How Can Low-Carbon Energy Dematerialize the Economy? Technological Transitions and the Political Economy of Electricity Generation

by

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DISSERTATION ABSTRACT

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This dissertation addresses features of the displacement paradox in the context of electricity generation, both at the cross-national level and within one region of the United States. The displacement paradox is the empirical phenomenon of substitutes to a specific product, here fuels used to generate electricity, do not necessarily replace incumbent products in a 1:1 ratio thus increasing total resource consumption, and in some examples are observed to increase consumption of the incumbent product. Chapter 1 describes how the displacement of fossil fuels with non-fossil fuels varies based on a nation's social structural position within the global capitalist world-system. I find that semiperiphery nations have higher predicted displacement of fossil fuels, possibly due to the dynamics of domestic elites. Chapter 2 asks how multiple dimensions of domestic inequality (gender inequality, economic inequality, and colonial history) may create landscapes of inequality on which nations are or will attempt to move away from fossil fuels. I find that much of the variation in national-level displacement of fossil fuels with alternatives can be attributed to the additive effects of each dimension of inequality, though there is some portion of variation which can be attributed to multiplicative effects. Chapter 3 traces the development of hydroelectricity in the U.S. Pacific Northwest, and subsequent growth of the region's consumption of fossil fuels. This history illustrates an example of the displacement paradox, whereby the growth of an alternative fuel (hydroelectricity) contributed to the growth of

fossil fuels in the region. This chapter points out the role of institutional continuance, grid management, and neoliberalization of the electricity industry in the growing reliance of the region on fossil fuels. In total, this dissertation demonstrates the roots of the displacement paradox in social organization and the distribution of social power as mediated by capitalist production.

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TABLE OF CONTENTS

Introduction 10

Chapter 1: Where are fossil fuels displaced by alternatives? World-systems and energy transitions 19

- Introduction 20
- Economic Growth, Modernization and Energy Transition 22
- Energy Transitions Over Time 24
- World-systems position, Inequality, and Energy Transition 26
- Data and Methods 29
- Results and Discussion 36
- Conclusion 45
- References 48

Chapter 2: Does decoupling of the economy and environment vary by multidimensional measures of domestic inequality? A multilevel model approach. 55

- Introduction 55
- Intersectionality, Theory and Methodology 56
- Methodology, Intersectionality, and Environmental Outcomes 57
- Cross-National Socio-Environmental Inequality 59
- How are contextual inequalities interrelated? 62
- Data and Methods 63
- Results and Discussion 69
- Conclusion 76
- References 79

Chapter 3: Cheap and abundant for whom? A history of industry and electricity in the Pacific Northwest 83

- Introduction 83
- The Displacement Paradox the Persistence of Fossil Fuels 84
- Dematerialization, Fossil and Electricity Capitals 88
- Foundations of hydroelectricity in the Pacific Northwest: Why Federal dams? 92
- The New Deal 93
- WWII, Defense Production, and Aluminum 97
- Full River Control, Expanding Dams for Navigation and Generation 101
- Electricity, Expansion, and the Pacific Northwest 105

  - Aluminum and BPA in Crisis 112
  - A Power Vacuum: A New Industrial Buyer 114
  - Discussion and Conclusions 119
  - References 121
- Conclusion 127

LIST OF FIGURES

Figure Page

1. Map of countries by world-systems position 33

2. Dotplot distribution of predicted displacement coefficient by world-systems Position based on Model 3 results. 39

3. Estimates displacement coefficient for periphery and core nations respectively with 95% confidence intervals 42

4. Estimated displacement coefficient for the semiperiphery over time 43

5. Estimated displacement coefficient for core and seiperiphery nations over time . 45

6. GDP per capita by strata 69

7. A caterpillar plot of strata and random slope term 71

8. Estimated coefficients for GDP per capita by strata 73

9. A caterpillar plot of random slopes including additive effects of GII, Gini, and colonial history 75

10. Estimated coefficient for GDP per capita with additive effects 76

11. A map of Washington state, including major rivers, cities, and roads 94

12. Total energy consumption for electricity generation by fuel in Washington state, 1960-2020 111

LIST OF TABLES

Table Page

1. Descriptive statistics by world-systems position 32

2. Nations classified by world-systems position 34

3. Chapter 1 results table 37

4. A list of countries included in analysis by colonization history 65

5. A description of each strata and number of observations within each strata 66

6. Chapter 2 results table 70

7. Key legislation and public reports 105

Introduction

The most recent IPCC summary of the impacts and dynamics of climate change, it acknowledged that private industry not only promoted/s misinformation about climate change, but also contributed to what it terms 'maladaptation.' Point C.4.1 states, "Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation if long-term impacts of the adaption option and long-term adaption commitment are not taken into account (*high confidence*)" (IPCC 2022:27). Also noted is that maladaptation is most often an unintended outcome of actions intended to mitigate climate change (15). A focus on producing viable substitutes, be that in energy or food or elsewhere, rather than suppressing the most harmful of material activities, like burning fossil fuels, is one such example of maladaptation with unintended consequences (Buller 2022).

This dissertation addresses the mechanisms of maladaptation in the energy sector across multiple scales, tracing the ways in which these unintended consequences or failed social action intersect with social inequalities.

What is an energy transition? A definitional dilemma

There are several different definitions of energy transitions, and this variation sharply changes both what is considered an energy (or technological) transition as well as what the socioenvironmental consequences might be. I examine a few definitions here to highlight common underlying assumptions about energy transitions in a broader social science literature on energy, as well as note the particular interventions of this dissertation through engagement with eco-Marxist theories.

While 'energy transitions' as a term is often employed uncritically and without explicit definition, some discussions do present precise definitions of what an energy transition entails.

Some definitions are quite exact for the purposes of measurement, while others take a broader approach connecting energy to other technologies and technological transition more generally. For example:

> "Here, the definition used for a transition was from 5% to 80% (or the peak, if it did not reach 80%) of the energy consumption for a particular service (e.g., heating, power, transportation or lighting) in a specific sector" (Fouquet 2016:7).
>
> "A transition is usefully defined as a change in the state of an energy system as opposed to a change in an individual energy technology or fuel source. A prime example is the change from a pre-industrial system relying on traditional biomass and other renewable power sources (wind, water and muscle power) to an industrial one, characterized by pervasive mechanization (steam power) and the use of coal. Market shares reaching pre-specified thresholds are typically used to characterize the speed of transition (e.g. coal versus traditional biomass). Typical market share thresholds in the literature are 1%, 10% for the initial shares and 50%, 90% and 99% for outcome shares following a transition" (Grubler, Wilson, and Nemet 2016:18).

Both of these definitions describe specific proportional shifts in a particular sector or industry. These kinds of shifts certainly reflect a paradigm shift in specific industries in how exactly raw materials are circulated, infrastructural needs, and spatial distribution (Gellert and Ciccantell 2020). However, it does not take into account the importance of the size of absolute consumption in the context of climate change, and the complexity of a globalized system with increasing diversification in energy mixes. This diversification in sources may have important implications in the ways in which various fuels interconnect in a political economy of energy, such that the introduction of new fuel sources is not reducing overall fossil fuel use and may even reinforce fossil fuel regimes.

There are broader definitions of energy transitions, centering social institutions as the content and context of transitions:

> "A broader conceptualization of an energy transition is that in addition to a shift in fuels and sources of primary energy supplies, it also entails a change in patterns of energy use among energy users in society, a change in the human dimensions related to energy (such as knowledge, values, or motivations), or a switch in the dependence of economic systems

> or markets from one form of energy source/technology or another" (Sovacool, Hess, and Cantoni 2021:2).
>
> "Transitions can be thought of as radical shifts in the provision of services such as energy, transport, or food and sanitation. They often refer to a change in the state of a system rather than merely a change in technology or fuel source, for example. They combine social and technical elements of finance and innovation, technologies, infrastructures, regulation, cultural change and social pressure and seek to disrupt and displace the previous way of doing things" (Newell and Simms 2020:2-3).

I would like to draw attention to the last clause of the first of the two definitions above. "A switch in the dependence of economic systems or markets," better highlights the material and spatial shifts industries and broader economic activity attributable to shifts in raw materials, but still suggests a proportional shift of 'dependance,' rather than an absolute shift of 'use.' Dependance may explain dominant market or industry strategies and interrelationships, but it does not explain the persistence of every major fuel in absolute terms. This framing is reiterated in the second of two definitions above, where 'socio-technical transitions' encompasses the social and organizational shifts associated with technological shifts. While there are some specific examples of technological changes, the framing of "transition" or changes in the "state of a [social] system" may be an overstatement of the foundational nature of these kinds of changes. The paperless office paradox highlights the complexity of these smaller shifts. Based on Abigail Sellen and Richard Harper's 2002 book, The Myth of the Paperless Office. This paradox points out that new technologies, such as digitized file systems in offices, are often thought to lead to the diminished use of the original technology or resource, in this case paper files. However, there are many cases in which this does not happen, and even the opposite may occur as, for example, access to digitized files and personal and organizational habits related to using paper may even lead to the increased use of paper as the same file can be printed many times as less value is placed on the single paper copy (York 2006).

Furthermore, these definitions and discussions have explicit and implicit underlying theories of the causality of technological transitions. The author of the first definition of the four presented above goes on to suggest the primary cause of technological transitions in the Global North: "...the speed of uptake of new technologies and energy transitions is influenced by the rise in demand for energy services" (Fouquet 2016:8). They go on to note that the fastest transitions have been from tallow to kerosene and from horse power to railways. The alternative in these cases, though it needed infrastructure, is framed as much more cost effective and a better service thus it transformed quickly. But what really is demand's role in energy transitions and the uptake of new technologies? At least for railroads, and for electrification, massive public investment and intensive, purposeful social action in pursuit of profit was present alongside and even preceding increased demand in at least some places and some times. I explore these dynamics further in Chapter 3 in the context of the U.S. and the Pacific Northwest as a region.

These definitions do not start from a framing of any fundamental connections between fossil fuels, specifically, and our present mode of production. Others have pointed out that the material properties of fossil fuels as well as the historical origins of the first intensive use of fossil fuels bundles the spread of the capitalist economic system as well as our present fossil fuel energy regime (Gellert and Ciccantell 2020; Huber 2009; Malm 2016, 2018). This bundling suggests that the events described as "radical shifts" above may be radical in many ways for cultural and organizational change, but not in the ways most critical for addressing climate mitigation.

Technology, Techno-fixes, and the Environment

Technological change is intertwined with the capitalist process of accumulation. In the context of monopoly capitalist system, expanded production leads to the reinvestment of profit due to gains from economies of scale and increased industrial efficiency, leading to the increase in the scale of environmental degradation through environmental "withdrawals" (i.e. natural resources) and "additions" (i.e. waste) (Schnaiberg 1980). Profits are often reinvested in technological change, which increases the capitalization of production, increasing the "productivity of labor" and driving the treadmill to ever accelerated revolutions (228). The investment in technology, as a sunk cost, encourages further investment in these production pathways (Gould, Pellow, and Schnaiberg 2004). Thus, labor and capital, production and consumption are pushing and pushed together, complicating the idea that demand drives technological shifts as described above.

The particular example of paper usage in offices post-computer described above is difficult to empirically address on a large scale, but this paradox has been further articulated particularly in relation to green technologies as the displacement paradox. A pertinent investigation has been that of whether alternative fuels displace fossil fuels, beginning at questioning whether there have ever been transitions in fuel use where previous energy regimes are entirely replaced, or even drop in absolute use, by new technology or resource availability. There is a fundamental difference between developing infrastructure for and expanding the production of new energy sources (energy additions) and transitioning away from current energy regimes. Claiming energy transitions implies both of these trends are happening at once. When one looks at the percent of total energy use, there does seem to be periods of transition, however, when one looks at the overall use of different fuels, one sees that absolute use has increased for all fuels (York and Bell 2019). Absolute trends have direct effects of climate crisis as a global phenomenon, and this troubles the definitions of energy transitions reliant on relative share of total consumption as a measure of transition.

