Resource Dependency and Sustainability in the United States

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Abstract

Recent research suggests that no country in the world meets its social needs in a sustainable manner. The U.S. is a prime example, as it has achieved a high standard of living but at a substantial cost to the environment. Although, research also suggests that subjective and objective measures of well-being are declining in the U.S. Thus, not only must the country reduce its emissions and environmental resource use, but it must also rethink its development strategy as well-being continues to deteriorate.

However, these trends are not homogeneous as there are significant differences in ecological degradation and well-being across the states. What could explain these differences? Resource dependency, which refers to economic overspecialization in the extractive natural resource sector, offers a promising theoretical perspective to apply to this question. In my four-part dissertation, I explore whether and how resource dependency impacts sustainability-related measures in the U.S. Using state-level panel data, I assess the effects of resource dependency on the carbon-intensity of well-being, the renewable energy-fossil fuel nexus, and CO_2 emissions in chapters two through four. In the fifth chapter, I describe three Stata commands (eiwb, xtasysum, and lreff) that I developed as part of my dissertation. Taken together, I show that resource dependency undermines environmental and social well-being outcomes in the U.S., but it does so in complex ways. I conclude by discussing the implications of my findings, this dissertation's contributions to sociology and sustainability science, and paths for future research.

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Chapter 1: Introduction

Recent research suggests that no country in the world meets its social needs in a sustainable manner (O'Neill et al. 2018). The U.S. is a prime example, as it has achieved a relatively high standard of living, but at a substantial cost to the environment. Although, research also suggests that subjective and objective measures of well-being are declining in the U.S. Thus, not only must the country reduce its emissions, but it must also rethink its development strategy as well-being continues to deteriorate.

With that said, there are significant differences in ecological degradation and well-being across the U.S. Take a state like New York for instance. New York has a personal income per capita of $64,286, an average health-adjusted life expectancy of 66.8 years, and emits 8.1 metric tons of CO_2 emissions per capita. These numbers suggest that New York achieves relatively high social well-being while using less ecological resources than most other states. Now compare that to West Virginia, which is only geographically separated from New York by way of Pennsylvania. West Virginia has a personal income per capita of $44,085, an average health-adjusted life expectancy of 61.8, and emits 50.3 metric tons of CO_2 emissions per capita. If West Virginia were its own country, it's health-adjusted life expectancy is comparable to that of Iraq and would have the highest emissions per capita in the World (GBD 2020; WHO 2023; World Bank 2023).

What could explain these remarkable discrepancies between states that are only a few hours' drive from one another? Resource dependency, which refers to economic overspecialization in the extractive natural resource sector, offers a promising theoretical perspective to help explain it. Extractive natural resource sectors are NAICS = 113 (forestry and logging), NAICS = 114 (fishing, hunting, and trapping), and NAICS = 21 (mining, quarrying, and oil and gas).

Economies overly reliant on natural resource extraction tend to be highly carbon-intensive given the amount of energy used in mining processes. According to the ecological unequal exchange tradition (a close theoretical cousin of resource dependency), these economies tend to serve as a "tap" for natural resources driven primarily by the structure of the global economic system (Givens, Huang, and Jorgenson 2019). Communities reliant on extractive industries tend to have little control over the local economy because they are at once subjected to fluctuations in energy and resource demand arising elsewhere, and they often lack the resources or institutions to regulate the socially and environmentally harmful practices of extractive firms (Freudenburg 1992; Havranek, Horvath, and Zeynalov 2016; Mueller 2021). Freudenburg (1992) refers to these communities as "addictive economies," because they often can't move away from extraction even if they want to. This happens because these communities become overadapted to the needs of industry as they do not want them to leave, and they lack opportunities to economically diversify.

The relationship between resource dependency and human well-being is complex and multidimensional. In terms of negative impacts on well-being, state regulatory capture by extractive industries like the fossil fuel industry and the environmental pollution created from extracting and burning fossil fuels are particularly notable. States overly reliant on fossil fuel extraction suffer from the energy industry having disproportionate political and economic power, which results in the undermining of regulations to protect the environment and human health (Adua and Clark 2021; Hill et al. 2019; Jorgenson et al. 2020; Thombs and Jorgenson 2020). The fossil fuel industry's control over policymaking not only slows and prevents the transition to renewables, but it also has considerable health implications as air pollution (often related to the burning of fossil fuels) is one of the leading causes of premature death globally (Landrigan et al. 2018). In the U.S., air pollution affects around 2 million people each year by causing mortality, hospital visits, heart attacks, chronic bronchitis, asthma, and lost work days (Clean Air Task Force 2010).

The public health impacts of coal mining are also more hazardous over time as surface mining increases, which makes up roughly 62% of the coal extracted in the U.S. (EIA 2020). The process of surface mining involves the removal of soil and rock to access the coal deposits underneath. In Appalachia, a significant portion of surface mining is done through mountaintop removal, which involves clearing and stripping forests and then using explosives to fracture rocks to mine the coal beneath. This process causes heavy metals to enter the water system, which is harmful to human and ecosystem health (Palmer et al. 2010). Surface mining also creates high levels of hazardous dust and particulate matter (Ghose and Majee 2007), which is a primary reason why coal-mining counties tend to have higher rates of mortality, lung cancer, heart disease, and kidney disease, even after controlling for various socioeconomic factors and smoking rates (Finkelman, Wolfe, and Hendryx 2021; Hendryx 2009; Hendryx and Ahern 2008).

Hydraulic fracturing (fracking), which is used to extract oil and gas, can also negatively affect health outcomes. In the short term, there is strong evidence that being near fracking is linked to higher rates of premature birth and low birth weight (Currie, Greenstone, and Meckel 2017). Research on the long-term health effects of fracking is still evolving as the technique only started being widely used over the past two decades, and therefore, many of the long-term effects have not yet been fully realized (Wright and Muma 2018). However, recent research finds that proximity to unconventional oil and gas wells is associated with higher mortality among the elderly (Li et al. 2022). Additionally, fracking may cause cancer as there are established human carcinogens that are used in the fracking process such as benzene, crystalline silica dust, and diesel engine exhaust that can be released into the air and water (Adgate, Goldstein, and McKenzie 2014). There is also evidence that fracking is linked to respiratory problems like asthma, but the impacts on respiratory health are still not entirely known (Bamber et al. 2019).

Although they are toxic to humans and ecosystems, employment in extractive industries can provide more economic security compared to other jobs in resource-dependent states and communities. As Lobao et al. (2016) note, coal mining jobs often pay more and have higher rates of unionization compared to other jobs in coal mining regions. Given that these communities often lack other employment opportunities, the decline of these industries has negatively impacted social and economic well-being. Many historically-dependent mining communities are at the center of the "deaths of despair" crisis in the U.S., which are deaths resulting from drugs, alcohol, and suicide (Case and Deaton 2020).

Recent research shows that U.S. counties with higher levels of mining employment have higher levels of drug-related mortality (Monnat 2018), which may be due to several factors. First, the importance of the mining sector is declining over time, which not only impacts those employed in mining but also affects the service jobs that support the mining sector in local communities (Monnat 2018). This can lead to economic and psychosocial distress, and drug use can function as a coping mechanism to feelings of hopelessness and lack of economic opportunity (Monnat 2018; Thombs et al. 2020). Second, due to the physical nature of mining jobs, mining-dependent communities suffer from higher rates of chronic illness and disability, and these areas, particularly in Appalachia, were the first places where OxyContin (an opioid pain reliever at the center of the drug epidemic) was advertised and distributed (Keyes et al.

2014; Rigg, Monnat, and Chavez 2018). Thus, the positive impacts stemming from reduced pollution could be offset by the negative health impacts associated with economic distress, but reducing dependence on the mining sector may also reduce chronic illness and disability in the long-run.

In my four-part dissertation, I build on these insights and explore whether and how resource dependency impacts sustainability-related measures in the U.S. Using state-level panel data, I assess the effects of resource dependency on the carbon-intensity of well-being, the renewable energy-fossil fuel nexus, and CO_2 emissions in chapters two through four. In my fifth chapter, I describe three Stata commands (eiwb, xtasysum, and lreff) that I developed to better assess the research questions I ask in this project. All three are publicly available for other researchers to use to explore similar research questions.

In chapter two, I examine fossil fuel dependency's (a subsector of resource dependency) effect on the carbon intensity of well-being (measured as the amount of CO_2 per year of life expectancy), which is a measure that simultaneously accounts for human well-being and ecological degradation. I examine the asymmetric effects of fossil fuel dependency (measured as the energy production-consumption ratio, the share of exports from the mining sector, and the share of GDP from the mining sector) on the carbon intensity of well-being (CIWB) at the U.S. state-level. I do so by estimating dynamic asymmetric models with fixed effects estimation. I find that increases in all three measures are associated with increases in the CIWB. Decreases in the energy production-consumption ratio and the share of exports from the mining sector do not affect the CIWB, while a decrease in the share of GDP from the mining sector produces a proportional reduction in the CIWB relative to an increase. The estimated net effect of all three variables suggests that an increase in fossil fuel dependency increases the CIWB, while a decrease has no effect. When the CIWB is disaggregated, I find that changes in the energy production-consumption ratio are driving changes in emissions and that changes in the share of GDP from the mining sector are responsible for changes in health-adjusted life expectancy. Given that the net effect of a decrease in fossil fuel dependency is not statistically significant, I conclude by arguing that a planned, managed transition away from fossil fuel extraction is critical to ensuring simultaneous improvements in human and environmental well-being.

In chapter three, I explore the relationship between international trade and CO_2 emissions at the U.S. state-level and test a range of competing perspectives on whether trade impacts the environment in Global North nations. The intensification hypothesis argues that trade increases emissions, whereas the abatement hypothesis argues that trade decreases or has no effect on emissions. There is also a third theory related to resource dependency that argues that states more dependent on extractive natural resource sectors have higher emissions. I test these perspectives by constructing state-level trade measures to examine the scale and resource dependency effects of U.S. state-level exports on industrial CO_2 emissions per capita from 2002-2019. The results support the intensification hypothesis. More specifically, the findings indicate that increases in the overall level of global economic integration (% GDP from exports) is associated with increases in industrial CO_2 emissions, and that this is primarily driven by a linear combination of exports from the agriculture, forestry, fishing, and hunting and manufacturing sectors. There is no evidence that dependence on extractive natural resource sectors is driving this relationship.

In chapter four, I explore the paradoxical phenomenon where many fossil fuel dependent states in the U.S. are also national leaders in renewable energy. Specifically, I ask the question, does renewable energy displace fossil fuels in the U.S.? Recent cross-national research finds mixed evidence, highlighting that effects are heterogeneous across contexts. I further explore this question by examining whether renewable energy production displaces fossil fuel production in the 33 fossil fuel producing states in the U.S. from 1997 to 2020. Using two different approaches (two-way fixed effects regression and the half-panel jackknife test for Granger causality), I find robust evidence that there is not an association between renewable energy production and fossil fuel production at the U.S. state-level. I further explore why this is the case by examining the recent history of North Dakota—a state that is a major fossil fuel and renewable energy producer. I find that renewable energy sources are increasingly viewed by the fossil fuel industry as a technological fix to an accumulation crisis, where renewable energy is used to support the industry rather than to replace it. Overall, this study contributes to our understanding of how and why energy sources tend to add to the existing energy mix rather than fundamentally change it.

In the fifth chapter, I outline three Stata commands (eiwb, xtasysum, and lreff) that I developed as part of my dissertation. eiwb is a command that generates the ecological intensity of well-being. xtasysum is a command that allows you to generate, summarize, and visualize partial sums for modeling asymmetry with panel data, and lreff is a command that allows users to compute long-run effects after estimating a dynamic model. All three commands are used extensively in my dissertation and should be useful for researchers using panel data and are particularly interested in modeling socioecological data.

In the sixth and final chapter, I summarize the findings across chapters two through four and discuss the implications of the findings as they pertain to resource dependency, the environment, and social well-being, and what they mean for resource dependent areas as non-fossil fuels become a larger share of the energy mix. I also discuss the limitations of this project and pathways for future research.

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Chapter 2: The Asymmetric Effects of Fossil Fuel Dependency on the Carbon Intensity of Well-Being: A U.S. State-Level Analysis, 1999-2017

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Abstract

The resource dependency literature argues that intensifying processes of dependency can lead to poorer socioecological outcomes, but the effects of reducing dependency remain untested. Some scholars argue that it improves socioecological conditions, while other strands of research suggest that it causes economic hardship, as evidenced by the deaths of despair crisis. Here, I examine the asymmetric effects of fossil fuel dependency (measured as the energy production-consumption ratio, the share of exports from the mining sector, and the share of GDP from the mining sector) on the carbon intensity of well-being (CIWB) at the U.S. state-level. I do so by estimating dynamic asymmetric models with fixed effects estimation. I find that increases in all three measures are associated with increases in the CIWB. Decreases in the energy production-consumption ratio and the share of exports from the mining sector do not affect the CIWB, while a decrease in the share of GDP from the mining sector produces a proportional reduction in the CIWB relative to an increase. The estimated net effect of all three variables suggests that an increase in fossil fuel dependency increases the CIWB, while a decrease has no effect. When the CIWB is disaggregated, I find that changes in the energy production-consumption ratio are driving changes in emissions and that changes in the share of GDP from the mining sector are responsible for changes in health-adjusted life expectancy. Given that the net effect of a decrease in fossil fuel dependency is not statistically significant, I conclude by arguing that a planned, managed transition away from fossil fuel extraction is critical to ensuring simultaneous improvements in human and environmental well-being.

1. Introduction

The climate and social well-being crises in the United States (U.S.) accelerated over the past two decades. The country continues to fail to take meaningful action to reduce greenhouse gas emissions, and social well-being is deteriorating as evidenced by rising rates of deaths of despair (deaths from alcohol, drugs, and suicide) and dwindling life satisfaction (Case and Deaton 2015; Helliwell et al. 2020; Smith et al. 2018; Thombs et al. 2020). Both of these crises are well-studied phenomena, but their underlying causes have rarely been explored together. In this study, I draw from the resource dependency literature and argue that both are shaped by fossil fuel dependency (defined as overspecialization in fossil fuel extraction), and to address one of these crises ultimately involves addressing the other.

I assess this argument by exploiting state-level panel data from 1999 to 2017 to test whether fossil fuel dependency drives the carbon intensity of well-being (CIWB), a measure of how efficiently a state turns ecological resources into human well-being. The CIWB is a ratio consisting of CO_2 emissions per capita in the numerator and a measure of human well-being in the denominator (Jorgenson 2014; Kelly 2020). In this study, well-being is measured as health-adjusted life expectancy, which accounts for morbidity (the average number of years someone is expected to live a healthy life without disease or illness) (GBD 2017 DALYs and HALE Collaborators 2018). I measure fossil fuel dependency in three ways that capture state-level dependency on the fossil fuel sector (mining share of GDP), whether a state is a net exporter of energy (energy production-consumption ratio), and the state's dependency on the global economy as it relates to fossil fuel extraction (mining share of total exports). I report the coefficients for each variable along with the net effect of fossil fuel dependency.

This study makes a novel contribution to the environmental change literature by using asymmetric models to test whether reducing dependency on fossil fuel extraction drives states toward more sustainable development (as measured by the CIWB).[1] A large body of literature finds that resource dependency undermines positive socioecological outcomes (Douglas and Walker 2017; Givens et al. 2019; Huang 2018; R. M. Mueller 2022; Mueller, Shircliff, and Steinbaum 2021), but whether reducing dependency improves these outcomes remains untested. Asymmetric effects potentially exist due to economic despair resulting from the decline of the

[1] Asymmetry in this study refers to whether a decline in fossil fuel dependency leads to the same proportionate decline in the CIWB as an increase in fossil fuel dependency does in increasing the CIWB (Lieberson 1985). For a review on asymmetric modeling with panel data see Allison (2019), Thombs, Huang, and Fitzgerald (2022), and York and Light (2017).

fossil fuel industry that dependent areas rely on for employment and government revenue (Cha 2020; Lobao et al. 2016; Monnat 2018). Declining employment opportunities in these areas are associated with deaths of despair (Monnat 2018), which potentially cancel out the health benefits from reduced environmental pollution.

The results from dynamic asymmetric panel models indicate that the relationship between fossil fuel dependency and the CIWB is nuanced and contingent on the measure of dependency. The energy production-consumption ratio and the share of total exports from the mining sector exhibit asymmetry, while an increase and a decrease in the share of GDP from the mining sector produce proportionate impacts on the CIWB. While an increase in all three measures is associated with an increase in the CIWB, a reduction in the energy production-consumption ratio and the share of total exports from the mining sector have no impact on the measure. However, the net effect of all three variables is much clearer. An increase in fossil fuel dependency increases the CIWB, while a decrease in fossil fuel dependency has no effect on the CIWB.

To further explore these findings, I disaggregate the CIWB and estimate separate regressions for CO_2 emissions per capita and health-adjusted life expectancy. I find that changes in the energy production-ratio are driving changes in emissions, and that changes in the share of GDP from the mining sector are driving changes in health-adjusted life expectancy—indicating that fossil fuel dependency undermines both social and environmental well-being.

This study contributes to our collective understanding of the drivers and social consequences of global environmental change in three ways. First, it establishes a connection between the drivers of climate change and the ongoing social well-being crisis in the U.S. Secondly, it illustrates that resource dependency drives unsustainable development at the subnational level in the U.S. in similar ways as it does in lower income nations (Dorninger et al.

2021; Givens et al. 2019). In particular, the findings suggest that U.S. states more dependent on the mining sector in terms of GDP and that primarily produce energy to export, disproportionately bear the ecological and social consequences of fossil capitalism. The third and final key takeaway is that reducing the magnitude of fossil fuel dependency can halt further unsustainable development, or even in some circumstances move fossil fuel-dependent states toward a path of more sustainable development. However, given that reducing the share of GDP from the mining sector is the only statistically significant indicator, and that the net effect of a reduction in fossil fuel dependency is not statistically significant, I argue that an unplanned transition to renewable energy is too slow and may not lead to proportionate improvements in environmental and human well-being. Thus, following calls for a just transition to renewable energy (Aronoff et al. 2019; Cha 2020; Healy and Barry 2017; Jenkins, Sovacool, and McCauley 2018; Newell and Mulvaney 2013; Sovacool et al. 2016), I conclude by arguing that a planned transition is likely necessary to maximize the potential social and environmental benefits of moving away from fossil fuel extraction.

