

GIS Modeling and Analysis of Ohio's CO₂ Budget: Mitigating CO₂ Emissions through Reforestation¹

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ABSTRACT. The United States has agreed to join with the international community in reducing its greenhouse gas emissions to 7% below 1990 levels. To aid in this goal a Geographic Information System (GIS) based deterministic model was created to assess the potential impact of different land-use strategies for mitigating Ohio's carbon dioxide (CO₂) emissions and lowering its total CO₂ budget. CO₂ was chosen as the greenhouse gas of focus for this study because it has been identified as a significant greenhouse gas impacting the climate and it is the only greenhouse gas capable of being anthropogenically sequestered from the atmosphere.

A comprehensive CO₂ emissions and absorptions database inventory using 1996 as a baseline was compiled for Ohio. A mathematical model of the total CO₂ budget and the relationship between CO₂ sources and sinks was developed. The model allowed for a quantitative assessment of features influencing Ohio's CO₂ budget.

Additionally, this study evaluated the ability of forestation to act as a sink for atmospheric CO₂ in the budget. Using a GIS, areas of new forest were created and the acreage of new forest created was used to recalculate the CO₂ budget model. The new forest areas were created by implementing theoretical policies within the GIS designed to create new forest throughout the state in an attempt to reduce its greenhouse gas emissions to 7% below 1990 levels by the commitment period of 2008-2011. Through the enactment of various forestation policies in this study, it was determined that practical and easily implemented increases in forestry could play a significant role in offsetting some of Ohio's CO₂ emissions. However, making these simple increases in Ohio's forest acreage will not meet the necessary reduction on its own. Ohio will also have to take action to lower its emissions of CO₂ by decreasing its dependency on fossil fuels. The techniques used in this study may be a valuable tool in helping to design strategies and practical policies to address our international responsibilities.

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INTRODUCTION

During July 1992, the United Nations Framework Convention on Climate Change (UNFCCC) met in Fortaleza, Brazil, to address the issue of climate change. The UNFCCC concluded at this meeting that precautionary measures should be taken to mitigate anthropogenic greenhouse gas emissions because of the mounting evidence linking the emissions to global climate change. The Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the World Meteorological Organization and the United Nations Environment Programme, specifically states that all United Nations parties should formulate, implement, publish, and update national and regional programs containing measures to mitigate anthropogenically related sources of greenhouse gases (IPCC 1996). The IPCC recognized that a regional focus is important for mitigating anthropogenic greenhouse gas emissions because activities that are responsible for these emissions differ greatly from one region to the next. Additionally, regional and state organizations have several advantages over national organizations that allow them to more easily pass legislation intended to mitigate these emissions, including the flexibility of collective action and a better capability to

negotiate and initiate policy (Glantz 1994).

More recently, during December 1997, the UNFCCC met in Kyoto, Japan, to once again address the issue of climate change. At this meeting it was agreed upon that measures should be taken to implement and/or further elaborate upon policies designed to reduce emissions and enhance sinks of greenhouse gases. Based upon the proceedings at the Kyoto conference, the UNFCCC drafted the *Kyoto Protocol to the United Nations Framework Convention on Climate Change* (UNFCCC 1997). It was concluded in Article 2 of this protocol that there is an urgent need for all parties of the United Nations to build upon policies such as those dealing with the:

"Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation; Promotion of sustainable forms of agriculture in light of climate change considerations; Promotion, research, development and increased use of new and renewable forms of energy, of carbon dioxide (CO₂) sequestration technologies and of advanced and innovative environmentally sound technologies" (UNFCCC 1997).

At the Kyoto convention, participating nations agreed upon specific quantified emission limitations and reduction commitments of greenhouse gas emissions to mitigate potential climate change. The agreed upon reductions

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were percentage values below each country's or community's 1990 emission levels, which that country or community will have to attain sometime during the commitment period of 2008 to 2012. The United States agreed to reach a reduction of 7% below 1990 emission levels by the commitment period.

The first objective of this research was to evaluate the CO₂ budget for the State of Ohio in order to evaluate the effects of forestation as a sink for atmospheric CO₂. The second objective in this study was to determine the potential impact that different hypothetical forestation policies could have on mitigating Ohio's CO₂ emissions. Although the methodologies developed through this study are presented using the State of Ohio, they are applicable to the rest of the United States. There were several procedural steps taken to accomplish the objectives of this study: 1) a comprehensive database inventory for major CO₂ sources and sinks for Ohio that quantified CO₂ emissions and absorptions was compiled, 2) a mathematical model of the total CO₂ budget that allowed for the investigation of the relationship between the major sources and sinks was developed, 3) a forestry focused land-use GIS model that allowed for the implementation of afforestation plans used to calculate changes in total forest cover was created, and 4) the changes in total forest were entered into the CO₂ budget model so that the effectiveness of the forestation policies could be evaluated.