York 2012b, in testing whether alternative fuels displace fossil fuels in the 1:1 ratio popularly assumed, finds that nuclear energy displaces fossil fuels the most, but all models (hydroelectric, total alternative electricity production) suggest a very modest level of displacement of fossil fuels. This is consistent even with the minimal displacement of more carbon intensive fossil fuels and natural gas and further research on the displacement of nuclear energy (Greiner, York, and McGee 2018, 2022). York writes that this is "probably in part attributable to the established energy system where there is a lock-in to using fossil fuels as the base energy source because of their long-standing prevalence and existing infrastructure and to the political and economic power of the fossil fuel industry" (2012: 442). This is further supported by evidence of asymmetric effects of economic growth and decline on carbon emissions, where economic growth produces durable goods (in addition to the infrastructure to use them) which are not removed by economic decline, further emphasizing the treadmill's lasting effects beyond continued reinvestment (York 2012a). Other work in environmental political economy has also suggested that infrastructural development and capital investment deeply affects the possibilities of change within, especially, extractive industries such as energy (Bunker 1985, 2005). This is further tied to ToP's portrayal of capital (re)investment and the profit imperative as explanations for the displacement paradox.

Political economic theorizing has illuminated that these entrenched industries may even spur on the development of alternative resources or fuels, as many alternative resources require intensive extraction and construction (i.e., lithium mining for solar panels, cement production for hydroelectric dams) where more environmentally friendly industries are spurred on by or entrenched in more harmful ones (York 2017). This suggests that active suppression of the fossil-fuel industry, paired with large social shifts in lifestyle tied to infrastructure and economic organization, are required to truly transition.

Chapter 1

In Chapter 1 I examine the displacement of fossil fuels with alternatives for generating electricity in 146 nations in 1960-2021. This chapter addresses between-nation inequalities, focusing on how nations are interconnected in a system of global hierarchy structured by the capitalist world-system. I examine how world-systems position as a measure of global trade inequality moderates national displacement of fossil fuels. I find that this structural measure indicates that semiperiphery nations have historically displaced fossil fuels at a higher rate than core or semiperiphery nations. I attribute this to domestic elite dynamics in semiperiphery nations which link directly to this hierarchical world-system. Furthermore, this analysis suggests that core and periphery nations are somewhat similar in displacement rates, though the periphery is more heterogeneous than the core. The lack of evidence for measurable change in displacement rate in core nations since 1960 further suggests that though energy transition motivated by environmentalism or climate crisis has not been achieved as a social goal in the core.

Chapter 2

In Chapter 2, I extend my analysis in Chapter 1 to multidimensional within-nation inequality, and whether these social inequalities moderate the relationship between economic growth and carbon emissions. I use multilevel modeling techniques to address gender inequality, income inequality, and colonial history. While previous research has examined the influence of one dimension of inequality or another, I combine these measures to assess whether their interaction with economic growth in predicting carbon emissions is due more to the specific processes underlying each individual dimension of inequality, or from broader interconnected connections between a matrix of inequality and socioenvironmental relations. I find that most variation in carbon emissions at the country level is attributable to the dynamics of individual axes of inequality, though there is some weak evidence for a multiplicative effect of the combined measure of inequalities. This suggests that research should likely focus on sifting through dynamics of gender inequality, economic inequality, and shared colonial history piece by piece.

Chapter 3

In Chapter 3, I adjust my focus from the cross-national scale to a regional scale, examining the history of industry and hydroelectricity in the U.S.'s Pacific Northwest. Using both primary and secondary sources, I trace the public investment in energy infrastructure in the region, and the interrelationship first with aluminum smelting and now Big-Tech data centers. The continuity and changes between these major industrial consumers of hydroelectricity reveals ways in which private capital accumulation occurs through the provision of electricity. Furthermore, this story complicates the idea of abundant and cheap electricity from low-carbon sources being sufficient for energy transition more generally.

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Chapter 1: Where are fossil fuels displaced by alternatives? World-systems and energy transitions

Abstract

In light of ongoing and accelerating climate change driven by human combustion of fossil fuels, researchers have found evidence that national-level inequality influences whether nations are able to replace fossil fuels with alternatives, like hydro or solar. In this paper, I ask whether the inequality between nations also influences the rate at which nations replace fossil fuels. I use multilevel modeling techniques, World Bank data and data aggregated by Our World in Data for 146 nations from 1960-2021 to tease out the variation in national-level displacement of fossil fuels and to characterize possible patterns in this process with a measure of inequality between nations. Findings suggest there has been only partial displacement of fossil fuels at the global level during this period. Can the variation in displacement of fossil fuels with alternative fuels at the national level be described by lasting global inequality among nations, here measured by world-systems position? Looking at 146 nations with world-systems classifications from Clark 2012, I find that semiperiphery nations displace fossil fuels at a higher rate on average as compared with core nations. This is further evidence for the importance of fossil fuel infrastructure and global inequality for the composition of future of fuel use at the global scale.

Key Words: energy transition; multilevel models; world-systems; displacement paradox

Introduction

Ongoing climate change is swiftly impacting the global environment along many dimensions, driven primarily by anthropogenic carbon dioxide emissions from burning fossil fuels. Debates about the nature and timing of the transition away from fossil fuels towards alternatives is varied and contentious, where technology is a contested tool for development and sustainability as a natural outcome of affluence (Grubler, Wilson, and Nemet 2016; Smil 2016; Sovacool 2016; Sovacool and Geels 2016). Environmental sociology has often addressed the political economic drivers of increased greenhouse gas emissions (Rosa and Dietz 2012), as well as highlighting paradoxes in technological transitions intended to combat climate change.

The purpose of this paper is to further describe displacement of fossil fuel generated electricity with non-fossil fuel generation. Previous work suggests that novel fuels intended to replace more carbon-intensive fuels do not do so proportionally, and these patterns may be influenced by domestic inequality (Greiner, York, and McGee 2018; McGee and Greiner 2018; York 2012). Given the linked systems of oppression which influence the continuation of within-nation inequality, particularly economic inequality, and inequality between nations, this paper extends discussions of the links between energy development and inequality by examining the variation in fuels use by a measure of inequality between nations (Alderson and Pandian 2018). My main research questions are, does the rate of displacement of fossil fuels by alternative fuels vary by nation? And if so, what is the influence of world-systems position on this variation? World-systems position has been used to describe lasting historical inequality among nations and regions, which has been connected to disparities of the environmental impact of global production and economic growth (Bunker 1985; Jorgenson 2006; Rice 2007; Wallerstein 2004).

This paper uses a multilevel model (MLM) with random slopes and unstructured covariance using World Bank Development Indicators and data aggregated by Our World in Data from 1960-2021 (WDI 2022; Ritchie et al. [2020] 2022). I find that overall, nations are only partially displacing fossil fuels with alternative fuels. Using a cross-level interaction with Clark's(20012) world-systems position classification, I find that core and periphery nations are only partially displacing fossil fuels with alternative energies. However, there is evidence that semiperiphery nations are replacing fossil fuel use with alternatives, possibly due to using alternative energies like hydroelectricity to expand domestic energy use and increase economic activity. These findings are consistent with previous research and further our understanding of the patterns of global movement towards renewable energies (York 2012). This suggests that core nations, though in a dominant economic position at the expense of the wellbeing and environment of other nations, are not sole leaders in replacing fossil fuels with alternative energies. This paper expands upon the evidence of a displacement paradox, where novel technologies intended to have fewer environmental impacts do not in fact displace higher impact technologies, but rather expand total consumption (McGee 2015; York 2004, 2017; York and Bell 2019).

Explanations for these findings either suggest why there *is* some estimated displacement in semiperiphery nations and why there *is not* some estimated displacement found in core or periphery nations. Domestic elites in semiperiphery nations may be promoting economic and energy development in opposition to the core rather than in alignment with the core in a form of resource nationalism. Large hydroelectric projects prevalent in some semiperiphery nations may be an example of this phenomenon. Path dependency, additional alternative fuels replacing incumbent alternatives like nuclear, and additional alternatives like ethanol promoting fossil fuel use may all be explanations for a lack of evidence for average displacement in either core or periphery nations. Further research could clarify the mechanisms driving this pattern, as well as bring closer attention to periphery nations, here indistinguishable from core nations in terms of displacement rate.

Economic Growth, Modernization and Energy Transition

At the intersection of environmental sociology and sociology of development is the question of whether affluence, or development, can alone lead to better environmental outcomes through technology and policy without further restructuring of our economic system or explicit and purposeful suppression of the causes of environmental harms. Furthermore, given that increased energy use has been associated with better health and wellbeing outcomes, a better understanding of the dynamics of increased energy use and diversification of fuels will aid in understanding development in the time of climate crisis (York 2016). To appropriately describe the dynamics of the steep diversification of fuels since 1960, I examine below two distinct perspectives on technological development as well as existing research on the relationship between socioeconomic indicators and the effective implementation of new energy technologies.

Ecological modernization proponents argue ecological rationalization of social institutions will lead to reduced environmental impacts, and they demonstrate this through specific case studies of environmentally reflexive institutions. We are assured that while these shifts are not yet seen more broadly across nations or even across institutions, they mark a potential or perhaps underlying transition to more ecologically rational institutions (Mol and Spaargaren 2000). Sustainable production and consumption are framed as a luxury naturally developed with increased modernization leading to a dematerialized society. Closely related is the environmental Kuznets curve (EKC) which asserts that as GDP increases, environmental degradation will increase only to a certain point of affluence, then begin to decline to create an inverted U shape relationship between GDP and environmental degradation (Panayotou, Peterson, and Sachs 2000; Shahbaz 2013). Thus, at a certain point of affluence, nations will turn to the relative luxury of environmental sustainability and develop dematerialized economic growth. Both EM and EKC imply that new technology is developed at the correct point of affluence as a rational response to a stated need. In the context of transitions away from fossil fuels, this suggests that more affluent nations will be replacing fossil fuels at a greater rate than less affluent nations.

In contrast, a treadmill of production (ToP) perspective presents a different theory of technological change with respect to the environment. ToP suggests that in the context of the monopoly capitalist system, expanded production leads to the reinvestment of profit due to gains from economies of scale and increased industrial efficiency, leading to the increase in the scale of environmental degradation through environmental "withdrawals" (i.e. natural resources) and "additions" (i.e. waste) (Schnaiberg 1980). Profits are often reinvested in technological change, which increases the capitalization of production, in turn increasing the "productivity of labor" and driving the treadmill to ever accelerated revolutions (228). The investment in technology, as a sunk cost, encourages further investment in these production pathways (Gould, Pellow, and Schnaiberg 2004). Thus, technology is a product of the production process in a cyclical sense, rather than as a product of affluence or political need or readiness.

Previous research has examined socioeconomic dynamics in the implementation of new energies. National energy history, including the level of historical reliance on fossil fuels, influences a nation's ability to grow renewable energies (Gellert and Ciccantell 2020; Hao and Shao 2021). For example, nations which have heavily invested in fossil fuel infrastructure like pipelines or extraction are less likely to move away from fossil fuels due to sunk costs of their investment; this concept is often termed path dependency. The effect of renewables on emissions may also fluctuate with time, possibly as new infrastructure takes hold or as global energy markets shift (Thombs 2018). There may be a threshold in the proportion of national energy use from renewables that needs to be achieved before renewables have a mitigating effect on carbon emissions (Chiu and Chang 2009). In asking whether increasing renewable energy generation decouples economic growth and carbon emissions, researchers have found mixed results which suggest different nations apply alternative fuel technology differently. Renewables may have their greatest mitigating effect on CO_2 emissions in low-income nations (Thombs 2017). One mechanism to explain this relationship is that renewables are replacing nuclear energy rather than fossil fuels in affluent nations moving away from nuclear energy (York and McGee 2017).