The remainder of the paper is separated into four sections. The next section outlines the relationship between fossil fuel dependency and the CIWB, disaggregated into fossil fuel dependency's effect on the environment and social well-being, and I explain why asymmetric effects may be present and are important to model. This is followed by the section that outlines the data and methods used in the study, subsequently followed by the results and a discussion, where I link them to the energy transitions literature and the need for a planned transition away from fossil fuels. I then end with a few concluding remarks.

2. Fossil Fuel Dependency and the CIWB

2.1. Fossil Fuel Dependency and the Environment: Extraction, Export-Oriented Production, and Global Economic Integration

Economies overly reliant on fossil fuel extraction are highly carbon-intensive given the amount of energy used in mining processes. According to the ecological unequal exchange tradition, these economies tend to serve as a “tap” for energy resources (particularly fossil fuels) driven primarily by the structure of the global economic system (Givens et al. 2019). Communities reliant on extractive industries tend to have little control over the local economy because they are at once subjected to fluctuations in energy demand arising elsewhere, and they often lack the resources or institutions to regulate the socially and environmentally harmful practices of extractive firms (Freudenburg 1992; Havranek et al. 2016; Mueller 2021b). Freudenburg (1992) refers to these communities as “addictive economies,” because they often can’t move away from extraction even if they want to. This happens because these communities become overadapted to the needs of industry as they do not want them to leave, and they lack opportunities to economically diversify.

Economic reliance on fossil fuel extraction varies across the U.S., with a handful of states responsible for most of the country’s energy production. As of 2018, the top 10 total energy-producing states generated 68% of the nation’s energy—led by Texas (EIA 2021b). These states tend to produce large amounts of energy relative to what they consume, with the surplus exported for use in other U.S. states and/or nations. They also tend to be more reliant on the fossil fuel sector compared to the rest of the country. For example, the median share of a state’s GDP from the mining sector is 0.4%, but the mining sector is responsible for significant shares of GDP in states like Wyoming (26%) and Alaska (23%) (Bureau of Economic Analysis 2021).

A state’s dependence on fossil fuel extraction is also driven by global dynamics tied to the integration of a state’s fossil fuel sector into the global economy, which differs significantly across U.S. states. For example, Wyoming is the nation’s largest coal producer, producing 39%

of the country’s coal as of 2019 (EIA 2021d). While nearly all of Wyoming’s coal is consumed in the U.S., the second-largest coal producer, West Virginia, exports over one-third of its coal to other nations (EIA 2021c).

As demand for coal in the U.S. has fallen, export markets act as a release valve for coal and other fossil fuels. The U.S. lifted its export ban on crude oil in 2015, which increased exports of the commodity by 2.5 million barrels per day by 2019 (GAO 2020)—further integrating the country’s fossil fuel industry into the global economy. This is troubling in terms of mitigating climate change, as prior research shows that integration into the global economy can drive increases in emissions (Teixidó-Figueras et al. 2016; Thombs 2018b). However, these findings are often in the context of lower income nations (Givens 2018; Huang 2018; Jorgenson 2012; Jorgenson et al. 2022a; Rice 2007; Theis 2021; Vesia, Mahutga, and Buì 2021), whereas other research finds that trade has no impact or even provides environmental benefits for high income nations (Givens 2018; Thombs 2018b). Thus, it remains unclear as to whether the negative impacts of trade on the environment hold at the subnational level in a high income country like the U.S.

2.2. Fossil Fuel Dependency and Human Well-Being: A Multidimensional Relationship

The relationship between fossil fuel dependency and human well-being is complex and multidimensional. In terms of negative impacts on well-being, state regulatory capture by the fossil fuel industry and the environmental pollution created from extracting and burning fossil fuels are particularly notable. States overly reliant on fossil fuel extraction suffer from the energy industry having disproportionate political and economic power, which results in the undermining of regulations to protect the environment and human health (Adua and Clark 2021; Hill et al. 2019; Jorgenson et al. 2020; Thombs and Jorgenson 2020). A prime example of this occurred in

West Virginia which became the first state to repeal its renewable portfolio standard—a policy tool that sets targets for renewable energy production—in 2015. The repeal was led by the American Legislative Exchange Council (ALEC)—a group closely tied to the fossil fuel industry. However, West Virginia is only one of many examples as it is well-documented that the fossil fuel industry leads disinformation campaigns and works to block and repeal laws they deem as harmful to their profits (Farrell 2016a, 2016b; Oreskes and Conway 2011; Stokes 2020). The fossil fuel industry's control over policymaking not only slows and prevents the transition to renewables, but it also has considerable health implications as air pollution (often related to the burning of fossil fuels) is one of the leading causes of premature death globally (Landrigan et al. 2018). In the U.S., air pollution affects around 2 million people each year by causing mortality, hospital visits, heart attacks, chronic bronchitis, asthma, and lost work days (Clean Air Task Force 2010).[2]

The public health impacts of coal mining are also more hazardous over time as surface mining increases, which makes up roughly 62% of the coal extracted in the U.S. (EIA 2020a). The process of surface mining involves the removal of soil and rock to access the coal deposits underneath. In Appalachia, a significant portion of surface mining is done through mountaintop removal, which involves clearing and stripping forests and then using explosives to fracture rocks to mine the coal beneath. This process causes heavy metals to enter the water system, which is harmful to human and ecosystem health (Palmer et al. 2010). Surface mining also creates high levels of hazardous dust and particulate matter (Ghose and Majee 2007), which is a primary reason why coal-mining counties tend to have higher rates of mortality, lung cancer,

[2] In a similar vein, Kelly, Thombs, and Jorgenson (2021) find that increases in greenhouse gas emissions are associated with lower life expectancy in the U.S. from 1913 to 2017.

heart disease, and kidney disease, even after controlling for various socioeconomic factors and smoking rates (Finkelman et al. 2021; Hendryx 2009; Hendryx and Ahern 2008).[3]

Hydraulic fracturing (fracking), which is used to extract oil and gas, can also negatively affect health outcomes. In the short term, there is strong evidence that being near fracking is linked to higher rates of premature birth and low birth weight (Currie et al. 2017). Research on the long-term health effects of fracking is still evolving as the technique only started being widely used over the past two decades, and therefore, many of the long-term effects have not yet been fully realized (Wright and Muma 2018). However, recent research finds that proximity to unconventional oil and gas wells is associated with higher mortality among the elderly (Li et al. 2022). Additionally, fracking may cause cancer as there are established human carcinogens that are used in the fracking process such as benzene, crystalline silica dust, and diesel engine exhaust that can be released into the air and water (Adgate et al. 2014). There is also evidence that fracking is linked to respiratory problems like asthma, but the impacts on respiratory health are still not entirely known (Bamber et al. 2019).

Although they are toxic to humans and ecosystems, employment in extractive industries can provide more economic security compared to other jobs in resource-dependent states and communities. As Lobao et al. (2016) note, coal mining jobs often pay more and have higher rates of unionization compared to other jobs in coal mining regions.[4] Given that these communities

[3] Coal mining is also a hazardous occupation as workers often suffer from lung conditions such as silicosis and black lung disease (Finkelman, Wolfe, and Hendryx 2021).

[4] However, as one reviewer noted, unionization can vary significantly across fuel type, regions, and even within states. For example, 21.1% of coal mining workers are unionized compared to 15.1% of workers in natural gas generation and 6.7% of workers in oil generation (DOE 2021; EIA 2021a). Even with high unionization rates in coal mining, unionization varies from 24.9% in Appalachia to only 6.9% in the interior region (Arkansas, Illinois, Indiana, Kansas, Louisiana, Mississippi, Missouri, Oklahoma, Texas, and Western Kentucky) (EIA 2021a). Extreme differences are present in states too, with 50.7% of northern West Virginia unionized, while only 4.8% of southern West Virginia is unionized. Thus, on average fossil fuel jobs have high unionization rates compared to other private sector jobs but significant heterogeneity exists.

often lack other employment opportunities, the decline of these industries has negatively impacted social and economic well-being. Many historically-dependent mining communities are at the center of the "deaths of despair" crisis in the U.S., which are deaths resulting from drugs, alcohol, and suicide (Case and Deaton 2020).

Recent research shows that U.S. counties with higher levels of mining employment have higher levels of drug-related mortality (Monnat 2018), which may be due to several factors. First, the importance of the mining sector is declining over time, which not only impacts those employed in mining but also affects the service jobs that support the mining sector in local communities (Monnat 2018). This can lead to economic and psychosocial distress, and drug use can function as a coping mechanism to feelings of hopelessness and lack of economic opportunity (Monnat 2018; Thombs et al. 2020). Second, due to the physical nature of mining jobs, mining-dependent communities suffer from higher rates of chronic illness and disability, and these areas, particularly in Appalachia, were the first places where OxyContin (an opioid pain reliever at the center of the drug epidemic) was advertised and distributed (Keyes et al. 2014; Rigg et al. 2018). Thus, the positive impacts stemming from reduced pollution could be offset by the negative health impacts associated with economic distress, but reducing dependence on the mining sector may also reduce chronic illness and disability in the long-run.

2.3. Are Delinking and Diversifying Key for Sustainable Development?

Prior research shows that resource dependency can produce poorer ecological and social well-being (Givens 2018; Givens et al. 2019; Jorgenson 2012), but there is little research on whether lessening the degree of dependency improves these outcomes. Whether countries or states should remove themselves or "delink" from the global economy is historically a key debate within development circles across disciplines. This debate is fundamentally about asymmetry as it centers on whether isolating or delinking from the global capitalist system leads to proportionate improvements in social well-being and environmental outcomes.

Frank (1966) argues that peripheral spaces within the global economy experience their greatest rates of development when ties to the global economy, particularly to high income nations, are at their weakest, pointing to the experiences of several Latin American countries as evidence. In other words, isolation allows for economic development, which runs counter to the neoclassical economics argument that greater integration into the global economy facilitates development. Dunaway (1996) makes a similar argument regarding Southern Appalachia in the U.S. by arguing that the dependence on export markets to the world economy ultimately stymied economic growth and deteriorated the environment in the region.

Amin (1990) develops the concept of "delinking," which argues that countries can develop not necessarily by isolating, but instead, working outside the logics of exploitation that are inherent to the global capitalist system. However, others argue that the effects of dependency on development are not as straightforward. Cardoso and Faletto (1979) argue that class structures and political movements could alter the ways that resource-dependent areas develop, potentially leading to *dependent development* (Evans 1979). In other words, states or countries may be dependent on foreign capital and the global capitalist system in general, but they can form class coalitions that wield power through the state to allow for improvements in social well-being.

At the subnational level in the U.S., researchers find that the effects of dependency on human well-being are heterogeneous across time and space (Betz et al. 2015; Curtis et al. 2019; Lobao et al. 2016; Mueller 2021a). However, especially in an era of stagnant and declining wages tied to the rise of neoliberalism, reducing dependence on extractive activities could lead to worse social outcomes given the lack of other economic opportunities. Thus, reducing dependence on the mining sector may not lead to beneficial effects. Reducing reliance on fossil fuel extraction could reduce emissions but negatively impact social well-being, thereby limiting its potential to shift the country toward a path of more sustainable development. In other words, the effects of a positive and negative change in dependency-related measures may be asymmetric.

Given that intensifying and lessening processes of dependency may have different effects, I model and test for asymmetric effects using three different indicators of fossil fuel dependency that capture processes discussed so far—the energy production-consumption ratio, mining share of total exports, and mining share of GDP—on the CIWB of U.S. states. The CIWB is a measure of sustainability that quantifies how efficiently a society turns ecological resources into human well-being. I outline these measures and modeling strategy in the following section.

3. Data and Methods

3.1. Sample

This study uses a perfectly balanced data set for all 50 states from 1999 to 2017.

3.2. Dependent Variable

The CIWB is the dependent variable used in this study, which I construct using the eiwb command in Stata 17 (Thombs 2022). Energy-related CO_2 emissions per capita (EIA 2020b) are used as the numerator in the CIWB ratio, whereas health-adjusted life expectancy (HALE) is the denominator (GBD 2020). HALE is a better indicator of overall well-being than average life expectancy because it accounts for years lived in less than ideal health, i.e., the average number of years someone is expected to live a healthy life without disease or illness (GBD 2020).

To ensure that neither the numerator nor denominator disproportionately drives the CIWB ratio, a correction factor is added to CO_2 emissions per capita to make the coefficients of variation equal (Dietz, Rosa, and York 2012; Givens 2017, 2018; Jorgenson 2014; Kelly 2020). The coefficient of variation for CO_2 emissions per capita is .80 and .02 for HALE. The correction factor is calculated based on (1):

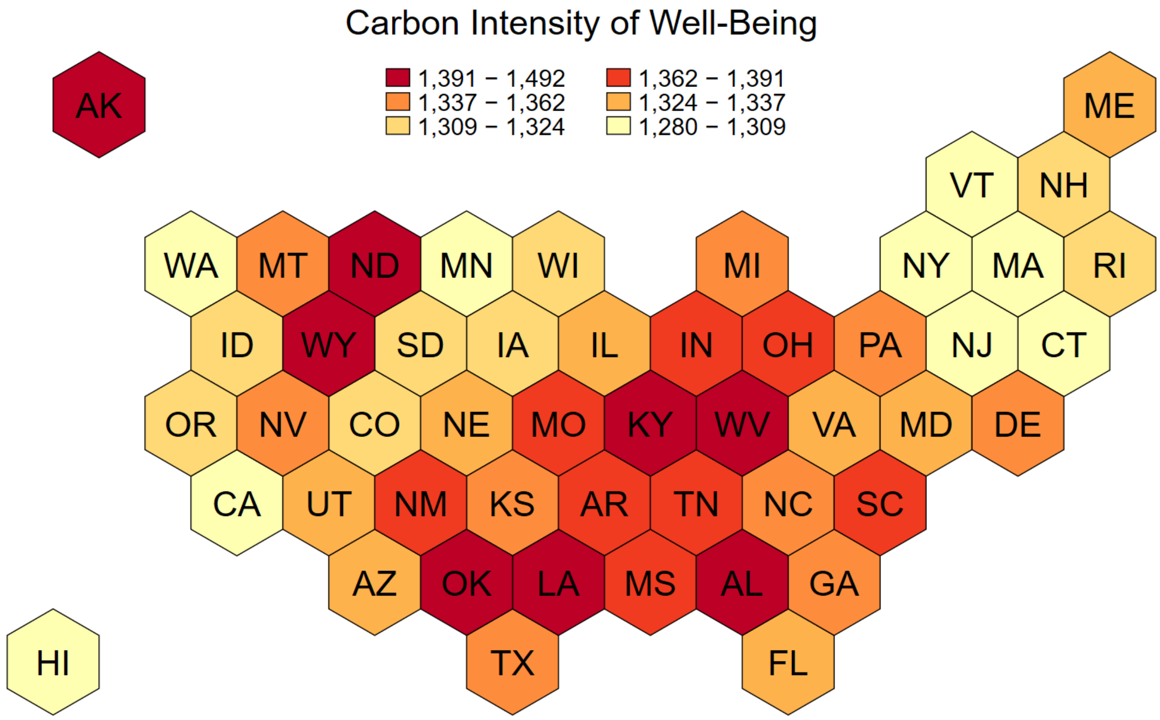
$$d = \left(\frac{sd_e * \ m_{HALE}}{sd_{HALE}}\right) - m_e \tag{1}$$

whereby *sd* = standard deviation, *m* = mean, *e* = CO_2 emissions per capita, and *HALE* = health-adjusted life expectancy. The correction factor is calculated as 858.175, which is added to the numerator to change the mean of CO_2 emissions per capita without shifting the variance (2):

$$CIWB = \left(\frac{CO_2 \ Emissions \ per \ capita + 858.175}{HALE}\right) * \ 100 \tag{2}$$

Following other CIWB studies (Dietz et al. 2012; Jorgenson 2014; Kelly 2020), the ratio is multiplied by 100 to scale it. Figure 1 illustrates the average CIWB for each state over the 1999 to 2017 period.

Figure 1. Average Carbon Intensity of Well-Being by State, 1999 – 2017



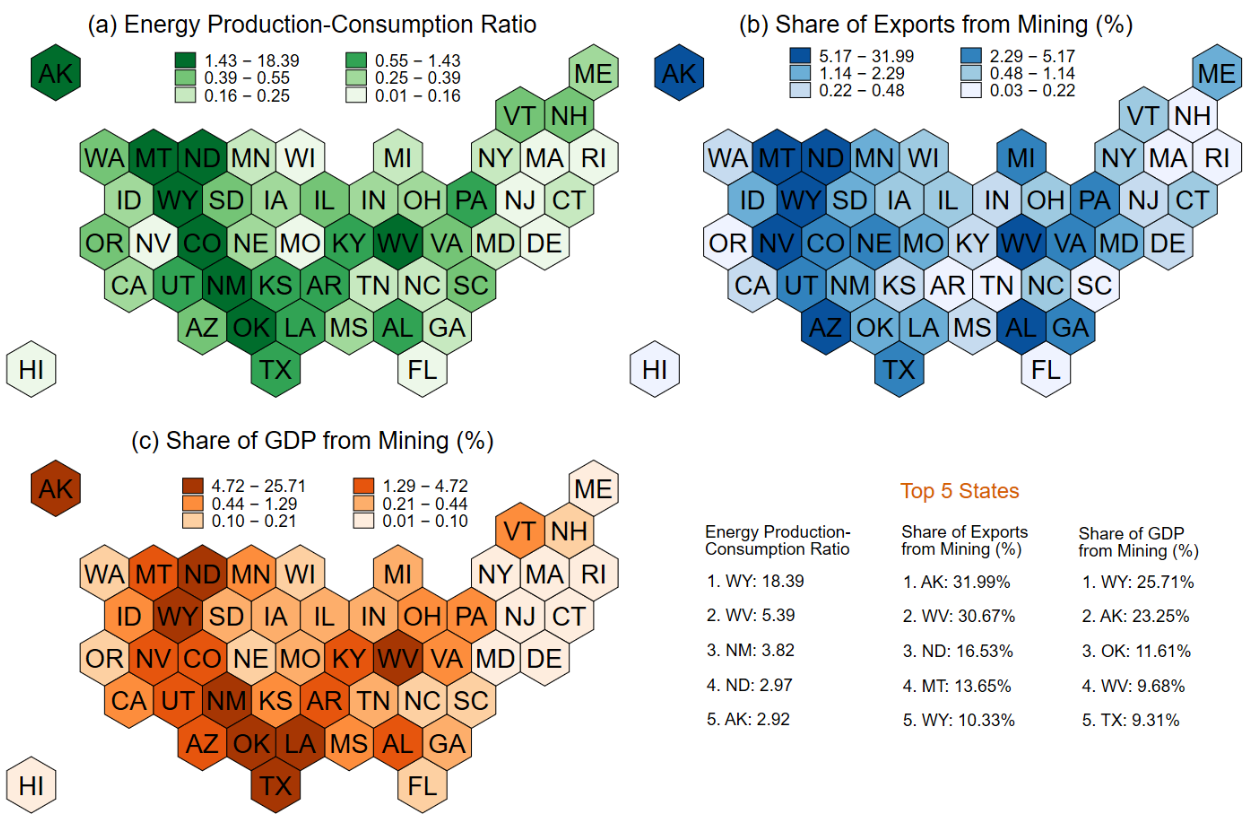
3.3 Key Independent Variables: Energy Production-Consumption Ratio, Mining Share of Total Exports, and Mining Share of GDP

This study uses three variables that capture the different components of fossil fuel dependency. The first is the energy production-consumption ratio that quantifies whether a state is a net exporter or importer of energy. This is a general measure of the flow of energy in and out of a state. The construction of this measure is motivated by dependency-based theories of trade, which argue that peripheral spaces within the global economy act as a "tap" for natural resources (Givens et al. 2019). States with a ratio greater than 1 produce more energy than they consume, while a ratio less than 1 indicates they consume more than they produce. Thus, it is a measure of the distributional effects of the energy system, as fossil fuel dependent states are more likely to take on the environmental and social costs of fossil capitalism. In contrast, net importing states utilize energy resources but displace their environmental and social costs elsewhere. This variable is similar to other environmental displacement measures such as the "environmental terms of trade" that is a ratio consisting of environmental pollution embodied in exports in the numerator and environmental pollution embodied in imports in the denominator (Muradian, O'Connor, and Martinez-Alier 2002). The key difference is that with the energy production-consumption ratio, energy production and consumption are not multiplied by emission intensity factors because CO_2 emissions are part of the CIWB—the key dependent variable used in the study. This measure is constructed using data from the EIA's (2021b) State Energy Data System.

