Economic Impacts of Climate Change on Tennessee

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CIER
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INTRODUCTION

Policymakers across the country are now seeking solutions to curb greenhouse gas emissions and to help us adapt to the impending impacts triggered by past emissions. The debate to date has primarily focused on the perceived costs of alternative solutions, yet there can also be significant costs of inaction. Climate change will affect our water, energy, transportation, and public health systems, as well as state economies as climate change impacts a wide range of important economic sectors from agriculture to manufacturing to tourism. This report, part of a series of state studies, highlights the economic impacts of climate change in Tennessee and provides examples of additional ripple effects such as reduced spending in other sectors and resulting losses of jobs, wages, and even tax revenues.

A Primer on Climate Change

Earth's climate is regulated, in part, by the presence of gases and particles in the atmosphere which are penetrated by short-wave radiation from the sun and which trap the longer wave radiation that is reflecting back from Earth. Collectively, those gases are referred to as greenhouse gases (GHGs) because they can trap radiation on Earth in a manner analogous to that of the glass of a greenhouse and have a warming effect on the globe. Among the other most notable GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). Their sources include fossil fuel combustion, agriculture, and industrial processes.

Each GHG has a different atmospheric concentration, mean residence time in the atmosphere, and different chemical and physical properties. As a consequence, each GHG has a different ability to upset the balance between incoming solar radiation and outgoing long-wave radiation. This ability to influence Earth's radiative budget is known as climate forcing. Climate forcing varies across chemical species in the atmosphere. Spatial patterns of radiative forcing are relatively uniform for CO_2, CH_4, N_2O and CFCs because these gases are relatively long-lived and as a consequence become more evenly distributed in the atmosphere.

Steep increases in atmospheric GHG concentrations have occurred since the industrial revolution (Figure 1). Those increases are unprecedented in Earth's history. As a result of higher GHG concentrations, global average surface temperature has risen by about 0.6°C over the twentieth century, with 10 of the last 12 years likely the warmest in the instrumental record since 1861.

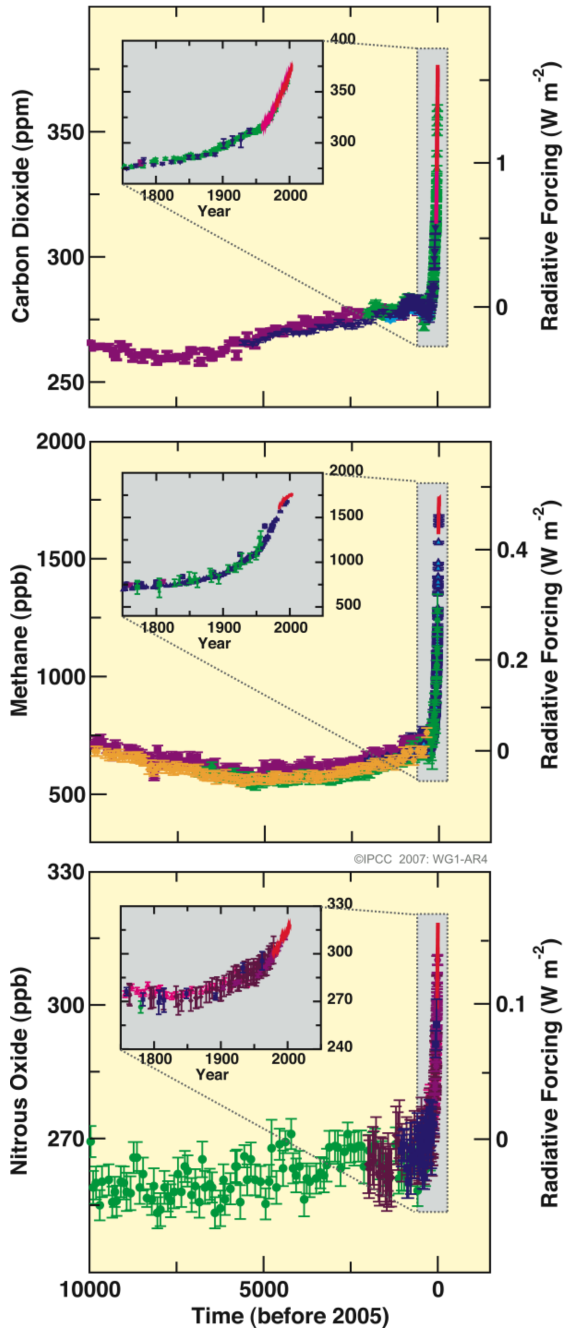

Figure 1: Atmospheric Concentrations of Carbon Dioxide, Methane and Nitrous Oxide (Source: IPCC 2007)

A change in average temperatures may serve as a useful indicator of changes in climate (Figure 2), but it is only one of many ramifications of higher GHG concentrations. Since disruption of Earth's energy balance is neither seasonally nor geographically uniform, effects of climate disruption vary across space as well as time. For example, there has been a widespread retreat of mountain glaciers during the twentieth century. Scientific evidence also suggests that there has been a 40 percent decrease in Arctic sea ice thickness during late summer to early autumn in recent decades and considerably slower decline in winter sea ice thickness. The extent of Northern Hemisphere spring and summer ice sheets has decreased by about 10 to 15 percent since the 1950s.