Energy Transitions Over Time

In this paper, alternative fuels include all non-fossil fuels: hydro, nuclear, biofuel (including waste and ethanol), and renewables such as solar, wind, and geothermal. Each of these alternatives to fossil fuels have specific material and political economic features which influence their substitutability in replacing fossil fuels in electricity generation. I discuss these features in more detail below and in the Results section. While an emphasis on energy transitions with the intent to reduce greenhouse gas emissions has dominated contemporary discussions of energy transition, attention to different fuels as substitutes predates explicit discussion of climate change (i.e., Fouquet and Pearson 2012; Smil 2017). It has been commonly stated that globally, energy transitions have happened before as the global economy shifted dominant energy regimes from coal to oil, and possibly natural gas, and while these are all fossil fuels, the shift in dominant energy regimes suggests that energy transitions are not just possible but somewhat common.

However, this has not necessarily been the case at an aggregate level. Previous research shows that when one looks at the absolute use of all fuels rather than percentages of total use, no fuel but nuclear has experienced any significant decline in use, but rather incumbent fuels persist alongside them (Gellert and Ciccantell 2020; York 2012). The displacement paradox suggests that the introduction of new materials or technologies intended as substitutes to incumbent technologies do not always act as 1:1 substitutes, and can even expand total consumption of resources through various mechanisms (McGee 2015; York 2006, 2017; York and Bell 2019).

We might not always expect the introduction of alternatives to replace incumbent fossil fuels, particularly in the earliest time periods of the 1960s and 1970s included in the analysis below. However, the 1960s-1970s saw a rapid expansion of hydroelectricity and some nuclear in the Global North, as well as the dual movement of the exporting of engineering regimes and the rise of post-colonial political and infrastructural projects in the Global South which further spread the growth of particularly hydroelectricity globally (Bunker and Ciccantell 2005; McCully 2001). Hydroelectricity remains the most prominent low-carbon source of electricity in the world, and is often framed as a utopian project of sovereignty and abundant, cheap electricity (McCully 2001; i.e., Norwood 1981). Nuclear power similarly had a utopian veneer of abundant and cheap energy, and often still does in the context of climate change (i.e., Qvist and Goldstein 2019). These utopian visions latched onto concerns about greenhouse gas emissions as these concerns grew to the chorus they became and remain, establishing a continuity in visions of a utopian energy future through energy transition. Therefore, examining the dynamics of energy transitions with respect to fossil fuels needs the wider view beginning in the 1960s and 1970s to establish a better understanding how the dynamics of energy transitions have changed historically, especially given the renewed urgency of an existential crisis beyond geopolitical power struggle.

World-systems position, Inequality, and Energy Transition

There is a growing emphasis on better understanding the dynamics of social inequality in implementing energy regimes, reflecting a broader move towards integrating understandings of social inequality and environmental degradation (Boyce 1994; Pellow and Nyseth Brehm 2013). For example, previous work has linked national-level energy use trends to within-nation economic and gender inequality (Ergas et al. 2021; McGee et al. 2020; McGee and Greiner 2018, 2019). The integration of nations in the global capitalist economy as well as shared historical origins link with- and between-nation inequality (Alderson and Pandian 2018). Given these previous findings linking domestic inequality with alternative energy implementation, between-nation inequality merits further investigation with respect to the dynamics of energy transition. In this paper, I turn my attention to between-country inequality using world-systems position.

World-systems theory builds on dependency theory, suggesting a core-periphery structure of the world-economy[i] to describe the international division of labor as well as the unequal international distribution of surplus profits (Chase-Dunn 1989; Wallerstein 2000). The relationship of core-periphery is one of exploitation and mutual constitution – one cannot exist without the other.

The semiperiphery has been a cause for debate—is it simply a way to denote some halfway point in the continuum of global national hierarchy, or a distinct position with qualitative differences from periphery and core nations (see Babones 2005:32-34)? The semiperiphery is presented as an intermediate position, both exploited by the core and exploiters of the periphery, with a mixed function in the world-economy. Semiperiphery nations have been theorized to have

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[i] World-economy is hyphenated, as is world-systems, to indicate that much like the world-system, there are world-economic systems which may not encompass the entire globe geographically, but constitute a cohesive system

internal tensions between domestic ruling classes, divided between those benefiting from relationships with the core and those opposed via nationalism to exploitation by the core (Terlouw 1993, 2002). One strategy for nationalism may include resource nationalism and efforts by elites to install energy capacity which does not rely on global commodity trading over time (Kaup and Gellert 2017). There is an implication of autocratic control or non-democratic decision making in this process, though some previous research suggests democracies are more likely to invest in pro-environmental fuels (Ramalho, Sequeira, and Santos 2018; Swyngedouw 2015). World-systems theory provides a framework to focus on the relationship between global processes and national-level outcomes, and has been used to assess drivers of GHG emissions, air pollution, deforestation, and other socioenvironmental outcomes (Burns, Davis, and Kick 1997; Grant, Jorgenson, and Longhofer 2018; Jorgenson 2006; Mejia 2020; Roberts, Grimes, and Manale 2003).

While much empirical research using world-systems theory have been historical case studies or national-level studies, there have been quantitative cross-national work presenting categorizations across nations. Snyder and Kick (Snyder and Kick 1979) used network blockmodeling to present an empirical measurement of a world-systems structure by examining the connections between nations based on diplomat exchange, military interventions, trade flows, and treaty memberships. They found evidence for distinct groupings and presented a classification of nations based on 1960s data. Clark (2012) presents an updated and exclusively economic empirical measurement of the core-semiperiphery-periphery structure of the world-system also using network blockmodeling of total international trade flows. They show the core as dense and interconnected, both among core nations and to the periphery. Periphery nations are isolated and connected almost exclusively with core nations—this sparseness facilitates and reflects the relative power of the core in trade relationships. The semiperiphery occupy a middling structural position in these trade networks – less densely connected than core nations but more interconnected than the periphery.

World-systems position can offer a testable dimension of geopolitical power and may be an important factor in national fuel mixes in a hierarchical nation-state system. Previous research has demonstrated that world-systems position moderates the relationship between economic growth and environmental harm using a multilevel modeling structure (Greiner 2022; Greiner and McGee 2018). This is a step towards better understanding past relationships between alternative energies and fossil fuels, given the landscape of global inequality and the relationship between exploitation and energy development (Alderson and Pandian 2018; McGee and Greiner 2020).

There are limitations to using world-systems position, as measured by Clark 2012, as an indicator of inequality between nations in a quantitative study. First, it relies on trade centrality and thus only includes economic dimensions of power differentials between nations. However, political dimensions such as military power, past colonial relationships, international finance and participation in international governance all are important dimensions of power at the global level and remain uncaptured by this specific measure, besides the ways that these dimensions are reflected in trade relationships. Second, world-systems theory itself pushes back against reifying the nation-state as the most important unit for thinking about the world-system—the complexity of the world-economy penetrates nation-states through commodity chain links and internal peripheries such that patterns of inequality may not affect every person or industry within a nation in equal ways. Keeping these limitations in mind, this study uses this classification world-systems position in an exploratory sense to better understand an underexamined factor in global energy transition.

This paper takes another look at describing the patterns of displacement or lack of displacement of fossil fuels at the cross-national level. I use multilevel modeling techniques to tease out the variation in national-level displacement of fossil fuels and try to characterize possible patterns in national displacement across nations using world-systems analysis. I ask first, is there variation in energy transition at the nation-state level? If so, can the variation in displacement of fossil fuels with alternative fuels at the national level be described by world-systems position? I use world-systems position as a descriptor of nations because this classification indicates trade centrality, which is linked to economic history and position in global networks of power. This may be a useful measure to describe different rates of displacement of fossil fuels because fuel use is deeply tied to these historical global power networks (Angus 2016; Malm 2016).

Data and Methods

This paper uses a multilevel model (MLM) with random slopes, a modeling structure uncommon in the quantitative cross-national human ecology literature. This is due to the differences in how random and fixed effects models estimate error terms, stemming from their respective approaches to addressing sampling—typically fixed effects are preferred to random effects for panel data of nations (Rabe-Hesketh and Skrondal 2021). The models presented in the Results section were also run using fixed-effects panel regression with robust standard errors, and the findings were substantively the same. The coefficients for the cross-level interaction were different in magnitude but not different in relation to each other than the results presented here. However, the parsing of variance making the following descriptive analysis was not accessible without using a multilevel modeling structure.

MLMs are advantageous as they are intended to account for clustering, in this case observations within nations, as well as allowing for detailed parsing of variance. Variance is parsed by clusters, such that within- and between-cluster error terms can be examined independently. Therefore, MLMs allow for greater options in investigating attributes of clustering to describe by what characteristics clusters, in this case of nations, may differ. Random slope models allow for each nation to have its own estimated displacement coefficient, further described below. By adding level 2 (country) variables and cross-level interactions, we can characterize the variance in those national-level predicted displacement coefficients by world-systems position.

Additionally, MLMs have been adopted in other social science research contexts to address issues of adjusting for numbers of observations within clusters, model parsimony, and ease of interpretation with respect to the interaction approach using fixed-effects (Alvarez and Evans 2021; Evans et al. 2018). MLMs can be useful when addressing clusters with very different numbers of observations—given that data tracking for core nations, for example, has been more long-standing due to the international inequalities that are the very subject of this analysis, MLMs allow for the inclusion of nations with very few observations without presenting extreme estimates for these underrepresented groups, drawing their estimates towards the grand mean (Evans et al. 2018). Recent work addressing the often unexamined characteristics of the most common modeling strategy in cross-national panel analysis have highlighted important concerns about autoregression, slope heterogeneity, and cross-sectional dependence (Thombs 2022). While MLMs can address some of these concerns (i.e., slope heterogeneity), they do not address all the listed concerns. Given the very narrow goal of this analysis to describe variation across nations grouped by world-systems position, and given that a causal analysis is not presented, I use MLM strategies. However, I would underscore that displacement coefficient estimates for nations, as described below, should not be over-interpreted and rather the analytical focus should be on the relative distribution of these scores and changes over time.

STATA was used for analysis using the command *mixed*. Data for this project was retrieved through the World Bank Development Indicators and data aggregated by Our World in Data for 1960-2021. The main dependent variable is fossil fuel-generated electricity in megawatts per capita. This is an aggregate of oil, coal, and natural gas generated electricity. This dependent variable was calculated by multiplying the proportion of total electricity generation from fossil fuels by the total kilowatts of electricity generated per year, dividing by 1000 to obtain megawatts, and dividing by total population for a per capita measure.

I focus on electricity generation here, rather than all forms of energy use. Focusing on electricity excludes important economic sectors such as transportation and more traditional fuels and energy uses such as firewood. This paper is taking a rather narrow look at the dynamics of substitution, which is most conceptually clear in the case of electricity generation. All fuels (including biofuels such as wood) are used to generate electricity in different places and times. The level of technological adaptation needed to generate electricity from different fuels, rather than to apply those fuels at the point of consumption in various activities, such as transportation, is quite different, meaning substitution of fuels to generate electricity is much easier than for other purposes. Finally, given the contemporary emphasis on electrification as a strategy in and of itself to promote the substitution of fossil fuels, a better understanding of existing dynamics of the diversification of fuels for electricity generation can contribute to this discussion.

The main independent variable is all non-fossil fuel generation of electricity in megawatts per capita. This includes hydroelectricity, nuclear, wind, solar, and geothermal electricity generation by nation. This variable is generated by subtracting fossil fuel-generated electricity from total electricity production, dividing by 1000 to again obtain megawatts, and dividing by total population for a per capita measure. The regression coefficient for this independent variable is the displacement coefficient, which is the metric of interest for this study. It describes the displacement, or replacement, rate of fossil fuels with alternative fuels holding other factors constant (York 2012). Displacement coefficients between 0 and -1 signify some level of displacement of fossil fuels with alternatives. For example, if the coefficient was -0.5, then it would take 2 megawatts per capita of alternative electricity generation to replace 1 megawatt per capita of fossil fuel electricity generation. If the coefficient is zero, this would indicate that alternative energies are added to total electricity generation on top of fossil fuels. Alternative electricity generation will also be the random slope variable, allowing for each nation to have a unique predicted displacement coefficient.

