EVIDENCE OF THE ENVIRONMENTAL KUZNETS CURVE AMONG U.S. STATES AND THE IMPACT OF LAND CONSERVATION

By

Trevor Church

A paper submitted in partial fulfillment of the requirements to complete Honors in the Department of Economics and Finance of the Cameron School of Business.

Examining Committee:

Daniel Soques

Dr. Daniel Soques
Economics and Finance

Christopher Frank Dumas

Dr. Chris Dumas
Environmental Sciences

Dr. Prosper Bangwayo-Skeete
Economics and Finance

Approved By:

Peter W. Schuhmann

Dr. Peter Schuhmann
Faculty Supervisor

Dr. Adam Jones
Chair, Economics and Finance Department

Dr. Shawn Bingham
Director of the Honors Scholars College

University of North Carolina

Wilmington Wilmington, North Carolina

May 2020

I would like to thank Dr. Schuhmann for accepting the role as my supervisor and for all of the time he committed to making this project possible. Thanks to his guidance and the quality of his feedback, I have been able to produce a project which I can confidently say that I am proud of.

I would also like to thank Dr. Dumas, Dr. Skeete, and Dr. Soques for their help both with this project and throughout my undergraduate career, as well as becoming part of my Committee for this project.

Without all of your help, none of this would have been possible.

ABSTRACT: This paper presents an empirical study which provides evidence of an Environmental Kuznets curve (EKC) at the United States state level, as well as the role that forest land conservation and other exogenous variables play within this relationship. We utilize U.S. state-level panel data to examine patterns of carbon dioxide emission inventories from fossil fuel combustion as a proxy for environmental degradation as well as per capita forms of personal income and real gross domestic product (RGDP) as proxies for economic growth. The effects of land conservation in this relationship are included through forest land area conserved under the United States Department of Agriculture's Forest Service. Other exogenous variables incorporated in our final model include capital investment and average energy prices. In addition to providing evidence of an EKC relationship in the U.S., we identify of states with the greatest baseline emissions and the estimates of a range of variables have on those emissions.

1. *Introduction*

Classical economics has considered land, labor, and capital as primary factors of production since the time of Adam Smith (Kaika & Zervas, 2013; Mankiw, 2014). Land and its stock of natural resources provide numerous goods and services that contribute to economic and human well-being, as shown in Table 1. However, many current economic models fail to recognize the importance of these resources (Costanza and Daly, 1992; England, 2000). Research has also shown the negative impact of economic growth on the natural environment through exploitation and increased levels of pollution, leading to the belief that environmental degradation is a negative externality of economic expansion (Grossman & Krueger, 1995; Brock & Taylor, 2004; Kaika & Zervas, 2013).

The trade-off between economic growth and environmental quality has been a prime focus in both academic and policy discussions, and past research has identified many forms in which it this tradeoff may occur. Among the most widely supported is the Environmental Kuznets Curve (EKC) hypothesis (Kaika & Zervas, 2013, Özokcu & Özdemir, 2017). First applied in the 1990s, the EKC is presented as an inverted U-relationship between per capita income and measures of environmental degradation (Grossman & Krueger, 1995; Shafic & Bandyopadhyay, 1992; Kaika & Zervas, 2013). Various studies have attempted to test the EKC hypothesis, as well as describe underlying factors which contribute to this relationship including consumption patterns, structural changes, technical progress, institutional framework and governance, and international trade (Kaika & Zervas, 2013). By bettering our understanding of the drivers behind this relationship, we can more accurately predict how environmental change may be related to economic development.

This paper specifically looks at carbon dioxide emissions as a proxy for environmental degradation. Within the last one hundred years, carbon dioxide (CO_2) emissions have increased by more than 25 percent, largely attributed to the use of fossil fuels in energy production and transportation (Smith & Smith, 2001; Campbell et al., 2009; Hamit-Hagga, 2012; U.S. Environmental Protection Agency, 2019). As a greenhouse gas (GHG), this surge of CO_2 has been shown to stimulate climate change at the global scale (Smith & Smith, 2001). In order to lower the concentration of CO_2, recent literature and policy have looked towards forest ecosystems to provide options for the mitigation of CO_2 from the atmosphere (van Kooten & Sohngen, 2007). A large amount of the forest land in the U.S. is held under public domain. As of September 30, 2019, the United States Department of Agriculture's (USDA) Forest Service (FS) manages 192,994,069 acres of land under the National Forest System (NFS) (United States Department of Agriculture, 2019). The FS manages these lands under a mandate to provide the sustainable yield of the multiple goods and services derived from the land, implying the conservation of these lands and its resources for future use (Cubbage et al., 2017). We explicitly model how the conservation of land under the FS influences the EKC relationship, hypothesizing that more conserved land puts downward pressure on the EKC and shifts the income threshold defining the peak of the EKC to a lower level. We also control for other variables of interest that appear in past literature. These variables include levels of physical capital and energy prices.

The paper proceeds as follows: Section 2 discusses relevant studies, followed by data description in Section 3 and methodology in Section 4. Finally, Section 5 discusses the results while Section 6 concludes.

2. *Literature Review*

The notion of the Kuznets curve was proposed by Simon Kuznets (1955) in regard to the relationship between income inequality and economic growth. Through both empirical information and speculation, Kuznets (1955) attempted to characterize and define the causes of long run changes in the distribution of income and found that the relative distribution of income trended toward equality in developed countries. Conversely, the income distribution in underdeveloped or developing countries was found to be relatively more unequal, resulting in the belief that as a country's economy develops, inequality will also rise until it reaches a certain level, after which inequality will begin to fall, eliciting an inverted- U shaped relationship.

Decades after Kuznets' (1955) study, a similar model was applied in the environmental domain. Grossman and Krueger (1991, 1995) have been credited as early pioneers in the use of the Kuznets curve hypothesis in the environmental realm (Kaika & Zervas, 2013). In 1991, Grossman and Krueger discovered a model with similar shape to Kuzents' while studying the potential environmental impacts of NAFTA. By examining air quality measures in a cross-section of 42 countries, Grossman and Krueger (1991) found that economic growth tends to alleviate pollution problems once a county's per capita income reaches around $4,000 to $5,000, with further growth resulting in increased political pressure for environmental protection and possible changes in private consumption behavior.

Grossman and Krueger (1995) conducted a similar study with a larger sample. This study analyzed a reduced form of the relationship between per capita income and four environmental indicators; urban air pollution, the state of the oxygen regime in river basins, fecal contamination of river basins, and contamination of river basins by heavy metals. By investigating the estimated cubic relationship between GDP and panel data regarding water and air quality collected from the World Health Organization and United Nations Environmental Programme GEMS, Grossman and Krueger (1995) were able to find evidence which supported the EKC hypothesis across nations. Their results suggest that increases in GDP initially worsen environmental conditions in very poor countries; however, air and water quality appear to benefit from economic growth once a critical level of income has been achieved. This critical level varied across the four environmental indicators but was centralized around $8,000 (1985 USD). Although they do not investigate the means by which changes in income may influence environmental outcomes, Grossman and Krueger (1995) speculate that substitutions towards cleaner technologies as well as structural transformations may be driving the reduction of environmental degradation. These structural transformations include policy regarding stricter environmental protection as well as the divestment from pollution-intensive goods.