Water vapor, methane (CH₄), carbon monoxide (CO), chlorofluorocarbons (CFCs), partially halogenated fluorocarbons (HCFCs), ozone (O₃), perfluorocarbons (PFCs), sulfur hexafluoride (SF₆), and nitrous oxide (N₂O) are all greenhouse gases along with CO₂ that are emitted into the atmosphere from anthropogenic activities. However, when comparing the relative anthropogenic contributions of these gases towards potential climate change, CO₂ has the greatest impact and was therefore chosen as the focus for this project. Increases in atmospheric CO₂ as a result of the industrial revolution and a rapidly rising world population have made the largest individual contribution to potential changes in the atmospheric greenhouse gas composition (IPCC 1995). Before the start of the industrial era in 1850, atmospheric CO₂ levels were approximately 280 parts per million by volume (ppmv), but in 1994 had risen to 358 ppmv, and are still rising today. Finally, CO₂ is also the only greenhouse gas capable of being anthropogenically sequestered out of the atmosphere.

METHODOLOGY

Compilation of Ohio's CO₂ Inventory

An inventory that quantified the principal sources and sinks of CO₂ (emissions and absorptions) within the state of Ohio was compiled using 1996 as a baseline year (Guy and Levine 1999). This inventory was used to calculate the annual CO₂ budget. The inventory was compiled following internationally accepted methodologies for the calculation of CO₂ emissions and absorptions that are published in: 1) the *IPCC Guidelines for National Greenhouse Gas Inventories: Vols. 1-3* (IPCC 1997), and 2) the *State Workbook: Methodologies*

for Estimating Greenhouse Gas Emissions, Second Edition (US EPA 1995). These references were created to encourage the development of both national and regional CO₂ inventories. The protocols provided by these references typically consisted of formulae that required the specific input of regional production or consumption figures, carbon content coefficients, and CO₂ emission coefficients. The figures necessary for input in these formulae were found through research and communication with various regional and national organizations and businesses. A detailed discussion of the steps taken, data sources used, and the assumptions made in quantifying CO₂ emissions and absorptions in Ohio for 1996 would be beyond the scope of this paper, however, detailed documentation is available through Bowling Green State University and the Ohio Environmental Protection Agency (Guy 1998; Guy and Levine 1999).

The primary sources and sinks of CO₂ in Ohio were identified as being part of one of four major categories in this inventory: energy related activities, production processes, landfills, and forestry. Energy related activities included CO₂ emissions from the combustion of fossil and biomass fuels. Fossil and biomass fuels included those combusted in Ohio's transportation, industrial, electric utility, commercial, and residential sectors. Production processes included CO₂ emissions from aluminum production, cement production, lime production, and limestone use. CO₂ emissions from municipal solid waste landfills were also considered. CO₂ absorptions in this inventory consisted of CO₂ absorbed from existing forest and from net new forest area created. The absorptions of CO₂ occurred due to biomass growth and the accumulation of soil carbon. Absorptions from net new forest also included CO₂ sequestered as a result of tree planting activities.

Limitations of the Inventory

Several qualitative and quantitative limitations existed during inventory development due to the availability and uncertainty of the data. In some cases the data limitations resulted in the exclusion of some CO₂ sources and sinks from this inventory. The protocols delimited in the greenhouse gas inventory workbooks permitted for the input of either statewide totals or county level data. Ohio CO₂ emissions and absorptions were assessed using specific county level data when available, under the presumption that these data would be more accurate than statewide totals. When county figures were unobtainable, CO₂ emissions and absorptions were calculated using the statewide totals. Additionally, some information sources are not published annually, but at intervals of several years. Therefore, if 1996 data were unobtainable the most recent data available were assumed to be similar to those from 1996.

Because the scientific understanding surrounding some CO₂ emissions and absorptions are uncertain, internationally accepted techniques necessary for the calculation of some CO₂ sources and sinks do not exist. Additionally, some internationally accepted methods did not apply to the available data. Therefore, in a few cases

methodologies had to be adapted to the available data in order to quantify some of the CO₂ emissions and absorptions documented in this inventory. The inventory was designed to allow for the quantities to be updated annually, as well as allowing the quantities to be compared to similar inventories from other states. Also, because this inventory was produced using internationally accepted methods, it is capable of being combined with similar regional, national, or international inventories.

CO₂ Budget Model Development

After the CO₂ inventory was complete, the calculation of Ohio's CO₂ budget for 1996 was made using a mathematical model developed with the STELLA modeling program (High Performance Systems Inc. 1996). The STELLA modeling program is an object oriented (visual) model-building environment. The software is commonly used for earth systems science applications where the complex relationships of multi-component dynamic systems can be better understood in a visual/flowchart representation. Models developed are a series of linked formulae that could have been implemented within a spreadsheet system or by writing a program. STELLA was chosen over the other modeling options because of its visual interface that allowed the state's CO₂ budget to be displayed as a conceptual mass balance model. A conceptual model illustrating the relationships between the CO₂ budget, the primary sources and sinks of CO₂ within Ohio, and

forest acreage changes within Ohio is presented as Figure 1.