To measure the specific effect of dependency on global markets, I include the mining share of total exports, which is calculated as the total value of mining exports in U.S. dollars divided by the total value of all exports in U.S. dollars. This measure is constructed from the TradeStats Express database that is housed by the International Trade Administration that is part of the U.S. Department of Commerce (U.S. Department of Commerce 2021). Compared to the energy production-consumption ratio, which serves as a general measure of the impact of export-oriented production, the share of a state's exports from the mining sector measures the direct impact of global economic integration of the state's fossil fuel sector. The last dependency measure is the share of GDP from mining that captures the reliance of each state's economy on the extraction of fossil fuels, which is constructed from GDP data from the Bureau of Economic Analysis (2021). For the mining share of exports and mining share of GDP, the mining sector corresponds to NAICS 21 in the North American Industry Classification System, which is comprised of firms in mining, quarrying, and oil and gas extraction. Figure 2 illustrates the average of each of these three variables for each state over the 1999 to 2017 period.

In the analysis below, I report the individual effects of each measure, as well as the total effect of fossil fuel dependency on the CIWB by taking the sum of the coefficients. The coefficients can be added together because I use log-log models, making their coefficients equivalent to elasticities (Wooldridge 2013), which drop the units of measurement for each variable allowing for their coefficients to be combined.

Figure 2. Average Value by Fossil Fuel Dependency Indicator and State, 1999 – 2017



3.4. Other Covariates

Real personal income per capita, renewable energy (% share of energy consumption), and income inequality (top 10% share) are controlled for as additional covariates in the model. The real personal income per capita measure is constructed by obtaining current personal income per capita data from the Bureau of Economic Analysis (2021), and it is deflated using the CPI data from Frank (2021) to adjust for inflation. Renewable energy (% share of energy consumption) comes from the EIA's State Energy Data System (2021c). The income inequality data are obtained from Frank (2021). Descriptive statistics are reported in Table 1.

Table 1. Descriptive Statistics

Variable	Mean (SD)	Between SD	Within SD	N/T	Obs.
CIWB	7.207 (.034)	.034	.008	50/19	950
EPCR	-.887 (1.369)	1.362	.233	50/19	950
MINEXP	-.230 (1.831)	1.630	.864	50/19	950
SHARE	-.616 (1.892)	1.867	.400	50/19	950
Y	10.610 (.149)	.131	.074	50/19	950
T10	3.786 (.114)	.102	.054	50/19	950
REN	-2.672 (.894)	.808	.400	50/19	950
$EPCR^+$	.350 (.392)	.237	.315	50/19	950
$EPCR^-$	-.302 (.306)	.228	.207	50/19	950
$MINEXP^+$	2.256 (2.130)	1.428	1.593	50/19	950
$MINEXP^-$	-1.808 (1.929)	1.331	1.408	50/19	950
$SHARE^+$	.778 (.675)	.330	.590	50/19	950
$SHARE^-$	-.539 (.704)	.451	.544	50/19	950

Note: Natural logarithms are reported. SD refers to standard deviation. CIWB = Carbon-Intensity of Well-Being, EPCR = Energy Production-Consumption Ratio, MINEXP = Mining Sector (NAICS 21) Share of Total Exports, SHARE = Mining Sector Share of GDP, Y = Real Income per capita, T10 = Top 10% Share of Income, REN = Renewable Energy (% of Total Energy Consumption), (+) = positive changes in variable, (-) = negative changes in variable.

4. Fixed-Effects Estimation of Dynamic Asymmetric Models

This study uses fixed effects estimation of dynamic asymmetric panel models to investigate how fossil fuel dependency is associated with the CIWB.[5,6] Asymmetry is defined as

[5] The fixed effects estimator is implemented with the `xtreg, fe` command in Stata 17.

[6] The regressors (besides the lag of the dependent variable) are assumed to be strictly exogeneous (i.e., the CIWB is not a determinant of the regressors at any point in time), which makes fixed effects estimation appropriate. Further empirical evidence (available upon request) suggest that this is a valid assumption based on a modified version of

a situation where an increase and a decrease in a causal variable have different effects on the outcome (Allison 2019; Thombs, Huang, and Fitzgerald 2022; York and Light 2017). Following Shin, Yu, and Greenwood-Nimmo (2014) and Thombs, Huang, and Fitzgerald (2022), asymmetry is modeled by using partial sums. Thus, $x_{i,t}$ is decomposed as $x_{i,t} = x_{i,0} + x_{i,t}^{+} + x_{i,t}^{-}$, where $x_{i,t}^{+}$ and $x_{i,t}^{-}$ are partial sums around a threshold of zero:

$$x_{i,t}^{+} = \sum_{j=1}^{t} \Delta x_{i,t}^{+} = \sum_{j=1}^{t} \max\left(\Delta x_{i,t}^{+}, 0\right)$$

$$x_{i,t}^{-} = \sum_{j=1}^{t} \Delta x_{i,t}^{-} = \sum_{j=1}^{t} \min\left(\Delta x_{i,t}^{-}, 0\right)$$

In other words, two series are generated that consist of the running totals of the positive and negative changes in $x_{i,t}$. The use of partial sums allows for long-run effects to be estimated because shocks can accumulate over time. The frequency distribution of the changes in the energy production-consumption ratio, mining share of total exports, and mining share of GDP is reported in Table 2, while the state-specific partial sums and frequency distributions are reported in the supplemental material (Figures S1-S6).

Kiviet's (2020) specification search procedure, which aims to correctly specify the regressors as endogenous, predetermined, or strictly exogenous.

Table 2. Frequency Distribution of Changes in the Energy Production-Consumption Ratio, Mining Share of Total Exports, and Mining Share of GDP

Direction of Change	Frequency	Percentage
EPCR		
+	500	55.56%
–	400	44.44%
MINEXP		
+	481	53.44%
–	419	46.56%
SHARE		
+	499	55.44%
–	401	44.56%

Note: There are 950 state-years in the sample. 50 observations are lost due to first differencing the variables. EPCR = Energy Production-Consumption Ratio, MINEXP = Mining Sector Share of Total Exports, SHARE = Mining Sector Share of GDP.

I use a general-to-specific modeling approach to determine the appropriate lag structure for the dynamic models (De Boef and Keele 2008; Hendry 1995). This approach works by estimating an initial model that represents a plausible fit of the underlying data generating process and removing the lags as necessary if they are not statistically significant. I first estimate an autoregressive distributed lag (ARDL) model with one lag of the dependent and independent variables (ARDL (1,1)), which is reported in the supplemental material (Table S1).[7]

The lags of the dependency variables and T10 are not statistically significant, so they are removed. The resulting restricted model that is estimated and reported is:

$$CIWB_{i,t} = \lambda_1 CIWB_{i,t-1} + \beta_1 EPCR^{+}_{i,t} + \beta_2 EPCR^{-}_{i,t} + \beta_3 MINEXP^{+}_{i,t} + \beta_4 MINEXP^{-}_{i,t} \qquad (3)$$

[7] ARDL models are written as (ARDL (p, q)). p refers to the number of lags of the dependent variable, and q to the number of lags for the independent variables.

$$+\beta_5 SHARE^{+}_{i,t} + \beta_6 SHARE^{-}_{i,t} + \beta_7 Y_{i,t} + \beta_8 T10_{i,t} + \beta_9 REN_{i,t} + \beta_{10} Y_{i,t-1} + \beta_{11} REN_{i,t-1} + \alpha_i + u_t + \varepsilon_{i,t}$$

CIWB = Carbon-Intensity of Well-Being

EPCR = Energy Production-Consumption Ratio

MINEXP = Mining Sector Share of Total Exports

SHARE = Mining Sector Share of GDP

Y = Real Income per capita

T10 = Top 10% Share of Income

REN = Renewable Energy (% of Total Energy Consumption)

(+) = positive changes in variable

(-) = negative changes in variable

α_i = Unit-Specific Effect

u_t = Time Effects

$\varepsilon_{i,t}$ = Error Term

The long-run (or total) effect in both models is calculated as the sum of the coefficients corresponding to each independent variable divided by 1-λ_1. For example, the long-run effect for $EPCR^+$ in (3) is $\frac{\beta_1}{1-\lambda_1}$. Wald tests are used to determine whether asymmetry is present by testing whether the positive and negative coefficients are equivalent for the short-run and long-run effects (Thombs et al. 2022).

5. Results

The results for the asymmetric model for the dependency-related variables are reported in Table 3 along with the Wald tests for asymmetry in the second column. The *F*-statistic is used to test for asymmetry in the short-run effects because the significance levels and confidence intervals use *t*-statistics, while the χ^2-statistic is used to test for asymmetry in the long-run effects because the significance levels and confidence intervals use *z*-statistics.[8] However, the difference between the two is negligible as the two distributions are nearly identical (Cameron and Trivedi 2010). The results for the other control variables in the model are found in Table S2 of the supplemental material.[9]

The estimates indicate that the individual effects for $EPCR^+$, $MINEXP^+$, $SHARE^+$, and their combined effect are positively associated with the CIWB in the short-run. In other words, an increase in fossil fuel dependency immediately increases the CIWB, which is troubling from a sustainability perspective. In contrast, only $SHARE^-$ has a statistically significant negative effect on the CIWB, while $EPCR^-$, $MINEXP^-$, and the combined effect of all three variables are not statistically significant. The results from the Wald tests indicate that the positive and negative changes for EPCR, MINEXP, and the total effect are asymmetric in the short-run, whereas the changes for SHARE are symmetric.

The same phenomenon holds for the long-run effects. $EPCR^+$, $MINEXP^+$, and the combined total effect of all three variables are positive and statistically significant in the long-run, while negative changes in these variables are not statistically significant. In contrast, $SHARE^+$ and $SHARE^-$ are statistically significant in the long-run. The Wald tests indicate that the positive and negative changes in the EPCR,MINEXP, and the total effect are asymmetric in the long-run, whereas the changes for SHARE are symmetric.

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[8] The long-run effects are estimated using the `nlcom` command in Stata 17, which uses the delta method. The total effect for the positive and negative partial sums are estimated with the `lincom` command.

[9] Notable among the control variables is the effect of renewable energy, which has a negative and statistically significant short-run effect, but the long-run effect is positive and statistically significant. Future research should consider the mechanisms driving these findings.

Table 3. Asymmetric Regression Models of the CIWB, 1999 to 2017

	OLS-FE (Restricted Model)	Wald Tests
$CIWB_{t-1}$	.7999*	
	(.0350)	
Short-Run Effects		*F*-stat
$EPCR^{+}$	.0010*	
	(.0005)	6.13*
$EPCR^{-}$	-.0009	
	(.0008)	
$MINEXP^{+}$	.0002*	
	(.0001)	5.78*
$MINEXP^{-}$	-.0001	
	(.0001)	
$SHARE^{+}$	.0005*	
	(.0002)	1.80
$SHARE^{-}$	.0008*	
	(.0003)	
Total $Effect^{+}$	.0017*	
	(.0005)	6.52*
Total $Effect^{-}$	-.0002	
	(.0007)	
Long-Run Effects		χ^2-stat
$EPCR^{+}$	.0049*	
	(.0022)	5.52*
$EPCR^{-}$	-.0045	
	(.0039)	
$MINEXP^{+}$	.0009*	
	(.0005)	5.13*
$MINEXP^{-}$	-.0004	
	(.0006)	
$SHARE^{+}$	.0026*	
	(.0012)	2.01
$SHARE^{-}$	.0038*	
	(.0013)	
Total $Effect^{+}$	.0084*	
	(.0025)	5.41*
Total $Effect^{-}$	-.0008	
	(.0037)	
Observations	900	
(N/T)	(50/18)	
BIC	-8395.037	

Note: *$p < .05$. Robust standard errors clustered by state are reported. CIWB = Carbon-Intensity of Well-Being, EPCR = Energy Production-Consumption Ratio, MINEXP = Mining Sector Share of Total Exports, SHARE = Mining Sector Share of GDP. Wald test H_0: symmetry. The *F*-statistic is used to test for asymmetry in the short-run effects because the significance levels and confidence intervals use *t*-statistics, while the χ^2-statistic is used to test for asymmetry in the long-run effects because the significance levels and confidence intervals use *z*-statistics. However, the two distributions are nearly identical (Cameron and Trivedi 2010).

To further explore these findings, I disaggregate the CIWB and run separate regressions for CO_2 emissions per capita and health-adjusted life expectancy (HALE). These results are reported in Table 4.[10] For CO_2 emissions per capita, $EPCR^-$ and total $effect^-$ are statistically significant in the short-run, but neither are statistically different from the positive changes in the variable. In the long-run, $EPCR^+$ and $EPCR^-$ are statistically significant and asymmetric. Changes in both variables are associated with increases in CO_2 emissions per capita, but increases in $EPCR^+$ produce a larger increase in CO_2 emissions than $EPCR^-$. Total $effect^+$ is also positive and statistically significant and statistically different than total $effect^-$. In other words, an increase in fossil fuel dependency is associated with increases in CO_2 emissions per capita, but a decrease in fossil fuel dependency is not associated with a change in CO_2 emissions.

Moving to the results for HALE, $SHARE^+$ is associated with decreases in HALE in the short-run and long-run, and $SHARE^-$ is associated with increases in HALE in the short-run and long-run. The effects of $SHARE^+$ and $SHARE^-$ are symmetric according to the Wald test. Total $effect^+$ is also negative and statistically significant but is not statistically different than total $effect^-$.

[10] Using the general-to-specific modeling approach, the lags of $EPCR^+$, $EPCR^-$, and REN are included for the model of CO_2 emissions per capita, and the lag of T10 is included for the model of HALE. The full results are reported in supplemental material Table S3.

Table 4. Asymmetric Regression Models of CO2 Emissions and HALE, 1999 to 2017

	OLS-FE (CO_2 pc)	Wald Tests	OLS-FE (HALE)	Wald Tests
$CIWB_{t-1}$	.7731*		.8065*	
	(.0281)		(.0479)	
Short-Run Effects		*F*-stat		*F*-stat
$EPCR^+$	-.0375		-.0002	
	(.0240)	1.12	(.0005)	1.08
$EPCR^-$	-.0657*		.0006	
	(.0231)		(.0007)	
$MINEXP^+$	.0018		-.0001	
	(.0022)	.08	(.0001)	1.88
$MINEXP^-$	.0024		.0001	
	(.0019)		(.0001)	
$SHARE^+$	.0028		-.0005*	
	(.0048)	.57	(.0002)	1.54
$SHARE^-$	.0060		-.0008*	
	(.0051)		(.0003)	
Total $Effect^+$	-.0329		-.0008#	
	(.0243)	.80	(.0005)	.95
Total $Effect^-$	-.0573*		-.0001	
	(.0246)		(.0007)	
x_{t-1}				
$EPCR^+$	.0660*			
	(.0232)			
$EPCR^-$	.0443#			
	(.0261)			
Long-Run Effects		χ^2-stat		χ^2-stat
$EPCR^+$	.1257*		-.0011	
	(.0470)	12.66*	(.0024)	1.08
$EPCR^-$	-.0943*		.0030	
	(.0440)		(.0038)	
$MINEXP^+$	.0079		-.0005	
	(.0096)	.08	(.0005)	1.87
$MINEXP^-$	.0108		.0004	
	(.0089)		(.0006)	
$SHARE^+$	.0125		-.0025*	
	(.0212)	.61	(.0009)	1.77
$SHARE^-$	.0262		-.0040*	
	(.0218)		(.0013)	
Total $Effect^+$	.1460*		-.0041#	
	(.0525)	12.53*	(.0022)	.92
Total $Effect^-$	-.0573		-.0005	
	(.0439)		(.0037)	
Observations	900		900	
(N/T)	(50/18)		(50/18)	
BIC	-3298.476		-8616.054	

Note: $*p < .05$, $\#p < .10$. Robust standard errors clustered by state are reported. CIWB = Carbon-Intensity of Well-Being, EPCR = Energy Production-Consumption Ratio, MINEXP = Mining Sector Share of Total Exports, SHARE = Mining Sector Share of GDP. Wald test H_0: symmetry. The *F*-statistic is used to test for asymmetry in the short-run effects because the significance levels and confidence intervals use *t*-statistics, while the χ^2-statistic is used to test for asymmetry in the long-run effects because the significance levels and confidence intervals use *z*-statistics. However, the two distributions are nearly identical (Cameron and Trivedi 2010).