Table 1: Descriptive Statistics by World-Systems Position

Variables	**Overall**	**Core**	**Semiperiphery**	**Periphery**
Mean *GDP per capita (GDPPC) (2010 const. dollars)*	11,494 (15,439)	21,648 (18,396)	5,485 (6,222)	3,201 (6,360)
Minimum *GDP per capita (2010 const. dollars)*	156	295	401	156
Maximum *GDP per capita (2010 const. dollars)*	111,574	111,574	41,171	65,129
Mean *Fossil Fuel Electricity Generation per capita (megawatts)*	1.74 (2.62)	2.81 (2.54)	1.25 (2.96)	0.80 (1.88)
Min *Fossil Fuel Electricity Generation per capita (megawatts)*	0	0.01	0	0
Max *Fossil Fuel Electricity Generation per capita (megawatts)*	21.70	13.87	21.70	17.65
Groups *(*nations*)*	146	47	35	64
Observations (nation-years)	5,620	2,341	1,418	1,861

Note: The standard deviation is in parentheses under each mean reported.

The controls for the full models use conventional controls in other human ecology and cross-national environmental sociology work on the drivers of CO_2 emissions: GDP per capita (in constant 2015 US$), percent of population in urban centers, and age dependency ratio (ratio of dependents to working age population) (Jorgenson et al. 2019). Quadratic terms are included for per capita GDP and urbanization to allow for nonlinear relationships.

Sensitivity checks were used to see if the substantive findings were consistent across smaller samples of the data. The sample was split at the median GDP per capita, and both analyses presented similar substantive results. The data used in the final modeling sequence does not include nations with populations smaller than one million.

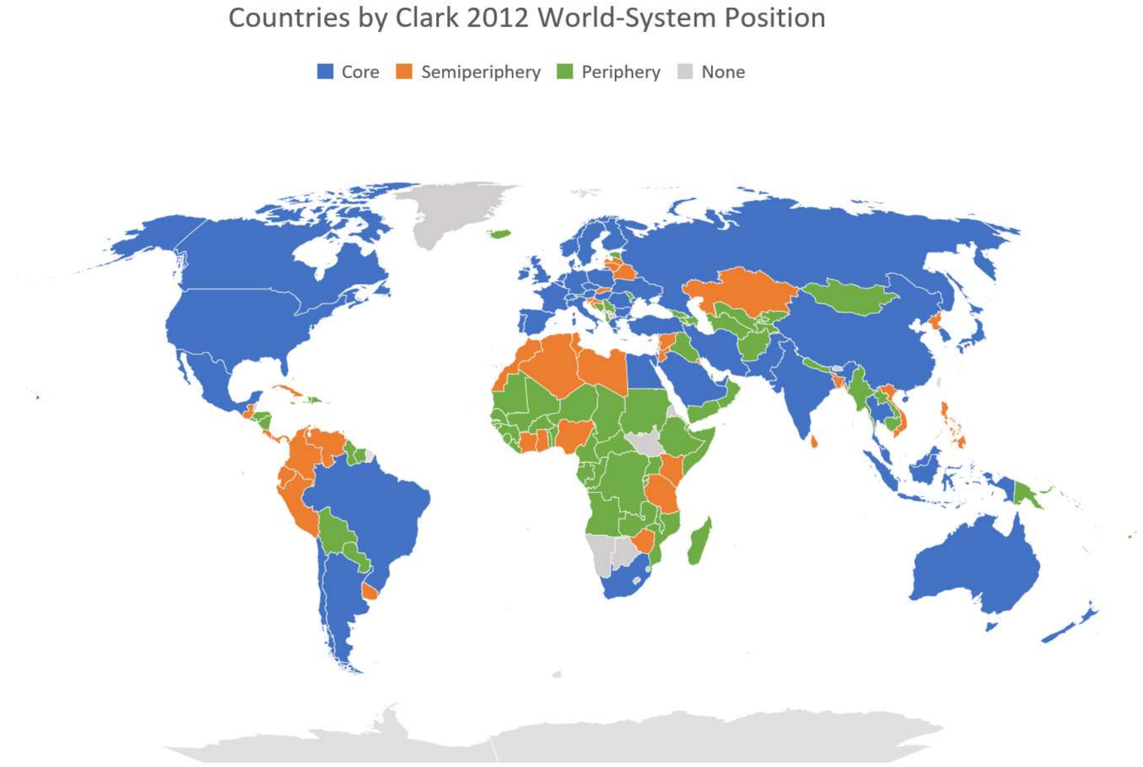

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Figure 1: Countries by Clark 2012 world-systems position.

I use the world-systems classification system noted below. Due to missing data and available world-systems classification information, there are 146 nations included in the full model.

Table 2: World-Systems Position measure national classifications, from Clark 2012

Core (47)	**Semiperiphery (39)**	**Periphery (62)**
Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, Denmark, Egypt, Finland, France, Germany, Greece, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, South Korea, Malaysia, Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Singapore, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, Ukraine, UAE, United Kingdom, United States	Algeria, Bahrain, Bangladesh, Belarus, Colombia, Costa Rica, Cote d'Ivoire, Croatia, Cuba Cyprus, Iraq, Israel, Kenya, Kuwait, Ecuador, Ghana, Guatemala, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Libya, Lithuania, Morocco, Nigeria, Panama, Peru, Philippines, Slovak Republic, Slovenia, Sri Lanka, Syria, Tanzania, Tunisia, Uruguay, Vietnam, Zimbabwe	Afghanistan, Albania, Angola, Armenia, Azerbaijan, Benin, Bolivia, Bosnia and Herzegovina, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Congo (Dem. Rep.), Congo (Rep.), Costa Rica, Dominican Republic, El Salvador, Equatorial Guinea, Estonia, Ethiopia, Gab on, Gambia, Georgia, Guinea, Guinea-Bissau, Haiti, Honduras, Iraq, Jamaica, Kyrgyz Republic, Laos, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Moldova, Mongolia, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Oman, Papua New Guinea, Paraguay, Qatar, Rwanda, Senegal, Serbia, Sierra Leone, Somalia, Sudan, Togo, Trinidad and Tobago, Turkmenistan, Uganda, Uzbekistan, Yemen, Zambia

The equation for Model 3, the model of interest and a random slope cross-level interaction model with unstructured covariance, is as follows:

$$\begin{aligned} ffmw_{ti} = \beta_0 &+ \beta_1(alternatives_{ti}) + \beta_2(gdppc_{ti}) + \beta_3(gdppc_{ti}^2) + \beta_4(urban_{ti}) \\ &+ \beta_5(urban_{ti}^2) + \beta_6(agedep_{ti}) + \beta_7(semiperiphery_i) + \beta_8(periphery_i) \\ &+ \beta_9(semiperiphery_i)(alternatives_{ti}) + \beta_{10}(periphery_i)(alternatives_{ti}) \\ &+ \mu_{0i} + \mu_{1i}(alternatives_{ti}) + e_{0t} \end{aligned}$$

$$Level\ 2\colon \begin{bmatrix} \mu_{0i} \\ \mu_{1i} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma_{u0}^2 & \\ \sigma_{u0u1} & \sigma_{u1}^2 \end{bmatrix}\right)$$

$$Level\ 1\colon [e_{0ti}] \sim N(0, \sigma_{e0}^2)$$

In this model μ_{0i} represents the nation-specific error term for the random intercept; μ_{1i} represents the nation-specific error term for the random slope, here alternative electricity generation per capita; e_{0ti} represents the error term for observations within nations. The covariance term is σ_{u0u1}. The included variables are as follows: $ffmw_{ti}$ indicates fossil fuel electricity generation per capita; $alternatives_{ti}$ indicates non-fossil fuel electricity generation per capita; $gdppc$ indicates GDP per capita; $gdppc_{ti}^2$ indicates the quadratic term for GDP per capita; $urban_{ti}$ indicates urbanization as percent of total population living in an urban area; $urban_{ti}^2$ indicates the quadratic term for urbanization; $agedep_{ti}$ indicates the age dependency ratio measured as a ratio of working-age population to dependent population (below age 15 or above age 65). The last two lines of the above equation indicate the distribution of error terms at each level, level 1 being the nation-year (within-nation variance), and level 2 being nations (between-nation variance).

From the above equation, nation-specific estimates of displacement can be found as follows:

$$\beta_1 + \beta_{10}(semiperiphery_i) + \beta_{11}(periphery_i) + \mu_{1i}$$

Given that world-systems position is a categorical variable, the precision weighted grand mean for core nations can be found as β_1, semiperiphery nations as $\beta_1 + \beta_9$, and periphery nations as $\beta_1 + \beta_{10}$. These are means across each world-systems position, weighted by the number of observations available within each nation. For national level estimates within each category, I add the random slope, country-specific error term μ_{1i}.

Results and Discussion

Results are displayed in Table 3. Model 1 looks at overall displacement across the full dataset, without restricting observations to those nations with a specified world-systems position.

I conducted a likelihood-ratio test against random intercept and random slope with structured covariance which suggested including unstructured covariance provided for a better model fit. Model 1's inclusion of unstructured covariance (σ_{u0u1}), where the slope and intercept are allowed to covary should that allow for a 'better' fit model, suggests that nations converge at some level of fossil fuel electricity generation per capita at higher levels of alternative electricity generation, before perhaps diverging again. The clearest finding associated with unstructured covariance here is that there is a relationship between the displacement coefficient and the amount of fossil fuels used to generate electricity per capita when alternative fuel use is at zero.

In Model 1, the displacement coefficient is less than zero though greater than negative one, suggesting there is partial displacement across all nations during this time period, on average.

Table 3: Results

Variables	**Model 1**	**Model 2**	**Model 3**
Level 1 Variables			
Displacement Coefficient	-0.79***	-0.77***	-0.38
Alternative Electricity Generation (MW per capita)	(0.18)	(0.18)	(0.26)
GDP per capita	$2.17\ \text{x}10^{-4}$***	$2.18\ \text{x}10^{-4}$***	$2.18\ \text{x}10^{-4}$***
	($4.96\text{x}10^{-6}$)	($4.98\text{x}10^{-6}$)	($4.98\text{x}10^{-6}$)
GDP per capita quadratic	$-1.84\ \text{x}10^{-9}$***	$-1.85\ \text{x}10^{-9}$***	$-1.85\ \text{x}10^{-9}$***
	($5.21\ \text{x}10^{-11}$)	($5.22\ \text{x}10^{-11}$)	($5.22\ \text{x}10^{-11}$)
Urbanization	-0.09***	-0.09***	-0.09***
	(0.01)	($5.30\ \text{x}10^{-3}$)	($5.29\ \text{x}10^{-3}$)
Urbanization quadratic	$1.05\ \text{x}10^{-3}$***	$1.05\ \text{x}10^{-3}$***	$1.05\ \text{x}10^{-3}$***
	($4.92\ \text{x}10^{-5}$)	($4.92\ \text{x}10^{-5}$)	($4.9\ \text{x}10^{-5}$)
Age Dependency Ratio	-0.03***	-0.03***	-0.03***
	($1.23\ \text{x}10^{-3}$)	($1.23\ \text{x}10^{-3}$)	($1.23\ \text{x}10^{-3}$)
Level 2 Variables			
Core (reference)		-	-
Semiperiphery		0.34	0.73
		(0.38)	(0.40)
Periphery		0.25	0.38
		(0.33)	(0.28)
Ex-Soviet Nation	1.34***	1.24**	1.31***
	(0.40)	(0.41)	(0.41)
Cross-Level Interaction			
Core x Displacement Coefficient			-
Semiperiphery x Displacement Coefficient			-1.25**
			(0.44)
Periphery x Displacement Coefficient			-0.32
			(0.41)
Constant	3.88***	3.69***	3.54***
	(0.26)	(0.33)	(0.34)
Variance Terms			
σ_{e0}^2	0.3341974	0.3341796	0.3344327
σ_{u0}^2	3.177303	3.112305	3.090355
σ_{u1}^2	3.176875	3.150729	2.894727
σ_{u0u1}	-1.383533	-1.266949	-1.297836
Nation-years	5,620	5,620	5,620
Nations	146	146	146

****p<0.001; **p<0.01; *p<0.05*

In Model 1, the estimated displacement coefficient suggests that across all nations, about 1.27 megawatts per capita alternative fuel generation would be needed to displace 1 megawatt per capita fossil fuel generation, on average.

