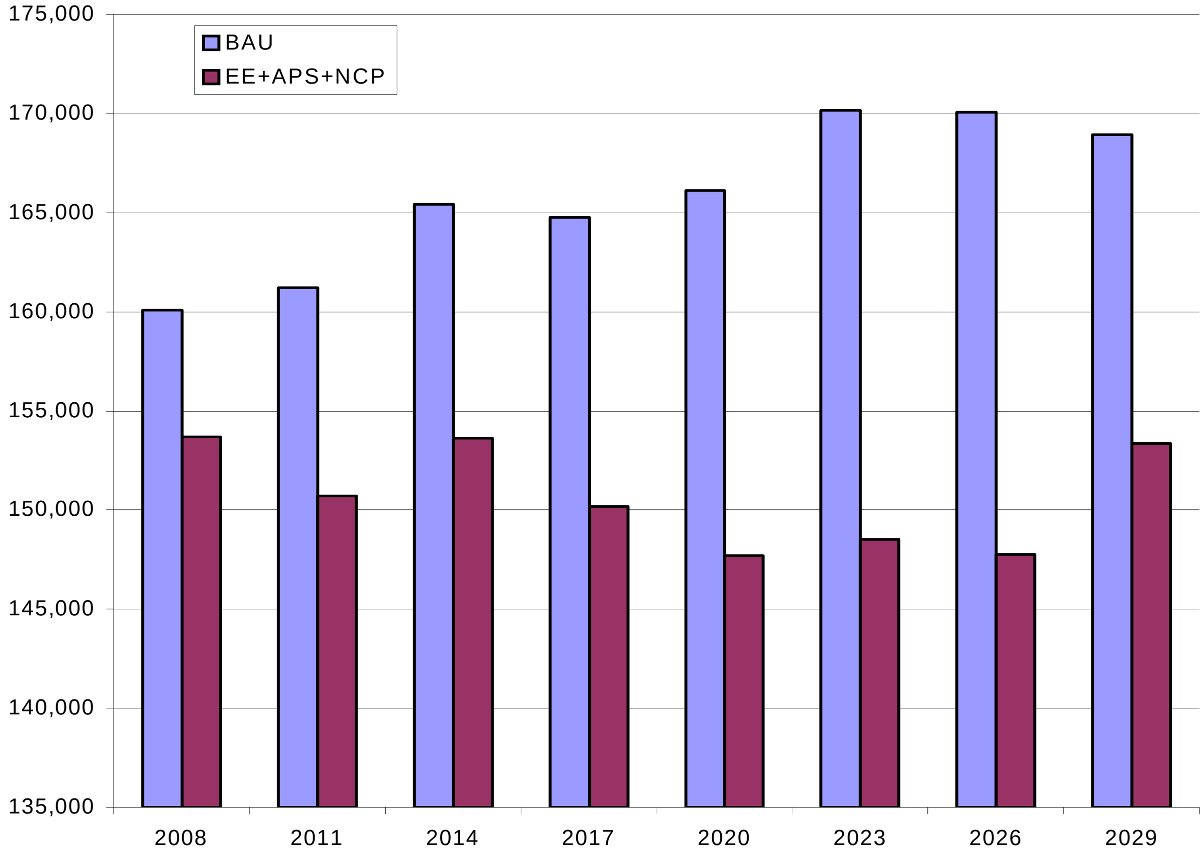

Figure 20 CO_2 Emission Reduction ('000 tons)

CAIR implementation is expected to reduce the NO_x level to 264,000 tons by 2009 and SO_2 emissions to 1,373,000 tons. Adoption of fuel mixing, purchasing permits and installing scrubbers, the acid gas emissions will be controlled. It is also expected that the old coal fired power plants will retire.

Table 33 Reductions in SO_2 Emissions by Internalizing Coal Mining Externalities (thousand tons)

Year	BAU	BAU NCP	Emission reduction	APS	APS+NCP	Emission reduction	EE+APS	EE+APS+ NCP	Emission reduction
2002	1,925.38	1,925.38		1,825.07	1,825.07		1,825.07	1,825.07	
2005	1,920.10	1,920.10		1,802.52	1,802.52		1,802.52	1,802.52	
2008	1,940.17	1,934.00		1,848.70	1,845.28		1,852.62	1,842.63	
2011	1,954.15	1,923.58	-6.17	1,836.54	1,833.61	-2.93	1,816.98	1,808.14	-8.84
2014	69.48	69.31	-30.57	66.99	66.92	-0.07	65.85	65.8	-0.05
2017	69.22	69.04	-0.17	66.28	66.25	-0.03	58.1	58.01	-0.09
2020	51.59	51.55	-0.18	47.85	47.85	0.00	45.88	45.83	-0.05
2023	52.84	52.84	-0.04	48.17	48.2	0.03	46.1	46.07	-0.03
2026	54.35	54.35	0.00	47.64	47.64	0.00	45.87	45.82	-0.05
2029	56.02	56.01	0.00	49.48	49.46	-0.02	48.46	48.43	-0.03
Average Annual Change			-4.424			-0.431			-1.306