Grossman and Krueger (1995) also compare their study to findings by Shafik and Bandyopadhyay (1992), which also supported the EKC Hypothesis a few years prior. In their study, Shafik and Bandyopadhyay (1992) discovered an inverted- U shaped relationship between indicators of environmental quality and national income. Indicators such as deforestation and sulfur oxides emissions were shown to worsen with high investment rates yet improved with higher incomes, directly supporting the EKC Hypothesis. Data for this study was collected from the World Bank, with a large portion from the World Development Report of 1992. However, unlike Grossman and Krueger's (1995) study, Shafik and Bandyopadhyay (1992) also explored the effect of policy differences across countries, while controlling for income. Policy variables such as trade, subsidies, and debt were shown to have little effect on environmental outcomes while policy measures such as electricity tariffs were shown to reduce carbon dioxide emissions.

Comparable to Grossman and Kreuger (1995), the results from this study have been interpreted to reflect the adoption of environmental policy and investments by developing countries.

More recently, CO_2 emissions have been a focal point for empirical EKC-studies due to their relevance in climate change (Kaika & Zervas, 2013). Kaika & Zervas (2013) reviewed the evolution of the EKC and 35 studies which dealt with the EKC pattern for CO_2 emissions across different samples. 16 of the 35 studies reviewed showed some evidence of the inverted-U relationship, while 20 of these studies report evidence of CO_2 increasing monotonically with income. Looking specifically at the United States, Aldy (2005) reviewed both state-level production and consumption-based CO_2 emissions from 1960-1999, presenting the first panel-based evaluation of the EKC with a novel data set constructed by the author. Aldy (2005) found evidence supporting the EKC in both production-based and consumption-based CO_2 emissions, with the production-based EKC relationship peaks ranging from $14,708 to $16,840 and consumption-based relationship having a higher peaks ranging from $20,389 to $23,870.

Other independent variables which have been included in past studies of the EKC include the price of natural resources, the innovation and adoption of new technologies, and environmental policy and regulation (Unruh & Moomaw, 1998; Dinda, 2005; Kaika & Zervas, 2013). Higher prices of natural resources result in the reduction of exploitation. Unruh and Moomaw (1998), note that the rising price of oil during the 1970s resulted in a shift towards alternative energy production as an example of the effect of increased prices. Technological progress through increased investments in research and development has also been hypothesized to lead to greater efficiency in the use of energy and inputs, reducing the degradation of natural resources and the environment (Dinda, 2005; Kaika & Zervas, 2013). However, there is a risk with new technologies, as the negative externalities of these technologies may be unknown in the early stages of their implementation (Dinda, 2005). Dinda (2005) also refers to a *race to bottom* scenario as a driver of the EKC, noting as developed countries impose high environmental standards, polluting activities are outsourced, leading to the reallocation of both capital and pollution to poorer nations. As capital accumulates, pollution increases as well.

As noted in the *race to bottom* scenario, environmental policy and regulations have also been shown to play a large role in mitigating environmental degradation (Dinda, 2005). As economies develop, institutional changes are triggered by social demand for cleaner environments as shown by an increase of environmental regulations in developed countries (Dinda, 2005; Kaika & Zervas, 2013). Shafik and Bandyopadhyay (1992) also note that environmental policy is heavily influenced by the public in democratic countries. Cubbage et al. (2017) state that successful natural resource policies and regulations "must consider sub-objectives such as providing food, shelter, and clothing; providing sufficient domestic commodities; protecting fish and wildlife from depredation or extinction; and protecting the environment while minimizing negative impacts on economic, political and religious freedom, and economic growth and employment levels" (pg. 24). Instruments for the implementation of these policies include pollution standards, the provision of services, financial incentives, and public ownership and management. Currently, more than one third of the land in the United States is designated under public ownership under four federal agencies; the FS, National Park Service, Fish and Wildlife Service, and Bureau of Land Management (Cubbage et al. 2017).

The FS is the oldest of these federal agencies and manages a large sum of forest lands across the country. In 1891, congress passed the Forest Reserve Act[1] in response to the negligent forestry practices of the preceding decades. Section 24 of this Act allowed the president to "set

---

[1] Also known as the Creative Act

apart and reserve, in any state or territory having public land bearing forests, in any part of public lands, wholly or in part covered with timber or undergrowth". Six years following the passing of this act, congress passed the FS Organic Act, which authorized the forest reserves to protect the lands, preserve waterflows, and provide timber. These uses were expanded in 1960 under the Multiple Use Sustained-Yield Act (MUSY), opening the lands to recreation, livestock grazing, and wildlife and fish habitat. Under MUSY, the FS was tasked to manage the NFS under a conservation-based mandate to provide the sustainable yield of the multiple aforementioned uses. (Cubbage et al., 2017).

The multiple uses of the NFS under the FS provide many opportunities for economic growth through the goods and services derived from the land; however, economic indicators such as gross domestic product (GDP) fail to account for the nonmarket value of ecosystem services which result in misleading signals of economic performance (Muller, 2014; Talberth & Bohara, 2006; Patil, 2012, Stjepanović et al., 2019; Alavalapati & Ochudho, 2016). In order to attempt to correct for this shortcoming, Vincent and Hartwick (1997) created an economic accounting framework which adjusts GDP for consumption-related nonmarket benefits of forests, defining forests as "a sink for and a source of carbon dioxide, which potentially damages other industries through global climate change". The U.S. Environmental Protection Agency (2019) confirmed this claim, presenting forest lands as the greatest sink of greenhouse gases under their land use, land-use change, and forestry (LULUCF) sector in 2017, as shown in Figure 1. This report also showed that forest lands which were converted to croplands or settlements were major sources of greenhouse gases.

The conservation of forest lands has also been shown to decrease long run emissions. Popp et al. (2012) described tropical deforestation as a main contributor to human induced CO2 emissions and global warming. Looking specifically at the long run demand for cellulosic bioenergy crops as a substitute for fossil fuel energy, their study found an increase of CO_2 emissions as a result of land use changes of forests to bioenergy croplands without conservation. Additional CO_2 emissions from land use change arose in their study in Sub-Saharan Africa, Latin America, and Pacific Asia. Adding forest conservation to this model resulted in a decrease of CO_2 emissions from land use change; but, limited the availability of land for biomass plantations consequently lowering the ability to replace fossil fuel use with cellulosic bioenergy.

Under MUSY, forest lands under the FS are meant to be conserved for future generations, which limits extensive land use changes. The conservation of these lands contributes a large amount of unvalued ecosystem services, including the mitigation of carbon emissions. By utilizing panel data of carbon emission across states and across time, this study seeks to create a model which estimates the impact that conserved lands under the FS has on the EKC relationship between carbon emissions and economic growth by state. Variables representing economic variability across states and time which have been mentioned in past literature will also be added to this model to test their impacts on the EKC hypothesis.