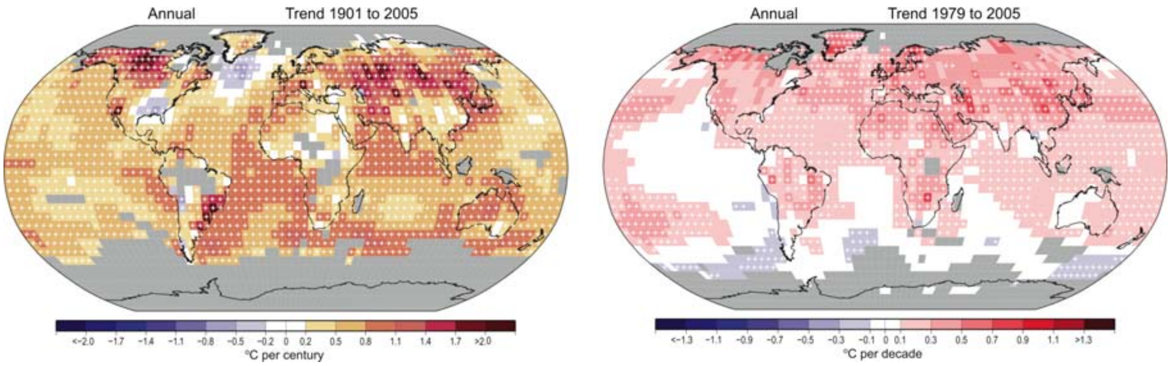

Figure 2: Annual Temperature Trends (Source: IPCC 2007)

The net loss of snow and ice cover, combined with an increase in ocean temperatures and thermal expansion of the water mass in oceans, has resulted in a rise of global average sea level between 0.1 and 0.2 meters during the twentieth century, which is considerably higher than the average rate during the last several millennia (IPCC 2007; Barnett 1984; Douglas 2001).

Changes in heat fluxes through the atmosphere and oceans, combined with changes in reflectivity of the earth's surface, may result in altered frequency and severity of climate extremes around the globe (Easterling and Mehl 2000). For example, it is likely that there has been a 2 to 4 percent increase in the frequency of heavy precipitation events in the mid and high latitudes of the Northern Hemisphere over the latter half of the twentieth century, while in some regions, such as Asia and Africa, the frequency and intensity of droughts have increased in recent decades (IPCC 2001). Furthermore, the timing and magnitude of snowfall and snowmelt may be significantly affected, influencing among other things, erosion, water quality and agricultural productivity. And since evaporation increases exponentially with water temperature, global climate change-induced sea surface temperature increases are likely to result in increased frequency and intensity of hurricanes and increased size of the regions affected. (Frederick and Gleick 1999)

Impacts of Climate Change throughout the US

This study on the economic impacts of climate change in the State of Tennessee is part of a series of state-focused studies to help inform the challenging decisions policymakers now face. It builds on a prior assessment by the Center for Integrative Environmental Research, US Economic Impacts of Climate Change and the Costs of Inaction, which concluded that throughout the United States, individuals and communities depend on sectors and systems that are expected to be greatly affected by the impacts of continued climate change.

- The **forest sector** is expected to benefit in the short term from carbon fertilizer and warmer temperatures. However, long term variability in precipitation and higher ozone concentrations may offset these short term gains.

- The **agricultural sector** is likely to experience uneven impacts throughout the country. Initial economic gains from altered growing conditions will likely be lost as temperatures continue to rise. Regional droughts, water shortages, as well as excess precipitation, and spread of pest and diseases will negatively impact agriculture in most regions.

- Increased incidence of asthma, heat-related diseases, other respiratory ailments and water contamination may result from climate change, affecting **human health** and well-being.

- The reliability of **water supply networks** may be compromised, influencing agricultural production, as well as availability of water for household and industrial uses.

As science continues to bring clarity to present and future global climate change, policymakers are beginning to respond and propose policies that aim to curb greenhouse gas emissions and to help us adapt to the impending impacts triggered by past emissions.

While climate impacts will vary on a regional scale, it is at the state and local levels where critical policy and investment decisions are made for the very systems most likely to be affected by climate change – water, energy, transportation and public health systems, as well as important economic sectors such as agriculture, fisheries, forestry, manufacturing, and tourism. Yet, much of the focus, to date, has been on the perceived high cost of reducing greenhouse gas emissions. The costs of inaction are frequently neglected and typically not calculated. These costs include such expenses as rebuilding or preparing infrastructure to meet new realities and the ripple economic impacts on the state's households, the agricultural, manufacturing, commercial, and public service sectors.

The conclusions from our nation-wide study highlight the need for increased understanding of the economic impacts of climate change at the state, local and sector level:

- Economic impacts of climate change will occur throughout the country.
- Economic impacts will be unevenly distributed across regions and within the economy and society.
- Negative climate impacts will outweigh benefits for most sectors that provide essential goods and services to society.
- Climate change impacts will place immense strains on public sector budgets.
- Secondary effects of climate impacts can include higher prices, reduced income and job losses.

Methodology

This report identifies key economic sectors in Tennessee, which are likely affected by climate change, and the main impacts to be expected for these sectors. The report provides examples of the direct economic impacts that could be experienced in the state and presents calculations of indirect effects that are triggered as impacts on individual sectors in the economy ripple through to affect others.

The study reviews and analyzes existing studies such as the 2000 Global Change Research Program National Assessment of the Potential Consequences of Climate Variability and Change which identifies potential regional impacts. Additional regional, state and local studies are used to expand on this work, as well as new calculations derived from federal, state and industry data sources. The economic data is then related to predicted impacts of climate change provided from climate models. To standardize the results, all of the figures used in this report have been converted to 2007 dollars (BLS 2008).

Since the early 1990s, and especially during the 21st century, significant progress has been made in understanding the impacts of climate change at national, regional, and local scales. The Canadian and Hadley climate change models are cited most frequently and we look first to these, yet there are many other valuable models used by some of the specialized studies we cite in this report.