Table 34 Reduction in NO_X Emissions by Internalizing Coal Mining Externalities (thousand tons)

Year	BAU	BAU NCP	Emission reduction	APS	APS+NCP	Emission reduction	EE+APS	EE+APS+ NCP	Emission reduction
2002	112.19	112.19		111.9	111.9		111.9	111.9	
2005	110.98	110.98		108.03	108.03		108.03	108.03	
2008	115.01	115.01		114.26	114.27		113.97	113.41	
2011	116.39	115.64	-0.75	113.89	113.2	-0.69	111.74	110.38	-1.36
2014	54.96	54.88	-0.08	54.15	54.11	-0.04	52.79	52.78	-0.01
2017	55.25	55.17	-0.08	54.05	54.04	-0.01	51.61	51.56	-0.05
2020	54.11	54.11	0.00	52.12	52.11	-0.01	49.83	49.81	-0.02
2023	55.41	55.41	0.00	52.81	52.77	-0.04	50.14	50.13	-0.01
2026	57.22	57.22	0.00	53.11	53.1	-0.01	50.3	50.3	0
2029	59.38	59.38	0.00	55.1	55.1	0.00	53.44	53.44	0
Average Annual Change			-0.303			-0.114			-0.29

4.6 Reclamation costs and offsets from benefits: PPI prospects

Total reclamation costs required to reclaim the coal mined lands was estimated to be $689.616 million until 2021.

Ongoing research was able to examine only the recreational benefits associated with reclamation of mines in the watersheds of certain impacted lakes and costs associated with them. The NPV of recreational benefits from five of the lakes is $13.12 million to $47.9 million. Several other impacted lakes and impacted streams are not investigated by this ongoing research. According to Sommer (2001), benefits from reclamation of the coal mines impacting Hocking River was $1.45 million per year. Benefits stream attributed to reclamation of 43 of the coal mining impacted rivers and streams segments can be realistically expected to be higher than the estimations of benefits from lakes in this study. Based upon the number of impacted streams and recreational impacts from coal mining, the NPV estimated in this research is a lower bound estimate of the total recreational benefits. Further benefits from reclamation are increased aesthetics, housing and land property values, clean water quality in streams and lakes. Earlier study by Randall (1978) shows that the recreational benefits constitute 0.47% of total benefits from reclaiming coalmining land. Therefore, total benefits from reclamation will likely be much higher.

Budget for reclamation is raised by taxing current coal mining companies. The coal mining companies translate the costs to consumers of electricity by increasing the price of electricity. Therefore, reclamation budget raised by imposing tax on coal mining companies eventually impacts the public, specifically the ratepayers.

Increased electricity price will be imposed on ratepayers regardless of their income levels. However, impacts of higher electricity price are different for high and low-income groups. In the meantime reclamation results in several benefits to society, which are location and income specific. A brief PPI prospectus on these issues is discussed here.

Recreational benefit streams are distributed to people participating in recreation on one of the studied lakes in eastern Ohio. Since recreation is income sensitive, people with higher income recreate more than the low-income people. Therefore, the benefit stream distribution is skewed towards higher income people.

In the meantime, higher income people own bigger homes and have more electric gadgets, and therefore they tend to pay higher electric bills. On this basis, higher utility from recreation in cleaner lakes might offset higher electric bills for higher income people. However, the low-income people pay higher electric bills, while they might not be able to reap the benefits of recreating in cleaner water in lakes.

Reclamation affects many other aspects of the region such as human health and safety issues related to mine subsidence, clogged streams, dangerous highwalls etc. Mitigation or elimination of such problems results in benefits to society, however this research does not include such benefits. Thus PPI of the proposed policy here is based on incomplete information regarding total benefits from reclamation. If at some point, all the benefits of reclamation are estimated, PPI will be different and most likely support the policy to revisit tax on coal mined in Ohio as a PPI policy.

Another way of analyzing this project would be by comparing the cost and benefits associated with the five impacted lakes.