Model 2 adds a level 2 variable, world-systems position, to the random slope unstructured covariance model. Neither semiperiphery and periphery coefficients are found to be significant at at least an 0.05 level, suggesting that each world-systems group does not have a different overall average fossil fuel electricity generation per capita when there are zero megawatts generated by alternative fuels, the intercept. The displacement coefficient across all nations is once again significant at a 0.001 alpha-level; about 1.30 megawatts per capita alternative fuel generation would be needed to displace 1 megawatt per capita fossil fuel generation.

Model 3 adds a cross-level interaction effect between world-systems classification and the displacement coefficient, allowing each world-systems group to have a group average displacement rate. I conducted a likelihood ratio test between models 2 and 3, the addition of the cross-level interaction provided for a better fit model.

Model 3 suggests that the semiperiphery has a statistically significant displacement coefficient distinct from the core on average, where the semiperiphery is displacing fossil fuels in electricity generation with alternative fuels at a greater rate than the core. The estimated displacement coefficient across semiperiphery nations is -1.25, suggesting alternatives replace fossil fuels in semiperiphery nations near a 1:1 ratio during this period. Meanwhile, periphery nations are not discernably different from core nations based on statistical significance, suggesting that periphery nations also only partially displace fossil fuels. Core nations have an estimated displacement coefficient of -.38, meaning about 2.63 megawatts per capita alternative fuel generation would be needed to displace 1 megawatt per capita fossil fuel generation in core nations, on average. This is lower than the estimated displacement rate across all nations in Model 1.

Figure 2 illustrates the distribution of predicted displacement coefficient (see equation above) of observations within each world-systems position. This figure shows the distribution for semiperiphery nation-years is set below (more negative) than core and periphery nation-years. However, there are nation-years in both the core and periphery with an estimated displacement coefficient around -1, suggesting that there are places and times where fossil fuels are being displaced 1:1 within all of these categories. Further parsing of national characteristics in future research may serve to explain some of this variation.

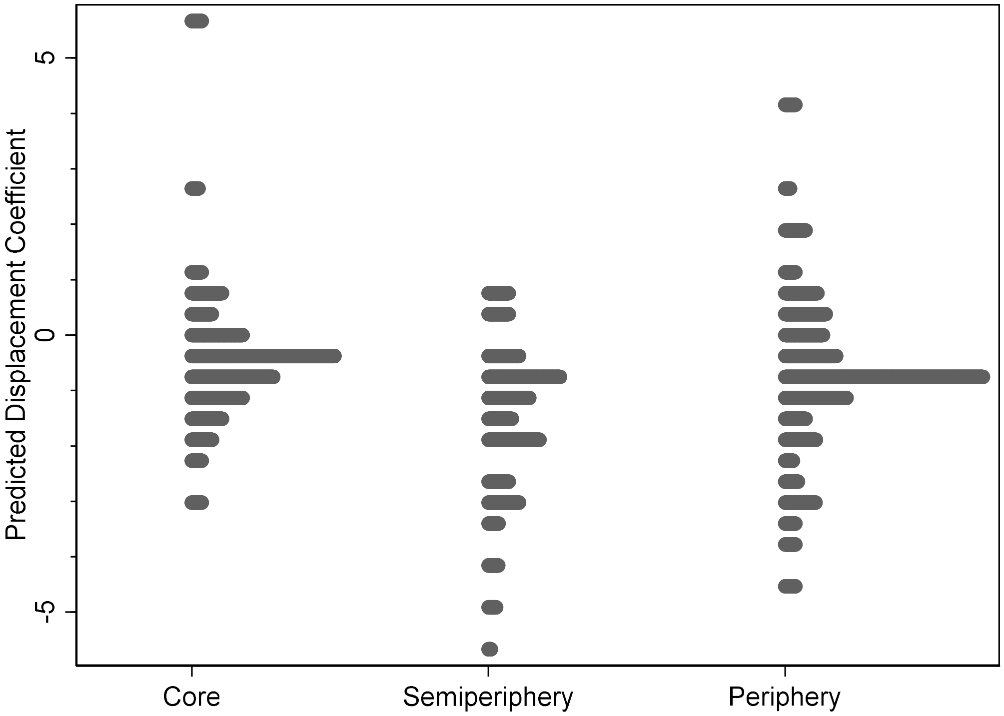

Figure 2: Dotplot distribution of predicted displacement coefficient by world-systems position, based on Model 3.

The greater displacement estimated for semiperiphery nations has several possible explanations. One may be path dependency – core nations have longer histories of and greater dependence on fossil fuels, while semiperiphery nations have laid down and continue to lay down electricity infrastructure later in time than core nations and sometimes without early dependence on fossil fuels. Periphery nations may have similar pathways as the core due to the lack of similar opportunities in the global capitalist economy as semiperiphery nations possess (Terlouw 2002). Peripheral nations experience a similar lock-in through exploitation and reliance on extractive industries flowing towards the core and semiperiphery, which prunes energy development pathways (Bunker 1985). As a system of exploitation, the capitalist world-system consists of extractive relationships, originally articulated as predominantly between the core and periphery. Given the reliance on fossil fuels in the core, these extractive relationships are deeply permeated by fossil capitalism and the concomitant infrastructures and technologies endemic to fossil capitalism. Therefore, the periphery experiences an underdevelopment which raises the barriers to alternatives to a fossil fuel-based economy.

This is also consistent with some work on unequal ecological exchange (UEE) which argues that there are nations which are in deeply unbalanced trade and ecological relationships with economically powerful nations in a capitalist world-system (Bunker 1985; Gellert, Frey, and Dahms 2017; Jorgenson 2006). The role of the semiperiphery and intermediary nations in general as exploiters alongside their own exploitation as well has been a topic of debate within UEE research (i.e., Theis 2021). Given that the Clark 2012 world-systems measurement is reliant on trade relationships and indicates relative trade integration of nations as a system of classification, this connection seems an important consideration in the development of diversified fuel use.

Returning to the variation in domestic elites based on world-systems position may provide further explanation of displacement described here in the semiperiphery. The semiperiphery has been theorized as having a division in domestic elites between those whose interests, like most elites in the periphery, align with the core, and those elites whose interests lie in domestic development in an effort to disengage with an exploitative relationship with the core (Terlouw 1993, 2002). It may be that elites aligned with domestic interests have been successful at least in some semiperiphery nations in disengaging with core-dominated fossil economy through domestic projects. Given the expense and disruption of large energy projects, like large hydroelectric projects, the involvement of the state and domestic elites is necessary and can be observed in many nations categorized as semiperiphery in this analysis in Eastern Europe and Central and South America (i.e., Duarte-Abadía, Boelens, and Roa-Avendaño 2015; Kappeler 2017; Martínez and Castillo 2016). This explanation does not necessarily mean that the resulting energy resource nationalism will necessarily result in pro-environmental outcomes (i.e., Kaup and Gellert 2017; Shriver, Longo, and Adams 2020), but low-carbon energy resource nationalism may stand out when looking at the semiperiphery in aggregate.

Finally, another possible explanation for the disparity between world-systems positions is that some nations may be displacing alternative fuels, like nuclear, with newer alternative fuels seen as cleaner options (i.e., wind, solar) (Greiner, York, and McGee 2022; York and McGee 2017). This would also include biofuels, which include traditional fuels like wood. However, since this particular model is examining electricity generation, direct use of traditional fuels for activities such as cooking or heating will not be captured by this analysis. To what extent wood and other biofuels are being used to generate electricity, there may be a similar dynamic as with nuclear power. The replacement of nuclear power with other alternatives is a phenomenon generally associated with core nations such as Germany, which may explain the lack of displacement seen in core nations overall (Greiner et al. 2022).

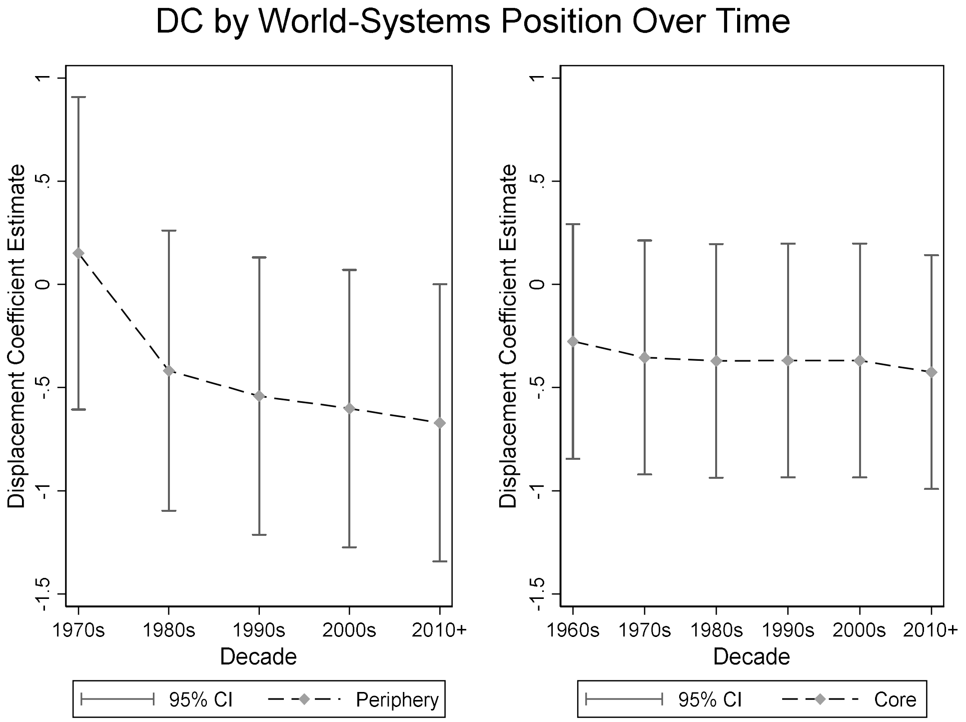

Figure 3: The estimated displacement coefficient for periphery and core nations respectively with 95% confidence intervals. The confidence intervals overlap, indicating no statistically significant across time within each world-systems position, and no statistically significant difference between core and periphery estimates.

There is further the question of the recent development of renewable energy, particularly hydroelectricity, solar, and wind in the past decade or two. Some might point to the drop in the price of solar as an indication of increased solar development and thus energy transition. However, the displacement paradox would suggest that the introduction of affordable alternatives does not always lead to the movement away from the original resource (McGee 2017; York 2012, 2017). While the estimate over the time period of available data across all nations and for core and periphery nations only show partial displacement, perhaps there is improvement over the past decade or two. Was there a change in the estimated displacement coefficient over this time period? Below I offer a brief supplemental analysis addressing this question.