In addition to looking at data that illustrates the direct economic impacts of climate change, the report also provides examples of the often overlooked ripple economic effects on other sectors and the state economy. To calculate these, we employed a modified IMPLAN^{TM} model from the Regional Economic Studies Institute (RESI) of Towson University. This is a standard input/output model and the primary tool used by economists to measure the total economic impact by calculating spin-off impacts (indirect and induced impacts) based upon the direct impacts which are inputted into the model. Direct impacts are those impacts (jobs and output) generated directly by the project. Indirect economic impacts occur as the project (or business owners) purchase local goods and services. Both direct and indirect job creation increases area household income and results in increased local spending on the part of area households. The jobs, wages, output and tax revenues created by increased household spending are referred to as induced economic impacts.

After reviewing climate and economic information that is currently available, the study identifies specific data gaps and research needs for further understanding of the significant economic impacts. There is no definitive total cost of inaction. Given the diversity in approaches among existing economic studies and the complexity of climate-induced challenges faced by society, there is a real need for a consistent methodology that enables more complete estimates of impacts and adaptation costs. The report closes with basic recommendations and concluding lessons learned from this series of state-level studies.

Not all environmentally induced impacts on infrastructures, economy, society and ecosystems reported here can be directly or unequivocally related to climate change. However, historical as well as modeled future environmental conditions are consistent with a world experiencing changing climate. Models illustrate what may happen if we do not act now to effectively address climate change and if adaptation efforts are inadequate. Estimates of the costs of adapting environmental and infrastructure goods and services to climate change can provide insight into the very real costs of inaction, or conversely, the benefits of maintaining and protecting societal goods and services through effective policies that avoid the most severe climate impacts. Since it is typically at the sectoral and local levels where those costs are borne and benefits are received, cost estimates can provide powerful means for galvanizing the discussion about climate change policy and investment decision-making.

These cost estimates may understate impacts on the economy and society to the extent that they simply cover what can be readily captured in monetary terms, and to the extent that they are calculated for the more likely future climate conditions rather than less likely but potentially very severe and abrupt changes. The broader impacts on the social fabric, long-term economic competitiveness of the state nationally and internationally, changes in environmental quality and quality of life largely are outside the purview of the analysis, yet likely not trivial at all. Together, the monetary and non-monetary, direct, indirect and induced costs on society and the economy provide a strong basis on which to justify actions to mitigate and adapt to climate change.

CLIMATE CHANGE IN TENNESSEE

The Intergovernmental Panel on Climate Change (IPCC) has been the main scientific assessment body on climate change since 1988. The Fourth Assessment Report by the IPCC, released in 2007, includes more detailed/improved analysis of regional climate change scenarios.

Since 1955, the Southeastern United States has experienced nearly a 1º C (1.8º F) temperature increase. If climate change continues to progress unmitigated, carbon dioxide concentrations could double relative to current levels during the 21st century, and temperature in Tennessee could rise between 2º and 6º C (3.6º and 10.8º F). The range in forecasts depends on development choices, technological progress, and the type of climate model used. A mean annual estimate is an increase of 3.5º C (6.3º F) as shown in Figure 3. It is likely that Tennessee will experience increased warming relative to the global average, as is the case with most mid-latitude locations (IPCC 2007).

Precipitation is more difficult to predict, but IPCC science has improved its modeling. On an annual basis, Tennessee could see a range relative to the current climate of a decrease of 3 percent to an increase of 15 percent, with an average increase of 7 percent (Figure 4). Much of the increased precipitation will occur during the winter, with near neutral conditions in the summer (Ibid).

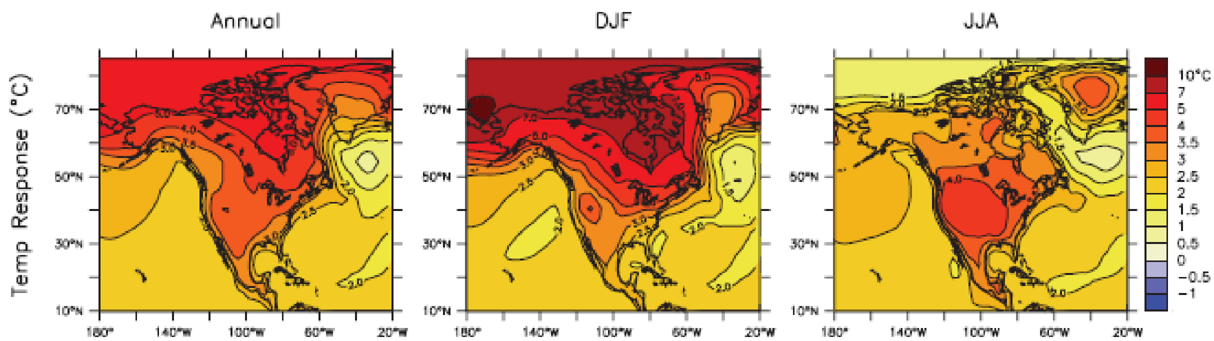

Figure 3: IPCC Fourth Assessment Report temperature projections for annual climate, winter (Dec-Jan-Feb) climate, and summer (Jun-Jul-Aug) climate. (Source: IPCC 2007)