The coal mined lands are located throughout eastern and south eastern counties of Ohio. Notwithstanding the fact that it may be important to reclaim all these mined lands, the budget constraint forces prioritizing the reclamation process of these mined lands. The benefit cost analyses of the reclamation is used here to set the reclamation priorities. In other words the first priority for reclamation should be given to the mined land associated with the highest recreation benefits from reclamation.

An analysis of the benefits and costs associated with five of the studied impacted lakes might provide implications for setting reclamation priorities.

Reclamation costs associated with coal mined land in watersheds of five of the lakes ranges from $312,000 for Wills Creek Lake to $27.4 million for the reclamation of coal mined land in the watershed of Piedmont Lake (Table 35). The coal mined lands in the watersheds of Tappan and Clendenin Lakes are not in AMLIS and thus it was not possible to identify the type and extent of the problem. Therefore, the cost estimates for the reclamation efforts for the watersheds of the two lakes could not be estimated.

Table 35 Lake-watershed wise reclamation costs

Lakes	Reclamation Costs (2009 $)
Seneca	3,830,478.06
Piedmont	27,393,978.29
Wills Creek	312,500.00
Clendenin	not in AMLIS
Tappan	not in AMLIS

An analysis of NPV of the costs and benefit streams from reclamation shows that it is most beneficial to reclaim coal mines in the watershed of Seneca Lake (Table 36).

Table 36 NPV of Benefits from Reclamation (2009 US dollars)

Lakes\Period	Year 2010-2021 With 15 % reduction in SO_4	Year 2010-2040 With 15 % reduction in SO_4
Seneca	8,519,059.91	21,137,942.76
Tappan	1,765,787.89	4,381,366.46
Piedmont	1,345,448.55	3,338,398.22
Clendenin	1,190,122.58	2,952,995.20
Wills Creek	632,005.18	1,568,164.72

The coal mined lands in the north east corner of Noble County in the watershed of Seneca Lake should be the first priority for reclamation.

CHAPTER 5

5 SUMMARY AND CONCLUSIONS

5.1 Recapitulation

This section summarizes the background and research problem, objectives, methodology, and principal findings of this study.

5.1.1 Background and objectives

Advancement in knowledge on global climate change and its impact has intensified the urgency for reducing GHGs emissions including CO_2. The CO_2 emissions from electricity sector make up 33 % of total anthropogenic CO_2 emissions and coal contributes 99% of CO_2 emissions from electricity sector (EIA, 2007). One way of reducing CO_2 emissions from a point source of pollution (example electricity sector) is through diversifying the electricity portfolio by increasing the share of renewable energy sources. However, coal based electricity makes up a large portion of electricity generation in states like Ohio, largely because it is considered the most cost effective source of electricity. The cost of coal-based electricity is comparatively lower because the externalities associated with it are not fully internalized due to inadequate regulations such as mandatory CO_2 emissions control. As a result, the market does not provide a level playing field for renewable sources of electricity, which could help reduce GHG emissions, improve the environment, and create green jobs.

Externality costs associated with coal based electricity generation are air borne pollutants including GHGs, and land use and water pollution issues associated with coal mining activities. Previous studies on externalities of coal power focus on air borne pollutants and not the coal mining impacts.

The principal objectives of this dissertation research were to identify the externalities associated with coal based electricity generation, evaluate a subset of the externalities namely coal mining and CO_2, and incorporate the estimated externality costs into OH-MARKAL model to examine the impacts of internalizing externalities on the electricity portfolio of Ohio. Specifically, externality costs were estimated using existing results from literature and extensive data and analyses on lake recreational impacts of upstream coal mining. In addition, estimates were used for reclamation costs of abandoned mine land in Ohio and the current tax structure in coal mining was revisited using data on estimated reclamation costs and monies from federal fees, state severance taxes, and leveraged funds. Finally, the reclamation costs and benefits were estimated and compared to the costs of electricity generated from various sources when externalities were internalized.

5.1.2 Method of Study

The visitation function model, a multiple regression model across twenty-two lakes in Eastern Ohio, used extensive data on lake characteristics, water quality, demographics and number of visits to the lakes to explain the relationship between visitation and explanatory variables. Geographic Information system (GIS) analyses and data on chemical concentration of lake water were used to identify coal mine impacts on the studied lakes. Chemical condition of the lakes sulfate (SO_4) and Specific Conductivity (SC) were the main variables of interest that signified coalmining impacts on visitation. The difference in number of visits to the lakes based on status quo and reduced SO_4 level were the impacts of coal mining. Using day use values derived from benefit transfer method for each type of recreation, the loss in recreation values were computed.

Reclamation costs are comprised of two components: construction and administrative costs. Construction costs were calculated on the basis of past costs required to reclaim per unit of each type of mining problem in each county. Administrative costs were estimated as a percentage of total reclamation costs based on ODNR data on reclamation efficiency. Reclamation efficiency is estimated as the percentage of total funds used for construction.