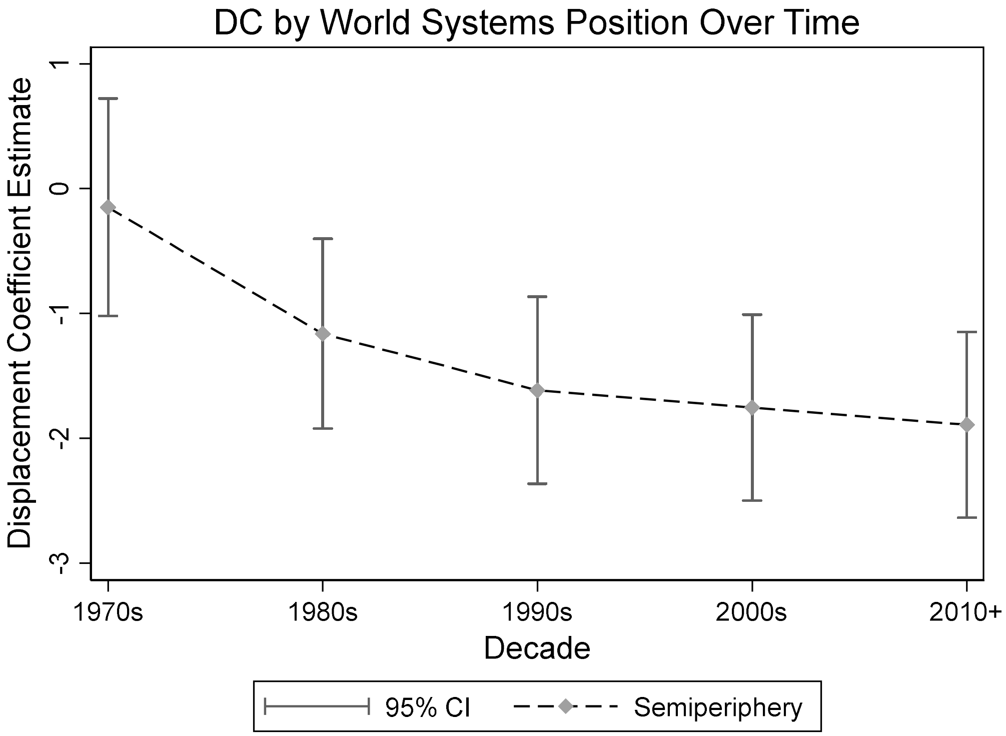

Figure 4: Estimated displacement coefficient for the semiperiphery over time with 95% confidence intervals. The estimates for the 1970s and 2010s have a statistically significant difference, indicating increasing displacement over time in semiperiphery nations on average.

Figure 3 presents key results from this supplementary analysis, identical to Model 3 but adds an interaction with decade to the cross level interaction between world-systems position and alternative electricity production. Figure 3 presents the estimated displacement coefficient for core and periphery nations each decade included in the analysis, with 95% confidence intervals. The confidence intervals overlap, both between core and periphery and across the time periods for each. Therefore, there is no evidence by the supplemental analysis with decade interactions that the average displacement rate for core or periphery nations has changed in a statistically significant way. Additionally, there remains no statistically significant difference between core and periphery nations.

Figure 4 presents the displacement coefficient estimate for semiperiphery countries by decade with 95% confidence intervals. The confidence intervals for the 1970s and the 2010s (which includes 2020 and 2021) do not overlap, suggesting that there is some evidence that there is greater displacement in semiperiphery nations in the last decade than in the 1970s. This demonstrates some amount of change in semiperiphery nations, unlike core and periphery nations. This is inconsistent with the ideas of ecological modernization where the wealthiest of nations will implement pro-environmental technologies first.

Figure 5 presents the estimated displacement coefficient for semiperiphery and core nations over time with 95% confidence intervals. The confidence intervals overlap from the 1970s, 1980s, and 1990s, but begin to diverge in the 2000s. This suggests that semiperiphery nations were indistinguishable in a statistically significant sense until the 2000s. Though the investment in renewable energies like wind and solar truly began in the 2000s, there isn’t evidence in this particular analysis that the core has employed these investments to reduce fossil fuel use, and remain unable to use nuclear and hydroelectricity to replace fossil fuels as well.

The results of this supplementary analysis suggest that there is no evidence of change in displacement since the 1960s in core or periphery nations. Given that the 1960s were before the Paris Agreement (2015), Kyoto Protocol (1997), or the UN Framework Convention on Climate Change (1992), and given the historical alignment of emission growth and climate projections, this lack of change is particularly alarming (Strandsbjerg Tristan Pedersen et al. 2021). The change in estimated displacement in semiperiphery countries aligns with the global boom in hydroelectricity construction of the 1980s and 1990s, including many projects funded by the World Bank and massive state investment (McCully 2001).

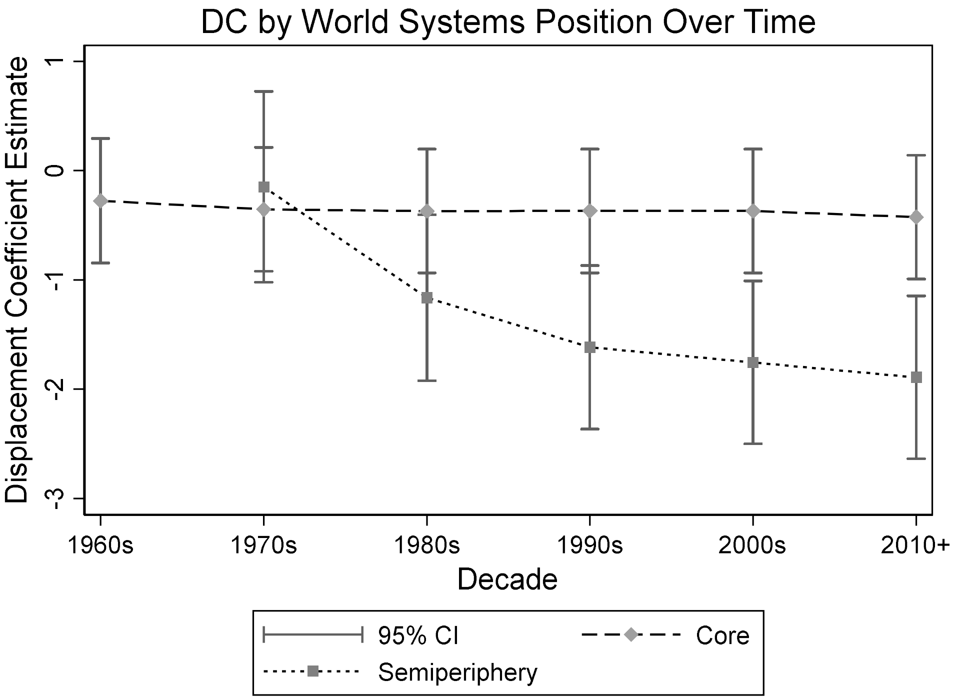

Figure 5: Estimated displacement coefficient for core and semiperiphery nations. The two world-systems positions diverge beginning in the 2000s.

Conclusion

These results present some evidence in contradiction with research which suggests that core nations which invest heavily in renewable and low-carbon energies are replacing fossil fuels with these alternatives, a view consistent with ecological modernization. It pushes us to look further into the conditions under which nations are able to effectively reduce their use of fossil fuels in favor of alternatives. For example, though Germany has developed an extensive transition program with *Energiewende*, this growth in renewable production has mostly replaced retired nuclear power production and coal mining in Germany has only accelerated (Greiner et al. 2022;

Smil 2016). The Fukashima-Daiichi disaster in 2011 and current fears for the safety of nuclear plants in Ukraine may extend the trend of new installation of renewables replacing politically unfavored nuclear energy, though the embeddedness of nuclear industry members in government and wider industry may limit the spread of the movement away from nuclear (Dreiling et al. 2019).

There are a few mechanisms which may contribute to this relationship. First, the economic inequality between nations is found to be associated with some level of domestic inequality (Alderson and Pandian 2018). World-systems theory suggests that this relationship is not just in the sense that nations at different levels of development have a corresponding or linear relationship with domestic inequality (i.e., less-developed nations are more unequal domestically, or vice versa, and will move in the opposite direction with development). Rather, as the whole of the world-system is the appropriate unit of analysis, domestic income inequality in one nation cannot be independent of domestic income inequality in another nation, either through commodity chain links, historical relationships, or economic embeddedness (Mahutga, Kwon, and Grainger 2011).

Second, there may be an amount of resource nationalism motivating the investment in alternatives, perhaps particularly hydroelectricity, which nations may use to disengage from the fossil fuel commodity trade and protect or grow national sovereignty (Kaup and Gellert 2017). Semiperiphery nations include many nations invested in hydroelectricity and other large alternative energy projects to grow electricity generation capacity rather than fossil fuels (i.e., Israel and Herrera 2020; Kappeler 2017; Martínez and Castillo 2016). Given the semiperiphery is conceptualized as nations which often have tensions between domestic elite who either align with core nations or push against them through nationalist policies, resource nationalism may be one strategy of the latter group and lead to greater levels of displacement. This tension may not always lean towards movement away from fossil fuels, though that might be the case here (Sovacool et al. 2022).

This paper gives attention to the dynamics of geopolitical power and historical global inequalities in the structure of energy transitions. Though transitions are often treated as a technical problem with a solution rooted in entrepreneurship and capitalist innovation (Goldstein 2018), there are structural constraints and persistent contradictions which influence pathways towards averting climate catastrophe.

Limitations of this study include data availability and the constraints of world-systems classifications. Testing other dimensions of global inequality unbounded by this limitation would provide a broader view of the relationship between structural inequality and energy transitions. Future research can deepen this thread by investigating further dimensions of geopolitical power, including perhaps colonial history, domestic inequality, and specific trade relationships. This quantitative work can serve as support alongside case studies and detailed qualitative work to further describe the influence of global inequality in systemic change, particularly in the crucial case of eliminating fossil fuel use.

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Chapter 2: Does decoupling of the economy and environment vary by multidimensional measures of domestic inequality? A multilevel model approach.

Abstract:

Introduction

Countries are addressing climate change but in very different domestic contexts. Previous research has suggested that various dimensions of domestic inequality, including gender inequality, income inequality, and disparate colonial histories, moderate the relationship between economic growth and environmental outcomes (Ergas et al. 2021; Ergas and York 2012; Greiner 2022; McGee et al. 2020; McGee and Greiner 2018, 2019). There are many theoretical arguments in environmental sociology linking multiple social inequalities in origin and reproduction, and in particular connection to the environment (Abram et al. 2022; Johnson et al. 2020; LeQuesne 2019; McGee and Greiner 2020; Robinson 2000; Saldanha 2020). Given calls for further research on climate and equity, this paper examines how multidimensional inequality moderates the relationship between GDP per capita and carbon emissions (Klinsky et al. 2017).

Countries are all tasked with addressing climate change, as most policy and social change is assumed to happen at the national-level or smaller geographic and political units. While there are numerous issues of climate justice as we reckon with the disproportionate contributions of various nations to our current climate crisis, nations effectively remain the primary actors against this crisis. However, as climate justice initiatives point out, nations have different histories and various forms of development which call into question the ethical distribution of responsibility with respect to climate change but also reflects the political, social, and economic landscape within which national-level action can and is taking place. This paper turns attention to these uneven landscapes of inequality in an exploratory study of how these dimensions may moderate the relationship between economic growth and carbon dioxide emissions, a key point of inquiry in environmental sociology as well as a key mechanism for the continuing degradation of our shared environment.

Using data on 180 nations from 1995-2019, I use multilevel modeling strategies to examine the moderating effect of the combined characteristics of income inequality, gender inequality, and colonial history on the relationship between GDP per capita and carbon dioxide emissions per capita. I find these dimensions of inequality have mostly additive effects on carbon dioxide emissions, though there are some multiplicative effects where nations with higher levels of inequality on all dimensions are observed to have tighter coupling between the economy and carbon emissions. These findings suggest that greater attention to the mechanisms connecting each respective dimension of inequality to climatic outcomes is worthy of further attention.

Intersectionality, Theory and Methodology

Intersectionality highlights that by shifting our gaze to the intersections of axes of inequality, we can render power in a unique and revealing light showing it for the social relationship it is (Hill Collins and Bilge 2016). There are a multitude of ways to define intersectionality. McCall defines intersectionality as “the relationships among multiple dimensions and modalities of social relations and subject formations” (McCall 2005:1771).

A defining puzzle in research engaging intersectionality research is the treatment of categories. Social categories, including race, gender, and class, have been clearly critiqued as sociology undermines the essentialist and biologically determinist presentations of these categories through empirical research. As such, some have called for the destruction of these categories through analytical erasure or social action, as these categories cannot easily summarize subjective experiences and are ultimately “social fictions that produce inequalities in the process of producing differences” (McCall 2005:1773).