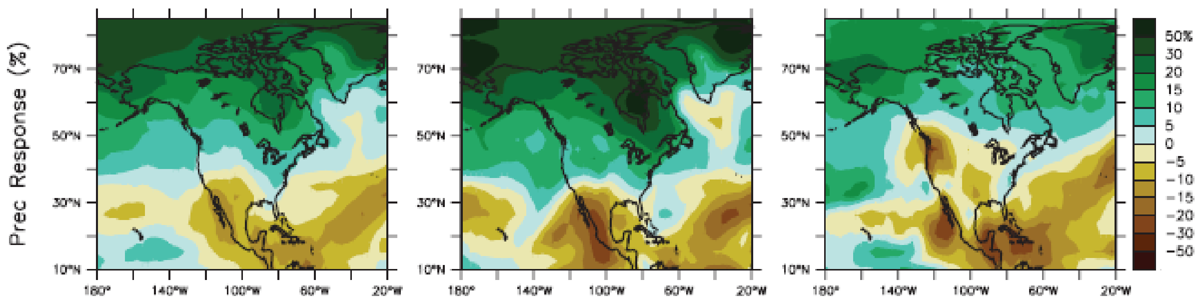

Figure 4: IPCC Fourth Assessment Report precipitation projections for annual, winter, and summer climate. (Source: IPCC 2007)

Other likely climate responses are increases in precipitation extremes (e.g., droughts and severe storms) and temperature extremes (e.g., heat waves). The distribution of these extremes for the nation and Tennessee is unclear.

MAJOR ECONOMIC IMPACTS

As an inland state, Tennessee will not be directly influenced by sea level rise. Additionally, much of the state's economy is based on the service sector, most of which is not directly linked to climate. Yet, the service sector will experience impacts to the extent that energy and water supply are affected by climate, and as other parts of the economy, for which services are provided, experience losses in productivity, revenue or employment. Other economic sectors in the states are directly linked to climate variables. The two industries most impacted by impending climate change will be forestry and agriculture.

Forestry

Tennessee has been dubbed the "Hardwood Capital of the World" for good reason—the state is the number one producer of hardwood flooring and is ranked second in the United States in hardwood lumber production (US Department of Commerce, Economics and Statistics Administration 2005a). In 2000, the forest product industry accounted for 6.6 percent of the state's GDP, generated $21.7 billion in economic output, and employed 180,000 people in the forest product industry (English et al. 2001).

Tennessee's forests are large, natural economic assets, covering 55 percent of the state's land. Hardwood species, including oak, maple, and hickory, constitute the majority of tress on forested lands (Tennessee Department of Agriculture 2008). In contrast to the national trend, forested land in Tennessee has increased in recent years due to farmland conversion. Almost all of the additional growth has occurred naturally.

Forest productivity is influenced by a variety of environmental factors – slight increases in temperature or precipitation may actually stimulate forest growth. Given the IPCC estimates of an average increase of 6.3 F in temperature and an increase of around 7 percent in precipitation, forest growth could be stimulated under this climate change scenario. Higher temperatures increase the metabolic rates of plants, and enhanced precipitation can also positively impact growth. Furthermore, higher concentrations of carbon dioxide can increase productivity through "carbon fertilization" (Fuhrer 2003). One research study has found that a 50 percent increase in atmospheric carbon dioxide concentrations resulted in a 23 percent increase in forest productivity (Zhang et al. 2007). If such an increase occurs, it would add nearly $8.7 billion in direct and indirect economic contributions to the state's economy (RESI 2008).

However, an increase of atmospheric carbon dioxide levels of 50 percent would result in an increase in global temperature of 5º F—a temperature rise that could cause catastrophic changes in sea levels, temperatures and precipitation, leading to a major disruption of the global economy (Metz 2008). Such pronounced climatic changes would counteract any potential benefits to the state's economy.

Also affecting the forestry sector is the concentration of ground-level ozone. Ozone is a pollutant formed from motor vehicle and industrial emissions during warm summer months. Ozone levels are predicted to increase throughout the U.S. as fossil fuel combustion increases and temperatures rise due to climate change. An increase in the amount of ground-level ozone, which is harmful to plants and human health, could counteract some of the productivity gains from carbon fertilization. Researchers estimate that if ozone levels increase as expected, plant productivity could decline by over 10 percent by 2100 (MIT 2007). Thus, the net effect on the productivity of the Tennessee forestry sector is uncertain.

The species composition of Tennessee's forests could change as species shift northward with increasing temperatures. Soil moisture—affected by evaporation rates and precipitation—also plays a major role in tree growth. Under increased temperatures and precipitation, soil moisture could increase or decrease depending on frequency and timing of rainfall. Drier soils resulting from longer periods between rainfall events could offset gains from carbon fertilization.

Agriculture

In 2007, crop and livestock production accounted for less than 1 percent ($1.7 billion) of Tennessee's state GDP (BEA 2007). Similar to forestry, the agriculture industry is one of the most highly impacted economic sectors from climate change. Cattle and calves are the top agricultural commodity with 18.8 percent of state agricultural receipts. Poultry is 2nd at 16 percent, followed by cotton, greenhouse/nursery products, and soybeans (USDA 2006). Tobacco, though a modest contributor to state sales, also remains an important crop, as Tennessee ranks third in the country in tobacco production. Most agricultural land is devoted to livestock foraging, followed by soybean and cotton production (USDA 2002).

Similar to forestry, agricultural impacts—particularly crops—will be dependent on temperature, precipitation, and carbon dioxide levels among other climate variables. Due to the projected increase in all three variables, crop productivity is likely to increase for specific crops. One study modeled the effect of doubled carbon dioxide on soybean yields; given warming alone, yields are likely to decrease. However, the effect of carbon fertilization dominates soybean yields, producing between a 14 and 30 percent increase in yields and between $350,000 and $750,000 in increased soybean sales depending on the climate scenario (Alexandrov and Hoogenboom 2000).

Cotton is projected to thrive under warmer and high carbon dioxide scenarios with cotton yields in Tennessee increasing between 6 and 37 percent. Such a change in productivity could increase annual cotton sales by $200,000 to $1.2 million (Doherty et al. 2003). The positive direct and indirect economic impacts from higher cotton and soybean yields top $2 million (RESI 2008).