Revenue generated from taxes on mined coal was estimated using data on coal production forecast from EIA, and information on tax structure obtained from ODNR. The reclamation costs, revenue generated including so called leveraged funds, and deficit amount for reclamation were used to revisit the tax structure on surface and underground mined coal in Ohio.

The uncompensated portion of the coal mining impacts that is not included in the current cost structure of coal electricity production is introduced into the OH-MARKAL model as coal mining externality costs.

5.1.3 Limitations of the Study

This study had to settle on best possible options in cases of some of the data collection and methodology. The research estimated only a subset of externality costs imposed by coal base electricity generation. Coal mining impacts are vast and beyond the scope of one dissertation, therefore only lake based recreational loss from coal mining impacts and externality costs associated with CO_2 were the focus of this study.

In case of visitation function model, there were some potential limitations. First, the visitation data on lakes collected from USACE might not be consistent over the lakes. The lakes are under scrutiny of several USACE offices and data collection method on visitation varies from office to office. The data set has visitation numbers for each activity. However, it is highly likely that some visitors participate in more than one activity, so there might have been some double counting in recreational losses. In order to address this problem, a sensitivity analysis was carried out assuming 15% double counting among the boaters and fishers. Second, either visitation data or water quality data were unavailable for several impacted lakes in Ohio, which limited their inclusion in the study. As a result, degrees of freedom were reduced in the empirical estimation of visitation function model on one hand and the total impacts from coal mining on the impacted lakes were excluded from the results on the other. Third, the day use values for boating, fishing, swimming were obtained using benefit transfer method, which has some disadvantages over the estimations on willingness to pay. Last but not the least, this research was unable to fully examine the relationship between reclamation and recreation visitation. Therefore, a sensitivity analysis was done based upon the reduction in SO_4 observed by (Hren, Wilson, and Helsel, 1984). Their study found 7.25% reduction in SO_4

in water from reclaimed watershed as compared to that in abandoned watershed in seven year period. Therefore, this research used 15% reduction in SO_4 level pertaining to reclamation as a close approximation within 12 years. A sensitivity analysis with 50% up and down in SO_4 level was then followed.

When revisiting the tax on coal mined in Ohio, some of the information was imperfect. Estimating the leverage funding, funding from other government agencies and watershed groups was complicated. Thus, the data were generated by interpolation based on past trends on leverage funding.

Electricity portfolio should be designed incorporating the social costs of all these impacts. However, implications drawn here are based upon the evaluations of a subset of these externalities, namely CO_2, and lake based recreational losses of coal mining and estimation of reclamation costs.

5.2 Key Findings

5.2.1 Visitation Function Model

An empirical analysis of the impacts of upstream coal mining on recreational activities such as fishing, swimming, and boating was accomplished using visitation function model. Number of visits was explained by area of the lake, distance from nearest highway, area of near by lake/s, SO_4, and income of population in tracts at 30 miles radius from lake. Horsepower allowed in the lakes was a variable added for visitation function model for the boaters. Estimated reduction in annual numbers of visitation for fishing ranged from 49,627 to 176,074 per lake, while reduction in swimming visitation ranged from 9,114 to 50,488 per lake. The least impact was observed for boating visitation, which might be because sulfate level does not have high correlation with non-contact water recreation such as boating. It should be noted here that siltation is a problem associated with coal mining, which impacts boating. Lakes such as Beach city have turned into a wetland due to siltation of the lake from upstream mining and the present visitation function model does not address siltation. McGreggor (1988) estimated agricultural siltation impacts on boater value loss at $470,000 in 46 lakes of Ohio. Siltation from agricultural practices such as, row cropping and sediment deposition because of erosion from loose layer of topsoil as a result of coal mining are different issues. Thus sedimentation impacts of coal mining needs separate study and analysis.

Had there been no upstream coal mining, the sulfate level in the impacted lakes would be around the sulfate level in Leesville Lake, a coal mining impact free lake in the studied region. The impact of differential sulfate level in a status quo lake and Leesville Lake on the recreational visitation to the lake is thus considered as the proxy for the externalities to the lake associated with upstream coal mining.

The externality costs associated with coal mining on these lakes ranges from $1.8 million per year for Wills Creek Lake to $4.3 million for Tappan Lake. These values were estimated using the reduction in number of visitations specific to coal mining pollution and the reduction in day use value per trip for the activity because of reduced water quality. The total loss from deteriorated water quality due to coal mining ranges from $1.83 million to $4.29 million per year per lake. Estimated loss to Piedmont Lake is $4.2 million (2006$). Recreational losses to five of the impacted lakes in eastern Ohio were estimated at $19.23 million per year. In other words, if there had been no mining upstream of these lakes, the revenue from recreational activities in these lakes would increase by $19.23 million dollars per annum.