Overall, these results indicate that increases in the energy production-consumption ratio, the share of exports from the mining sector, the share of GDP from the mining sector, and the combined effect of all three measures are associated with increases in the CIWB, and when I disaggregate the CIWB, I find that EPCR is driving emissions and SHARE is driving HALE. Thus, from a sustainability perspective, it is clear that fossil fuel dependency undermines environmental and social well-being alike. However, the null findings for the decrease in the EPCR and MINEXP suggest that moving away from export dependence halts further unsustainable development, but it does not reverse the process. One possible reason a reduction in the EPCR is not associated with the CIWB is that production levels do not necessarily change when the ratio decreases, and a potential reason why a reduction in the share of mining exports is not associated with the CIWB is that energy gets sent to other U.S. states instead of global markets. Thus, limiting export dependence on fossil fuels appears to be a necessary but insufficient condition in moving toward a path of more sustainable development at the subnational level in the U.S.[11]

Yet, the decrease in the overall economic reliance on mining appears to have a proportionate effect on the CIWB relative to an increase in the measure. Supplemented with the results from the disaggregated measures, reducing dependence on the mining sector in terms of GDP improves life expectancy even though it does not lead to changes in emissions. Although prior research shows that a declining mining industry is likely a key driver of the drug overdose epidemic (Monnat 2018), these results indicate that the health benefits from reducing pollution outweigh the health costs associated with economic despair.

[11] Future research should examine the effects of trade on a larger set of sustainable development-related outcomes, as has been done at nation-state level (Xu et al. 2020). Interestingly, Xu et al. (2020) find that trade aided progress towards sustainable development goals in developed countries, but this study finds that this is not the case at the subnational-level in the U.S.

5.1. Sensitivity Analysis: Nickell Bias, State Environmentalism, and Potential Outliers

A set of sensitivity analyses were conducted to test the robustness of the results to the Nickell bias, state environmentalism, and potential outliers. Estimating a dynamic model with a short time dimension relative to the number of cross-sectional units produces the "Nickell bias" (Nickell 1981). This bias stems from the lagged dependent variable being correlated with the error term, which is a product of the demeaning process of fixed effects estimation, which decreases as T increases (Hsiao, Pesaran, and Tahmiscioglu 2002; Nickell 1981). Although the 19 waves of data in this study are not minuscule, the bias may still not be inconsequential. For instance, Nickell (1981) showed that the bias is approximately $-(1 + \rho)/(T - 1)$, so the bias can still be sizeable with 19 waves of data.[12] Given this, I estimate the asymmetric models with the bias-corrected method-of-moments estimator (henceforth referred to as BC-FE) proposed by Breitung, Kripfganz, and Hayakawa (2022). (see the supplemental material for a description of the BC-FE).

The results for the BC-FE models with the variables of interest are reported in Table S4 of the supplemental material along with the Wald tests for asymmetry in the second column. The results for the other control variables in the model are found in Table S5 of the supplemental material. The findings for this sensitivity analysis are generally consistent with the main results. Like with OLS, the BC-FE finds that the $EPCR^+$, $MINEXP^+$, $SHARE^+$, $SHARE^-$, and total effect$^+$ have immediate effects on the CIWB. In the short-run, the $EPCR^+$, $MINEXP^+$, $SHARE^+$, and their combined effect have a positive effect on the CIWB, whereas the $SHARE^-$ has a negative effect on the CIWB. In the long-run, $EPCR^+$, $MINEXP^+$, $SHARE^+$, and their combined

[12] ρ represents the autoregressive coefficient. For $\rho = 0.2$, the bias at $T = 20$ is ~ -.067, and at $\rho = 0.9$, the bias is ~ -.106. Thus, the bias is largest when the autoregressive coefficient is near 1, and this can lead to highly biased estimates of the long-run effect.

effect have a positive effect on the CIWB, and $SHARE^-$ has a negative effect, which is also the same as the main results.

The Wald tests for the BC-FE are also similar to the OLS results. The short-run effects for EPCR, MINEXP, and the total effect are statistically different in the short-run and long-run, while $SHARE^+$ and $SHARE^-$ are statistically equivalent. Taken together, these results suggest that the impact of the Nickell bias is relatively small.

As an additional sensitivity analysis, the League of Conservation Voters (LCV) score for each state is controlled for, which is an indication of state-level environmentalism based on the environmental voting record of each member of congress for each state (Dietz et al. 2015; League of Conservation Voters 2020). State environmentalism is found to influence environmental outcomes at the state-level making it an important variable to control for (Adua and Clark 2021; Lyon 2016; Thombs and Jorgenson 2020). The variable is not statistically significant and does not substantively change the coefficients on the dependency-related variables of interest.[13] These results are reported in Table S4 and S5 in the Supplemental Material.

A limitation of this analysis is that the mining sector as a whole (NAICS 21) is used as a proxy for fossil fuel dependency even though it contains non-fossil fuel extraction. This is done because the state-level GDP and export data do not disaggregate further than a 3-digit NAICS code. Thus, NAICS 211 corresponds to oil and gas extraction, but NAICS 212 contains coal mining along with metal ore mining and nonmetallic mineral mining and quarrying. However, given that the correlation coefficient between fossil fuel production and the share of GDP from

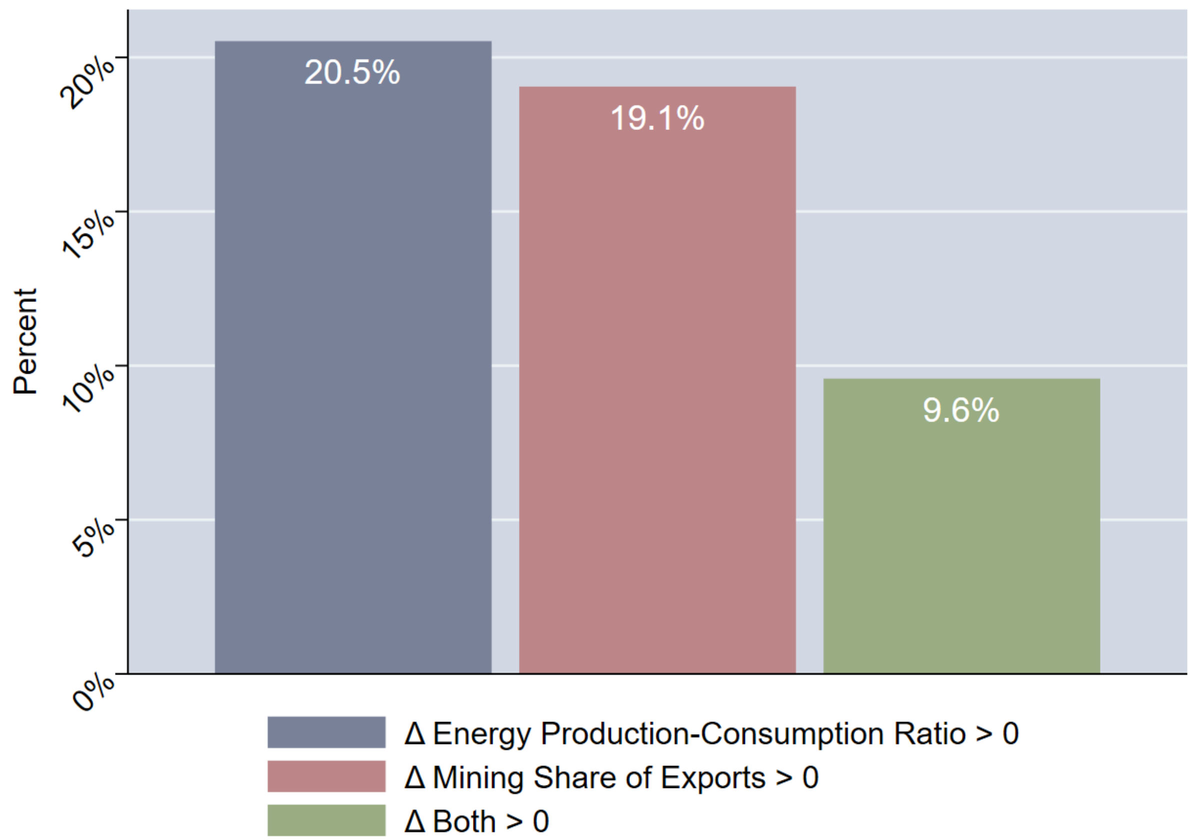
[13] As one reviewer noted, the null result for state environmentalism may be due to much of its explanatory power being captured by the fossil fuel dependency measures. A potential avenue for future research could be to examine the relationship between the two.

the mining sector is .74, it suggests that using the mining sector as a whole serves as a good proxy variable. With that said, Nevada is a possible outlier due to having a large mining sector tied to metal mining instead of fossil fuels. Thus, an additional analysis with Nevada omitted was conducted (available upon request), with the results being substantively the same both in terms of the magnitude and the significance levels of the coefficients and the Wald tests.

6. Discussion and Conclusion

The U.S. must reduce its dependence on fossil fuels, but an unplanned transition to renewable energy is too slow to reduce emissions promptly and may not lead to proportionate improvements in social and environmental well-being. Based on the data used in this study, when states reduce their reliance on the mining sector as a share of GDP, it does not necessarily mean dependence on export markets decreases and vice versa (Figure 3). The energy production-consumption ratio increased 20.5% of the time that the share of GDP from the mining sector declined, and the share of exports from the mining sector increased 19.1% of the time. They both increased simultaneously 9.6% of the time as the mining share from GDP decreased. From the results reported in Table 3, the combined effect in this instance is .0003 (.0004) in the short-run and .0017 (.0023) in the long-run with neither effect being statistically significant. Thus, the socioecological benefits from economic diversification are canceled out by intensifying dependence on domestic and global markets, thereby further prolonging the transition to renewables and a carbon-free economy.

Figure 3. Percent of Years the Energy Production-Consumption Ratio and the Share of Exports from the Mining Sector Increased when the Share of GDP from the Mining Sector Decreased.



The protracted process does not make it any more socially just, and in fact, a long, drawn-out transition hampers well-being because it prevents the necessary economic restructuring and investment that would benefit fossil fuel-dependent areas from occurring earlier (Oei, Brauers, and Herpich 2020). The decline of the U.S. fossil fuel industry is already felt by many areas and will continue to impact communities moving forward. Accordingly, policies that support transitioning workers into other sectors, increase labor protections, protect state and local government revenues from the negative impacts of economic diversification, invest in social welfare programs, and are driven and supported by impacted communities, are all essential to move to a carbon-free economy in a just and temporally appropriate way (Cha et al. 2021).

I argue in this study that the climate and social well-being crises in the U.S. are interrelated through processes of fossil fuel dependency, and I test whether reducing dependence on fossil fuel extraction pushes states toward a path of more sustainable development. I test this argument by assessing the asymmetric effects of fossil fuel dependency (measured as the energy production-consumption ratio, the share of exports from the mining sector, and the share of GDP from the mining sector) on the CIWB at the U.S. state-level. The findings suggest that all three measures (and their combined effect) of fossil fuel dependency are driving unsustainable development at the U.S. state-level, but a decrease in these measures produces nuanced results. Decreases in the energy production-consumption ratio, the share of exports from the mining sector, and the combined effect of all three variables are not associated with a decrease in the CIWB, whereas a reduction in the share of GDP from the mining sector produces proportional reductions in the CIWB relative to an increase. When the CIWB is disaggregated, I find that changes in the energy production-consumption ratio are driving changes in emissions and that changes in the share of GDP from the mining sector are responsible for changes in health-adjusted life expectancy. These findings suggest that different dependency-related factors have varying effects, but the conclusions here are not generalizable outside of the U.S. Future research should consider whether these same relationships hold across global, national, and other subnational-level contexts.

As the U.S. is facing two mounting crises in the forms of climate change and declining well-being, reducing dependence on fossil fuel extraction is pivotal to counteract both of these processes. The findings for this study indicate that U.S. states more dependent on the mining sector in terms of GDP and that primarily produce energy to export, disproportionately bear the ecological and social consequences of fossil capitalism. However, as this study shows, decreasing fossil fuel dependence may not produce proportionate declines in emissions and improvements in life expectancy, particularly in an expedited manner. In addition to the theoretical and methodological advancements made here, this study underscores the need for a planned transition that moves the U.S. economy to renewable energy in a just and equitable way. This planned transition must address the economic stress placed on communities and states dependent on fossil fuel extraction to fully maximize the potential benefits from decarbonizing the economy.

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Chapter 3: Does International Trade Drive Emissions at the U.S. State-Level? Examining Scale and Resource Dependency Effects on CO_2 Emissions

Abstract

There are competing perspectives on whether trade impacts the environment in Global North nations. The intensification hypothesis argues that trade increases emissions, whereas the abatement hypothesis argues that trade decreases or has no effect on emissions. There is also a third theory related to resource dependency that argues that states more dependent on extractive natural resource sectors have higher emissions. I test these perspectives by constructing state-level trade measures to examine the scale and resource dependency effects of U.S. state-level exports on industrial CO_2 emissions per capita from 2002-2019. The results support the intensification hypothesis. More specifically, the findings indicate that increases in the overall level of global economic integration (% GDP from exports) is associated with increases in industrial CO_2 emissions, and that this is primarily driven by a linear combination of exports from the agriculture, forestry, fishing, and hunting and manufacturing sectors. There is no evidence that dependence on extractive natural resource sectors is driving this relationship.

1. Introduction

The relationship between international trade and carbon emissions is a key question in the global environmental change literature. A substantial body of research that spans numerous social science disciplines produced significant insights into the many ways that trade can impact emissions (Antweiler, Copeland, and Taylor 2001; Cole and Elliott 2003; Givens et al. 2019; Huang 2018; Jorgenson 2012; Jorgenson et al. 2022a; Sommer, Restivo, and Shandra 2021; Thombs 2018b; Thombs, Huang, and Jorgenson 2021; Vesia et al. 2021). Within this literature, researchers often analyze the effects of greater global economic integration on emissions, which is known as the scale effect of trade (Antweiler et al. 2001). Much of this research finds that trade has no effect or even offers environmental benefits to high income nations like the U.S. (Jorgenson et al. 2022a; Thombs 2018b; Xu et al. 2020). Although this research greatly advances our understanding of the trade-emissions nexus, it overwhelmingly focuses on the nation-state. This makes sense given the role of nation-states in facilitating and regulating trade, but whether observed relationships hold across subnational contexts remains an understudied question.

Building on the trade-emissions literature, I test whether trade has a scale effect on industrial emissions at the U.S. state-level using panel data from 2002 to 2019. To test for a scale effect, I first construct an export measure based on U.S. Census Bureau, USDA, and U.S. BEA data. I then include the exports share of GDP in dynamic two-way fixed effects regression models, and I also disaggregate the total exports share measure into its industrial components (agriculture, forestry, fishing, and hunting (NAICS = 11), mining (NAICS = 21), and manufacturing (NAICS = 31-33)) to determine whether the association is driven by specific sectors. Additionally, I test whether states more dependent on extractive natural resource sectors have higher emissions, which is one reason advanced in the cross-national literature to explain the trade-emissions relationship.

Before moving to the analyses, I first discuss the different theoretical perspectives on the trade-emissions relationship. As I highlight below, the competing perspectives related to the scale effect can be categorized into two camps that I term the *intensification* and *abatement* hypotheses. I also outline the resource dependency hypothesis, which as I noted above, argues that states more dependent on extractive natural resource sectors have higher emissions.

Overall, I find robust evidence that greater economic integration is associated with increases in industrial CO_2 emissions at the U.S. state-level, which supports the intensification hypothesis. Furthermore, I find that this relationship is primarily driven by a linear combination of exports from the agriculture, forestry, fishing, and hunting and manufacturing sectors. However, I do not find evidence that dependence on extractive natural resource sectors is driving this relationship.

2. Background

2.1. The Scale Effect

There are a number of theories related to the relationship between trade and emissions. These theories do not fit neatly within ideological camps or by discipline. Rather, the best way to categorize them is into what I refer to as the intensification and abatement hypotheses. The intensification hypothesis expects that increases in global economic integration at the U.S. state-level increases emissions. On the other hand, the abatement hypothesis expects that increases in global economic integration at the U.S. state-level decreases or has no effect on emissions.

Which theoretical perspectives fall within these hypotheses? For the abatement hypothesis, one line of argument within neo-classical economics stems from modernization theory and maintains that trade doesn't have an impact on emissions in high-income countries because demand for greater environmental protection increases as income increases, and clean technologies are most advanced in a country like the U.S. (Grossman and Krueger 1995; Mol 1995). Another popular argument within neo-classical economics is the pollution haven hypothesis, which expects a similar relationship as modernization theory but for different reasons. The pollution haven hypothesis argues that corporations move to the Global South where there are more lax regulations (Antweiler et al. 2001; Cole 2004; Millimet and Roy 2016; Wagner and Timmins 2009). The intuition here is that environmental policies make production more costly causing the country to lose its comparative advantage in producing the commodity. Thus, trade is assumed to lessen or have no effect on emissions in the U.S. because pollutive industries have shifted to lower income nations.

However, another strand of neo-classical theory, based on the factor endowment hypothesis, argues that the effect of trade on emissions is greater in high-income countries. This is because capital-intensive production, which is typically more carbon-intensive than labor-intensive production, is more likely to locate to a capital-intensive country like the U.S. for comparative advantage reasons (Antweiler et al. 2001). Thus, the factor endowment hypothesis aligns with the intensification hypothesis.

Both sides of this argument are also present within political economy circles, albeit for different reasons and with less of an explicit focus on comparative advantage. Theories like the treadmill of production argue that intensified economic growth, which exports are part of, is likely to lead to increasing emissions (Gould, Pellow, and Schnaiberg 2004; Schnaiberg 1980). However, other arguments coming out of the global political economy literature claim that shifts in the global economy since the 1970s moved carbon-intensive production to Global South nations over time to take advantage of cheap labor and natural resources (Jorgenson 2012; Thombs 2018b). This perspective expects that trade has no effect or even offers environmental benefits to high income nations—a similar argument to the pollution haven hypothesis.

One commonality between these various theoretical perspectives is that the scale effect is usually captured with a trade openness measure (exports % of GDP), which makes the scale effect relatively simple to operationalize. Using this measure, I test the intensification and abatement hypotheses as described above. The formal hypotheses are as follows.

> *Intensification Hypothesis*: increases in global economic integration at the U.S. state-level increases emissions.

> *Abatement Hypothesis*: increases in global economic integration at the U.S. state-level decreases or has no effect on emissions.