Despite these gains in the state's agricultural sector from higher temperatures and carbon dioxide concentrations, many uncertainties exist, including precipitation variability and ozone levels. For example, researchers at MIT predict a reduction in crop yield by as much as 10 percent when changes in ground-level ozone concentration are considered (Reilly et al. 2007).

While precipitation is likely to increase for Tennessee on an annual average basis, so are extreme events such as heat waves, droughts, and floods. Because these types of events are highly unpredictable, a large amount of uncertainty exists for agricultural and forestry productivity. While the IPCC predicts an increase in temperature and precipitation, precipitation variability is the most important component. Infrequent yet intense storm events will not maintain adequate and continuous soil moisture for plant survival. Because of this, precipitation variability is the biggest uncertainty for the forestry and agricultural sectors under climate change. For example, a study examining profit damages from projected climate change impacts on Midwest agriculture found that climate variability can have a severe impact on the overall profit margin. The report found that if the variability of temperature and precipitation increased from 10 percent to 25 percent, agricultural losses would increase by 150 percent, even while holding average temperature and total precipitation increases constant (Dixon and Segerson 1999).

Furthermore, crop pests could expand their habitats and become an agricultural nuisance. Typically, the winter season kills off existing insect pests and limits the number of generations of pests living at any given time. Since rising temperatures will primarily result in higher wintertime lows, winters in the future may become incapable of killing off pest generations (Patterson et al. 1999). A lengthening of the warm season will allow greater numbers of pest generations to coexist (Porter et al. 1991). It is unknown what effect climate change will have on cotton and soybean crop pests, but researchers have generalized that crop pests may become more prevalent with climate change.

The situation for cattle and poultry production remains less clear. Livestock depend on forage and feed for their development, which are intimately tied to changes in temperature, precipitation, and carbon levels. Not all crops will increase in yield (e.g., corn), and corn is a main component of feed (Alexandrov and Hoogenboom 2000). Another study shows that above a critical temperature threshold, dairy cows produce less milk. Since dairy products account for $1.7 million of Tennessee's agricultural sales, warming is a threat to the dairy industry. Moreover, since multiple other industries – such as processing, packaging, and shipping dairy products – are tied to the productivity of the dairy industry, the direct and indirect economic impacts are expected to be over $3.1 million (RESI 2008).

OTHER ECONOMIC IMPACTS

Water Resources and Quality

While forestry and agriculture are the primary sectors that will be influenced by climate change, a variety of other sectors could be impacted as well. The western border of Tennessee—the Mississippi River—has created a large area of low-lying land (Figure 5). If the middle Mississippi were to flood more often under climate change, economic impacts would be significant (e.g., infrastructure loss, agriculture). This possibility may also hold true for all the major Tennessee rivers if extreme rainfall events become prevalent.

Another possibility is the effect of more sporadic rainfall and decreased snowmelt from the Appalachian Mountains on the hydrologic cycle. Timely snowmelt is directly linked to groundwater availability during critical dry summer months. If an increase in winter temperatures occurs, which is likely, melting would happen sooner in the spring, disrupting groundwater recharge timing. Much of the projected precipitation increases are likely to occur in the form of rain during the winter months – not during the critical summer months. Lack of surface water during the growing season could counteract any yield gains for the forestry and agriculture sectors. Changes in precipitation are likely to decrease municipal water supplies along the Tennessee and Cumberland rivers (University of Tennessee 2008).

Figure 5: Tennessee topography (Source: www.maps.com)

Higher water temperatures are expected to affect water quality by lowering oxygen levels – thereby concentrating pollutants, which may increase the cost of water treatment (Barker 2003). The State of Tennessee has already seen a 54 percent increase in its water treatment needs between 2000 and 2004. The EPA reports that the state needed $1.13 billion in 2004 to meet its current wastewater treatment needs (USEPA 2004). As climate change impacts exacerbate, the cost of clean water will likely rise. For example, a study in Texas showed that increased pollution required a 27 percent increase in treatment expenditures (Dearmont et al. 1997). If the costs went up by the same percentage in Tennessee, an additional $305 million will be needed for water treatment costs. The total direct and indirect costs of water treatment top $480 million (RESI 2008). The watersheds are already in trouble in the state with many of the aquifers being 15 percent or more impaired (See Figure 6).

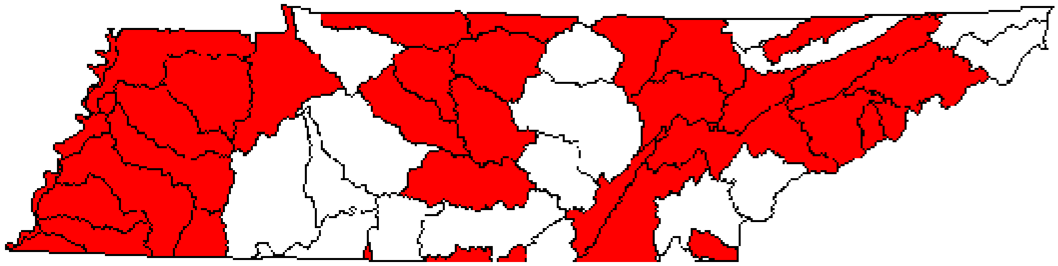

Figure 6: Tennessee's Unified Watershed Assessment Categories. Watersheds in red are over 15 percent impaired. (Source: Tennessee Department of Environment 2008)

Moreover, water withdrawals are on the rise and are expected to increase by 15 percent by 2030 (Hutson et al. 2000). This will likely further strain this important resource, imposing high economic costs on the state and by extension on the population. The Tennessee Department of Environment estimates that nearly 40 percent of the state's streams and 32 percent of the state's reservoirs are impaired and not supporting their designated uses. The Department further states that polluted water not only increases treatment costs, but can also cause health disruptions, productivity losses, economic losses to commercial fisheries, and decreased commercial navigation (Tennessee Department of Environment 2008b).