Hitzhusen *et al.* (1997) estimated the benefits from improving water quality of Piedmont Lake as \$1.5 million (updated value for 2006). Ongoing research estimated the benefits from each of the impacted lakes with improvement in water quality of the lakes by reducing SO_4 level by 6.5%, 15%, and 35%. The benefit of reducing SO_4 level by 15% in Piedmont Lake is estimated as \$434,000.

There are several lakes for which data on sulfate was unavailable and were not included in this research. Similarly, smaller lakes and private lakes impacted by mine drainage were excluded in this research. Therefore, the estimated damage is a lower bound estimate. Further research is needed to assess the full impacts of upstream coal mining.

In addition to these lakes, surface and deep coal mining in Ohio impacts are observed in 92 rivers and streams segments. According to OEPA report, AMD impacts were observed in 1300 stream miles in 42 of the river segments. Sommer (2001) estimations shows that improving water quality in AMD impacted segment of Hocking River will bring \$1.45 million benefit per annum from recreational activities. Estimation of impacts on all of the rivers would likely exceed the impacts on the lakes estimated here. Additionally, this study does not cover the costs associated with drinking water pollution problems and losses of ecological habitat downstream due to mine drainage.

According to an earlier study by Randal (1978) in Kentucky, the recreational losses constitute 2.6% of total loss from mining. So, even if recreation has increased over time, the total losses associated with mining in Eastern and South eastern Ohio including aesthetics, housing property values, value of lands would likely to be considerably higher than the estimated losses in this research.

5.2.2 Reclamation Costs

Another aspect of coal mining is the reclamation costs. Reclamation costs range from $223.4 per feet of high wall to $41.3 per feet ($218,129 per mile) of clogged stream problem, which are priority one and two problems (ODNR). Reclamation of all problematic mined land costs $ 689.616 million dollars over the period of 11 years, out of which $383.807million is construction costs and the rest is administrative costs. Total monies generated from federal and state tax through 2021 will be $ 36.356 million nominal value, since the interest is provisioned for retired coalmine workers. However, federal budget allocated for reclamation of mined land in Ohio is $157.899 dollars. Leverage fund is not a reliable source of funding; nevertheless expected funds of $1.05 million dollars will be allocated based upon the current trend on leverage fund. There might be more leveraged funds with increased awareness but this is uncertain. Netting out the federal and state monies, and leveraged fund from the required reclamation funds, there still will be a large deficit of $512.899 million for reclamation of all abandoned mines by 2021.

One way of securing the deficit funds would be by increasing the federal fees and state severance tax per ton of coal. Analyses in this research found that a federal fee of $2.68 and $2.04 per ton of surface and underground mined coal respectively until 2012 followed by $2.30 and $2.04 for the period of 2013 -2021 will generate required reclamation funds assuming leverage funds *ceteris paribus*.

5.2.3 Reclamation Costs and Recreation Benefits

By completing the reclamation, several externalities associated with coal mined lands will be mitigated. One of them is water quality improvement in lakes. A sensitivity analysis assuming sulfate reduction of 15% and 50% up and down of the reduced level was pursued. If SO_4 level will be reduced by 15%, then reclamation benefits would increase to $6.408 million per year. The most conservative assumption of 6.5% reduction in SO_4 level as compared to status quo sulfate level attributed to reclamation, in five of the studied lake resulted in an annual increase of $5.267 million dollars of recreational benefits. While an ambitious 30 % reduction will generate an additional $10.026 million of recreational benefits per year. The NPV of the benefits by reclaiming the coal mined lands in the watersheds of the five of the impacted lakes ranges from $32.5 million to $47.9 million dollars.

5.3 Implications:

The major implications of this research are on coalmine reclamation policy and restructuring the electricity portfolio of Ohio.

5.3.1 Reclamation of Coal Mined Land and Revisiting Tax on Coal

Reclamation effort should be expedited in order to complete reclamation of coal mined land problems in Ohio by the year 2022 as proposed by the federal government. Reclamation activity will need to increase by four to ten times that in 2005 and 2007 to meet the target, which translates to a large budget deficit. This research proposed increasing the tax as a measure to generate the necessary budget.