Emission and absorption quantities calculated in the CO₂ inventory were entered into the model in order to define each source and sink of CO₂, and were related to the total CO₂ budget using equations within the model. Sources of CO₂ within Ohio were designated as positive flows in the CO₂ budget because they contributed to atmospheric CO₂, while sinks of CO₂ were designated as negative flows from the total CO₂ budget because they sequestered atmospheric CO₂. Hypothetical forestation policies were enacted in this study using a GIS (these hypothetical policies are discussed in the following section). The policies were intended to offset the CO₂ emitted by creating additional forest acreage within Ohio. The initial calculation of Ohio's CO₂ budget for 1996 was used as a baseline for all potential changes resulting from the forestation policies. The equations in the mathematical model were set up so that any changes in forest acreage could be used to calculate an amended total CO₂ budget value. Changes in Ohio's forest acreage enhanced CO₂ sequestration through additional biomass growth and soil carbon accumulation. The policies were then evaluated by the impact that they had on mitigating CO₂ emissions and lowering the total CO₂ budget.

Modeling Effects of Land-Use Forestation Policies Using GIS

In order to evaluate the possibility of using increases in forestry within the state of Ohio to offset some or all

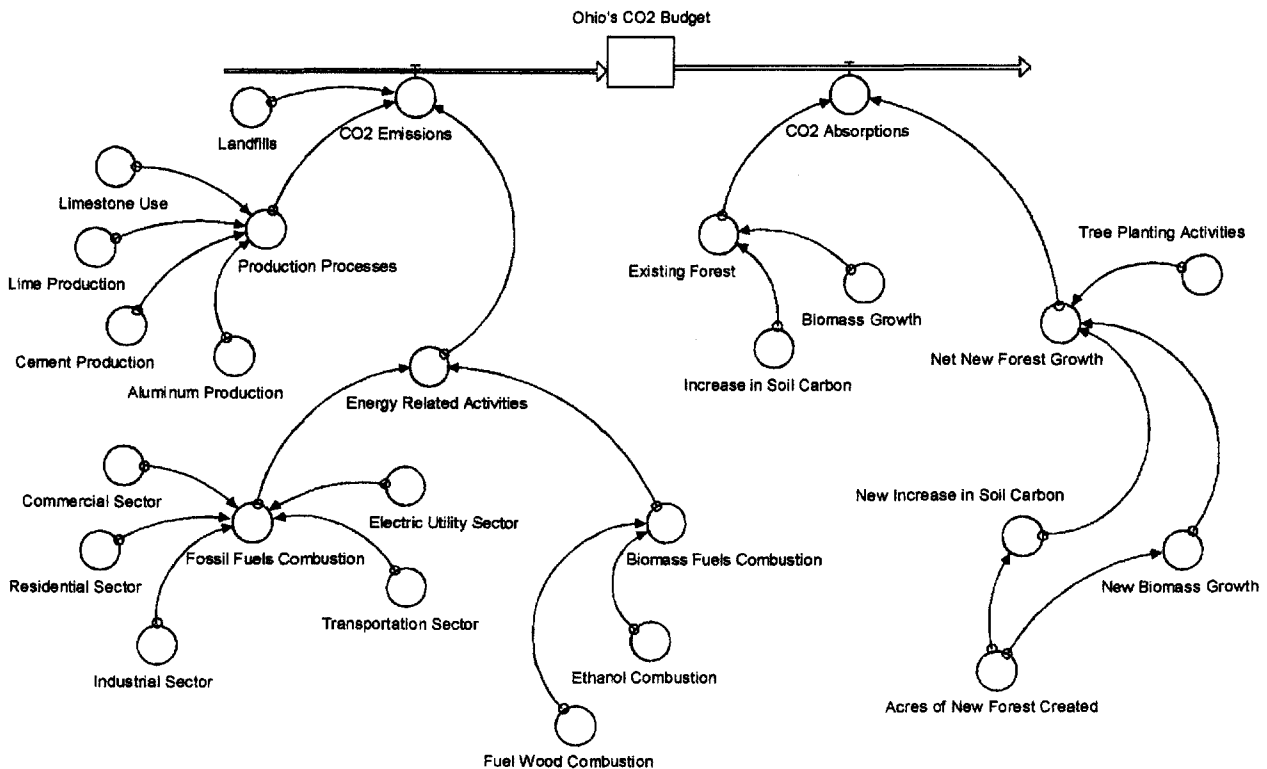


FIGURE 1. Conceptual model of Ohio's CO₂ budget showing major sources and sinks, and the relationship between new forest acreage created and CO₂ absorbed.

of the state's CO₂ emissions, hypothetical land-use policies designed to create more forestry within the state were enacted using a GIS. These policies were designed to produce additional forest in a way that would be as least disruptive to the people of the state as possible. The new forest areas were created alongside existing forests, railroads, primary roads, and rivers/streams of the state as buffer zones. These areas were chosen because they are places where there would most likely be minimal impact on existing land uses and development. Additionally, these areas often remain free of forest and brush despite not being used for any type of development. Different forested buffer zones along existing forests, railroads, primary roads, and rivers/streams created different totals of new forest. Through the enactment of these various land-use forestation policies, data were produced which provide a clearer picture of the role that increasing Ohio's forestry could play in offsetting CO₂ emissions and lowering the CO₂ budget for the state through sequestration of CO₂ in the newly forested areas.