The state's rivers are likewise susceptible. About 147 miles of rivers are closed off to the public because of bacterial contamination. An additional 119 river miles are closed because fish are contaminated with mercury or PCBs (Tennessee Department of Environment 2008a). Changes in the timing and frequency of precipitation events will likely impact natural water resources. More sporadic and frequent runoffs may increase pollution loading, while lower flow rates may increase concentrations of the contaminants already entering or in the water system.

Tennessee is home to around 787,000 acres of wetlands, which have been called nature's water filters (Association of State Wetland Managers 2008). These are highly susceptible to higher temperatures, increases in atmospheric carbon dioxide, and changes in precipitation. Yet wetlands provide important ecological and water purification services for the state. For example, one study quantifying the impacts of water construction on wetlands estimated that the replacement costs per acre range from $350 to over $25,000 (USEPA 1997). A 20 percent loss of wetland acreage would cost the state from $55 million to nearly $4 billion. A $2 billion cost to the state would amount to nearly $3.5 billion in direct and indirect expenses throughout the state's economy (RESI 2008).

Hunting

Tennessee also has a significant hunting economy; hunting expenditures in 2006 totaled $495 million, with migratory bird hunting bringing in over $33 million annually (US Fish and Wildlife Service 2006). Many game bird species nest in the Prairie Pothole region of Canada and northern United States, and migrate southward to spend the winter in

Tennessee wetlands. Climate change threatens the critical breeding grounds of the Prairie Pothole region, and the population of migratory birds that rely on it. Changes in precipitation and temperature patterns brought about by climate change, along with land use changes, could shrink the nesting grounds of the Prairie Pothole region by as much as 90 percent, significantly reducing migratory bird populations (Glick 2005). A warming climate also may push the bird's winter habitat northward out of Tennessee. If these changes cause the bird population to decline and result in a 10 percent decrease in hunting revenues, the state would lose over $80 million annually in direct and indirect economic contributions (RESI 2008).

Infrastructure

Increased temperatures and altered precipitation patterns could lead to more drought, flooding, and extreme weather events in the state at the expense of property and infrastructure. Floods will become more prominent as warmer temperatures dry out the soil making it less permeable and as rainfall, which is predicted to increase by 7 percent in the state, comes in the form of extreme weather events (IPCC 2007). Flooding is most likely to occur in the center of the state where an array of rivers and streams has carved out the Tennessee Valley. The Tennessee Valley Authority estimates that it prevents $230 million in flood damage each year and has taken steps to adapt to future needs (TVA 2007). However, the TVA simply does not have the capacity to deal with all flood threats. As evidenced by the floods in Chattanooga in May of 2003, which caused $18 million in damage, the dams are not a cure-all for flooding in the region. The 2003 flood’s total economic damages are almost double the direct costs at $34 million (RESI 2008). Additionally, energy demands are likely to rise with increases in temperature; and hydroelectric power, which accounts for 10 percent of the TVA’s energy production, may struggle amid periods of drought.

Lastly, Tennessee experiences tornadoes and hurricanes, albeit minor in frequency and intensity compared to other parts of the country. Nonetheless, the “Super Tuesday tornadoes” of 2008 resulted in 32 deaths in Tennessee and several million dollars in damage (The Tennessean 2008). Tornadoes, which are influenced in part by dry air, could become more common in the state. In 2006, Tennessee lost about $920 million in catastrophe damages, which could increase as events of extreme weather rise (III 2008). The indirect impact of such damages on the economy – through disruption of business, supply chains, and overall demand for products and services because resources are funneled to address climate impacts – amount to another $800 million for an overall impact of $1.72 billion in damages (RESI 2008).

Health Impacts

The warmer, wetter climate projected for Tennessee as a result of climate change will likely create negative health impacts. The EPA projects that Tennessee’s environment may become more hospitable to disease-carrying insects, potentially increasing incidences of malaria, Lyme disease, and dengue fever. East Tennessee, which is already suffering from smog and poor air quality, may be further impacted by poor air quality and an increase in rates of respiratory diseases and heat-related health issues (Barker 2003). An estimated 12.4 percent of the population in Tennessee suffers from asthma, although the percentage of high school students suffering from asthma neared 20 percent in 2005 (Trust for America's Health 2008). Costs of asthma, including health care costs and lost productivity (30 days annually for an average asthmatic), topped $16.5 billion in the United States (Tennessee Department of Health 2008; Long 2007). Assuming the expenditures are distributed evenly throughout the country, Tennessee spends around $625 million annually to treat the disease. If incidence of asthma is increased by 30 percent, an additional $187 million will be required to meet the need. The direct and indirect economic impacts of such an increase would amount to an expense of around $360 million (RESI 2008).

Higher temperatures and heat waves will likely increase the number of heat-related deaths and illnesses. Temperature increases will be higher in cities like Memphis and Nashville relative to surrounding rural areas as a consequence of heat-absorbing buildings and concrete. Known as the urban heat island effect, this phenomenon could have a detrimental impact on densely populated areas. Higher temperatures will also increase demand for water supplies used for both drinking and irrigation. To be sure, low quantities of water are a serious threat to human health, but perhaps more insidious is the problem of impaired water associated with a reduced supply and flooding. Reduced water supplies lead to a higher concentration of bacteria, pesticides and other unwanted bodies than would be present under normal conditions. Moreover, warmer water and longer seasons facilitate the growth of algae and harmful bacteria that lead to fish kills and other water contamination.