There is certainly an element of irreducible complexity of intersectional experiences and subjectivities. However, social science researchers have found a utility in using existing categories to investigate key research questions around difference and disparity in the context of social justice. Furthermore, I use intersectionality not necessarily to draw attention to specific marginalized or overlooked groups, in this case of countries, but as a framework shaping systematic social processes and as a theoretical and methodological approach to inequality (Choo and Ferree 2010). Intersectionality points out the important non-additive, qualitative differences of specific social positions in subjective experience as well as interaction with social structural forces. This particular conceptualization of intersectionality has relevance to ongoing scholarly discussions of inequality on a national and cross-national scale as it pertains to efforts towards climate mitigation.

Much of environmental justice research have adopted categories, sometimes critically, in order to evaluate how outcomes like environmental health differ by these categories and how these differences change along perpetually reinforced social categories. I engage with intersectionality literature for the key insight of the uniqueness of particular points of intersection of axes of oppression, as well as for the methodological advances made by the quantitative studies engaging intersectionality.

Methodology, Intersectionality, and Environmental Outcomes

In much conventional quantitative intersectionality research, an interaction effect is used to detect interactions between multiple categories of difference, say gender and race. Similarly, research on the moderating effect of contextual inequalities in quantitative cross-national environmental sociology scholarship uses interaction effects. These interaction effects include main effects of a given contextual inequality on the outcomes of interests, and shares weaknesses with methodologically similar intersectionality research.

There have been key interventions in the methodological approaches to address multidimensional positions within larger social structural systems of power through a comparison of conventional fixed effects approaches and multilevel models and strata. Fixed effects approaches using interaction effects have been powerful tools in cross-national quantitative research, but they also have distinct methodological limitations including scalability, model parsimony, dealing with small sample sizes in certain intersections, and sometimes complicated interpretations (Evans et al. 2018). If a researcher would like to include more dimensions of inequality beyond just one dimension, interaction effects become increasingly complicated to interpret and grow in number such that models become less parsimonious. Additionally, some points of intersection, as the number of dimensions increase, may have small numbers of observations within that stratum such that the usefulness of a fixed effects estimation of an interaction effect may not be a useful or reliable one.

Another key methodological intervention is the use of strata as a strategy to address clustering an multidimensional interactions (Alvarez and Evans 2021). A stratum is an analytical category, rather than a geographic or other concrete category, and represent unique social positions. Strata are used in lieu of interaction effects. Including the variables which together compose a stratum in the fixed effects portion of the multilevel model allows researchers to test the relative influence of additive versus multiplicative effects, better addressing a key theoretical tenant of intersectionality, as described above. An additive effect is when the addition of a variable representing an axis of inequality influences the outcome in question *in addition* to other dimensions of inequality. A multiplicative effect would suggest that there is a qualitative difference in occupying a specific intersection of inequalities beyond what each isolated component would suggest.

Often in cross-national quantitative environmental sociology research addressing social equity variables modifying the relationship between economic growth and carbon emissions are testing hypothesis where comparison between different configurations of affluent nations and ‘the rest.’ By employing multilevel models and strata, wider comparisons can be made without selecting a reference category. Furthermore, testing for multiplicative effects of nations with similar histories and domestic inequality contexts in moderating the relationship between economic growth and carbon dioxide emissions would be helpful for understanding the nature of the relationship between social inequalities and climate mitigation.

A more detailed discussion of the methodological choices relevant to this particular analysis can be found in the Data and Methods section, building on this more conceptual methodological discussion.

Cross-National Socio-Environmental Inequality

In Marx’s articulation of metabolic rift, he connects the destruction of lasting fertility and natural cycles and the destruction of the sources of all true wealth, “the soil and the worker,” by the capitalist process of valorization (Marx [1867] 1990:638). The destruction of the worker, people of a distinct class position, is intertwined with the destruction and depletion of the soil. Further modes of distinction, particularly race, coloniality, and gender, are further subsumed into this system of valorization, such that socially constructed lines of difference are critical for and (re)created by the valorization process (Pulido, Kohl, and Cotton 2016; Robinson 2000). Attention to the dynamics of gender, race, coloniality, and class serve to historicize modernity and climate mitigation, particularly important as technical qualities of climate change as a social problem are often drawn, floating above and apart of all other social ills, to the fore of our public discourse and action (Holleman 2017).

It has been established that demographic and developmental factors such as GDP, urbanization, the relative size of working populations, and manufacturing are associated with higher levels of environmental degradation (Rosa and Dietz 2012; York, Rosa, and Dietz 2003a). Greater attention has been paid recently to social inequalities in addition to these demographic and developmental characteristics of nations. Social inequality both causes and is exacerbated by environmental harms. Previous research has highlighted how inequality along lines of gender, income, colonial history and relative position in the capitalist world-system moderate the human ecological dynamics of carbon emissions and environmental degradation more broadly.

The IPCC, again confirming anthropogenic climate change and urging immediate comprehensive action to address it, further noted that relative vulnerability to the effects of climate change are "often influenced by historic development processes, such as structure that originated with colonization" (IPCC 2022:8). A nation's history as an extractive colony explains some variation in national-level per capita carbon emissions, and this suggests that colonial history influences climate mitigation (Greiner 2022). Extractive colonial conditions persist to some extent through unequal ecological exchange and inequalities between countries in a global capitalist world-system (Burns, Davis, and Kick 1997; Clark and Foster 2009; Givens 2018). However, by including a measure of extractive colonial relationships, I attempt to address the latent structuring of these unequal power relationships within nations in addition to how they fit into a larger schema of multidimensional inequality.

Gender has been found to be a critical dynamic for environmental degradation. The number of women participating in national-level politics is associated with that nation being a signatory in international environmental treaties (Norgaard and York 2005). Women's political participation is associated with lower carbon emissions when accounting for world-systems position (Ergas and York 2012). McGee et al. 2020 demonstrate that movement towards greater gender equality is associated with decoupling between GDP per capita and CO2 emissions. This relationship is sharper for less developed nations than developed nations. Importantly, the authors note that these results do not imply a reduction in emissions, simply an attenuation of the relationship between economic growth and carbon emissions. The relationship between gender and the environment is multidimensional: while increased political participation and higher educational attainment attenuates environmental degradation, increased participation of women in the workforce increases environmental degradation (Ergas et al. 2021). This highlights how not all equality is equal – equality narrowly defined within a production system associated with environmental degradation is unlikely to lead towards climate mitigation.

Income inequality has somewhat more mixed results. Increasing income inequality, as measured by the Gini index, in nations has been associated with a tighter coupling of economic growth and carbon emissions in developed nations (McGee and Greiner 2018). On the other hand, increasing income inequality is also associated with renewable energy installation mitigating carbon emissions at a greater rate (McGee and Greiner 2019). This may be due to the concentration of political control that often occurs in tandem with deep income inequality. However, income inequality does not seem to moderate the emissions suppression of new renewable energies when controlling for total fossil fuel use, pointing again to how our current fossil-based energy regime is co-constituted with contemporary inequalities.

How are contextual inequalities interrelated?

What are the connections between gender inequality, income inequality, and colonial history to suggest they can combine into an understandable specific landscape of inequality?

There are conflicting explanations for considering domestic inequality in a global context. First is a view where domestic, or within-nation, inequality a result of a nation's position in a stage model of economic development, such that as a nation progresses through stages of development, domestic inequality abates (Mahutga, Kwon, and Grainger 2011). This approach is consistent with the Kuznets curve, suggesting that as national affluence increases, economic inequality decreases (Kuznets 1954). The second approach is one where within-country inequality is a function of the larger international division of labor and hierarchical production system, as argued by many in the world-systems tradition, who additionally point out that the development process is deeply influenced by the capitalist-world-system (Mahutga et al. 2011). These connections illustrate how colonial history may influence contemporary levels of inequality, economic as well as gendered inequality, through the influence colonial history has on the development process more broadly. Given understandings of underdevelopment and the lasting impacts of extractive colonialism, this is likely the case (i.e., Bunker 1985).

Gender and income inequality further correlate with other types of inequality which have been found to moderate the relationship between economic growth and carbon emissions. Political equality, as measured by the distribution of political power by socioeconomic group, has been found to moderate the relationship between GDP per capita and carbon emissions, mitigating emissions in times of economic stagnation or contraction with no effect during economic expansion (Thombs 2020). The distribution of political power is certainly influenced by and reflects income inequality and gender inequality.

The interrelationships between gender inequality, income inequality, and colonial history are a web of causal and corresponding links documented in an extensive social science literature (Johnson et al. 2020; LeQuesne 2019; Robinson 2000). However, they share an etiology I summarize as the origins of capitalism, though I resist the reduction of these forms of inequality solely to mode of production, but a longer historical process which manifests in difference, disparity, and extraction.

Combined, levels of gender and income inequality alongside colonial history provide a context, or a landscape, upon which climate mitigation is to happen or is happening. Each of these dimensions has been found to moderate the relationship between social structural and demographic factors driving carbon emissions and other climate outcomes. However, how would looking at the combinations of these factors which constitute unique positions in the global economy help clarify how landscapes of inequality moderate direct connections between economic growth and carbon emissions?

Data and Methods

The data for this project are from the World Bank Development Indicators (WDI), the United Nations Human Development Report (UN HDR), and Our World in Data (OWID) (Roser and Ortiz-Ospina 2013; United Nations 2019; World Bank 2020). In include data from 180 nations 1995-2019 (with time gaps noted below). Key independent variables, GDP per capita, urbanization, and age dependency ratio are included as common structural and demographic controls associated with environmental degradation. The main dependent variable, CO_2 emissions per capita, are also from the WDI. All dependent and independent variables are logged, reporting elasticity coefficients, following STIRPAT conventions (York, Rosa, and Dietz 2003b). While other factors such as manufacturing as percent of GDP or quadratic terms for GDP per capita and urbanization are commonly used elsewhere to control for non-linear relationships and more dimensions of social structural factors, here I include simplified controls to focus on exploratory results and my methodological intervention.

The Gender Inequality Index (GII), as calculated by the UN HDR, includes elements of health, educational attainment, political participation, and labor force participation to calculate the relative inequality between men and women within a nation in a given year (United Nations 2019). Possible values for the GII range from 0, where men and women fair equally, to 1, where one gender has the lowest possible outcomes on all included dimensions. The median GII across all nation-years is 0.331. GII data were available for the years 1995, 2000, and 2005, and begin to be available every year starting in 2010. This index was the limiting factor in data availability for this analysis. One strategy in future work would be to adopt a partial dimension of inequality, following Ergas et al. 2021, and analyze political participation, education attainment, health (life-expectancy) and labor force participation as independent dimensions. Additionally, Ergas et al. 2021 indicates countervailing relationships between these dimensions and environmental harm, where increased labor participation of women contributes to higher emissions, therefore breaking these dimensions down allow for a more nuanced analysis of gender inequality and the environment.

The Gini coefficient measures income inequality such that a value of 0 indicates perfect equality and a value of 1 indicates one person controls all the wealth in a given nation-year. I use Gini data downloaded from OWID and the World Bank Poverty and Inequality Platform. Notably, these data use either disposable income or consumption per capita depending on the year, which may influence the reliability of the measure. Other measures of income inequality include the share of either GNP or consumption expenditures by the top 10% of income earners in a given nation, or top 1%. The median Gini coefficient for the analytical dataset is 35.48503.

Table 1: A list of countries by colonization history included in the analysis.