3. *Data*

CO2 Emissions and Energy Prices. State emissions by year from 1997 – 2017 in million metric tons of CO_2 were collected from the U.S. Energy Information Administration (EIA)'s State Energy Data System (SEDS). This time series uses fuel-based estimates from primary fuel consumption of coal, natural gas, and petroleum to produce state totals. By multiplying consumption levels in Btu by national- carbon emissions factors in kilograms of CO_2 per million Btu, the EIA estimates energy-related CO_2. Sequestered carbon such as unburned coal has also been subtracted from this value.

The total energy average price in dollars per million Btu (TETCD) was also collected from the EIA's SEDS. These prices were estimated by dividing the total expenditure of total energy (TETCV) by the total net energy consumption, adjusted for process fuel, intermediate products, and fuels with no direct cost (TNSCB), then multiplying that total by 1000. This formula can be expressed as:

$$TETCD = \frac{TETCV}{TNSCB} * 1000$$

Economic Variables. Real total gross domestic product per state was collected from the Federal Reserve Economic Data Bank (FRED) of the St. Louis Federal Reserve. Real GDP per state was computed by the Bureau of Economic Analysis (BEA) and is the aggregation of compensation of employees (COMP), taxes on production and imports (TOPI), subsidies (SUB), and gross operation surplus (GOS). This can be shown as:

$$GDP = COMP + TOPI - SUB + GOS$$

These indices are in real terms and are presented as millions of chained 2012 dollars and span from 1997 – 2018 (Bureau of Economic Analysis, 2017).

Data on personal income and total population by state were collected from the U.S.

Department of Commerce's Bureau of Economic Analysis. Personal income consists of the income an individual receives and "is calculated as the sum of wages and salaries, supplements to wages and salaries, proprietors' income with inventory valuation (IVA) and capital consumption adjustments (CCAdj), rental income of persons with capital consumption adjustment (CCAdj), personal dividend income, personal interest income, and personal current transfer receipts, less contributions for government social insurance plus the adjustment for residence" based on the Regional Economic Accounts: Regional Definitions. Both real gross domestic product and personal income have been adjusted to per capita forms by dividing each variable by the total population in each state and time period.

Private capital by state was collected from El- Shagi and Yamarik (2019), who presented an updated data set of U.S. state-level private capital stock and investment. Improving on prior methodology, El-Shagi and Yamarik (2019) utilized the national capital stock estimates by The Bureau of Economic Analysis to estimate state levels of capital stock by using SIC or NAIC industry level earnings data. The previous model was improved upon by adjusting for the mining sector. Capital was estimated in terms of capital stock in millions of 2009 USD and was adjusted into 2012 USD.

Land Area. Land area of the NFS in acres was collected from the yearly Land Area Reports produced by the USDA FS from 1997-2017. The most recent data from this report was generated from the Forest Service Electronic Land Status Record System geodatabase which utilizes vector data in decimal degrees. Rounding errors from this set average less than 0.000005%, however prior years may be subjected to larger errors. Total land area of each state was collected from a report titled "Public Land Ownership by State" from the Natural Resources Council of Maine (NRCM), and are from the U.S. Bureau of the Census, Statistical Abstract of the United States: 1991 (11th ed.). To adjust for outlying states with no significant amount of land area, we removed states with less than one hundred acres of land under the FS. These states include Connecticut, Delaware, Hawaii, Iowa, Maryland, Massachusetts, New Jersey, and Rhode Island.

Variables are described more in depth in Table (2) and descriptive statistics are shown in Table (3).

4. *Methodology*

This study attempts to estimate the effect that conserved land acreage protected under the FS in each state has on the EKC relationship. Popp et al. (2012) reference changes in land use as a driving factor in $CO2$ emission. By utilizing longitudinal panel data of personal income and real gross domestic product, collected from the U.S. Bureau of Economic Analysis and the St. Louis Federal Reserve Economic Database, and $CO2$ emissions by end use sector in millions of metric tons from the EIA, we are able to identify the EKC relationship within the U.S. as well as determine both cross-sectional fixed effects and time fixed effects within the model. A variable for forest acreage over time sourced from the annual Land Area Reports produced by the USDA FS is added to quantify area of conserved land to determine the effects of land conservation within this EKC model. By only including states with greater than 100 acres of NFS land, we rule out any states with insignificant levels of protected land which may skew the results.

Following the standard EKC regression model presented by Aldy (2005), our baseline Models (1) and (2) explore the EKC hypothesis in relation to $CO2$ emissions at the state level at state *s* ant time period *t*. a_s and y_t represent state and year fixed effects while ε_{st} is an error term which capture the effects of omitted variables. Model (1) explores per capita personal income while per capital real gross domestic product is investigated in Model (2).

(1) $CO2_{st} = \beta_1(PC\_PERINC)_{st} + \beta_2(PC\_PERINC)_{st}{}^2 + a_s + y_t + \varepsilon_{st}$

(2) $CO2_{st} = +\beta_1\,(PC\_RGDP)_{st} + \beta_2(PC\_RGDP)_{st}{}^2 + a_s + y_t + \varepsilon_{st}$

Models (3) and (4) explore the effects of land conservation under the USDA FS within the EKC relationship to test Popp et al.'s (2012) hypothesis. Because the total national forest system area ($TNFS_{st}$) is highly skewed to the left, we take the natural log of this variable to normalize the data.

(3) $CO2_{st} = \beta_1(PC\_PERINC)_{st} + \beta_2(PC\_PERINC)_{st}{}^2 + \beta_3\ln\,(TNFS)_{st} + a_s + y_t + \varepsilon_{st}$

(4) $CO2_{st} = \beta_1(PC\_RGDP)_{st} + \beta_2(PC\_RGDP)_{st}{}^2 + \beta_3\ln\,(TNFS)_{st} + a_s + y_t + \varepsilon_{st}$

Finally, Models (5) and (6) include other exogenous variables which have been historically referenced to have an impact on the EKC relationship. Dinda (2005) and Kaika Zervas (2013) note that the price of natural resources has an inverse relationship with CO2 emissions. We utilize the average total energy price per state as a proxy for natural resource prices to test this hypothesis. We also test the impacts of capital accumulation as measured by millions of 2012 USD within this relationship, also presented by Dinda (2005).