The land-use policies were enacted using a GIS with ARC/INFO software (ESRI 1995). The primary data sets consisted of a natural area land cover image provided by the Ohio Department of Natural Resources (ODNR) – Division of Wildlife (ODNR 1987), and coverages of the railroads, primary roads, and rivers/streams within the United States published by Environmental Systems Re-

search Institute (ESRI 1992). A total of eleven hypothetical policies were enacted using the GIS: two using Ohio's existing forests, three using Ohio's railroads, three using Ohio's primary roads, and three using Ohio's rivers/streams.

The *Distribution of Ohio's Wetlands and Woodlands* (ODNR 1987) image was assembled from Landsat 5 images, aerial photographs, and United States Geological Survey digital line graph files, and was converted into a grid format so that its forest data could be manipulated. An ArcInfo polygon coverage of Ohio's forests was then constructed from this image (Fig. 2). When looking at this coverage there appears to be solid forest across many parts of the state where in actuality there may not be. This is because some of the detail of the forest polygons was unable to be represented when printing this coverage at such a small scale. The enlarged view of the forest areas in Athens County (southeastern Ohio) illustrates that many areas that appear to consist of only forest at a smaller scale actually do not. Coverages of Ohio's primary roads, railroads, and rivers/streams were constructed from the ESRI (1992) coverages of the United States. A polygon coverage of Ohio's boundary was created so that the United States coverages of primary roads, railroads, and rivers/streams could be clipped to fit into it to create final coverages. These final coverages were then projected from decimal degrees to UTM zone 17 (the same projection as the forest