2.2. The Resource Dependency Effect

The research on resource dependency, broadly defined as economic overspecialization in the natural resource sector (Mueller 2021a), offers a rich body of scholarship that examines the impacts of resource dependence on socioeconomic outcomes, well-being, and ecological degradation across multiple scales (Freudenburg and Wilson 2002; Givens 2018; Huang 2018; Jorgenson 2012; Lobao et al. 2016; J. T. Mueller 2022; Vesia et al. 2021). Findings in this body of work consistently show that extractive, export-oriented economies are both producers of environmental harm and sinks for environmental waste (Althouse, Guarini, and Gabriel Porcile 2020; Givens et al. 2019; Hornborg 2009; Huang 2018; Jorgenson 2016; Jorgenson and Clark 2009; Rice 2007; Sommer et al. 2021). The theory of ecological unequal exchange offers a dependency-informed explanation for ecological harm tied to the structure of the world-economy and the ways that international trade shapes ecological outcomes across nations (Givens et al. 2019). As Bunker (1984) illustrates in the case of the Amazon, raw materials tend to flow from less developed countries to more powerful countries in the core, leading to ecological pollution and underdevelopment in the periphery. A similar process known as “internal colonialism” occurs when rather than the unequal exchange occurring between nation-states, the unequal exchange occurs subnationally (Love 1989; Nedham 2014; Peluso, Humphrey, and Fortmann 1994). In the U.S., historical examples of this phenomenon are resources and value flowing from Appalachia to the Northeast, and coal production in the territory of the Navajo Nation fueling the development of Phoenix.

The mechanisms responsible for resource dependency are tied to both the special characteristics of extractive economies and of the world economy more broadly. Bunker (1989) argues that time and space in extractive and agricultural production function differently than in the industrial sector. Extractive and agricultural production are relatively fixed in space, whereas industrial capital has more freedom to move across space to pursue profits (see also Bunker and Ciccantell 2005; Harvey 2006). Mueller (2021a) argues that resource dependent areas become increasingly exploited when they are rich in an array of natural resources, arguing that this stems from the contradiction between natural resources being fixed in space and capital needing to be in perpetual motion.

Bunker (1984) contends that extractive processes are facilitated by both local elites and transnational capital. Local elites seek to benefit from demand for products in wealthier nations, while in the case of Brazil, the nation became indebted to international capital, leading the state to make various concessions to natural resource interests (Bunker 1984). Many of the processes Bunker identified are commonly referred to as state capture (or rent seeking), where producers aim to increase their wealth through influencing state and social apparatuses (Gylfason 2001). Such behavior can induce inefficient uses of resources, cause corruption, and limit investment (Mueller 2021b).

Freudenburg (1992) advances the notion of "addictive economies," where the presence of extractive industries leads regions to form an economic addiction rather than pursue economic development. Addictive economies resemble drug dependence, where economies built on extraction may have pleasurable experiences early on, but which will ultimately result in debilitating long-term effects. This creates a path dependency where communities are unable to move away from extractive activities in the future even if they want to. Freudenburg attributes this dependency to price volatility (large payoffs happen just enough to keep communities invested in extraction), overadaptation (communities become overly adapted to the needs of a particular industry), uncertain employment opportunities in the area, and threats by the industry to shut down. This addiction is hard to break because these areas have little to no negotiating leverage, there are substantial power imbalances between industries and impacted communities, and remote communities often lack opportunities to diversify.[14]

To test the resource dependency hypothesis, I follow a common approach in the cross-national literature and construct a measure of the share of exports from the natural resource sectors. Following Mueller (2021a), extractive natural resource sectors are NAICS = 113 (forestry and logging), NAICS = 114 (fishing, hunting, and trapping), and NAICS = 21 (mining, quarrying, and oil and gas).[15] The formal hypothesis I test is as follows.

> *Resource Dependency Hypothesis*: increases in the share of exports from the extractive natural resource sector at the U.S. state-level increases emissions.

3. Measuring Trade at the U.S. State-Level

Estimating the effect of trade at the state-level is difficult because of data validity issues. The Census Bureau offers state-level trade data by NAICS code (downloaded from https://tse.export.gov/tse/TSEHome.aspx , but it measures trade based on the location where the commodity begins its journey to a port for export (known as origin of movement (OM)). These data come from shipper export declarations for goods being exported. The issue with these data is that OM is not necessarily the same location where the good is produced (known as origin of production (OP)). Cassey (2009) conducted an extensive analysis showing that OM data can be used as a measure for OP for manufacturing exports, but the data are highly skewed for the agricultural sector. For instance, according to OM data, Louisiana is consistently the nation's largest exporter of agricultural goods, but this is because agricultural goods are often

[14] Peluso, Humphrey, and Fortmann (1994) highlight several limitations of Freudenburg's account, a main one being that resource dependency and its effects are more heterogeneous across space and can differ depending on the commodity.

[15] NAICS = 1153 (support activities for forestry) is also an extractive natural resource industry, but this sector is not included in export data.

consolidated and then shipped from New Orleans. This leads to inland agricultural states being undervalued in the export data and port states like Louisiana overvalued.

To deal with the agricultural sector distortion, I use the USDA's (2022) state-level agricultural exports based on cash receipts estimates. These data attribute exports to the state where cash receipts are received, which is an indication of where the good was originally produced. These data provide a more realistic and accurate picture of a state's agricultural exports. I also estimate exports from forestry and logging (NAICS 113) and fishing, hunting, and trapping (NAICS 114) by allocating national exports from NAICS 113 and NAICS 114 to states based on their percentage of total, national NAICS 113 and NAICS 114 production (obtained from BEA (2022b)). These data are added to agricultural sector exports to develop an alternative NAICS 11 export dataset.

Table 5 confirms that the OM agricultural export data tend to overvalue exports in port states and undervalue inland states. On average, Louisiana is the most overvalued state with the OM data overestimating their exports by 4.81 percentage points. In contrast, North Dakota (exports underestimated by 6.05 percentage points) and South Dakota (exports underestimated by 6.04 percentage points) are the most undervalued states. However, the percent difference is miniscule for most states, as 34 of them have a percentage point difference less than 1%.

Table 5. Difference (% GDP) Between NAICS = 11 OM Trade Data and Constructed Trade Measure by State on Average (Percent Difference = Constructed Measure – OM Data)

State	Percent Difference	State	Percent Difference
Alabama	0.54	Montana	2.36
Alaska	-4.34	Nebraska	3.98
Arizona	0.26	Nevada	0.07
Arkansas	2.19	New Hampshire	0.03
California	0.38	New Jersey	-0.03
Colorado	0.47	New Mexico	0.73
Connecticut	0.07	New York	0.06
Delaware	0.11	North Carolina	0.47
Florida	0.23	North Dakota	6.05
Georgia	0.27	Ohio	0.23
Hawaii	0.31	Oklahoma	0.81
Idaho	2.48	Oregon	0.40
Illinois	0.65	Pennsylvania	0.22
Indiana	1.17	Rhode Island	0.02
Iowa	4.64	South Carolina	0.27
Kansas	1.97	South Dakota	6.04
Kentucky	0.91	Tennessee	0.21
Louisiana	-4.81	Texas	0.05
Maine	-0.49	Utah	0.16
Maryland	0.14	Vermont	0.54
Massachusetts	-0.01	Virginia	0.03
Michigan	0.45	Washington	-1.35
Minnesota	1.56	West Virginia	0.19
Mississippi	1.11	Wisconsin	0.68
Missouri	1.00	Wyoming	0.86

Although the Census Bureau highlights that the OM data are most problematic with agricultural data, the same may be true for the mining sector. It is unknown to what extent the mining sector data are distorted, but as a robustness check, I generate an alternative dataset and compare it to the OM data. As I did with NAICS = 113 and NAICS = 114, I create this dataset by allocating national mining exports to states based on their percentage of total national mining production. For example, Texas produced roughly 61% of the U.S.' GDP in the oil and gas sector (NAICS = 211) in 2019, so 61% of the nation's oil and gas exports are allocated to Texas. Although this approach is also limited as it assumes each state's propensity to export is the same as its production level, it nevertheless is a common approach to estimating exports (see the Brookings' Export Monitor (Parilla and Marchio 2018)) and offers a robustness check to the OM data. The percent differences presented in Table 6 suggest that there is little difference between the OM data and the constructed measure. The percent different is less than 1% for 46 states. Unlike the agricultural sector, the biggest differences between OM and this constructed value are not port states compared to inland states. Instead, the notable differences are for the two largest coal producing states in Wyoming (undervalued) and West Virginia (overvalued). Data from the EIA (2022a) notes that although Wyoming produced 158,491.9 thousand short tons more of coal than West Virginia in 2021, West Virginia exported 29,380 thousand short tons more of coal to foreign markets than Wyoming. This suggests that the OM data are relatively accurate for the mining sector. However, no definitive claim can be made because, to the best of my knowledge, there are no other alternative datasets to compare mining exports to.

Table 6. Difference (% GDP) Between NAICS = 21 OM Trade Data and Constructed Trade Measure by State on Average (Percent Difference = Constructed Measure – OM Data)

State	Percent Difference	State	Percent Difference
Alabama	-0.32	Montana	0.39
Alaska	-0.57	Nebraska	-0.21
Arizona	-0.03	Nevada	0.34
Arkansas	0.13	New Hampshire	0.02
California	0.03	New Jersey	-0.00
Colorado	0.38	New Mexico	0.90
Connecticut	-0.02	New York	-0.03
Delaware	-0.02	North Carolina	0.01
Florida	0.02	North Dakota	-1.00
Georgia	-0.08	Ohio	0.04
Hawaii	0.02	Oklahoma	1.20
Idaho	0.16	Oregon	0.02
Illinois	-0.03	Pennsylvania	-0.05
Indiana	0.07	Rhode Island	0.01
Iowa	-0.03	South Carolina	0.03
Kansas	0.06	South Dakota	0.01
Kentucky	0.44	Tennessee	0.05
Louisiana	-0.50	Texas	-0.04
Maine	-0.12	Utah	0.14
Maryland	-0.07	Vermont	0.05
Massachusetts	0.01	Virginia	-0.12
Michigan	-0.41	Washington	-0.06
Minnesota	-0.00	West Virginia	-1.23
Mississippi	0.10	Wisconsin	0.01
Missouri	-0.04	Wyoming	3.15

To further compare the alternative datasets to the OM data, I use a fixed effects regression to test whether the measures are substitutable. I also include a set of regressions comparing the total OM exports as a percentage of GDP using the original OM dataset to total exports as a percentage of GDP using my constructed datasets, and I compare the constructed datasets to one another. The dataset that contains the original OM manufacturing and mining data plus my constructed NAICS = 11 dataset is referred to as ALT1, and the dataset that contains the original OM manufacturing plus my constructed NAICS = 11 and 21 dataset is referred to as ALT2. A coefficient that is statistically equivalent to one means that the datasets are fully substitutable.

As Table 7 shows, the alternative datasets are comparable to the OM data and to one another. The coefficients for NAICS = 11 and for total exports (% of GDP) are statistically equivalent to one at the .05 level, and NAICS = 21 is statistically equivalent to one at the .05 level but statistically different at the .10 level. Furthermore, ALT1 and ALT2 are statistically equivalent OM and to one another, suggesting they are substitutable for one another. Below I report the scale effects using each alternative measure, and I report the effects using the original OM data for comparison.

Table 7. Fixed Effect Regression of OM Trade Data on Constructed Trade Measure

	NAICS = 11 OM	**NAICS = 21 OM**	**OM Compared to ALT1**	**OM Compared to ALT2**	**ALT1 Compared to ALT2**
Constructed Measure	0.804* (0.129)	0.690* (0.179)	1.004* (.033)	0.923* (0.051)	0.926* (0.044)
H_0: $\beta = 1$	2.30	2.98#	0.01	2.30	2.78

Note: Note: *p < .05. #p < .10. Robust standard errors clustered by state are reported. Unit-specific intercepts are not reported.

4. Data and Methods

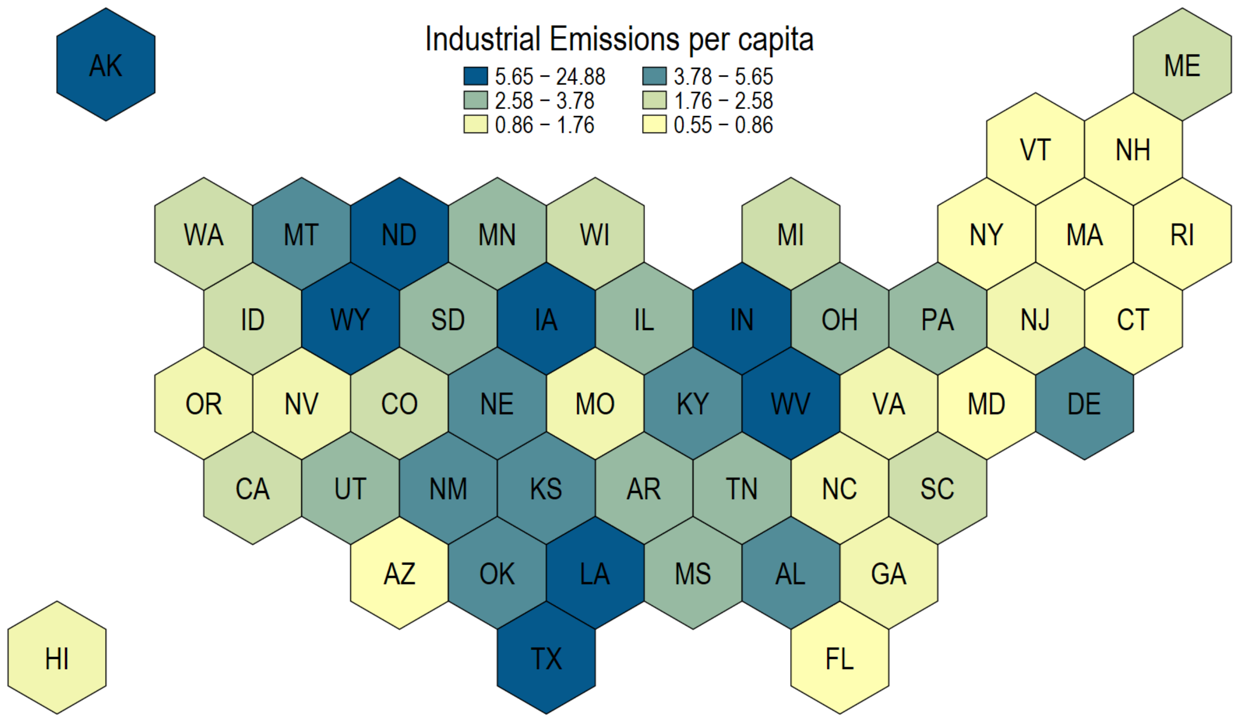
4.1. Sample and Dependent Variable

This study analyzes perfectly balanced panel data for the 50 U.S. states from 2002 to 2019 (900 total observations).[16] This study models energy-related industrial CO_2 emissions (measured in million metric tons) per capita (IEPC), which are emissions attributed to agriculture, forestry, fishing and hunting (NAICS = 11), mining (NAICS = 21), construction (NAICS = 23), and manufacturing (NAICS = 31-33). Total energy-related industrial CO_2

[16] The District of Columbia is not included because it did not emit any industrial emissions for most of the years in the analysis.

emissions are obtained from the EIA (2022c) and are converted to per capita emissions using population data from the state energy data system (SEDS) database (EIA 2021b). Industrial emissions are more appropriate to use than overall CO_2 emissions given that emissions attributed to exports are primarily from the industrial sector (the average industrial share of exports is 92.33% over the 2002-2019 period). Figure 4 illustrates the average industrial emissions (thousand metric tons) per capita for each state from 2002 to 2019.

Figure 4. Average Industrial Emissions (Thousand Metric Tons) per capita by State, 2002-2019

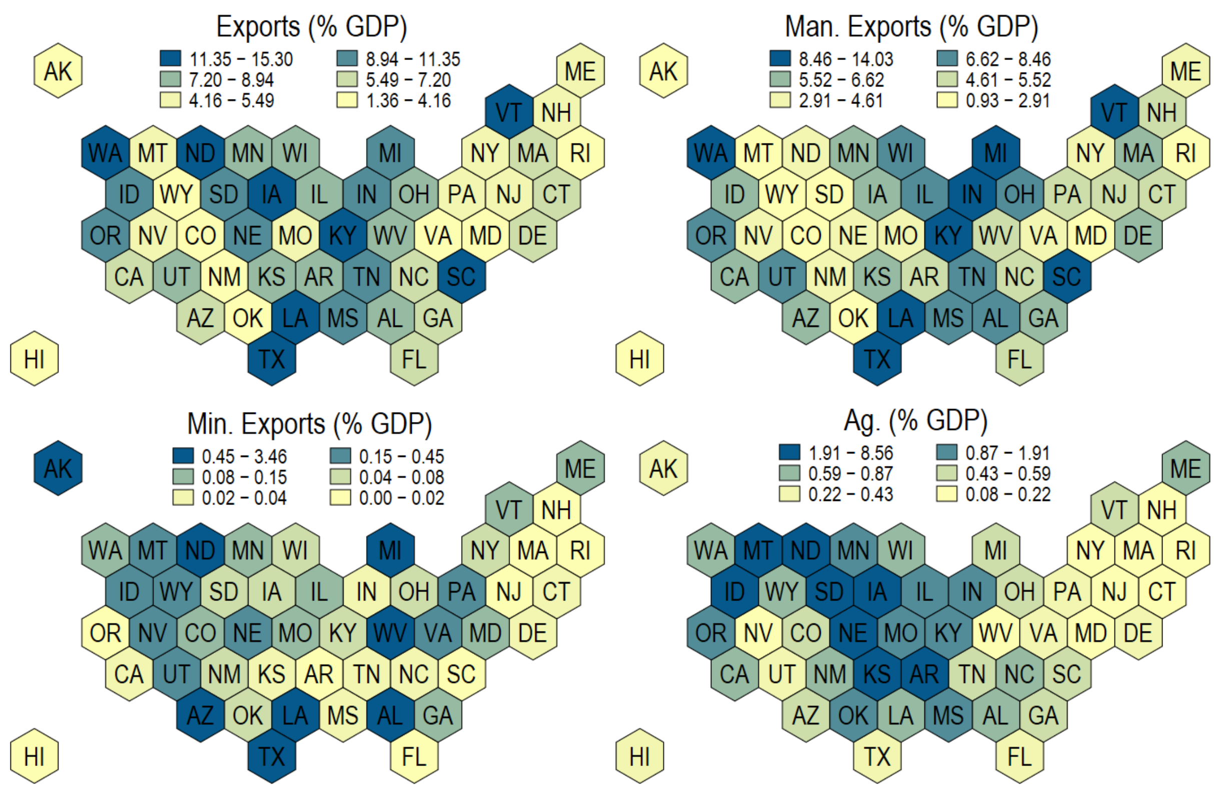


4.2. Measures of Trade

As previously discussed, the scale effect is measured by my alternative measures or by the original OM data. These measures are generated by dividing the export data by GDP data from the BEA. Both measures are in current dollars, but this is not an issue since the currency unit in the numerator and denominator cancel out. Figure 5 illustrates the average percentage of