MISSING INFORMATION AND DATA GAPS

Relative to other southern states, some economic sectors in Tennessee may actually stand to gain from climate change. Modeling studies suggest increased carbon dioxide will increase photosynthesis and forest/crop yields. However, this projection is critical on the availability of timely precipitation, lack of disease-causing pests, and sufficient soil moisture, all of which are questionable under climate change scenarios. Furthermore, other gases such as ozone could counteract the carbon fertilization effect. Most importantly, perhaps, the negative impacts associated with disruption and destruction of infrastructure as a result of more frequent and severe weather events such as floods, droughts, tornados, and extreme rainfall, could undermine the economic performance of the forestry and agricultural sector, as well as the rest of the economy, even if crop productivity were to increase.

The IPCC is much more confident about its temperature forecasts, less confident in precipitation forecasts, and even less confident about the frequency of precipitation events, let alone the strength and recurrence interval of tornados. Therefore, it would behoove Tennessee to proceed with caution and develop adaptation and mitigation plans for its most vulnerable industries.

CONCLUSIONS

Tennessee's greatest challenge is likely to be in adapting to the effects that climate change may have on water resources and infrastructure. Understanding how climate change will affect water quality and availability will be crucial to balancing development and population growth where water supplies may be compromised. Policymakers may wish to investigate the degree to which changes in water quality will increase water treatment and management costs, and what steps can be taken to integrate possible scenarios into planning and budgeting.

Since the likelihood of flooding is predicted to increase, policymakers can promote additional state-specific research on potential precipitation changes. Creating assessments that designate which regions are most susceptible to an increase in flooding and revising flood response and mitigation plans would also be useful. Revisiting zoning and development in susceptible areas and modifying them to prevent development in highest risk areas could be helpful in avoiding future disasters and their associated costs.

Since climate change is likely to place more stress on wildlife, policies that create large, inter-connected wildlife preserves with varied ecosystems will improve the ability of flora and fauna to adapt to changes

Lessons Learned

As we begin to quantify the potential impacts of climate change and the cost of inaction, the following five lessons are learned:

1. There are already considerable costs to society associated with infrastructures, agricultural and silvicultural practices, land use choices, transportation and consumptive behaviors that are not in synch with past and current climatic conditions. These costs are likely to increase as climate change accelerates over this century.

2. The effects of climate change should not be considered in isolation. Every state’s economy is linked to the economies of surrounding states as well as to the national and global economy. While the economic costs of climate change are predicted to vary significantly from state to state, the negative impacts that regional, national and global markets may experience are likely to affect all states and many sectors.

3. While some of the benefits from climate change may accrue to individual farms or businesses, the cost of dealing with adverse climate impacts are typically borne by society as a whole. These costs to society will not be uniformly distributed but felt most among small businesses and farms, the elderly and socially marginalized groups.

4. The costs of inaction are persistent and lasting. Benefits from climate change may be brief and fleeting - for example, climate does not stop changing once a farm benefited from temporarily improved growing conditions. In contrast, costs of inaction are likely to stay and to increase.

5. Climate models and impact assessments are becoming increasingly refined, generating information at higher spatial and temporal resolutions than previously possible. Yet, little consistency exists among studies to enable "summing up" impacts and cost figures across sectors and regions to arrive at a comprehensive, state-wide result.

6. To provide not just a comprehensive state-wide assessment of impacts and cost, but to develop optimal portfolios for investment and policy strategies will require support for integrative environmental research that combines cutting-edge engineering solutions with environmental, economic and social analysis. The effort and resources required for an integrative approach likely pales in comparison to the cost of inaction.

WORKS CITED

Alexandrov, V.A., and Hoogenboom, G., (2000), 'Vulnerability and adaptation assessments of agricultural crops under climate change in the Southeastern USA.' *Theoretical and Applied Climatology*, v. 67, p. 45-63.

Association of State Wetland Managers, (2008), 'Tennessee.' Available online: www.aswm.org/swp/tn9.pdf

Barker, (2003). 'Scientists agree on climatic change, differ on severity.' *News-Sentinel*. Available online: www.csm.ornl.gov/PR/NS-10-25-03.html

Barnett, T.P, (1984), 'The estimation of "global" sea level change: a problem of uniqueness', *Journal of Geophysical Research*, 89: 7980-7988.

Bureau of Economic Analysis (BEA), (2007). Available online: www.bea.gov

Bureau of Labor Statistics (BLS), (2008), 'Consumer Price Indexes: Inflation Calculator.' Available Online: www.bls.gov/cpi/

Dearmont, D., McCarl, B.A., and Tolman, D.A, (1997), 'Costs of Water Treatment Due to Diminished Water Quality: A Case Study in Texas.' Available online: http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/535.pdf

Dixon, B. L. and Segerson, K., (1999), 'Impacts of Increased Climate Variability on the Profitability of Midwest Agriculture.' *Journal of Agricultural and Applied Economics*, 31, 3. December, 1999. p. 537-549.

Doherty, R.M., Mearns, L.O., Reddy, K.R., Downton, M.W., and McDaniel, L., (2003), ‘Spatial scale effects of climate scenarios on simulated cotton production in the southeastern USA.’ *Climatic Change*, v. 60, p. 99-129.

Douglas, B.C. (2001), ‘An introduction to sea level’, in *Sea level rise: history and consequences*, B.C. Douglas, M.S. Kirney, and S.P. Leatherman (eds), San Diego, CA: Academic Press, pp. 1-11

Easterling, D. R., G. A. Mehl, et al. (2000), ‘Climate extremes: observations, modeling, and impacts’, *Science*, 289: 2068-2074

English, B., K. Jensen and, and J. Menard, (2001), ‘Economic impacts of agriculture and forestry in Tennessee, 1997.’ The University of Tennessee, Institute of Agriculture, Dept. of Agricultural Economics Research Series 04-01. p.143.