(5) $CO2_{st} = \beta_1(PC\_PERINC)_{st} + \beta_2(PC\_PERINC)_{st}{}^2 + \beta_3\ln(TNFS)_{st} + \beta_4\ln(CAP)_{st} + \beta_3\ln(TETCD)_{st} + a_s + y_t + \varepsilon_{st}$

(6) $CO2_{st} = +\beta_1(PC\_RGDP)_{st} + \beta_2(PC\_RGDP)_{st}{}^2 + \beta_3\ln(TNFS)_{st} + \beta_4\ln(CAP)_{st} + \beta_3\ln(TETCD)_{st}{+}a_s + y_t + \varepsilon_{st}$

5. *Results*

We have estimated regression models with CO2 measures specified as a function of state-specific quadratic per capita personal income with state-fixed effects and year-fixed effects, as well as state-specific quadratic per capita real gross domestic product also with the state and year fixed effects. For our study, Wyoming and 2017 were used as the baseline state and year. These baseline estimates are expressed within the intercept term in Tables (4) and (5). Land conservation, capital accumulation, and energy prices were also added into our models to test their relevance within the EKC. Results of Model (1) and Model (2), support the EKC hypothesis at the U.S. state-level from 1997-2017. Model (1) looks specifically at per capital personal income's effect on CO2 emissions, with peak CO2 emissions occurring around $61,239 nominal USD. Similarly, Model (2), which investigates the relationship between real gross domestic product (in 2012 USD) and CO2 emissions, suggests that emissions peaked around $69,288 USD. The estimated peaks remain relatively constant after adding other independent variables, as shown in Table (6).

The natural log of each independent variable were all shown to be statistically significant when included in Models (3), (4), (5), and (6), also shown in Tables (4) and (5). The effects of a one percent increase of NFS acreage was shown to decrease CO2 emissions by around 49 MMT across models, while the effects of energy prices and capital accumulation varied between Models (5) and (6). While the signs of the coefficients remained constant, energy prices have a more substantial impact in Model (5) as compared to Model (6), as an one percent increase in energy prices is shown to decrease emissions by 23 MMT in Model (5) and 12 MMT in Model (6). Conversely, capital accumulation increases emissions at a higher rate of nearly 9 MMT in

Model (6) as compared to 6 MMT in Model (5). The addition of these independent variables also influenced the significance and magnitude of the state fixed effects and time fixed effects.

Within the Models which explore the EKC through per capita personal income – Models (1), (3), and (5) – the significance of the time fixed effects remains constant, with every year except 2016 being positive and statistically significant at the 95% confidence level. The addition of the natural log of the NFS decreases the number of significant state-level fixed effects from 40 to 24 at the 90% confidence level shown in Models (1) and (3). Conversely, the addition of the natural logs of energy prices and capital accumulation results in 26 of the state fixed effects being statistically significant as shown in Model (5). The signs and significance of some state fixed effects were also changed; however, California, Texas, and Florida were shown to have the largest estimates across these three models.

The models which explored the EKC through per capita real GDP, Models (2), (4), and (6), produce similar results in regards to time fixed effects, as each time fixed effect except for 2015 and 2016 are significant at the 95% confidence level in Models (2) and (4); however, the estimates for 1997-1999 also become statistically insignificant in Model (6) along with the aforementioned years. The state fixed effects in these models follow a similar pattern as the models which explore per capita income. The baseline model, Model (2), has 39 significant state effects. This number decreases to 21with the addition of the natural log of the NFS in Model (4), then increases to 23 in Model (5) with the addition of the natural logs of energy prices, and capital accumulation. California, Texas, and Florida are again shown to have the largest estimates across these models.

6. *Conclusion*

This paper has analyzed the environmental Kuznets curve relationship for CO_2 emissions at the U.S. state-level from 1997-2017. Results from parametric quadratic models indicate evidence of the existence of the EKC hypothesis, with the inverted-U relationships varying across several specifications. We also include variables in our model which have been mentioned in past literature to be a driver to the EKC curve, or which have a substantial impact on CO_2 emissions.

Following Aldy (2005), who conducted a similar study which also confirmed the EKC at the U.S. state level, we utilize nominal per capita personal income as a proxy for economic growth, as well as per capita real GDP to test the effects of an inflation adjusted independent variable. Per capita personal income was also adjusted and tested in real terms; however, this transformation resulted in statistically insignificant estimates. Both independent variables, personal income and real GDP, and their quadratic counterparts were statistically significant and found similar peaks at $61,239 and $69,288 respectively. Our estimated peaks are substantially greater than the peaks found by Aldy (2005), with eleven states having per capita personal income beyond our estimated peak and eight states having per capita RGDP past our peak. As of 2019, Connecticut has the highest per capita personal income at $79,087, followed by Massachusetts at $74,967. For real GDP, New York claims the highest levels at $73,463 followed by Massachusetts at $73,321 as of 2018 according to the BEA. Coincidently, both New York and Connecticut have been omitted from our models due to their insignificant sum of NFS acreage.

We also tested the effects of land conservation, total average energy prices, and capital accumulation by state as drivers of environmental degradation through increased CO_2 emissions. Our results confirm hypotheses put forth by Dinda (2005) and Kaika and Zervas' (2013), as we found that as energy prices rise, CO_2 emissions fall. Conversely, as capital rises, CO_2 emissions are also shown to rise. Although the magnitude of emissions changes varies between models, the signs of each coefficient remains constant for each regression. Additionally, we have found that increases of land conservation under the NFS are associated with lower CO_2 emissions, confirming the findings of Popp et al. (2012) and Dinda (2005).

It is important to note that current trends in income and emissions may contradict some of our findings. Average state level CO_2 emissions from 1997-2017 appear to be trending downward, as shown in Figures (2) and (3). Simultaneously, state average of per capita personal income and RGDP are increasing monotonically from 1997-2017 shown in Figure (4), with an exception of the drop during the 2008 recession. These estimates have not reached either peak, signifying the impacts of drivers of CO_2 emissions outside of the EKC. Broadly interpreted, our study suggests that state level CO_2 emissions can be mitigated with an increase of conserved land under the FS, increased energy prices, and a decrease of capital accumulation. We have also identified two states, California and Texas, which could largely benefit from mitigation efforts due to their relatively high amounts of CO_2 emissions based on the coefficient estimates of state fixed effects. Future research could expand our analysis by further examining different drivers behind these estimates across a larger time period.

In regard to policy, the significance of conserved lands on carbon emissions of US states creates scope for nationwide emissions reductions. In particular, certain states could consider action regarding environmental degradation from economic growth. Although current state level CO_2 emissions are trending downwards, it is still necessary for certain steps to be made to lower emissions and mitigate climate change.