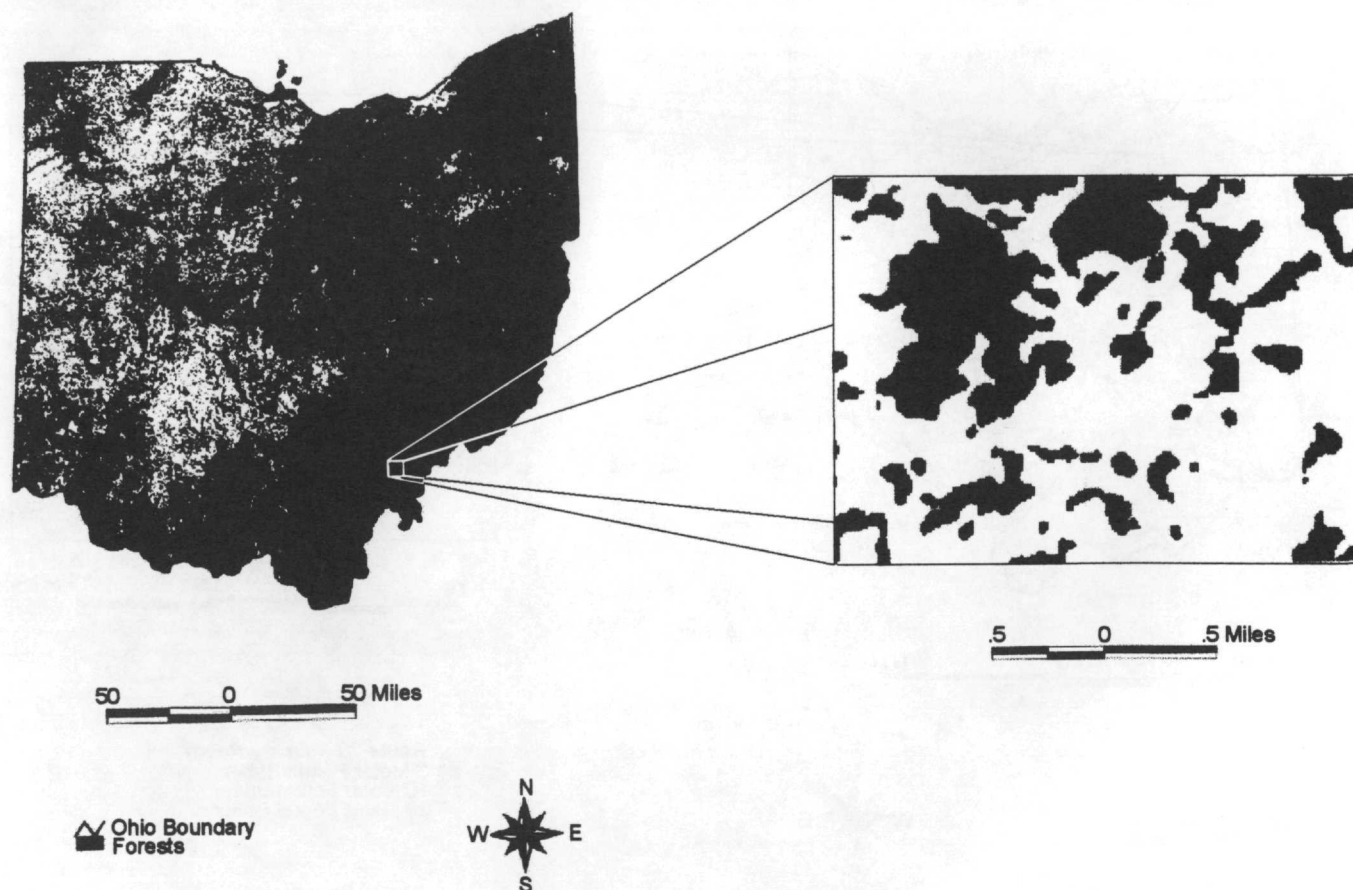


FIGURE 2. Polygon coverage of Ohio's forests (7,819,500 total acres of forest), along with a zoomed in look at an area in Athens County. Coverage constructed using data from ODNR (1987).

coverage). The primary roads, railroads, and rivers/streams coverages were then buffered to create zones of new forest. Buffer zones of 3, 10, and 20 m were created along Ohio's primary roads, railroads, and rivers/streams. A coverage of Ohio's primary roads and a coverage showing the 3, 10, and 20 m buffer zones of new forest created along Interstate 75 (a primary road) are shown in Figure 3. Distances of 3 and 20 m were thought to represent the smallest and largest rational amounts along Ohio's primary roads, railroads, and rivers/streams that could be buffered. The determination of rational distances for the buffer zones was made by analyzing selected imagery for open space adjacent to these features. The existing forest coverage was also buffered by zones of 3 and 10 m to simulate new forest creation along existing forest boundaries. Distances of 3 and 10 m were determined to represent the smallest and largest rational amounts along Ohio's existing forests that could be buffered.

A series of intersections were performed with the existing forest polygon coverage and the buffered railroads, buffered primary roads, and buffered rivers/streams coverages to produce new coverages containing the polygons common only to both input coverages. An intersection of these coverages with the original forest coverage was used so that a determination of new forest acreage could be made. Once the newly created forest acreage figures were determined for each GIS hypo-

thetical policy, the CO₂ budget mathematical model for Ohio was utilized to calculate and evaluate the impact that the policies had on lowering Ohio's CO₂ budget.

Issues in Data Accuracy and Map Scale

When dealing with the manipulation and generation of data using GIS, a major concern exists regarding the quality of the data used. The scale of a map expresses the relationship of the actual size of a geographic feature on the surface of the earth to its size depicted on a map. At smaller scales, geographic features cannot be displayed with the same amount of detail as with larger scales. The amount of detail that is omitted is inversely proportional to the scale. Because all of the detail displayed at a larger scale can not be displayed at a smaller scale, features must be generalized (Thompson 1981).

The coverages of Ohio's railroads, primary roads, and rivers/streams constructed from the ESRI (1992) data were at a scale of 1:2,000,000. Because the data existed at such a small scale, it is likely that the amounts of area constructed as new forest buffer zones are somewhat conservative estimates. This is due to the fact that some of the curvature that may actually exist along these features is lost due to generalization, thereby making the perimeter of these features less than it actually is. The same holds true with the buffers created along Ohio's forests using the *Distribution of Ohio's Wetlands and Woodlands* (ODNR 1987) at a scale of