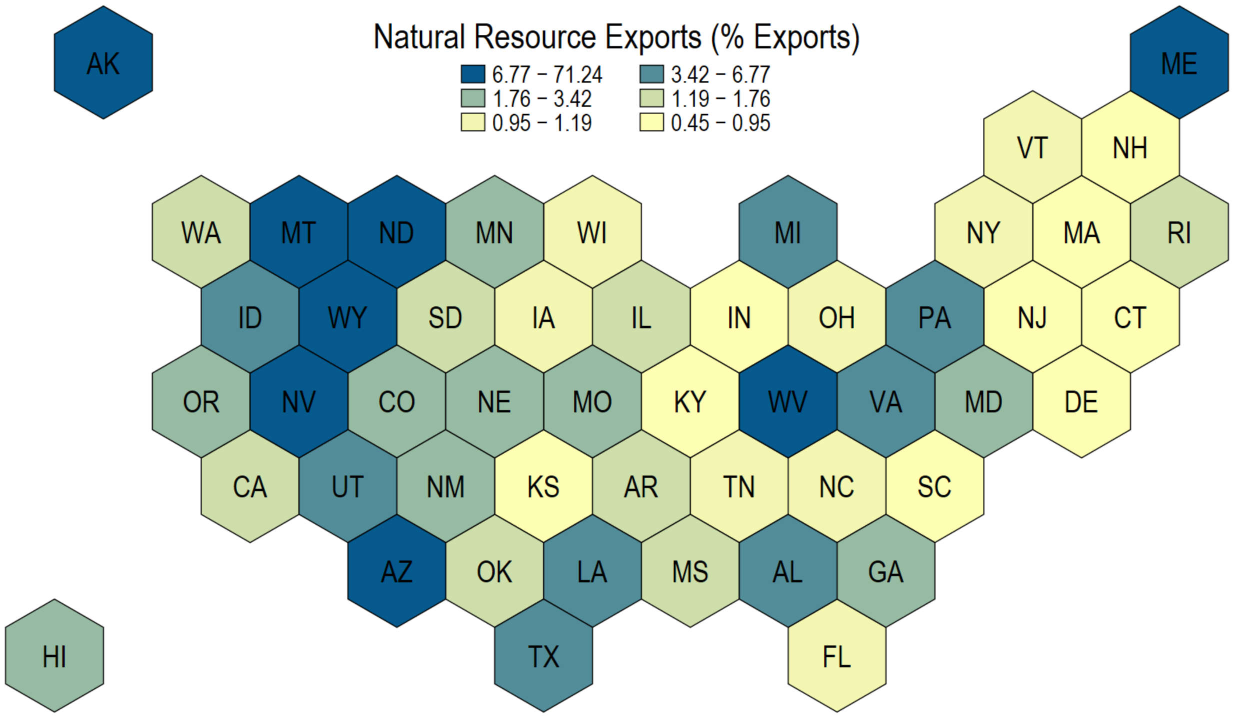
GDP from exports along with the average the percentage of GDP by each export sector for each state, and Figure 6 illustrates the average percentage of extractive natural resource exports as a percentage of total exports.

Figure 5. Average Exports in Total and by Sector by State, 2002-2019



Note: Man. = Manufacturing, Min. = Mining, Ag. = Agriculture, Forestry, Fishing, and Hunting. Percentages correspond to the ALT1 measure (constructed Agriculture, Forestry, Fishing, and Hunting, OM mining, OM manufacturing).

Figure 6. Natural Resource Exports Percentage of Total Exports by State, 2002-2019



Note: Natural Resource Exports = NAICS = 21 (OM data) + NAICS = 113 (Constructed data) + NAICS = 114 (Constructed data).

4.3. Other Controls

Four other variables are included as controls: industrial sector GDP per capita, the average industrial sector energy price, renewable energy (% of energy consumption), and state environmentalism (measured as the League of Conservation Voters (LCV) score for each state). A description of each control is below, and the descriptive statistics are presented in Table 8.

Industrial Sector GDP per capita (IGDP): Industrial sector GDP per capita data are obtained from the BEA (2022b). The industrial sector encompasses agriculture, forestry, fishing and hunting (NAICS = 11), mining, including oil and gas extraction (NAICS = 21), construction (NAICS = 23), and manufacturing (NAICS = 31-33).

Average Industrial Energy Price (AIEP): The average energy price is the average of the real industrial electricity (EIA 2022b) and real industrial primary energy prices (EIA 2021b). Primary energy prices are from SEDS. Both price values are deflated using the CPI-U-RS series.

Renewable Energy (% Energy Consumption) (RE): This variable measures the percentage of total energy consumption from renewable energy (biodiesel, fuel ethanol, wood, waste, hydroelectric, geothermal, solar, and wind energy).

LCV Average Score (LCV): The League of Conservation Voters (LCV) score for each state captures state-level environmentalism based on the environmental voting record of each member of congress for each state (Dietz et al. 2015; League of Conservation Voters 2020). This measure is constructed by averaging the LCV score of the house and senate for each state.

Table 8. Descriptive Statistics

Variable	Mean (SD)	Between SD	Within SD	N/T	Obs.
ICO_2PC	-5.983 (0.991)	0.987	0.164	50/18	900
Trade Measures					
OM	1.817 (0.560)	0.524	0.211	50/18	900
ALT1	1.904 (0.539)	0.504	0.203	50/18	900
ALT2	1.920 (0.524)	0.486	0.208	50/18	900
AG_OM	-1.753 (1.393)	1.356	0.370	50/18	900
AG_ALT	-0.494 (1.188)	1.182	0.203	50/18	900
MIN_OM	-2.905 (1.983)	1.789	0.890	50/18	900
MIN_ALT	-2.377 (1.705)	1.624	0.564	50/18	900
MAN	1.644 (0.614)	0.580	0.216	50/18	900
RES	-5.190 (0.923)	0.892	0.265	50/18	900
Other Controls					
IGDP	2.306 (0.375)	0.361	0.114	50/18	900
RE	2.042 (0.854)	0.769	0.385	50/18	900
AIEP	2.128 (0.293)	0.246	0.163	50/18	900
LCV	47.371 (30.413)	28.126	12.201	50/18	900

4.4. Dynamic Two-Way Fixed Effects Estimation and the Estimated Models

This study uses a dynamic two-way fixed effects regression, which allows for short-run and long-run effects to be estimated and controls for unit-specific time-invariant heterogeneity and common shocks that affect each unit homogeneously in the analysis. To correctly specify the dynamics in the model, a program in Stata 17 is written to determine the appropriate lag length based on all possible lag combinations (up to one lag for each variable). The model that best fits the data is then selected based on Schwarz's Bayesian information criteria. The three models I estimate are as follows[17]:

Scale Effect (Table 5)

$$ICO_2PC_{i,t} = \lambda_1 ICO_2PC_{i,t-1} + \beta_1(ALT1, ALT2, or\ OM)_{i,t} + \beta_2 IGDP_{i,t} + \beta_3 RE_{i,t} + \beta_4 RE_{i,t-1} + \beta_5 AIEP_{i,t} + \beta_6 LCV_{i,t} + \alpha_i + u_t + \varepsilon_{i,t}$$

Scale Effect Disaggregated (AG, MIN, MAN) (Table 6)

$$ICO_2PC_{i,t} = \lambda_1 ICO_2PC_{i,t-1} + \beta_1 AG_{i,t} + \beta_2(MIN\_ALT\ or\ MIN\_OM)_{i,t} + \beta_3 MAN_{i,t} + \beta_4 IGDP_{i,t} + \beta_5 RE_{i,t} + \beta_6 RE_{i,t-1} + \beta_7 AIEP_{i,t} + \beta_8 LCV_{i,t} + \alpha_i + u_t + \varepsilon_{i,t}$$

Resource Dependency Effect (Table 7)

$$ICO_2PC_{i,t} = \lambda_1 ICO_2PC_{i,t-1} + \beta_1 RES_{i,t} + \beta_2 ALT1_{i,t} + \beta_3 IGDP_{i,t} + \beta_4 RE_{i,t} + \beta_5 RE_{i,t-1} + \beta_6 AIEP_{i,t} + \beta_7 LCV_{i,t} + \alpha_i + u_t + \varepsilon_{i,t}$$

5. Results and Discussion

I report the short-run and long-run effects of the scale effect in Table 9 for the constructed measures and the original OM measure. The results for all three measures are substantively the same—all of which indicate that greater global economic integration increases emissions at the U.S. state-level. The short-run effects for ALT1 (coefficient = 0.050) and ALT2 (coefficient = 0.048) are statistically significant at the .05 level (ALT1 95% CI = 0.011 — 0.089, ALT2 95% CI = 0.007 — 0.088), and the short-run effect for OM (coefficient = 0.032) is statistically significant at the .10 level (OM 95% CI = -0.0001 — 0.064). The long-run effects for ALT1 (coefficient = 0.183, 95% CI = 0.042 — 0.324), ALT2 (coefficient = 0.174, 95% CI = 0.026 — 0.322), and OM (coefficient = 0.119, 95% CI = 0.007 — 0.231) are all statistically significant at the .05 level. The long-run effect is similar in magnitude to recent cross-national

[17] The dependent and independent variables except for LCV are naturally logged.

analyses examining the effect of trade on emissions (Jorgenson et al. 2022a; Thombs 2018b). This finding supports the intensification hypothesis, which expects that global economic integration to increase emissions.

Table 9. Regression Models of Industrial CO2 Emissions per capita by Exports Measure, 2002-2019

	ALT1		ALT2		OM	
	SR	LR	SR	LR	SR	LR
$IEPC_{t-1}$	0.727*		0.726*		0.732*	
	(0.044)		(0.043)		(0.044)	
ALT1, ALT2, OM	.050*	0.183*	.048*	0.174*	0.032#	0.119*
	(.019)	(0.072)	(0.020)	(0.075)	(0.016)	(0.057)
IGDP	0.114*	0.417*	0.112*	0.411*	0.108*	0.403*
	(0.024)	(0.095)	(0.026)	(0.101)	(0.023)	(0.095)
RE	-0.036	0.125*	-0.037	0.115*	-0.036	0.125*
	(0.036)	(0.044)	(0.036)	(0.044)	(0.036)	(0.046)
RE_{t-1}	0.070*		0.069*		0.069*	
	(0.034)		(0.034)		(0.034)	
AIEP	-0.140*	-0.511*	-0.138*	-0.504*	-0.143*	-0.533*
	(0.040)	(0.151)	(0.041)	(0.155)	(0.040)	(0.154)
LCV	0.000	0.001	0.000	0.001	0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
N/T/Obs.	50/17/850		50/17/850		50/17/850	
BIC	-1857.271		-1856.754		-1853.314	

Note: *$p < .05$, #$p < .10$. Robust standard errors clustered by state are reported. State and year-specific intercepts are not reported. ALT1, ALT2, OM = % of GDP from exports; IEPC = Industrial CO_2 Emissions per capita; IGDP = Industrial sector GDP per capita; RE = Renewable Energy (% Energy Consumption); AIEP = Average industrial energy price; LCV = LCV average score. SR = Short-Run; LR = Long-Run.

Moving to Table 10, the effects are once again similar across all three measures of trade. The results indicate that the AG sector is primarily driving the scale effect. In the first two models, AG is positive (ALT 1 and 2 coefficient = 0.054) and statistically significant at the .10 level in the short-run and the long-run (ALT 1 coefficient = 0.198, 95% CI = -0.026 — 0.422, ALT 2 coefficient = 0.197, 95% CI = -0.026 — 0.420). The results for OM, which are presented for comparison reasons, are similar. The short-run effect (OM coefficient = 0.020, 95% CI = 0.002 — 0.038) and long-run effect (OM coefficient = 0.074, 95% CI = 0.006 — 0.142) are statistically significant at the .05 level. MIN and MAN are not statistically significant in any of the three models.

However, the results also indicate that the scale effect cannot be reduced to a single sector as the results of the linear combinations indicate that AG + MAN has a larger effect in magnitude than the AG sector alone. This result holds true across all three trade measures. For ALT1 and ALT2, the short-run effect for AG + MAN is 0.074 (ALT 1 95% CI = 0.007 — 0.140, ALT 2 95% CI = 0.008 — 0.140), and the long-run effect is 0.269 (ALT 1 95% CI = 0.013 — 0.525, ALT 2 95% CI = 0.014 — 0.523), AG + MAN + MIN is also statistically significant, but the coefficient is approximately equal to the AG + MAN coefficient. The OM coefficients are similar but smaller in magnitude. The short-run effect for AG + MAN is 0.040 (95% CI = 0.002 — 0.077), and the long-run effect is 0.148 (95% CI = 0.010 — 0.283).

Table 10. Regression Models of Industrial CO2 Emissions per capita by Export Sector, 2002-2019

	ALT1		ALT2		OM	
	SR	LR	SR	LR	SR	LR
$IEPC_{t-1}$	0.726*		0.725*		0.729*	
	(0.043)		(0.042)		(0.044)	
AG	0.054#	0.198#	0.054#	0.197#	0.020*	0.074*
	(0.028)	(0.114)	(0.028)	(0.114)	(0.009)	(0.035)
MIN	-0.000	-0.001	0.001	0.005	0.000	0.001
	(0.004)	(0.015)	(0.010)	(0.035)	(0.004)	(0.016)
MAN	0.019	0.071	0.020	0.072	0.020	0.073
	(0.019)	(0.069)	(0.019)	(0.069)	(0.019)	(0.070)
IGDP	0.125*	0.454*	0.124*	0.449*	0.109*	0.402*
	(0.028)	(0.114)	(0.029)	(0.118)	(0.026)	(0.104)
RE	-0.039	0.114*	-0.039	0.113*	-0.040	0.105*
	(0.036)	(0.046)	(0.036)	(0.046)	(0.036)	(0.048)
RE_{t-1}	0.070*		0.070*		0.068*	
	(0.034)		(0.035)		(0.034)	
AIEP	-0.137*	-0.499*	-0.136*	-0.496*	-0.133*	-0.490*
	(0.043)	(0.164)	(0.044)	(0.169)	(0.042)	(0.160)
LCV	0.000	0.001	0.000	0.001	0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
Linear Combinations						
AG + MIN	0.054#	0.197#	0.056#	0.202#	0.020#	0.075#
	(0.029)	(0.116)	(0.030)	(0.120)	(0.011)	(0.041)
AG + MAN	0.074*	0.269*	0.074*	0.269*	0.040*	0.147*
	(0.033)	(0.131)	(0.033)	(0.130)	(0.019)	(0.070)
MIN + MAN	0.019	0.070	0.021	0.077	0.020	0.074
	(0.018)	(0.066)	(0.021)	(0.077)	(0.018)	(0.066)
AG + MIN + MAN	0.073*	0.268*	0.075*	0.274*	0.040*	0.148*
	(0.033)	(0.130)	(0.034)	(0.135)	(0.018)	(0.067)
N/T/Obs.	50/17/850		50/17/850		50/17/850	
BIC	-1842.801		-1842.826		-1844.077	

Note: *p < .05, #p < .10. Robust standard errors clustered by state are reported. State and year-specific intercepts are not reported. AG = agriculture, forestry, fishing and hunting sector exports % of GDP; MIN = mining sector % of GDP; MAN = manufacturing sector % of GDP; IEPC = Industrial CO_2 Emissions per capita; IGDP = Industrial sector GDP per capita; RE = Renewable Energy (% Energy Consumption); AIEP = Average industrial energy price; LCV = LCV average score. SR = Short-Run; LR = Long-Run.

The effects of resource dependency (RES) are reported in Table 11. The effect of resource dependency is not statistically significant across the three trade measures. These findings indicate that resource dependency is not a primary driver of the trade-emissions relationship.

Table 11. Regression Models of Industrial CO2 Emissions per capita by Resource Dependency Measure, 2002-2019

	ALT1		ALT2		OM	
	SR	LR	SR	LR	SR	LR
$IEPC_{t-1}$	0.727*		0.720*		0.731*	
	(0.044)		(0.044)		(0.044)	
RES	0.002	0.006	0.030	0.106	0.002	0.008
	(0.007)	(0.025)	(0.021)	(0.069)	(0.005)	(0.018)
ALT1, ALT2, OM	0.050*	0.184*	0.079*	0.282*	0.032*	0.119*
	(0.019)	(0.069)	(0.021)	(0.084)	(0.016)	(0.057)
IGDP	0.113*	0.412*	0.105*	0.375*	0.107*	0.398*
	(0.025)	(0.101)	(0.026)	(0.101)	(0.023)	(0.096)
RE	-0.036	0.124*	-0.040	0.096*	-0.035	0.126*
	(0.036)	(0.044)	(0.037)	(0.046)	(0.036)	(0.046)
RE_{t-1}	0.070*		0.067*		0.069*	
	(0.034)		(0.033)		(0.034)	
AIEP	-0.140*	-0.511*	-0.134*	-0.479*	-0.144*	-0.534*
	(0.040)	(0.151)	(0.039)	(0.143)	(0.040)	(0.153)
LCV	0.000	0.001	0.000	0.001	0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
N/T/Obs.	50/17/850		50/17/850		50/17/850	
BIC	-1850.606		-1853.21		-1846.757	

Note: *$p < .05$, #$p < .10$. Robust standard errors clustered by state are reported. State and year-specific intercepts are not reported. ALT1, ALT2, OM = % of GDP from exports; RES = % of exports from extractive natural resource sectors; IEPC = Industrial CO_2 Emissions per capita; IGDP = Industrial sector GDP per capita; RE = Renewable Energy (% Energy Consumption); AIEP = Average industrial energy price; LCV = LCV average score. SR = Short-Run; LR = Long-Run.

6. Conclusion

In this study, I build on the trade-emissions literature by examining the effect of trade on industrial emissions at the U.S. state-level using panel data from 2002 to 2019. I find that greater economic integration into the global economy is associated with increases in industrial CO_2 emissions at the U.S. state-level, and that this relationship is driven primarily by a linear combination of exports from the agriculture, forestry, fishing, and hunting and manufacturing sectors. I also find that greater export reliance on extractive natural resource sectors is not associated with increases in emissions. Overall, these findings support what I term the intensification hypothesis, which argues that increases in global economic integration at the U.S. state-level increases emissions.

One limitation should be noted about the results, which is related to the quality of the mining exports data. The quality of the OM mining exports data could not be verified in this study. I constructed an alternative mining exports data measure based on national production, but the quality of this measure does not appear to be as good as the OM data, which suggests that the OM data may be a good substitute for OP data. Future research should delve further into this issue and examine particular mining sectors. One suggestion would be to start by examining the effect of coal dependence on the environment, which is a sector that has high quality data available. The EIA (2022a) provides detailed state-level export data for coal producing states through their Annual Coal Distribution Report.