Tables and Figures

Table 1 Categories of ecosystem service and examples of related services based on Table 2.2 (p.33) in the Millennium Ecosystem Assessment (2005)

Type of Service	Service
Provisioning Services	Food
	Fiber
	Genetic resources
	Bio-chemicals, natural medicines, etc.
	Ornamental resources
	Fresh Water
Regulating Services	Air quality regulation
	Climate regulation
	Water regulation
	Disease regulation
	Pest regulation
	Pollination
Cultural Services	Cultural diversity
	Spiritual and religious values
	Recreation and ecotourism
	Aesthetic values
	Knowledge systems
	Educational Values
Supporting Services	Soil formation
	Photosynthesis
	Primary production
	Nutrient cycling
	Water cycling

Table 2 Description of Variables

Variable	Symbol	Description	Source
National Forest System Land in State *s* at Year *t*	$TNFS_{st}$	Total land area of the national forest system under the USDA Forest service in acres	USDA FS Land Area Reports
CO2 emissions in State *s* at Year *t*	$CO2_{st}$	Million metric tons of carbon dioxide emissions	U.S. Energy Information Administration, State Energy Data System
State	$State_{s}$	state fixed effect constant across time	-
Year	$YEAR_{t}$	Yearly fixed effects constant across region	-
Per Capita Real Gross Domestic Product in State *s* at Year *t*	PC_RGDP_{st}	Real Gross Domestic Product in thousands of chained 2012 dollars	Federal Reserve Economic Database (FRED)
Per Capita Personal Income in State *s* at Year *t*	PC_PERINC_{st}	Per capita Personal Income in thousands of dollars	Bureau of Economic Analysis SAINC1- Personal Income Summary: Personal Income, Population, Per Capita Personal Income
Capital Stock in State *s* at Year *t*	CAP_{st}	Capital Stock in Millions of chained 2012 dollars	El-Shagi & Yamarik (2019)
Total Energy Average Price in State *s* at Year *t*	$TETCD_{st}$	Dollars per million Btu	U.S. Energy Information Administration

Table 3 Descriptive Statistics of Independent Variables

Variable	(n)	Mean	Median	Standard Deviation	Min	Max
CO2	1100	123.40	92.75	119.04	5.42	718.09
TNFS	1100	4586951	1173898	6420387	16068	22237933
PC_RGDP	1100	46.60	45.25	8.87	29.96	79.89
PC_PERINC	1100	36.06	35.30	8.64	19.22	65.64
CAP	1100	370996	231491	455807	3.01	10.44
TETCD	1100	15.38	15.79	5.12	0.09	-0.88

Table 4 Coefficient Estimates of Independent Variables In Per Capita Personal Income Models

Dependent Variable: CO_2

Variable	(1)	(3)	(5)
Intercept (Baseline)	-54.93 (16.19)***	743.61 (235.2)***	726.82 (237.4)***
PC_PERINC	3.53 (0.56)***	3.51 (0.55)***	3.53 (0.61)***
$(PC\_PERINC)^2$	-0.03 (0.01)***	-0.03 (0.01)***	-0.03 (0.01)***
LN(TNFS)		-49.68 (14.60)***	-49.05 (14.45)***
LN(CAP)			5.63 (3.12)*
LN(TETCD)			-23.38 (5.91)***
Root MSE	8.62	8.57	8.46
R-Squared	0.9951	0.9952	0.9953
Cross Sections	42	42	42
Time Series Length	21	21	21

*p <.10 **p<.05 ***p<.01

Table 5 Coefficient Estimates of Independent Variables In Per Capita Real GDP Models

Dependent Variable: CO_2

Variable	(2)	(4)	(6)
Intercept (Baseline)	-29.28 (16.80)*	757.32 (237.9)***	696.54 (241.5)***
PC_RGDP	2.35 (0.55)***	2.36 (0.55)***	1.55 (0.59)***
$(PC\_RGDP)^2$	-0.02 (0.01)***	-0.02 (0.01)***	-0.01 (0.01)**
LN(TNFS)		-48.97 (14.78)***	-47.95 (14.69)***
LN(CAP)			8.95 (3.61)**
LN(TETCD)			-12.42 (6.04)**
Root MSE	8.71	8.65	8.60
R-Squared	0.9950	0.9951	0.9952
Cross Sections	42	42	42
Time Series Length	21	21	21

*p <.10 **p<.05 ***p<.01

Table 6 Estimated Peaks of EKC

Model	USD
(1)	61,239
(2)	69,288
(3)	60,732
(4)	68,234
(5)	61,682
(6)	67,386

Table 7 Cross Sectional Fixed Effects Estimates For Per Capita Personal Income Regressions

Variable	(1)	(3)	(5)
AL	81.06905***	-49.6996	-48.399
AK	-24.9944***	18.22326	17.44685
AZ	37.34669***	46.8883***	52.47482***
AR	14.32688***	-49.1204***	-45.7186**
CA	301.249***	341.4968***	332.7675***
CO	26.15199***	48.53967***	47.0038***
FL	177.0149***	74.19754*	74.60638**
GA	102.9632***	-14.8254	-16.3418
ID	-34.774***	4.47173	10.958
IL	162.4032***	-8.47001	-12.8058
IN	159.4889***	-30.8883	-33.7361
KS	12.37964***	-208.468***	-203.229***
KY	90.84109***	-31.2932	-29.0653
LA	173.2307***	37.6126	32.22701
ME	-36.9912***	-293.203***	-280.715***
MI	117.8848***	59.6232***	56.36758***
MN	30.04035***	-28.5604	-29.8727*
MS	17.88258***	-84.9556***	-78.8554***
MO	74.48543***	-16.1689	-14.2602
MT	-19.8848***	10.18918	19.33357**
NE	-14.1394***	-176.555***	-170.249**
NV	-19.8702***	-43.1141***	-34.4643***
NH	-49.5077***	-175.117***	-160.13***
NM	5.639301	6.021175*	12.02968***
NY	118.044***	-196.988**	-196.996**
NC	82.64688***	-16.8374	-15.1521
ND	-5.60061**	-111.15***	-109.148***
OH	188.3455***	6.384221	4.579982
OK	48.33552***	-107.949**	-106.61**
OR	-17.1261***	8.983971	11.8958
PA	194.1946***	50.56564	48.06052
SC	27.53568***	-106.526***	-102.034***
SD	-44.0794***	-119.907***	-107.994***
TN	59.58104***	-68.8298*	-67.3619*
TX	629.4338***	506.0366***	494.7959***
UT	13.33501***	7.053034*	9.618975**
VT	-54.1386***	-210.887***	-190.655***
VA	47.36472***	-37.7988	-37.9264
WA	9.999845***	10.20885***	7.924809*
WV	57.56407***	-51.2476	-45.3833
WI	42.22374***	-47.33***	-47.0589*

*p <.10 **p<.05 ***p<.01

Table 8 Cross Sectional Fixed Effects Estimates For Per Capita Real GDP Regressions