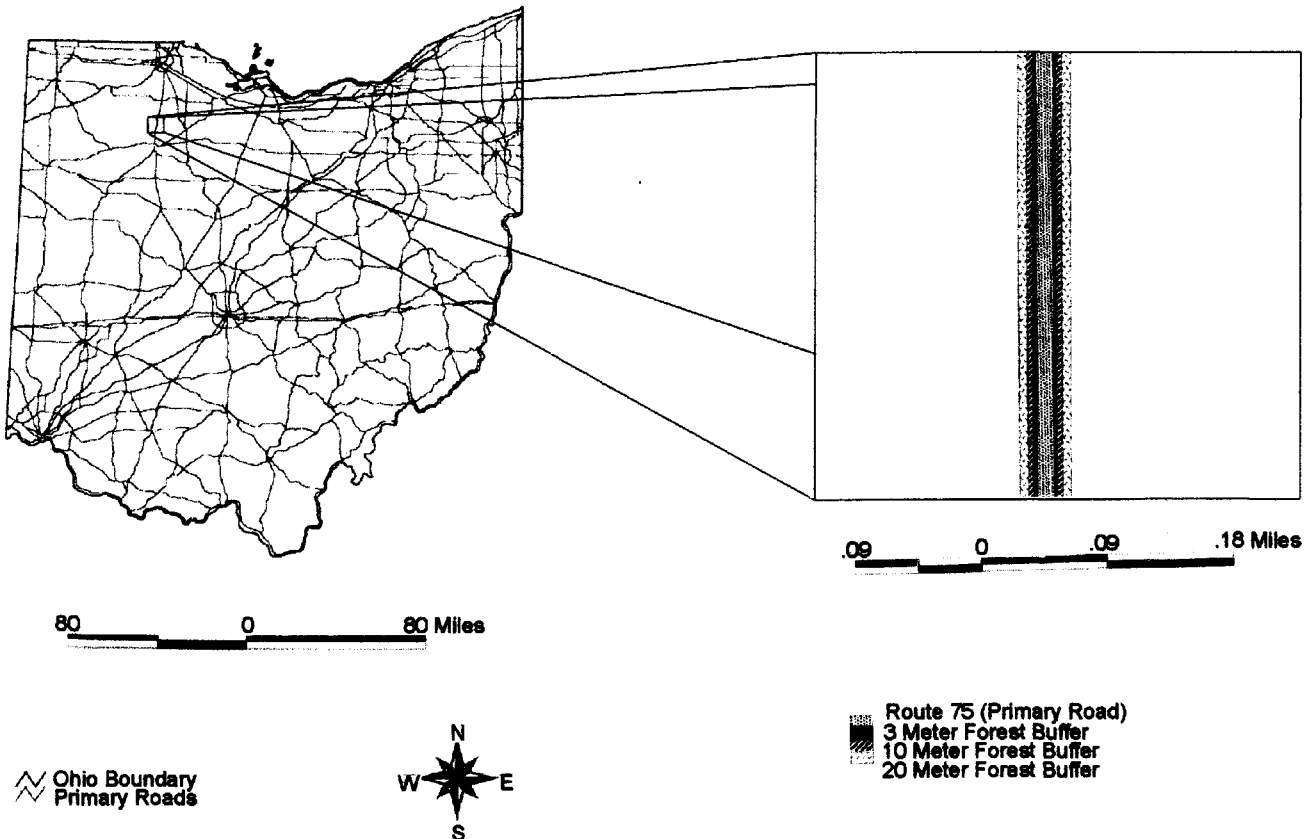


FIGURE 3. A coverage of Ohio's primary roads, and a coverage showing 3, 10, and 20 m buffer zones of new forest created along Interstate 75. Coverages constructed using data from ESRI (1992).

1:40,000. Because this map is at a larger scale than the ESRI (1992) coverages, there would be less generalization; however, the amount of new forest area created in the buffer zones are probably conservative figures as well. When calculating the amount of buffer area in any of the individual coverages, errors that exist deal with the magnitude of the area and not position of the buffers.

When the coverages of Ohio's railroads, primary roads, and rivers/streams were intersected with Ohio's forest coverage to determine how much forest existed originally in the buffer zones, possible errors regarding the position of the buffers were introduced. At different map scales there is a different amount of possible positional error associated with the displayed geographic features. Therefore, it is possible that there is some error regarding the area of forest that existed in the buffer zones due to the effects of the different scales.

RESULTS AND DISCUSSION

Ohio's CO₂ Budget for 1996

Ohio was found to have a net emission of 214,038,081 tons of CO₂ into the atmosphere during 1996 (Table 1). This CO₂ budget was calculated as the net balance of CO₂ emissions and absorptions within the state during 1996. Emissions from energy related activities (which included emissions from the combustion of fossil and biomass fuels in Ohio's transportation, industrial, electric utility, commercial, and residential sectors) were found to contribute far more CO₂ to the atmosphere than any other major source category of CO₂ in Ohio during 1996. Emissions of CO₂ from energy related activities comprised over 98% of the total CO₂ emissions from major source categories in Ohio during 1996, as compared to less than 1% each for landfills and production processes. CO₂ absorbed from existing and new forestry in Ohio during 1996 was equal to 89,227,483 tons.

TABLE 1

CO₂ emissions and absorptions in Ohio during 1996 by major source and sink category.

| Major CO ₂ Source or Sink Category | CO ₂ Emission and Absorption Amounts (tons CO ₂)* |
|--|--|
| Energy related activities** | 297,957,759 |
| Production processes*** | 2,272,804 |
| Landfills | 3,035,001 |
| Forestry (existing and new)**** | -89,227,483 |
| Total CO ₂ budget for Ohio during 1996: | 214,038,081 |

*Positive values are emissions, negative values are absorptions.

**Includes CO₂ emissions from the combustion of fossil and biomass fuels in Ohio's transportation, industrial, electric utility, commercial and residential sectors.