There are multiple other avenues for future research that could explore similar questions pondered in the cross-national literature. First, future research should consider whether trade impacts other environmental outcomes like air and water pollution (Givens et al. 2019; Oita et al. 2016; Xu et al. 2020, 2020). Second, examining the effects of foreign direct investment on environmental and economic outcomes should also be considered (Jorgenson 2007b, 2007a; Jorgenson et al. 2022b). These potential avenues for future research would greatly enhance our understanding of the effects of trade on various socioecological outcomes beyond focusing exclusively on the nation-state.

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Chapter 4: Does Renewable Energy Production Displace Fossil Production in the U.S.? A Panel Data and Case Study Analysis of Fossil Fuel Producing U.S. States, 1997 – 2020

Abstract

Does renewable energy displace fossil fuels? Recent research finds mixed evidence, highlighting that effects are heterogeneous across contexts. I further explore this question by examining whether renewable energy production displaces fossil fuel production in the 33 fossil fuel producing states in the U.S. from 1997 to 2020. Using two different approaches (two-way fixed effects regression and the half-panel jackknife test for Granger causality), I find robust evidence that there is not an association between renewable energy production and fossil fuel production at the U.S. state-level. I further explore why this is the case by examining the recent history of North Dakota—a state that is a major fossil fuel and renewable energy producer. I find that renewable energy sources are increasingly viewed by the fossil fuel industry as a technological fix to an accumulation crisis, where renewable energy is used to support the industry rather than to replace it. Overall, this study contributes to our understanding of how and why energy sources tend to add to the existing energy mix rather than fundamentally change it.

Introduction

We must transition to renewable energy as quickly as possible to move to a carbon free economy (IPCC 2021). Although policymakers are reluctant to accelerate this transition at the needed pace, investment in renewable energy now makes up the largest percentage of new energy generation (International Energy Agency 2021). The growth in renewable investment has produced considerable optimism among various policymakers, institutions, and commentators on energy transitions, highlighted by former President Obama (2017) arguing that "the trend toward clean energy is irreversible" (127).

Such optimism, however, assumes that growth in renewable energy corresponds with a proportional decrease in fossil fuels. This view assumes, often implicitly, that there is a fixed energy pie, where renewables are increasingly crowding out fossil fuels. Whether renewables substitute for fossil fuels has generated a number of studies producing conflicting results that differ across country samples and time period (Apergis et al. 2010; Liddle and Sadorsky 2017; Shafiei and Salim 2014; Thombs 2018; York 2012).

Similarly, research on the drivers of renewable energy is inconclusive and fragmented. A recent systematic review of the literature by Bourcet (2020) indicates that there is no consensus regarding the magnitude or direction of many political, social, economic, and technological factors in shaping renewable energy deployment, and cross-national research finds that driver effects are heterogeneous across different spatial contexts. Most research on renewable energy in the U.S. assumes that deployment is primarily a product of policy differences between states (Carley et al. 2018; Lyon 2016; Thombs and Jorgenson 2020). Policy plays a role (Carley et al. 2018; Crago and Koegler 2018; Dorrell and Lee 2020), but this assumption overlooks the fact that many of the top renewable energy producers are also among the largest fossil fuel producers. Thus, a more comprehensive evaluation of the political economic forces driving the renewable-fossil fuel energy nexus is needed.

To further explore this relationship, I examine whether renewable energy production displaces fossil fuel production in the 33 fossil fuel producing states in the U.S. from 1997 to 2020. I use two different modeling approaches—two-way fixed effects regression and the half-panel jackknife test for Granger causality—which allows me to account for dynamic processes, feedback effects, slope heterogeneity, and cross-sectional dependence. Across both approaches, I find robust evidence that there is not an association between renewable energy production and fossil fuel production at the U.S. state-level.

Based on these findings, I examine the case of North Dakota to dive deeper into the null relationship found in the panel data analysis. I find that the competition and collaboration between the renewable and fossil fuel sectors creates a set of contradictions between various interests in the state that operate relationally to changes in the global energy sector. I show that the state's dependency on fossil fuels allows the industry to seek state support to pursue technological fixes to preserve its profits, which ultimately creates an environment where the interests of renewable energy become interwoven with fossil fuels. In this way, the state becomes increasingly dependent on both fossil fuel and renewable energy, where renewable energy is not seen as so much of a threat, but instead, becomes a support for continual fossil fuel extraction.

The paper is separated into four sections. The first section outlines the prior literature on the renewable energy-fossil fuel nexus and details the U.S. case. The second section describes the data and methods to test the hypothesis, which are subsequently followed by the results and the case study of North Dakota. I then end with a few closing remarks.

Background

Whether renewable energy displaces fossil fuels has stimulated a number of studies by energy researchers (Apergis et al. 2010; Liddle and Sadorsky 2017; Shafiei and Salim 2014; Thombs 2018a; York 2012). These studies vary widely in their approach to testing the question, which has produced inconclusive evidence. York (2012) found that non-fossil fuel energy sources displace less than one-quarter of a unit of fossil fuel consumption, which they argue means that relying on renewable energy deployment is not enough to curtail fossil fuel use. In a more recent study, Liddle and Sadorsky (2017) find that both non-fossil fuel consumption per capita and the share of non-fossil fuels in electricity generation reduce CO_2 emissions, but that increasing the share of non-fossil fuels has a greater mitigating effect than increases in per capita use. Liddle and Sadorsky also find that this effect is larger in non-OECD countries than OECD ones. Apergis et al. (2010) observe that nuclear energy consumption reduces emissions but renewable energy increases emissions, and they argue that this is due to the lack of supportive infrastructure for renewable energy sources. Others like Thombs (2018) note that the effect of non-fossil fuel energy sources on CO_2 emissions changes over time, suggesting that displacement may be a time-varying process.

There are several reasons why renewables may not substitute for fossil fuels. The first is tied to capitalism's growth dynamics. The capitalist system is built on continual growth and economic growth is closely coupled with energy use (Haberl et al. 2020; Jorgenson and Clark 2012; Magdoff and Foster 2011; York and Bell 2019). Since 1800, new energy sources have emerged and shifted the composition of energy use but have not displaced one another at scale (York and Bell 2019). As new energy sources emerge, traditional energy sources get used for other products, or newer energy sources even intensify the use of more traditional sources. York and Bell (2019) note that the use of wood did not decline with the arrival of fossil fuels. Instead, wood is still used for lumber and paper and its use has even expanded with fossil fuel powered machinery. Similarly, petroleum didn't replace whale oil consumption; it intensified it as more whales could be caught with ships fueled by fossil energy (York 2017; York and Bell 2019).

Another reason renewables may not substitute for fossil fuels is tied to how energy siting decisions are made in the U.S. Recent work by O'Shaughnessy et al. (2022) finds that wind and solar siting is primarily driven by technoeconomic factors. In other words, renewables are placed where production potential is greatest, which in many cases, is where fossil fuels are most heavily extracted. For example, the greatest potential for wind energy (the second most consumed renewable source after biomass) is in the Great Plains region, which contains major fossil fuel producing states like North Dakota, Oklahoma, Texas, and Wyoming.[18]

[18] Based on the EPA's (2021) level 1 ecoregions, all or parts of Colorado, Iowa, Illinois, Kansas, Louisiana, Minnesota, Missouri, Montana, North Dakota, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, Wisconsin, and Wyoming are in the Great Plains region. Louisiana is also a major fossil fuel producer, but I exclude them here because only the southwestern part of the state is considered part of the Great Plains. The state also has lower wind potential compared to others in the region.

In this sense, renewables suffer from the same issues that all extractive industries do, which is that "the location, production rates, and turnover time of extraction are inexorably constrained by geological, hydrological, and biological forces" (Bunker 1989, 592).[19] Without adequate storage technologies to support them, renewable production might not match demand in real time, which limits where renewable companies can locate. In other words, it makes financial sense for firms to locate in areas with a continuous supply of renewable energy where intermittency is less of an issue, and many of these places are in predominately rural, fossil fuel dependent states.

As I have highlighted, the U.S. is a particularly interesting case because many of the locations in the country with the greatest renewable energy potential are also where fossil fuels are extracted. Thus, examining the subnational level context in the U.S. can provide important insights regarding how renewables and fossil fuels operate within close proximity to one another. In the following section, I outline and discuss the data and modeling strategy used in this study. I then test whether renewables substitute for fossil fuels substitute in the 33 fossil fuel producing U.S. states from 1997 to 2020.

Data and Methods

Data

This study analyzes perfectly balanced data for the 33 U.S. states that produced fossil fuels annually from 1997 to 2020. 1997 marks the beginning of the analysis as this is the first year that NAICS-based GDP by state are available from the BEA (2022a).

[19] An important difference between fossil fuels and renewables like solar and wind is that efficiency improvements in their extraction do not speed up their rate of depletion. However, solar and wind do face a limitation in that humans cannot control how windy or sunny it is, whereas there is a definitive resource supply of fossil fuels.

Dependent Variable: Fossil Fuel Energy Production per capita

The primary variable of interest in this study is fossil fuel energy production per capita (FFPC). Fossil fuel production includes coal production, natural gas production, and crude oil production. These data are obtained from the EIA's State Energy Data System (SEDS) and are labeled as CLPRB (coal), NGMPB (natural gas), and PAPRB (crude oil production) in SEDS. Fossil fuel production per capita is estimated by adding these three series together and dividing by population estimates from SEDS. These data are measured in Billion BTU per capita.

Key Independent Variable: Renewable Energy Production per capita

Renewable energy production (RENPC) is comprised of energy produced from geothermal, conventional hydroelectric, solar thermal and photovoltaic, wind, wood and waste, and biofuels. These data are obtained from the SEDS' REPB (total renewable energy production) series. Per capita estimates are calculated by dividing total renewable energy production by the population estimates from SEDS. These data are measured in Billion BTU per capita.

Other Covariates

GDP per capita (GDPPC), the League of Conservation Voters (LCV) score for each state, the average fossil fuel price (FFPRICE), and the share of the state's revenue from severance taxes (SEV) are included in the models. GDP per capita data are obtained from the BEA (2022a). The LCV score for each state is a measure of state-level environmentalism based on the environmental voting record of each member of Congress for each state (Dietz et al. 2015; League of Conservation Voters 2020). The LCV average scores from each state are calculated from the League of Conservation Voters (2020) scorecards by averaging the scores of the house and senate. Each score is on a scale from 0 to 100. The average fossil fuel price is the average price across coal, all petroleum products, and natural gas for all sectors, which are obtained from SEDS (series CLTCD, PATCD, and NGTCD). These data are deflated using the energy CPI for all urban consumers from BLS (2023). To calculate the share of a state's revenue from severance taxes, I divide the total annual amount of severance taxes collected from the Census Bureau's (2023) Annual Survey of State Government Tax Collections (STC) by the state's total revenue obtained from the Urban Institute's (2023) State and Local Finance Data tool, which are data also from the Census Bureau.

The variables except for the share of a state's revenue from severance taxes and the LCV average (because some values are zero) are naturally logged, making them equivalent to elasticity models. Thus, these coefficients can be interpreted as the percentage change in the dependent variable corresponding to a 1% change in the independent variable. The coefficient for the severance tax share and the LCV variable can be interpreted by multiplying it by 100 to obtain the percentage change in the dependent variable. Table 12 presents the descriptive statistics for the variables analyzed in this study.

Table 12. Descriptive Statistics

	Mean (SD)	Between SD	Within SD	N/T	Obs.
FFPC	4.427 (2.268)	2.678	0.487	33/24	792
RENPC	3.174 (0.940)	0.830	0.463	33/24	792
GDPPC	10.761 (0.193)	0.171	0.093	33/24	792
LCV	37.828 (26.323)	23.230	12.998	33/24	792
FFPRICE	1.522 (0.122)	0.078	0.095	33/24	792
SEV	2.007 (4.868)	4.069	2.761	33/24	792

Note: Natural logarithms are reported except for SEV and FFPRICE. SD refers to standard deviation. RENPC = Renewable Energy Production per capita, FFPC = Fossil Fuel Production per capita, GDPPC = Real GDP per capita, LCV = League of Conservation Voters Score, FFPRICE = Average Real Fossil Fuel Price, SEV = Share of State's Revenue from Severance Taxes.

Methods

I use two modeling approaches in this study. The first approach is a two-way fixed effects regression where I regress fossil fuel production per capita on renewable energy production per capita. I specify a first difference model with unit-specific trends:

$$\Delta FFPC_{i,t} = \beta_1 \Delta RENPC_{it} + \boldsymbol{\beta}_{\boldsymbol{j}}' \boldsymbol{\Delta x_{it}} + \alpha_i + u_t + \varepsilon_{i,t}, \quad (1)$$

where fossil fuel production per capita is a function of renewable energy production per capita and a vector of control variables. Before deciding on this model, I specified a generalized error correction model (GECM), which is a reparameterization of the autoregressive distributed lag (ARDL) model. The GECM regresses the first difference of the dependent variable on its own lags in levels and the first difference and lags in levels of the regressors. However, the speed of adjustment term was not statistically significant (indicating that there is no long-run relationship), so I restricted the model to a first difference regression.

Bidirectional feedback effects are a potential concern between fossil fuel production and renewable energy (and the other control variables). A variable Granger causes another variable when the inclusion of its lags in the model better predict *y* then just regressing *y* on its own lags (Granger 1969). The intuition behind this concept is that the cause precedes the effect. Thus, to test for Granger causality, the contemporaneous value of y is regressed on its own lags and the lagged values of a set of regressors.

In the panel data context, several different approaches have been advanced to test for Granger causality. Seminal work by Holtz-Eakin et al. (1988) proposed a GMM approach that is best suited for small *T* data with homogenous slope coefficients. However, this approach is not appropriate to use when *T* is even moderately large because it leads to too many instruments being used causing inaccurate estimates (Xiao et al. 2021). Dumitrescu and Hurlin (2012) developed an approach for large *T* data that allows for heterogeneous coefficients. More recent work by Juodis, Karavias, and Sarafidis (2021), which I use here (henceforth HPJ-G), offers an approach that uses the half panel jackknife method developed by Dhaene and Jochmans (2015). This approach offers advantages over alternative methods because it allows for homogenous or heterogeneous coefficients, and it offers superior performance compared to Dumitrescu and Hurlin's approach when *T* is smaller than *N* (the case in this study). It also accounts for the Nickell bias, which the Dumitrescu and Hurlin approach does not do. I implement this approach with the community contributed xtgrangert command. Based on xtgrangert's built in BIC lag selection program that chooses the model that best fits the data, I estimate the following model that allows for heterogeneous autoregressive and feedback coefficients:

$$FFPC_{i,t} = \beta_{1,i}RENPC_{i,t-1} + \beta_{2,i}RENPC_{i,t-2} + \sum_{p=1}^{2}\boldsymbol{\beta}'_{p,i}\boldsymbol{x}_{it-p} + \alpha_i + \varepsilon_{i,t}. \qquad (2)$$

I allow for cross-sectional dependence by using the bootstrap option that uses bootstrap variance of the HPJ estimator that allows for cross-sectional dependence.

Results and Discussion

Panel Data Analysis

The results are reported in Table 13 for each of the models. Endogeneity does not appear to be a significant issue given the findings are consistent across the models—both indicate that renewable energy production is not associated with fossil fuels. Renewable energy has a negative sign in each model but is not near statistical significance. These results provide strong evidence that renewable energy production per capita is unrelated to fossil fuel production at the U.S. state-level, but why is this? I explore the relationship between fossil fuel and renewable energy production in more detail in the case of North Dakota in the following section.

Table 13. Regression Models of Fossil Fuel Production per capita on Renewable Energy Production per capita, 1997 to 2020

Contemporaneous Effects	FD	HPJ-G
ΔRENPC	-0.078	
	(0.055)	
ΔGDPPC	-0.460	
	(1.212)	
ΔLCV	0.043	
	(0.083)	
ΔFFPRICE	-0.143	
	(0.235)	
ΔSEV	0.165	
	(0.344)	
x_{it-1}		
RENPC		0.023
		(0.077)
GDPPC		-0.210
		(0.509)
LCV		-0.214
		(0.242)
FFPRICE		-0.007
		(0.350)
SEV		-1.101
		(0.973)
x_{it-2}		
RENPC		-0.288#
		(0.165)
GDPPC		0.999
		(0.950)
LCV		0.326
		(0.223)
FFPRICE		0.215
		(0.246)
SEV		0.160
		(0.741)
Sum of Lagged Coefficients		
RENPC		-0.265
		(0.204)
GDPPC		0.789
		(0.981)
LCV		0.112
		(16.629)
FFPRICE		0.208
		(0.306)
SEV		-0.009
		(47.19)
Observations	759	759
(N/T)	(33/23)	(33/22)
BC Q(p)-Test	0.99	
BC HR-Test	-0.20	

Note: *$p < .05$, # $p < .10$. Robust standard errors clustered by state are reported. RENPC = Renewable Energy Production per capita, FFPC = Fossil Fuel Production per capita, LCV = League of Conservation Voters Score, GDPPC= Real GDP per capita. Wald Test H_0: symmetry. LCV coefficient and standard error is multiplied by 100 because it is not naturally logged. BC Q(p)-Test = Bias-corrected Born and Breitung (2016) Q(p)-test. BC HR-Test = Heteroskedasticity-robust Born and Breitung (2016) HR-test.

The Case of North Dakota: Exploring the Relationship Between Fossil Fuel and Renewable Energy Production

Based on the results of the statistical analyses, I examine North Dakota to further explore the relationship between fossil fuel and renewable energy production. North Dakota is an ideal case to analyze for three reasons: 1) the state has an abundant supply of fossil fuel and renewable resources, 2) it is produces the 2nd most fossil fuels and renewables on a per capita basis, and 3) the state is immersed in battles over the future of its energy sector. As I discuss below, the intensity at which internal and external political economic factors are driving change in the energy composition of the state make the tensions and contradictions between interest groups quite visible and transparent.

The prominence of the state's fossil fuel industry is both a function of its abundant supply of fossil fuel reserves and the development of horizontal drilling and hydraulic fracking, which made it easier to recover tight oil deposits in the Bakken formation in the Western part of the state (U.S. Energy Information Administration 2021a). The state's oil and natural gas boom over the past decade is well documented (U.S. Energy Information Administration 2021a), which resulted in North Dakota becoming the six largest energy producer in the U.S. even though it is the 4th smallest state in terms of population. Along with its oil and natural gas reserves, it is the 8th largest coal producer in the U.S., making North Dakota a key player in every fossil fuel resource (U.S. Energy Information Administration 2021b). The state also generates 31% of its electricity from wind energy (the fifth highest share of any state in the country) and is a major producer of ethanol (U.S. Energy Information Administration 2021b). Although much of its energy resources are exported for use elsewhere, its substantial renewable resources have made North Dakota the largest consumer of renewable energy on a per capita basis in the country.