Variable	(2)	(4)	(6)
AL	83.83921***	-45.4287	-52.0959
AK	-23.7507***	19.01387	14.43058
AZ	38.81271***	47.86565***	41.7381***
AR	17.00029***	-45.9165**	-50.4998***
CA	305.2577***	344.6251***	320.6886***
CO	29.44707***	51.20939***	42.97207***
FL	184.3258***	82.52724***	69.03897**
GA	102.3413***	-14.0365	-24.2531
ID	-30.75***	7.533428	8.096858
IL	165.477***	-3.22505	-15.1687
IN	160.092***	-27.8701	-36.55
KS	15.5552***	-202.489***	-201.881***
KY	91.32495***	-29.3975	-34.2966
LA	168.1471***	34.29598	26.16259
ME	-30.1984***	-283.178***	-273.723***
MI	121.6961***	63.88567***	50.35606***
MN	33.62217***	-24.4518	-31.3811*
MS	21.12261***	-80.6132***	-83.5812***
MO	76.39244***	-13.3109	-19.7513
MT	-17.1246***	12.12588	16.46959*
NE	-12.6401***	-173.008***	-168.087***
NV	-18.7323***	-41.9116***	-38.8021***
NH	-40.6365***	-164.93***	-154.615***
NM	3.16127	3.245678	0.923352
NY	122.4691***	-188.217**	-197.998**
NC	82.69601***	-15.6681	-23.9737
ND	-4.29427	-108.53***	-104.801***
OH	189.3719***	9.70619	-1.19071
OK	50.55319***	-103.854**	-109.948**
OR	-13.692***	11.66306	6.294914
PA	199.0917***	57.1316	44.41094
SC	30.04998***	-102.462**	-106.531***
SD	-41.123***	-116.22***	-104.993***
TN	61.11838***	-65.7975*	-72.5293*
TX	627.8923***	506.0462***	484.5365***
UT	9.839464***	3.3854	0.434613
VT	-46.0726***	-201.052***	-184.438***
VA	52.61083***	-31.6984	-38.7975
WA	12.58306***	12.53649***	3.630864
WV	58.61185***	-48.9906	-49.2141
WI	45.90012***	-42.7402	-49.9427***

*p <.10 **p<.05 ***p<.01

Table 9 Time Series Fixed Effects Estimates for Per Capita Personal Income Models

Variable	(1)	(3)	(5)
1997	42.69203***	40.93892***	28.07166***
1998	40.95775***	39.46076***	24.74317***
1999	40.24719***	38.73908***	24.77415***
2000	41.07495***	39.94545***	30.02407***
2001	36.98197***	35.94566***	26.77704***
2002	37.31382***	36.31794***	25.72603***
2003	36.59037***	35.66181***	27.50425***
2004	36.77773***	35.97785***	30.50999***
2005	34.55291***	33.82606***	32.43248***
2006	30.04501***	29.40948***	30.25272***
2007	29.4121***	28.85462***	30.79537***
2008	23.5098***	23.0126***	28.37094***
2009	16.2031***	15.69681***	16.0368***
2010	19.19707***	18.75304***	21.28273***
2011	13.52989***	13.71261***	19.67061***
2012	7.257419***	6.945288***	12.99281***
2013	9.860485***	9.665081***	15.1925***
2014	8.958308***	8.835314***	14.11825***
2015	4.241229***	4.155866**	4.415626**
2016	1.832802	1.776501	-0.00686

*p <.10 **p<.05 ***p<.01

Table 10 Time Series Fixed Effects Estimates for Per Capita Real GDP Models

Variable	(2)	(4)	(6)
1997	16.71224***	15.40674***	7.797861
1998	16.86252***	15.79103***	7.393078
1999	16.91623***	15.83199***	8.038296
2000	20.13193***	19.39396***	13.9022***
2001	17.86462***	17.19434***	11.91533***
2002	18.29381***	17.6663***	11.6773***
2003	18.53883***	17.96884***	13.45409***
2004	20.30808***	19.85143***	16.97464***
2005	19.77217***	19.37354***	18.81975***
2006	17.86812***	17.52979***	18.22622***
2007	19.50521***	19.20775***	20.39839***
2008	15.53973***	15.2588***	18.04518***
2009	7.637939***	7.357469***	6.910455***
2010	11.63472***	11.39153***	12.27434***
2011	8.259975***	8.584474***	11.38017***
2012	3.780271***	3.583798***	6.425819***
2013	6.392149***	6.307017***	8.876597***
2014	7.002406***	6.950231***	9.474052***
2015	3.129741	3.090425	3.09185
2016	0.99849	0.972368	-0.09575

*p <.10 **p<.05 ***p<.01

Figure 1 LULUCF Chapter Greenhouse Gas Sources and Sinks (MMT CO2 Eq.)

Source: The U.S. Environmental Protection Agency (2019)