***Includes CO₂ emissions from aluminum production, cement production, lime production, and limestone use.

****Includes CO₂ absorption from biomass growth, soil carbon accumulation, and tree planting activities.

Necessary Reductions of Ohio's CO₂ Budget

At the Kyoto conference, the United States agreed to reductions in its greenhouse gas emissions by 7% below 1990 levels by the commitment period of 2008 to 2012 (UNFCCC 1997). This research was adapted to address commitments similar to those made at Kyoto. This study differs, however, in that it concentrates only on CO₂, and uses 1996 instead of 1990 as the baseline year from which Ohio will reduce CO₂ emissions by 7%. The choice was made to use 1996 rather than 1990 emissions and absorptions data as the basis for this study so that the most current information on Ohio's CO₂ budget could be provided. This study evaluates the potential for using increases in forest acreage as an approach towards offsetting Ohio's CO₂ emissions. Ohio's CO₂ budget for 1996 was a net emission of 214,038,081 tons of CO₂ (Table 1). This study attempted to lower the total CO₂ budget for Ohio solely through increased sequestration in forestry to a net annual emission of 199,055,415 tons of CO₂ (7% below 1996 levels). Assuming a CO₂ emissions freeze at 1996 levels, Ohio would have to absorb an additional 14,982,666 tons of CO₂ annually, sometime before the end of 2011 (the end of the commitment period) in order to meet the goals established in this study.

It was assumed, based upon data from the natural area land-cover image (ODNR 1987) and supplemental information, that during 1996 Ohio had 7,819,500 acres of existing forests (equivalent to 29.6% of the total state land area). The 1987 image was used because it is the only complete GIS image that contains forest coverage data for the entire state of Ohio. The assumption made on the amount of forest acreage for 1996 within the state for this study was reasonable based upon the fact that during 1991 Ohio had 7,620,300 acres of forest (Griffith and others 1993), and that this acreage was projected to increase by 85,200 acres on an annual basis over the next several years. This amount of forest was calculated in the CO₂ inventory to sequester 88,308,220 tons of CO₂ annually.

It was determined that in order to sequester the necessary amount of CO₂ to lower Ohio's CO₂ budget by 7% (assuming an emissions freeze at 1996 levels), 1,326,682 acres of new forest would need to be created by the end of the year 2011. The amount of new forest that must be created is equivalent to converting approximately an additional 5% of the state of Ohio to forest. Assuming a CO₂ emissions freeze at 1996 emission levels, and that the proposed increases in Ohio's forestry would begin during the year 2000 for the purpose of meeting this goal, an average of 120,607 acres of new forest would need to be created each year before the end of 2011 in order to meet the goals established in this research that are similar to those made in the Kyoto agreement.

Evaluation of Enacted Hypothetical Forestry Policies

Theoretical land-use policies were designed to create areas of new forest with the least disruption of existing land-uses. The amount of CO₂ sequestered out of the

atmosphere from the enacted land-use forestation policies depended on whether Ohio's forests, primary roads, railroads, or rivers/streams were buffered (Table 2). The results were somewhat similar when Ohio's railroads, primary roads, or rivers/streams were buffered with 3, 10, or 20 m of forest, as not enough forest was created in any of these policies to come close to reducing Ohio's CO₂ budget by the desired 7%. When Ohio's existing forests were buffered, however, much greater reductions in Ohio's CO₂ budget were attained. A 3 m buffer on Ohio's forests was able to reduce Ohio's CO₂ budget by over 1%, while a 10 m buffer accomplished a reduction of over 4%. Figure 4 illustrates the effects that different combinations of land-use policies had on Ohio's CO₂ budget. A policy that buffered Ohio's primary roads, railroads, and rivers/streams at the same time was more successful in reducing Ohio's CO₂ budget than if any one of these features were buffered alone. However, less significant reductions were made by buffering Ohio's railroads, rivers/streams, and primary roads simultaneously than were made by buffering Ohio's existing forests using a 3 or 10 m buffer distance. By buffering Ohio's existing forests, railroads, rivers/streams, and primary roads simultaneously, the most significant reductions in Ohio's CO₂ budget were made. However, none of the land-use policies or land-use policy combinations were able to attain the desired 7% reductions.

SUMMARY AND CONCLUSIONS

The development of Ohio's CO₂ inventory for 1996 provided information on the significance of each source and sink of CO₂ within the state. Energy related activities were found to account for over 98% of the total CO₂ emissions for the state, while emissions from landfills and production processes comprised the remaining 2%. The CO₂ budget information from this inventory

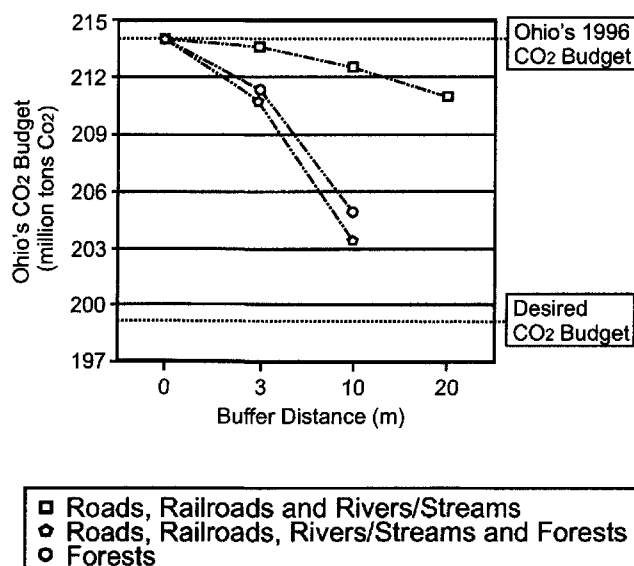


FIGURE 4. Effects of different land-use policies on Ohio's CO₂ budget relative to the desired CO₂ budget set in this study (7% below 1996 levels).