Frederick, K.D. and P.H. Gleick, (1999), ‘Water And Global Climate Change: Potential Impacts on US Water Resources.’ Washington, DC: Pew Center on Global Climate Change.

Fuhrer, J., (2003), ‘Agroecosystern responses to combinations of elevated CO2, ozone, and global climate change.’ *Agriculture Ecosystems & Environment*, v. 97, p. 1-20.

Hutson, S. S, M. Koroa, and C. Murphree, (2004), ‘Estimated Use of Water in the Tennessee River Watershed in 2000 and Projections of Water Use to 2030.’ US Geological Survey (USGS), Water-Resources Investigations Report 03-4302. Nashville, TN: USGS. Available online: http://pubs.usgs.gov/wri/wri034302/

Insurance Information Institute (III), (2008). ‘Tennessee.’ Available online: www.economicinsurancefacts.org/economics/searchbystate/state.Tennessee/

Intergovernmental Panel on Climate Change (IPCC), (2007), ‘Synthesis Report for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.’ Available online: www.ipcc.ch/ipccreports/ar4-syr.htmwww.ipcc.ch/ipccreports/ar4-syr.htm

Intergovernmental Panel on Climate Change (IPCC), (2001), ‘The Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change.’ Eds. J.T. Houghton. Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson. Cambridge, England and New York, NY: Cambridge University Press. Available online: www.grida.no/climate/ipcc_tar/

Long, A, (2007), ‘Asthma Prevalence Rates and Employer-Paid Costs.’ Available online: www.medicalnewsinc.com/news.php?viewStory=60

Patterson, D.T., Westbrook, J.K., Joyce, R.J.V., Lingren, P.D., and Rogasik, J., (1999), ‘Weeds, insects, and diseases.’ *Climatic Change,* v. 43, p. 711-727.

Porter, J.H., Parry, M.L., and Carter, T.R., (1991), *The Potential Effects of Climatic-Change On Agricultural Insect Pests*: Agricultural and Forest Meteorology, v. 57, p. 221-240.

Regional Economic Studies Institute (RESI) 2008. Calculations using modified IMPLAN™ economic model from the Regional Economic Studies Institute (RESI) of Towson University.

Reilly, J., Paltsev, S., Felzer, B., Wang, X., Kicklighter, D., Melillo, J., Prinn, R., Sarofim, M., Sokolov, A., and Wang, C., (2007), 'Global economic effects of changes in crops, pasture, and forests due to changing climate, carbon dioxide, and ozone.' *Energy Policy*, v. 35, p. 5370-5383.

Sitch, S., Cox, P.M., Collins, W.J., and Huntingford, C., (2007), 'Indirect radiative forcing of climate change through ozone effects on the land-carbon sink.' *Nature*, v. 448, p. 791-U4.

Tennessee Department of Agriculture, (2008), Available online: www.state.tn.us/agriculture/forestry/

Tennessee Department of Environment, (2008a), 'Posted Streams, Rivers, and Reservoirs.' Available online: www.tennessee.gov/environment/wpc/publications/advisories.pdf

Tennessee Department of Environment, (2008b), 'The Status of water quality in Tennessee.' Available online: www.tennessee.gov/environment/wpc/publications/2008_305b.pdf

Tennessee Department of Health, (2008), 'Asthma.' Available online: http://health.state.tn.us/FactSheets/asthma.htm

Tennessee Valley Authority (TVA), (2007), 'Flood Damage Reduction.' Available online: www.tva.gov/river/flood/index.htm

The Tennessean, (2008). 'Tennessee Tornado.' Available online: www.tennessean.com/apps/pbcs.dll/section?Category=NEWS15

Trust for America's Health, (2008), 'The State of your Health: Tennessee.' Available online: http://healthyamericans.org/state/index.php?StateID=TN

US Department of Agriculture, (2002), 'Census of Agriculture.' Available online: www.agcensus.usda.gov/Publications/2002/index.asp

US Department of Agriculture, (2006), 'Economic Research Statistics.' Available online: www.ers.usda.gov/statefacts/

US Department of Commerce, Economics and Statistics Administration. (2005a), 'Lumber production and mill stocks.' *Current Industrial Reports*. MA321T(04)-1. Washington, D.C.

US Environmental Protection Agency (EPA), (2004), 'Tennessee: Clean Watersheds Needs Survey 2004.' Available online: www.epa.gov/cwns/tn.pdf

US Environmental Protection Agency (EPA), (1997), 'Quantifying the Impacts of Road Construction on Wetlands Loss: Final Report.' *Road Management Journal*. Available online: www.usroads.com/journals/p/rmj/9712/rm971203.htm

US Fish and Wildlife Service (USFWS), (2001), 'National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.' Available online: www.library.fws.gov/nat_survey2001.pdf

University of Tennessee, (2008), *Long-term Challenges to Tennessee's Water Supply*. Chapter 6. Available online: http://eerc.ra.utk.edu/divisions/wrrc/water_supply/chapter6.htm

Wullschleger, S.D., and Hanson, P.J., (2006), 'Sensitivity of canopy transpiration to altered precipitation in an upland oak forest: evidence from a long-term field manipulation study.' *Global Change Biology*, v. 12, p. 97-109.

Zhang, C., Tian, H.Q., Chappelka, A.H., Ren, W., Chen, H., Pan, S.F., Liu, M.L., Styers, D.M., Chen, G.S., and Wang, Y.H., (2007), 'Impacts of climatic and atmospheric changes on carbon dynamics in the Great Smoky Mountains National Park.' *Environmental Pollution*, v. 149, p. 336-34