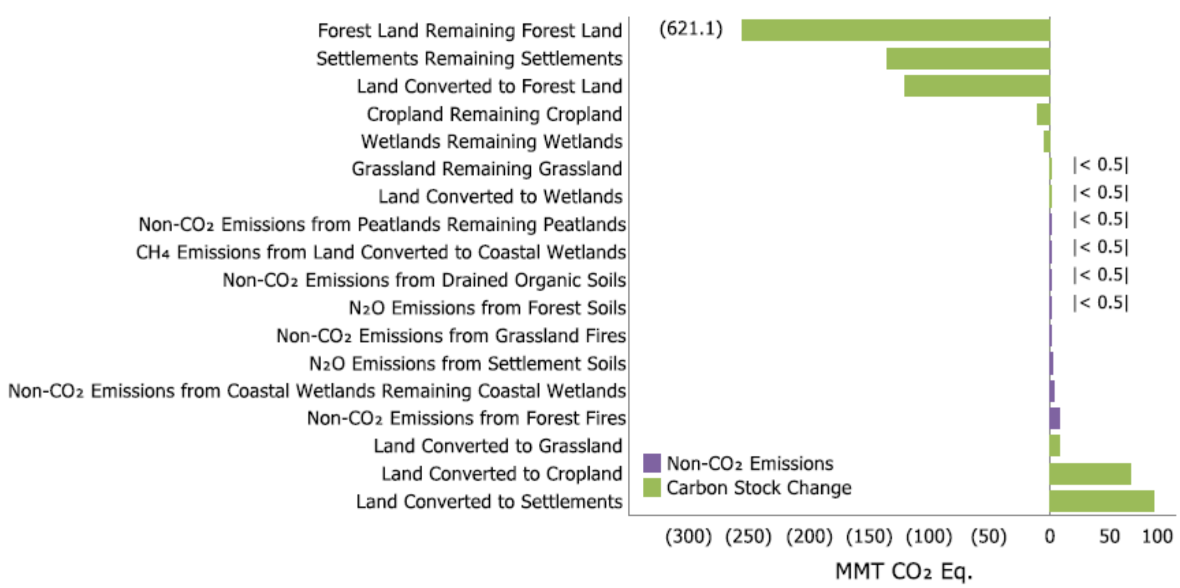


Figure 2 Average State-Level CO2 Emissions Per Year 1997-2017

Source: U.S. Energy Information Association

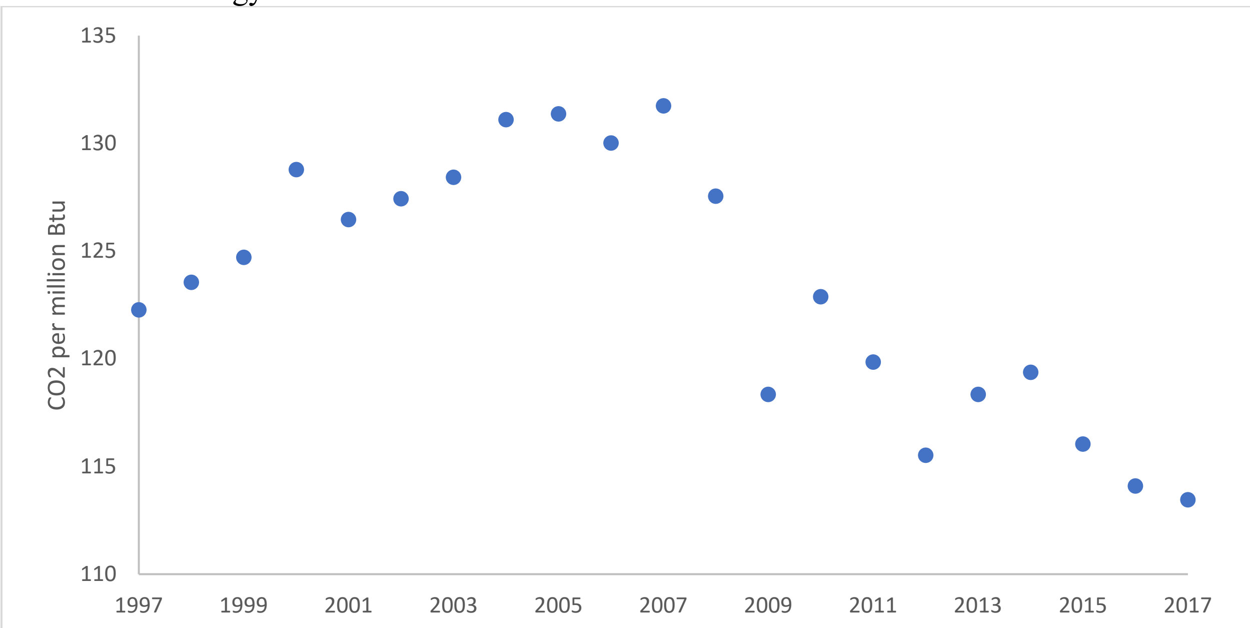


Figure 3 Average State-Level Per Capita CO2 Emissions 1997-2017

Source: U.S. Energy Information Association

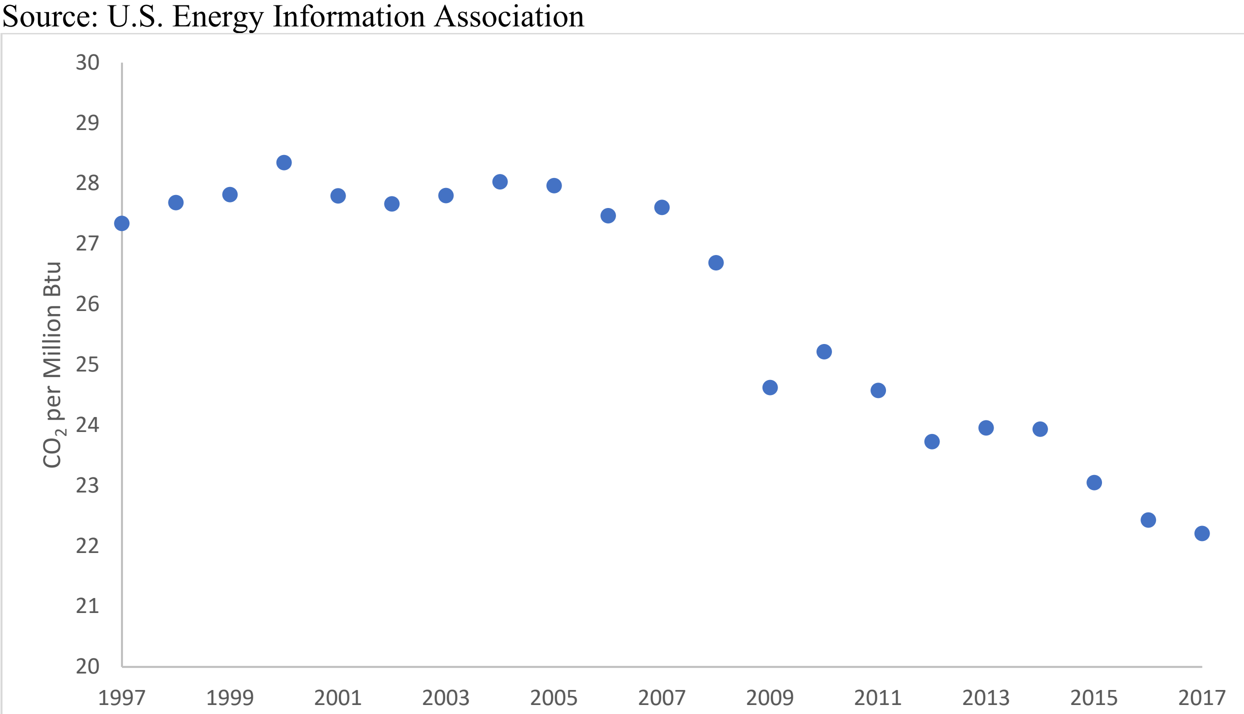
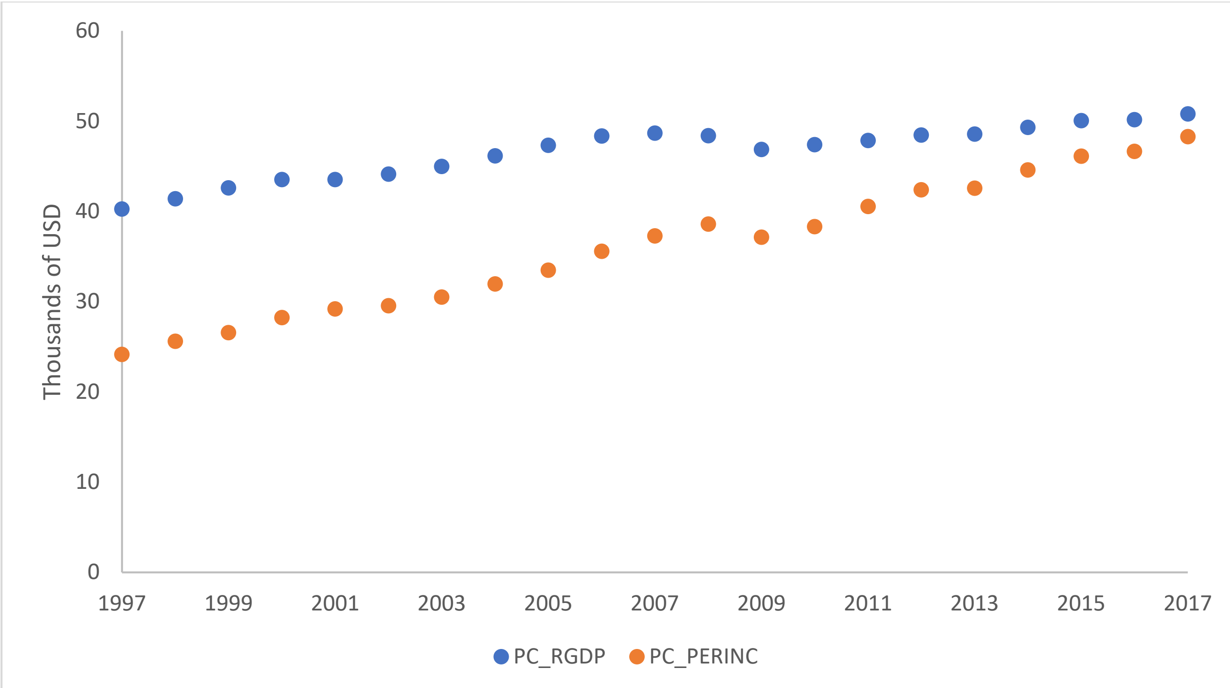