TABLE 2

*Reduction in Ohio's annual CO₂ budget that would be attained prior to the end of 2011 from each land-use forestation policy enacted.**

| Policy Target | Buffer (meters) | Forest created (acres) | CO ₂ Sequestered (tons) | Budget reduction (%) |
|----------------|-----------------|------------------------|------------------------------------|----------------------|
| Railroads | 3 | 12,398 | 140,014 | 0.07 |
| | 10 | 44,961 | 507,760 | 0.24 |
| | 20 | 90,469 | 1,021,696 | 0.47 |
| Rivers/Streams | 3 | 12,291 | 138,806 | 0.06 |
| | 10 | 41,593 | 469,723 | 0.22 |
| | 20 | 83,297 | 940,704 | 0.44 |
| Primary Roads | 3 | 11,391 | 128,643 | 0.06 |
| | 10 | 46,488 | 525,004 | 0.25 |
| | 20 | 93,462 | 1,055,498 | 0.49 |
| Forests | 3 | 240,081 | 2,711,316 | 1.27 |
| | 10 | 806,374 | 9,106,650 | 4.26 |

*Assuming a CO₂ emissions freeze at 1996 levels and that the increase in forest acreage would be completed prior to the end of 2011.

also served as the basis for evaluating the hypothetical land-use policies developed to mitigate Ohio's CO₂ budget. The mathematical model permitted the assessment of the effectiveness of the hypothetical land-use policies based on the total CO₂ budget for Ohio.

It was determined through the enacting of the land-use forestation policies in this study that increases in Ohio's forest acreage could prove useful in offsetting some of its CO₂ emissions. The most successful single policy enacted through this study was one that buffered Ohio's existing forests with 10 m of new forest and subsequently reduced Ohio's CO₂ budget by over 4%. Therefore, if Ohio is to lower its annual CO₂ budget 7% by 2008-2012 in order to be in accordance with the goals established in this study that are similar to the national goals made at Kyoto, not only will it have to make realistic increases in its forestry acreage, but will also have to take action to lower its emissions of CO₂.

Part of the difficulty in lowering Ohio's CO₂ budget is due to the fact that Ohio is a tremendous contributor of CO₂ to the atmosphere, typically ranking in the top 25 by per capita of all nations and states in the world (Lashof and Washburn 1990). Although none of the land-use policies were able to lower Ohio's CO₂ budget by 7%, the United States may be able to lower its total CO₂ budget by 7% by enacting similar policies concurrently in other states. The amount of forest needed for a US reduction of CO₂ to the 1990 levels could be calculated using the methodology developed in this study. Based on the total acreage of additional forest needed, policies could be enacted at a national level to meet our international commitments.

Increasing the amount of forest area within Ohio may

appear a very difficult task, due to conflicts in land-use and resource allocation. However, since 1940 the amount of forested land in Ohio has been determined to have already experienced a net increase on an annual basis (Powell and others 1993). Further practices to ensure the continued and accelerated net increases in forested land could be accomplished by sustaining existing forest cover while slowing deforestation, regenerating natural forest areas, establishing new tree plantations, and promoting agro-forestry practices. Governmental policies, industry support, and community action are all integral parts in creating new forest, which in turn will help to sequester atmospheric CO₂. In addition to mitigating atmospheric CO₂, increases in Ohio's forest area would provide many other environmental benefits as well. Through increasing its forest area Ohio would decrease soil erosion and runoff, create new wildlife habitats, and also decrease air pollution. It is also likely that some of the additional biomass created could be used to produce needed energy, thereby being developed into an economically feasible form of alternative and renewable energy to replace some fossil fuel usage.

Although it may be impractical to think that a state's contributions to potential climate change could be entirely offset by increasing forestry alone, forestation policies could play a significant role as a component integrated plan to decrease a state's atmospheric CO₂ levels. It is important to realize that the economic, political, societal, and ecological costs of reforestation could be quite lower than the costs of suddenly decreasing the use of fossil fuels. Because it may be difficult for Ohio to immediately decrease its CO₂ emissions from fossil fuel usage, short term ways to lower the CO₂ budget must be evaluated and developed for implementation while economically sensible alternative energy practices to replace some fossil fuel usage are developed. As agricultural, grasslands, and urban lands are converted to forest, the amount of carbon stored in biomass above and below ground on these lands increases. Therefore, forestation increases offer the potential of dramatically lowering Ohio's or any state's CO₂ budget through the sequestration of CO₂.

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