One of the major arguments on the foregoing increase in tax would be the intergenerational issue of the distribution of responsibility; whether the current generation should be charged for the historical damages. But a common issue that arises with cleaning up of historic pollution is that since the defunct businesses cannot pay for it the current generation needs to pay for the clean up. The Super Fund toxic sites clean up program is an example of the latter approach.

It should be noted here that, the tax on coal mining companies is eventually passed on to the ratepayers of electricity. The tax is internalized into cost of coal, so the price of electricity will rise. Eventually, the society as a whole pays for the reclamation.

Another side of the coin to these costs is the benefits from reclamation or mitigation of all these coalmining problems. Reclamation efforts enhance recreational and other ecological services from affected land and water. Based upon the estimated recreational benefits from five of the impacted lakes, a Potential Pareto Improvement (PPI) cannot be demonstrated from reclamation of all the priority-1, priority-2, and priority-3 coal mined lands and impacted areas. However, our analysis does not include all the impacted lakes and notably excludes several issues that would otherwise escalate the recreational and other benefits attributed to reclamation. The NPV of the total recreational benefits from five lakes ranges from $32.5 million to $47.9 million, while the reclamation costs of coal mined land in their respective watersheds is $31.5 million. Estimation of revenue from increased house values and land values, aesthetic improvement, water treatment costs, mine subsidence, recreation on streams and lakes, and wild life habitat attributed to reclamation effort would provide a clear picture on whether it is socially desirable or not to address all the coal mined land problems as proposed by this research.

5.3.2 Analysis on Internalizing Externalities

Internalization of the externality costs associated with coal mining and CO_2 increase the cost of electricity from coal. Furthermore, including these externality costs impacts on emissions of GHGs and acid gasses as well as on the mix of coal-based and renewable-based electricity generation in Ohio. When the externalities from coal mining is internalized, average annual share of coal based electricity generation will be reduced by 0.3 % under business as usual scenario which will be compensated by the wind, solar and biomass based electricity generation. More importantly, average annual emissions of CO_2 will be reduced by 15,000 to 574,000 tons per year. Since, a large part of emissions of SO_2 and NO_X will be taken care by CAIR implementation, SO_2 and NOx emissions reduction associated with new coal pricing are respectively 0.43% and 0.2% respectively, which is not a large change. CAIR is expected to reduce the NO_x level to 264,000 tons by 2009 and SO_2 emissions to 1,373,000 tons.

5.3.2.1 Distribution issues:

In Ohio, price of electricity differs depending upon the electricity provider to a region. Price of electricity is governed by several factors. *Ceteris paribus*, the share of Ohio coal used by the electricity generator affects the price of electricity distributed to a region. Increased tax is thus distributed throughout the state and beyond as an increase in electricity price.

The benefit from incorporating externalities has two spatial dimensions to it. First, mitigating CO_2 externalities involves global benefits. Second, reclamation of coal mining problems offers primarily local benefits.

From a micro level analytical view, the whole region pays higher electricity price to generate funds for reclamation, while the benefits attributed to reclamation from increased lake recreation, increased land and house values, and improved aesthetic values will be enjoyed by a population with specific demographic characteristics, living near the coalmines. One way of responding to this distribution issue would be by channeling a portion of tax/revenue from increased recreation and property values to reclamation efforts. In order to quantify this distribution issue, benefit streams from land and housing properties, and recreational values from the rest of the impacted lakes and all of the impacted streams needs to be evaluated. Furthermore, demographics such as income and/or wealth levels of the population participating in recreational activities in the region and owning the houses and land needs to be determined and analyzed.

In a separate analysis of the reclamation costs associated with coal mined lands in the watersheds of five of the impacted lakes and the recreational benefits associated with them, the net benefits from reclamation outweighs the total costs associated with them. The total benefits ranged from \$32.1 million to \$47.9 million, while the costs associated with reclaiming all mines in five lakes' watersheds was \$31.5 million. This analysis also concludes that reclamation of the mines in watershed of Seneca Lake should be given the first priority for their reclamation since the benefit to cost ration is the highest.

5.3.2.2 Competitiveness renewable and fossil fuel based electricity generation

When the externalities from coal mining and CO_2 are internalized, price of electricity from coal increases lessening the gap between the price of electricity from fossil and non fossil fuel based electricity generation. This will create a more level playing field for renewable electricity production and supply in Ohio. It can be expected that with the revised electricity portfolio standard for Ohio and technological innovations on wind and solar energy lowering the production, storage, and distribution costs, renewable sources will become more competitive with fossil fuel based electricity. As a result, electricity will be supplied at more efficient prices from both renewable and fossil fuel sources, GHGs and other pollutants emissions will be mitigated, and more jobs will be created in development, manufacturing, and installation of renewable energy in Ohio.