Given the presence of various energy sources within its borders, North Dakota serves as a microcosm of many of the same battles occurring across the country and world. As is the case elsewhere, the state's coal industry is facing financial turmoil. The state's largest coal plant (Coal Creek Station) planned to shut down in 2022 (but was recently purchased and will continue to operate), which drove state legislators to try and save the state's coal industry by offering tax breaks and other incentives (Schramm 2021). Thus, although the coal industry is treading water financially, it still has substantial sway in the state legislature to enact favorable policy legislation.

The issues facing the coal industry are not just internal but are products of broader global political economic forces that are shifting investment into natural gas and renewables, while the industry also faces mounting pressure to reduce its emissions. These processes have forced the state's coal industry to pursue carbon capture technologies as a potential technological fix, which the industry hopes North Dakota's government will help fund and develop (Schramm 2021). This pursuit has facilitated a partnership with the ethanol industry in the state. Although ethanol is considered a renewable, its production process is carbon intensive due to CO_2 being released during the fermentation processes. The primary reason the ethanol industry in North Dakota wants to reduce its emissions is to penetrate the California market, which offers tax credits to low carbon-intensive fuels (Sisk 2021a). These seemingly unaligned industries have therefore merged their interests, where the two industries view themselves as partners in facilitating carbon capture and storage in the state. Coal views this as a means to potentially save itself, whereas the ethanol industry sees it as a way to pursue additional profitable opportunities elsewhere.

In April 2021, House Bill 1452 passed in the state legislature to create a clean sustainable energy authority and clean sustainable energy fund (Sisk 2021a), which helps fund carbon sequestration technologies while offering the renewable industry, at least symbolically, a position at the table. Representative Matt Ruby argues that the bill is aimed to support both the fossil fuel and renewable industries:

> "This bill is a great step to continue innovation and best practices across the entire energy spectrum. Membership of this commission includes representation of both fossil fuels and renewable energy to ensure each industry has a chance at these funds. This is an investment into the future of North Dakota's biggest industry and I believe it will be a great benefit to the state" (Schramm 2021).

However, environmental groups worry that insufficient funds will be distributed to non-combustible renewables, and instead go to supporting unproven carbon capture technologies (Schramm 2021). Although non-combustibles like wind have received limited support from the state legislature, the industry has benefited from the federal production tax credit that provides incentives to wind farms.[20] The tax credit is viewed as a threat to the fossil fuel industry by some legislators, with Rep. Dave Nehring proposing legislation in spring 2021 to tax wind farms to "bring back part of the federal tax credit," which would then go to supporting the coal industry (Sisk 2021b). However, the proposed measure received resistance from utility companies that have interests in both coal and wind energy as the energy sector becomes increasingly diversified. As an alternative, the utility industry advocated for relief for the coal industry, while also supporting House Bill 1452. Thus, while the non-combustible renewable sector has not received much backing from the North Dakota's state legislature, the assistance from federal tax credits combined with just enough support from the utility industry to fend off harmful legislation, has allowed the wind industry to turn the state's abundant wind resources into a profitable endeavor.

[20] The Inflation Reduction Act provides additional incentives to projects located in "energy communities", which are fossil-fuel dependent communities.

Like ethanol, coal and other fossil fuels are increasingly trying to link their interests with those of wind to preserve their profits, while the wind industry is favorable to these partnerships as it creates opportunities for growth. These contradictory interests have stimulated projects between the two industries, as they see mutual benefits. For example, Coal Creek Station was recently bought by Rainbow Energy Center, LLC, which will continue producing coal but will use carbon capture technology that is powered by wind energy (Great River Energy 2021). Even if the technology fails to adequately capture CO_2, such technology is energy-intensive and will take considerable amounts of energy to support it, creating profitable outlets for the wind industry. The wind industry sees no problem with such an approach. In fact, the industry is publicly on board with these types of plans, as a spokesman from American Clean Power, a trade group of the renewable industry, says he and others in the renewable sector support the "all-of-the-above energy" strategy that North Dakota has adopted, as long as it does not hinder the development of the wind industry (Springer and Willis 2021).

The synthesizing of interests between the two industries are a way to appease different interest groups in local communities as well. A prime example of this is what has transpired in Mercer County. Mercer County implemented a moratorium in 2020 on new wind farms that was meant to help save the coal industry, but the county also worries of the negative long-term impacts of thwarting wind investment on the local economy (Willis 2021b). These competing interests place county leaders in a contradictory position where they are once trying to slow down wind development to save the coal industry, but not slow wind investment so much so that the industry leaves. To satisfy both sides, county officials asked that the coal and wind industries work together to find a solution, which they both agreed to do. At the time of writing this, regulatory details are still being worked out, but it does illustrate that tensions between the competing interests have driven them to seek common ground.

The belief that the industries can coexist and complement each other is also held by state government officials. Governor Burgum recently announced that North Dakota aims to be carbon neutral by 2030, which was announced at the largest oil industry conference held in the state (Willis 2021a). Burgum believes the state can become carbon neutral by deploying carbon capture and sequestration technologies powered by renewable energy. Burgum foresees the state utilizing its advantageous geology to import CO_2 from other states and storing it underground. The governor imagines this strategy will allow the fossil fuel industry to continue to thrive in North Dakota, while simultaneously supporting the development of the renewable sector. In this view, renewables are treated as an aid to the fossil fuel industry's attempt to preserve its power, rather than being a technology that eventually replaces fossil fuels. As more of these joint projects develop, the renewable industry could increasingly have their future tied directly to the growth of the fossil fuel industry.

The forces at work in North Dakota highlight the contradictions and tensions between renewables and fossil fuels. As is the case in many resource dependent places, the state is seemingly captured by fossil fuel interests. The power that the coal industry still has over policy in the state shows that the industry is not going to cease to exist due to market pressures, particularly as the industry still has a strong backing from many local communities. The abundance of energy resources and potential for renewable production in the state have placed governmental officials in a contradictory position where they are openly in support of fossil fuel and renewable energy development, with an emphasis on saving the former while slowing, but allowing, the development of the latter. As they increasingly feel pressure from both fossil and renewable capital, state officials view the path forward as growing overall energy production and demand to dampen the competition between the two, which ultimately leads to an intensified reliance on the energy sector. However, North Dakota cannot make this happen on their own, as the energy production occurring within the state is primarily a function of energy demand arising elsewhere. Thus, the state is in a battle with external political economic forces, where North Dakota's energy sector and government officials are at once subjected to the will of global political economic forces that are reshaping the sector, while also actively trying to steer the future of the global energy sector. The synthesis of these forces results in the state's dependence on the energy sector becoming increasingly intense and multifaceted.

Conclusion

This study set out to explore whether renewable energy substitutes for fossil fuel energy production in the 33 U.S. fossil fuel producing states. Using a battery of dynamic panel data approaches, I find robust evidence that renewable energy production is not associated with fossil fuel production in the U.S. To supplement the panel analyses, I explored the case of North Dakota, which has abundant fossil fuel and renewable energy resources. As I show, the competition between renewables and fossil fuels stimulates conflict between interests within the state that operate relationally to shifts in the global energy sector. As the global energy sector changes, fossil fuels try to maintain their market share while renewables aim to expand theirs. The state's dependency on fossil fuels permits the industry to seek state support to pursue technological fixes to its accumulation crisis, which as I demonstrate, leads to renewables being treated as an aid to the fossil fuel industry's attempt to preserve its power, rather than being a technology that eventually replaces it. A consequence of this is that the interests of fossil fuels and renewables become increasingly interwoven as the fossil fuel industry pursues carbon capture and sequestration technologies to mitigate their emissions that are powered by renewable energy sources. As more joint projects between the two develop, the renewable industry could increasingly have their future tied directly to the growth of the fossil fuel industry. In this way, states like North Dakota may become increasingly dependent on both the fossil fuel and renewable energy sectors.

A limitation of this study is that the results apply to the U.S. context and may not be applicable elsewhere. Whether the relationships found here hold in other subnational contexts is a question for future research. Furthermore, the results are also contextualized by the specific historical period. It is possible that renewables will substitute for fossil fuels as the broader political economy transforms, particularly if strong state regulations are implemented. However, these findings do demonstrate that any such transition will be hindered by the close proximity of renewable and fossil fuel resources in many fossil fuel dependent states. Given that fossil fuel dependent states are largely captured by fossil fuel interests, it is unlikely these states will voluntarily restrict their fossil fuel sectors. This points to the necessity of federal government involvement to reduce emissions.

The recent passage of the inflation reduction act (IRA) by the U.S. federal government provides incentives for green energy but does not directly limit fossil fuel energy. The REPEAT project estimates that the IRA will reduce emissions by an additional 1 billion metric tons by 2030 compared to current policy and lead to a 42% reduction in emissions by 2030 relative to 2005 levels (Jenkins et al. 2022). However, the results of this study here suggest that without policies to directly limit fossil fuel production and use then the potential emissions reductions from the IRA may not come to fruition.

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Chapter 5: Stata Programs Created for Dissertation

As part of my dissertation, I developed three Stata programs. These programs—eiwb, xtasysum, and lreff—are used extensively in my dissertation. eiwb and xtasysum were pivotal to conducting my analyses for chapter two, and lreff is used in chapters two-four. Below, I provide a description for each program. Each program is available for download through my GitHub page.

eiwb

eiwb generates a variable for the ecological intensity of well-being (EIWB) based on the work of Dietz et al. (2009; 2012). The EIWB measures how much stress is placed on the environment per unit of human well-being (environmental stress/human well-being). To prevent the numerator or denominator from dominating the ratio, the coefficient of variation of the two variables must be constrained to be equal (see New Economics Foundation 2009; Dietz et al. 2012). This is done by adding a constant (referred to as the correction factor) to the variable with the larger coefficient of variation, which shifts the mean without changing the variance. The ratio is then multiplied by 100 to scale it. Following the generation of the variable, the coefficients of variation and the calculated correction factor are displayed on screen.

xtasysum

xtasysum generates, summarizes, and visualizes partial sums for modeling asymmetry with panel data. If no options are specified then positive and negative partial sums around a threshold of zero are created. The two new variables appear as *var*_p and *var*_n, respectively. The partial sums can be used to model and test for asymmetry using regression analysis as discussed in Thombs, Huang, and Fitzgerald (2022). The user may also generate frequencies and summary tables, test for cross-sectional dependence and non-stationarity, and generate graphs of the partial sums as well as their frequencies.

lreff

lreff computes the long-run effect for each variable specified after estimating a dynamic model using Stata's time series operators (e.g., L.). The command assumes that an autoregressive distributed lag (ARDL) model is estimated. To compute the long-run effect after estimating an error-correction model (ECM), the user should specify the ecm option. Standard errors are estimated using the delta method by collecting the coefficients and passing them to Stata's nlcom command.

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Chapter 6: Conclusion

This dissertation explores the relationship between resource dependency and sustainability-related outcomes at the U.S. state-level. As I argue across chapters two through four, resource dependency offers important insights into the wide subnational level disparities in social and ecological outcomes across the U.S. Overall, this dissertation makes contributions to several subfields in sociology including environmental sociology, natural resource sociology, sociology of development, and health sociology, as well as the broader literature on the social dimensions of energy and sustainability science.

Each specific chapter makes its own unique contribution to these fields. In chapter two, I examine fossil fuel dependency's effect on the carbon intensity of well-being (CIWB), which is a measure that accounts for human well-being and ecological degradation. I examine the asymmetric effects of fossil fuel dependency on the CIWB at the U.S. state-level. I do so by estimating dynamic asymmetric models with fixed effects estimation. I find that increases in all three measures are associated with increases in the CIWB. Decreases in the energy production-consumption ratio and the share of exports from the mining sector do not affect the CIWB, while a decrease in the share of GDP from the mining sector produces a proportional reduction in the CIWB relative to an increase. The estimated net effect of all three variables suggests that an increase in fossil fuel dependency increases the CIWB, while a decrease has no effect. When the CIWB is disaggregated, I find that changes in the energy production-consumption ratio are driving changes in emissions and that changes in the share of GDP from the mining sector are responsible for changes in health-adjusted life expectancy. Given that the net effect of a decrease in fossil fuel dependency is not statistically significant, I conclude by arguing that a planned, managed transition away from fossil fuel extraction is critical to ensuring simultaneous improvements in human and environmental well-being.

In chapter three, I explore the relationship between international trade and CO_2 emissions at the U.S. state-level and test a range of competing perspectives on whether trade impacts the environment in Global North nations. The intensification hypothesis argues that trade increases emissions, whereas the abatement hypothesis argues that trade decreases or has no effect on emissions, and resource dependency argues that states more dependent on extractive natural resource sectors have higher emissions. I test these perspectives by constructing state-level trade measures to examine the scale and resource dependency effects of U.S. state-level exports on industrial CO_2 emissions per capita from 2002-2019. The results support the intensification hypothesis. More specifically, the findings indicate that increases in the overall level of global economic integration (% GDP from exports) is associated with increases in industrial CO_2 emissions, and that this is primarily driven by a linear combination of exports from the agriculture, forestry, fishing, and hunting and manufacturing sectors. There is no evidence that dependence on extractive natural resource sectors is driving this relationship.

In chapter four, I explore the paradoxical phenomenon where many fossil fuel dependent states in the U.S. are also national leaders in renewable energy. Specifically, I ask the question, does renewable energy displace fossil fuels in the U.S.? Recent cross-national research finds mixed evidence, highlighting that effects are heterogeneous across contexts. I further explore this question by examining whether renewable energy production displaces fossil fuel production in the 33 fossil fuel producing states in the U.S. from 1997 to 2020. Using two different modeling approaches, I find robust evidence that there is not an association between renewable energy production and fossil fuel production at the U.S. state-level. I further explore why this is the case by examining the recent history of North Dakota—a state that is a major fossil fuel and renewable energy producer. I find that renewable energy sources are increasingly viewed by the fossil fuel industry as a technological fix to an accumulation crisis, where renewable energy is used to support the industry rather than to replace it. Overall, this study contributes to our understanding of how and why energy sources tend to add to the existing energy mix rather than fundamentally changing it.

In the fifth chapter, I outline three Stata commands (eiwb, xtasysum, and lreff) that I developed as part of my dissertation. eiwb is a command that generates the ecological intensity of well-being for a user. xtasysum is a command that allows you to generate, summarize, and visualize partial sums for modeling asymmetry with panel data. Lastly, lreff is a command that allows users to compute long-run effects after estimating a dynamic model. All three commands were used extensively in my dissertation and should be useful for researchers using panel data and for those interested in modeling socioecological data.

Overall, chapters two through four find that resource dependency negatively impacts the environment and social well-being subnationally in the U.S., but the relationship is complex and nuanced. For example, in chapter two, the estimated net effect of resource dependency increases the CIWB, while a decrease has no effect. These findings suggest that reducing resource dependence, such as on fossil fuels, will not necessarily simultaneously improve human and environmental well-being. The findings also support arguments made by just transition proponents who contend that relying on an unplanned transition to drive the shift to renewable energy is not sufficient on its own, and that a planned transition that accounts for issues of equity, justice, and well-being is necessary to maximize the potential social and environmental benefits of moving away from fossil fuel and natural resource extraction (Aronoff et al. 2019;

Cha 2020; Healy and Barry 2017; Jenkins, Sovacool, and McCauley 2018; Newell and Mulvaney 2013; Sovacool et al. 2016).

However, my findings in chapter three on trade and emissions complicate the picture. In chapter two, I find that greater dependence on mining exports is associated with a higher CIWB, but this is not the case when emissions alone are assessed. The findings indicate that increases in the overall level of global economic integration is associated with increases in industrial CO_2 emissions, and that this is primarily driven by a linear combination of exports from the agriculture, forestry, fishing, and hunting and manufacturing sectors but not from extractive natural resource sectors. These findings suggest that the impacts of resource dependency on emissions in the U.S. are not primarily driven through global trade networks, which has been a major focus of the literature in the cross-national context (Givens et al. 2019; Huang 2018; Jorgenson 2016). Combined with chapter two, these findings illustrate the importance of examining different measures of resource dependency (and outcomes) as the effects can vary. They also suggest that a focus on more specific mechanisms is required in future research.

Lastly, chapter four, which examined the relationship between renewable and fossil fuel energy production, brings additional nuance into the picture as it pertains to resource dependency, fossil fuels, and renewable energy. The analyses suggest that renewables add to the energy mix without having any effect on fossil fuel production. The case study of North Dakota also shows that renewable energy sources are increasingly viewed by the fossil fuel industry as a technological fix to an accumulation crisis, where renewable energy is used to support the industry rather than to replace it. These findings highlight a major limitation of not directly curtailing fossil fuel production. Without stricter regulations to reduce production, renewables complement fossil fuels rather than substitute for them, which ultimately slows down the mitigation of greenhouse gas emissions. Although similar findings have been observed in the cross-national context (York 2012), this chapter advances our understanding of this process by scaling the analyses down to the sub-national level in the U.S. and showing that state capture by the fossil fuel industry and the economic logics of resource dependency play a major role in driving this relationship.

The primary limitations of this dissertation project are tied to the scale and generalizability of the analyses across spatial and temporal contexts. Examining these relationships at the state-level is insightful, but it does not capture heterogeneity within states. Communities deemed resource dependent tend to be geographically concentrated, so it is unknown whether the effects observed in this project are driven by only a small number of geographical locations. This could potentially limit the generalizability of the findings and hide important differences between resource dependent locations across the U.S. The analyses also do not examine changes over time, which could be significant given how much the mining and energy sectors have changed, and will continue to change, as renewable energy sources add to the energy mix and coal use further declines in the U.S.

Given these limitations, the next iteration of this project will be to scale down the analyses to smaller geographical units. This is a multifaceted project that first entails building a longitudinal, county-level database of coal, natural gas, and oil production, and a variety of economic, social, health, and technological data. I have begun collecting coal-mine level data from the Energy Information Agency and oil and natural gas production/well-specific data from the private energy analytics company Enverus. These data will be used to build on the analyses conducted in this project and explore how (and why) effects change over time and differ across place. With the increased focus on expanding renewable energy, I also plan to collect data and assess the impacts of the mining of critical minerals for renewable energy sources and compare them to the effects of mining related to fossil fuels.

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