Figure 4 Average State-Level Per Capita Personal Income and Per Capital Real GDP 1997-2017

Source: St. Louis Federal Reserve Economic Database and U.S. Bureau of Economic Analysis


60
50
40
30
20
10
0
Thousands of USD
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
PC_RGDP
PC_PERINC

References

Alavalapati, J. R. & Ochuodho T. O. (2016). Integrating Natural Capital into System of National Accounts for Policy Analysis: An Application of a Computable General Equilibrium Model. *Forest Policy and Economics, 72*, 99-105. https://doi.org/10.1016/j.forpol.2016.06.020

Aldy, J. E. (2005) An environmental Kuznets Curve analysis of U.S. state-level carbon dioxide emissions. *The Journal of Environment & Development, 14*(1), 48-72. https://doi.org/10.1177/1070496504273514

Brock, W. A. & Taylor, M. S. (2005). Economic growth and the environment: a review of theory and empirics. *Handbook of Economic Growth, 1,* 1749-1821. https://doi.org/10.1016/S1574-0684(05)01028-2

Campbell, J. E., Lobell, D. B., & Field, C. B. (2009). Greater transportation energy and GHG offsets from bioelectricity than ethanol. *Science*, 324(5930), 1055-1057. https://doi.org/10.1126/science.1168885

Costanza, R. & Daly, H. (1992). Natural Capital and Sustainable Development. *Conservation Biology*, *6*(1), 37-46. https://doi.org/10.1046/j.1523-1739.1992.610037.x

Cubbage, F. W., O'Laughlin,J., & Peterson, M. N. (2017), *Natural Resource Policy,* Long Grove, IL: Waveland Press.

Dinda, S. (2004). Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics, 49* (4), 431-455. https://doi.org/10.1016/j.ecolecon.2004.02.011

El- Shagi, M. & Yamerik, S. (2019). State-level capital and investment: Refinements and update. *Growth and Change, 50*(4), 1411-1422. https://doi.org/10.1111/grow.12332

Grossman, G. M & Krueger, A. B. (1991). Environmental Impacts of North American Free

Trade Agreement. *National Bureau of Economic Research Working Paper 3917.* https://doi.org/10.3386/w3914

Grossman, G. M. & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, *110* (2), 353-377. https://doi.org/10.2307/2118443

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics, 34*(1), 358-364. https://doi.org/10.1016/j.eneco.2011.06.005

EL-Shagi, M. & Yamarik, S. (2019). State-level capital and investment: Refinements and update. *Growth and Change, 50*(4), 1411-1422. https://doi.org/10.1111/grow.12332

England, R. W. (2000). Natural capital and the theory of economic growth. *Ecological Economics*, *34* (3), 425-431. https://doi.org/10.1016/S0921-8009(00)00187-7

Kaika, D. and Zervas, E. (2013). The Environmental Kuznets Curve (EKC) theory – Part A: Concept, causes and the CO2 emissions case. *Energy Policy*, *62*, 1392-1402. https://doi.org/10.1016/j.enpol.2013.07.131

Kuznets, S. (1955). Economic Growth and Income Inequality. *The American Economic Review, 45*(1), 1-28. https://www.jstor.org/stable/1811581

Mankiw, N. G. (2014). *Macroeconomics* (8th edition). Worth Publishers.

Muller, N. Z. (2014). Boosting GDP Growth By Accounting for the Environment. *Science, 345*(6199), (873-874). https://doi.org/10.1126/science.1253506

Özokcu, S. & Özdemir, O. (2017). Economiv growth, energy, and environmental Kuznets curve. *Renewable and Sustainable Energy Reviews, 72*, 639-647. https://doi.org/10.1016/j.rser.2017.01.059

Patil, P. G. (2012). *Moving beyond GDP: how to factor Natural Capital into Economic Decision*

Making (English). Washington, DC: World Bank. http://documents.worldbank.org/curated/en/724461468157521765/Moving-beyond-GDP-how-to-factor-natural-capital-into-economic-decision-making

Popp, A. Krause, M. Dietrich, J. P., Lotze-Campen, H., Leimbach, M., Beringer, T. Bauer, N. (2012). Additional CO2 emissions from land use change – Forest conservation as a precondition for sustainable production of second generation bioenergy. *Ecological Economics*, (64-70). https://doi.org/10.1016/j.ecolecon.2011.11.004

Shafic, N., & Bandyopadhyay, S. (1992). Economic growth and environmental quality: time-series and cross-country evidence (Vol. 904). World Bank Publications.

Smith, R. L. and Smith, T. M. (2001). *Ecology & Field Biology*. San Francisco, CA: Benjamin Cummings.

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development, 32*(8), 1419-1439. https://doi.org/10.1016/j.worlddev.2004.03.004

Stjepanović, S., Tomić, D., and Škare, M. (2019). Green GDP: An Analyses for Developing and Developed Countries. *E & M Ekonomie A Management*, 22 (4), (4-47) https://doi.org/10.15240/tul/001/2019-4-001

Talberth, J. and Bohara, A. K. (2006). Economic Openness and Green GDP. *Ecological Economics*, 58 (4), 743-758. https://doi.org/10.1016/j.ecolecon.2005.09.002

United States Department of Agriculture. (2019). *Land Areas of the National Forest System.* Washington, DC. USDA Forest Service. https://www.fs.fed.us/land/staff/lar/LAR2019/FY2019_LAR_Book.pdf

Unruh, G. C. & Moomaw, W. R. (1998). An alternative analysis of apparent EKC-type transitions. *Ecological Economics, 25* (2), 221-229. https://doi.org/10.1016/S0921-8009(97)00182-1

U.S. Environmental Protection Agency. (2019). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017.* EPA 430-R-19-001. Washington, D.C. https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-main-text.pdf

van Kooten, G. C. and Sohngen, B. (2007). Economics of forest ecosystem carbon sinks: a review*. *International Review of Environmental and Resource Economics. 1* (3). 237-269. https://doi.org/10.1561/101.00000006