5.4 Further Research Areas

In order to assess economic efficiency of a program, it is necessary to put all the pieces of the puzzle together. This research was dedicated to the evaluation of a subset of the externalities associated with coal based electricity generation. Therefore, assessment of the rest of the pieces and improvement in current estimation methods are discussed as further research needs.

5.4.1 Evaluation of Externalities of Other Excluded Sectors

This research focused on only externality associated with one sector of the electricity portfolio. OH-MARKAL model would provide a more robust result if the externalities associated with other sources of electricity is also included into the model. Evaluation of any externalities from wind energy generation and electricity generation from biomass needs to be pursued. Incorporation of externalities from all sectors of electricity generation into the OH-MARKAL model would provide stronger policy recommendations.

The externality costs of coal based electricity generation estimated in this research represent a subset of the total externality costs and thus is a lower bound estimate of the externality cost. Regarding the air borne externalities, CO_2 is the only externality incorporated in this research. Some of the pollutants such as SO_2 and NO_X were assumed adequately addressed by the implemented regulations under Clean Air Act. Externalities associated with PM and O_3 are not internalized or included in this research.

Among the externalities associated with coal mining, the following sectors were not included in this research: mine subsidence, health impacts of dusts, sedimentation, impacts on streams, drinking water quality, ecological and aesthetic losses, value of land and housing properties, and methane emissions. Incorporation of all these impacts will increase the magnitude of externality costs associated with coal mining.

5.4.2 Improvement in Current Estimations

Visitation function model is a cross sectional multi regression model. If data on visitation can be obtained for a number of years, panel data estimation could be done. Panel data model is capable of capturing changes over time. Impact of coal mining over the period of time can be estimated using that method. In addition to that sedimentation is another large issue pertaining to coal mining. Evaluation of impacts of sedimentation from coal mining is another area that needs further research and incorporation into the visitation model.

While valuating the impacts on the lakes, it was not possible to fully model the sulfate loadings into the lakes as a function of reclamation. Therefore, a sensitivity analysis was pursued. Hydro-geologic modeling and analysis of sulfate loading from coal mining and reduction in the loading due to reclamation is another venue for further research.

Evaluation of loss associated with coal mining using a contingent valuation method is an alternative way to estimate both use and non-use values of lakes and streams impaired by coal mining.

5.4.3 Reclamation Costs

Estimation of reclamation costs using dynamic linear programming as a cost minimization problem might provide more accurate results. If time and budget allows, this would be another area for research.

5.4.4 Distribution Issues

Research shows that additional funds need to be generated for reclaiming problematic coal mined land. However, the process for generating funds is a complicated process. Estimation of total benefits from reclamation and specific groups of beneficiaries needs to be determined in order to examine the appropriate allocation of reclamation costs responsibilities. This is another area that requires further research.

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Appendix A

Lake Condition Index (LCI)

Lake condition index is estimated using the physical, chemical, biological, and aesthetic properties of a lake. Thirteen parameters are used to construct LCI.

Biological Conditions
- Integrated Biotic Index
- Nuisance Growth Macrophytes
- Faecal Coliform Bacterial Contamination
- Primary Productivity Based on Chlorophyll
- Fish Tissue Contamination

Chemical Conditions
- Non Priority Pollutants
- Priority Organics
- Priority Metals
- Sediment Contamination
- Nutrients Based on Spring Total Phosphorous
- Acid Mine Drainage

Physical Conditions
- Volume Loss Due to Sedimentation

Public Perception of Lake Condition
- Aesthetics

Each parameter was evaluated depending upon either monitored data or best professional judgment to attain either full use, threatened use, or impaired use. Full use means 24% or less of shoreline is affected by the problem, while threatened and impaired status is given if 50% of the shore is affected. Numerical values were assigned for each of the sub-indices were as follows: 10 points for impaired monitored data, 10 points for hypereutrophic monitored threatened condition, 5 points for threatened status observed from monitored data, 2 points for threatened status based on evaluated data, one point for full use status, and if the lake was not assessed for that parameter. Score was calculated for each of the lakes and was divided by the number of assessed parameters.

The LCI ranges from 10 to 100, and according to the report, LCI of 21.5 or less implies 0 probability of impacts while >30.8 implies 100% probability of impaired use of one of the designated uses. LCI between 21.5 and 30.8 means full use attainment for some of the designated use and some with partial use attainment.

The LCI for coal mine impacts can thus be computed using the monitored and evaluated data on selected parameter reports for the water quality parameters directly related to the abandoned mines (OEPA report, 1996). LCI for abandoned mines and designated use status of the lakes are given in the following table.

S.N.	Lakes	AMDLCI	Recreation Use status	Shoreline miles	Impacted Shoreline miles (average)
1.	Atwood	15.00	T	28	3.50
2.	Dillion	25.00	P	25	9.38
3.	Leesville	_	F	28	0.00
4.	Piedmont	14.28	T	38	4.75
5.	Senecaville	_	_	48	
6.	Wills Creek	22.50	T	52	6.50
7.	Tappan	21.25	T	41	5.13
8.	Lake Rupert	21.40	T		
9.	Jackson Lake	24.28	P		
10.	Lake Hope	31.40	P		
11.	Wolf run	_	T		
12.	Evans Lake	10.00	T		

Appendix B

Rivers impacted by coal mining in Ohio

Streams affected by surface mining

S.N.	River/stream	River miles
1	Middle Fork	12.92
2	McMahon Cr	12.74
3	Williams cr	8
4	Sugar creek	12.3
5	Goettge run	5.14
6	Brandy wine cr	3.5
7	broad run	6
8	cherry run	3.74
9	turkey foot run	3.3
10	Walnut run Tributary	0.6
11	Sugar cr (South fork)	22.7
12	Sugar cr trib	4.9
13	Sugar cr trib	2.4
14	Sugar cr trib	3.3
15	Sugar cr (East br)	9.7
16	Sugar cr (Trib. East br)	2.9
17	Sugar cr (Trib. East br)	2.1
18	Troyer Valley Cr.	3.2
19	Brush Run	3.4
20	Brush run (trib)	0.43
21	Stillwater Cr	25.8
22	Wills Cr.	15.1
23	Wills Cr.	16.3
24	Wills Cr.	35.1
25	Wills Cr.	14.8
26	Wills Cr.	16.47
27	Chapman run	6.9
28	Mohaxala Cr	24.66
29	Hocking river	13.96
30	Sunday cr	13.15
31	Sunday cr (trib)	1.45
32	West branch shade river	20.8
33	Campaign cr	19.2
34	Leading cr	8.49
35	Leading cr	10.6

Table: Rivers impacted by coal mining in Ohio (contd)

Streams affected by surface mining

S.N.	River/stream	River miles
36	Leading cr (trib)	10.01
37	Leading cr (trib)	14.5
38	Thomas Fork	7.2
39	Dunckle cr	4.85
40	Siverly cr	5.7
41	Big beaver cr	23.2
42	East fork little miami	14.69
43	Turtle Cr	8.5
	Total	454.7

AMD impacted rivers in Ohio.

S.N.	Rivers/streams	River miles
1	Buffer run	2.4
2	Coal run	4
3	Coal Run	1.6
4	Dickason run	11.2
5	Dorr run	2.8
6	Elk fork	18.6
7	Factory cr	6.3
8	Flint run	2.2
9	Goose run	1.8
10	Greasy run	2.6
11	Huff run	9.9
12	Kimble Cr	3.45
13	Little Monday cr	14.3
14	Little racoon cr	12.57
15	Meadow run	5.1
16	Merrit run	2.1
17	Middle fork duck cr	13.8
18	Monday cr	27
19	Mulga run	4.9
20	Negro Cr	2.3
21	pierce run	8.5
22	Pine cr	9.26
23	Pine Run	2.1
24	Racoon cr	10.12
25	Racoon cr	18.97
26	Racoon cr	22.9
27	Racoon cr	13.52
28	Racoon cr	8.9
29	Racoon cr (East Branch)	9.3
30	Racoon cr (West Branch)	8.1
31	Rockcamp run	2.1
32	Salt run	2.8
33	Sand run	3.1
34	Sandy run	6
35	Scioto Big Run	8
36	Shawnee cr	1.6
37	Snow fork(trib)	3.52
38	Stone church run	3.46
39	Sugar run	3.05
40	Sycamore fork	4.7
41	Tedroe Run	2.5
42	Two mile run	4.3
	Total	305.72

Appendix C

Runoff Measure

Runoff from an area is calculated using the following equation

$R = CiA$

where, R is the amount of runoff, C is the coefficient according to the type of soil, i is the rainfall coefficient, and A is the contributing area.

Runoff contributed from the coal mined land to the impacted lakes was estimated using the data collected for the area of the impacting mines in the watershed of the lake, rainfall data from the weather station in the closest vicinity of the lake, and the coefficient for the given soil type in the area.

Lake	Coefficient of land	Runoff
Piedmont Lake	1	2687.151
	2	649.7946
Seneca Lake	1	73.04018
	2	58.3905
	3	109.0425
	4	5.628