Extractive Colonial History	**Settler/No Colonization**
Algeria, Angola, Armenia, Azerbaijan, Bangladesh, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Chile, Colombia, Democratic Republic of Congo, Republic of Congo, Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Eswatini, Ethiopia, Gabon, The Gambia, Georgia, Ghana, Guatemala, Haiti, Honduras, Iran, Iraq, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Republic of Korea, Laos, Lebanon, Lesotho, Liberia, Malawi, Malaysia, Mali, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Niger, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Rwanda, Senegal, Sierra Leone, Slovenia, South Africa, Sudan, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Uganda, UAE, Uruguay, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe	Albania, Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Kyrgyz Republic, Latvia, Lithuania, Moldova, Mongolia, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States

Table 1 displays countries included in the analysis by colonial history. I base this categorization on Greiner 2022 and Ziltener, Künzler, and Walter 2017. Global colonial history is complex, and there are many ways of conceptualizing or operationalizing what characteristics on which to focus. Here, I separate most settler colonial nations into the settler/no colonization category, including the United States, Canada, Israel, and Australia. However, I retain South Africa in the extractive colonial history category.

I split the Gini coefficient and GII at the median to create a binary categorical variable denoting nation-years with more or less inequality than the median over the full analytical dataset. Combined with my operationalization of colonial context, there are eight possible combinations of binary characteristics. These combinations are strata, and are described in Table 2.

Table 2: A description of each strata and number of observations within each strata

Strata Number Label	**Characteristics**	**Nations**	**Nation-Years**	**Example Nations**
111	Never colonized, low Gini, low GII	36	345	Austria, Belgium, Finland, Poland
121	Never colonized, high Gini, low GII	18	90	Bulgaria, Israel, Russia, United States
112	Never colonized, low Gini, high GII	4	7	*Kyrgyz Republic, Latvia, Mongolia, Romania
122	Never colonized, high Gini, high GII	3	4	*Kyrgyz Republic, Moldova, Russia
211	Colonial history, low Gini, low GII	14	109	Azerbaijan, Japan, Slovenia, Ukraine
221	Colonial history, high Gini, low GII	19	106	Costa Rica, Trinidad and Tobago, Uruguay, Georgia
212	Colonial history, low Gini, high GII	21	109	Bangladesh, Iraq, Jordan, Mali
222	Colonial history, high Gini, high GII	65	359	Bolivia, Brazil, Syria, Panama

*Starred example nations are a comprehensive list rather than a sampling of nations. For non-starred cells in the example nations column are nations with the most observations in that stratum.

Analytical Approach

Multilevel models (MLMs) are not the conventional modeling strategy in cross-national environmental sociology scholarship, but they have been used in this area for the modeling strategy's unique strengths (e.x., see Greiner 2022; Greiner and McGee 2018). Strata have been used in previous research on environmental inequalities as an approach to deal with contexts with multiple categories of difference. Here I nest nation-years (observations) within nations, and nations within strata. MLMs address clustering directly in model structure, rather than including dummies for countries and/or time. While often clustering addresses spatial or other concrete clustering (for example, individuals in neighborhoods), clustering can also address abstracted contextual factors such as positions within a larger social structural system. Here, I cluster nations within strata comprised of income inequality, gender inequality, and colonial history, which combined constitute a landscape of inequality within which nations are tasked with addressing climate change. This approach allows me to examine clustering by analytical groupings, rather than solely through geographical groupings. These analytical groupings would describe similar historical processes nations share, shifting the focus of analysis to these historical processes from exclusively time-variant, national-level characteristics.

One strength of MLMs is that they allow for clear partitioning of variance, which allows researchers to attribute amounts of variance in the dependent variable to different nested levels of analysis. Here, I estimate two random intercept models and use the variance components to estimate the Variance Partition Coefficient (VPC). The VPC provides insight to the total proportion of variance in carbon dioxide emissions that exists between nations and between strata. The VPC for the random intercept models and stratum-level is expressed by the following equation:

$$VPC = \frac{\sigma_m^2}{\sigma_e^2 + \sigma_\mu^2 + \sigma_m^2} \times 100$$

Where σ_μ^2 represents variance at the nation level (level 2), σ_e^2 represents variance at the nation-year level (level 1), and σ_m^2 represents variance at the strata level (level 3). I further calculate a Proportional Change in Variance (PCV), which is a measure indicating the extent to which observed between-stratum variation in the null model is explained by the additive effects of the characteristics which make up each stratum. The value of 100-PCV is the percent of residual between-stratum variation which isn’t explained by the additive effects, and can indicate that there are interaction or multiplicative effects (Alvarez and Evans 2021). The equation for the PCV is below:

$$PCV = \frac{\sigma^2_{m\ Null\ model} - \sigma^2_{m\ Non-null\ model}}{\sigma^2_{m\ Null\ model}} \times 100$$

Lastly, I estimate a random slope model where GDP per capita is random at both the country- and stratum-levels. The equation for the full random slope model is below:

$$carbonemissions_{tij} = \beta_0 + \beta_1(GDP\ per\ capita_{jit}) + \beta_2(urbanization_{jit})$$
$$+\beta_3(age\ dependancy\ ratio_{jit})$$
$$+m_{0j} + m_{1j}(GDP\ per\ capita_{jit}) + \mu_{0ji} + \mu_{1ji}(GDP\ per\ capita_{jit}) + e_{0jit}$$

$$Level\ 3\text{:}\ \begin{bmatrix} m_{0j} \\ m_{1j} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma^2_{m0} & \\ 0 & \sigma^2_{m1} \end{bmatrix}\right)$$

$$Level\ 2\text{:}\ \begin{bmatrix} \mu_{0ji} \\ \mu_{1ji} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma^2_{u0} & \\ 0 & \sigma^2_{u1} \end{bmatrix}\right)$$

$$Level\ 1\text{:}\ [e_{0jti}] \sim N(0, \sigma^2_{e0})$$

Where m_{0j} represents the strata-specific error term for the intercept, m_{1j} represents the strata-specific error term for the random coefficient, μ_{0i} is the nation-specific error term for the random intercept, and μ_{1i} is the nation-specific error term for the random coefficient, and e_{0ti}represents the nation-year specific error term. GDP per capita is a random coefficient at the nation and strata level, meaning that each nation has a specific estimated relationship between GDP per capita and carbon dioxide emissions, as expressed below:

$$\beta_1 + \mu_{1ji}$$

Here, β_1 represents the overall mean estimated coefficient for GDP per capita. Additionally, each strata has an estimated relationship between GDP per capita and carbon dioxide emissions, as expressed below:

$$\beta_1 + m_{1i}$$

Comparing stratum-level error term allows for a comparison of strata relative to each other and the grand mean estimate of β_1 across all strata and nations. I do this in Figure 3 below.

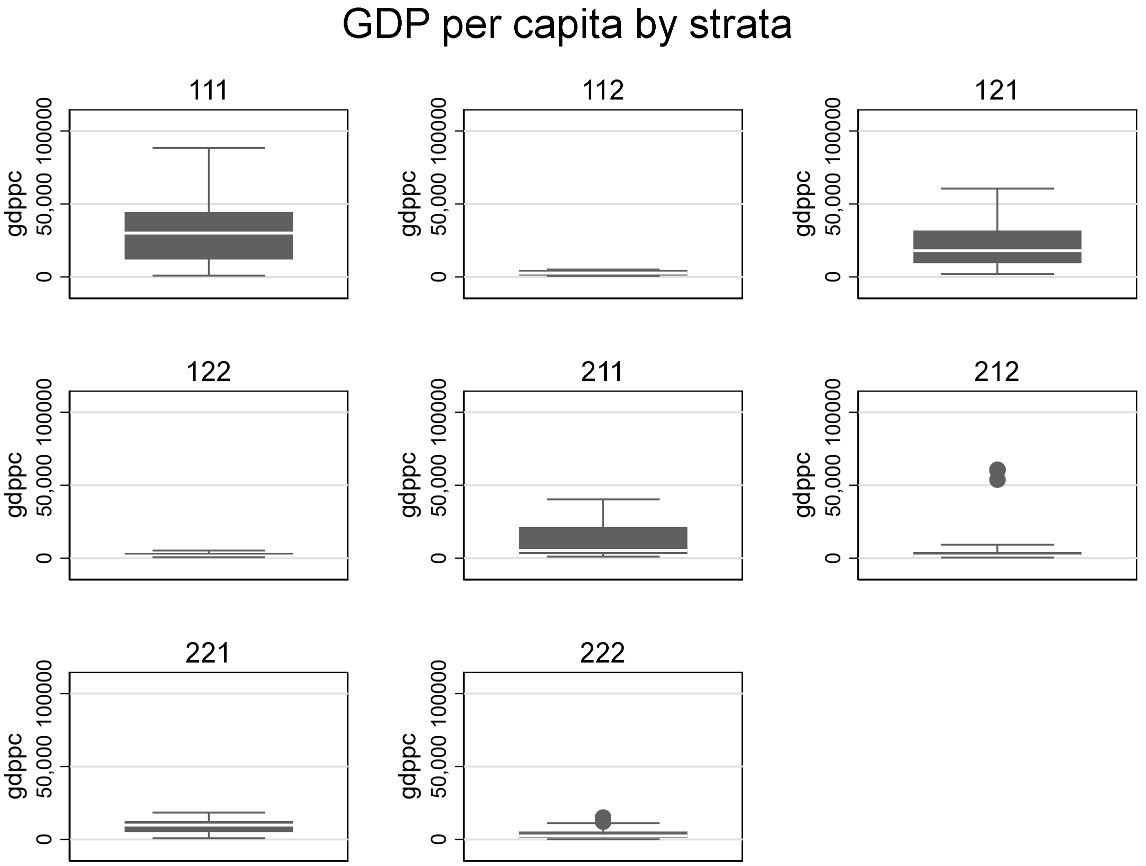

Figure 1: A series of boxplots displaying the distribution of GDP per capita by strata, described in Table 2.

Results and Discussion

I first analyzed the structure of variance in national CO_2 emissions by analyzing the variance components in a null three-level random intercepts model. About 1.56% of variation in carbon emissions is attributable to the nation-year level, or within-nation variation. About 66.67% of variation is attributable to the country-level, or between-nation variation. Finally, about 31.78% of variation in carbon emissions is attributable to the stratum-level. This suggests that national inequality context can explain some variation in national carbon emissions.

Next, I added natural logged fixed effects covariates of GDP per capita, urbanization, and age dependency ration to the random intercepts model. Conditional on these covariates, about 4.09% of variation in the dependent variable, carbon emissions, is attributable to the nation-year level, 73.45% to the country-level, and 22.46% to the strata level.

Table 3: Model results

Variables	Random Intercept			Random Slope	
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Model Description	*Null Model*	*+Additive*	*Additive + Controls*	*+Controls*	*Controls+ Additive*
GDP per capita (natural log)			0.33***	0.39***	0.36***
Urbanization (natural log)			0.71***	0.52***	0.53***
Age Dependency Ratio (natural log)			-0.78***	-0.52***	-0.53***
Gini (categorical)		-0.19	-0.18		-1.45*
GII (categorical)		-1.21***	-0.31*		-2.06**
Colonization (categorical)		-0.75***	-0.43**		-3.50***
Intercept	-5.93***	-4.98***	-8.06***	-9.05***	-5.33***
Variance Terms					
σ_{e0}^2	0.0280783	0.028079	0.0131499	0.0205461	0.0206182
$\sigma_{\mu0}^2$	1.198515	1.176321	0.4128071	0.3363216	0.3378355
$\sigma_{\mu1}^2$				0.0003215	0.0002538
σ_{m0}^2	0.5712791	4.27x10^{-14}	0.0131499	5.979533	0.247033
σ_{m1}^2				0.0655648	0.0491979
Nation-Years	1,129	1,129	1,129	1,129	1,129
Nations	180	180	180	180	180

***p<0.001; **p<0.01; *p<0.05

The Gini and GII variables included in the models above are binary categorical variables split at the median across the analytical dataset. The colonization variable above is a binary variable, splitting countries by colonial history outlined in Table 1.

Then, I ran a random slopes (random coefficients) model with GDP per capita as the random variable at both level 2 (nations) and level 3 (strata). This allows for two additional error terms estimating a coefficient for GDP per capita for each nation as well as for each strata. By comparing these estimates, we can parse some patterns suggesting how strata might reveal the dynamics of inequality landscapes and the relationship between economic growth and emissions.

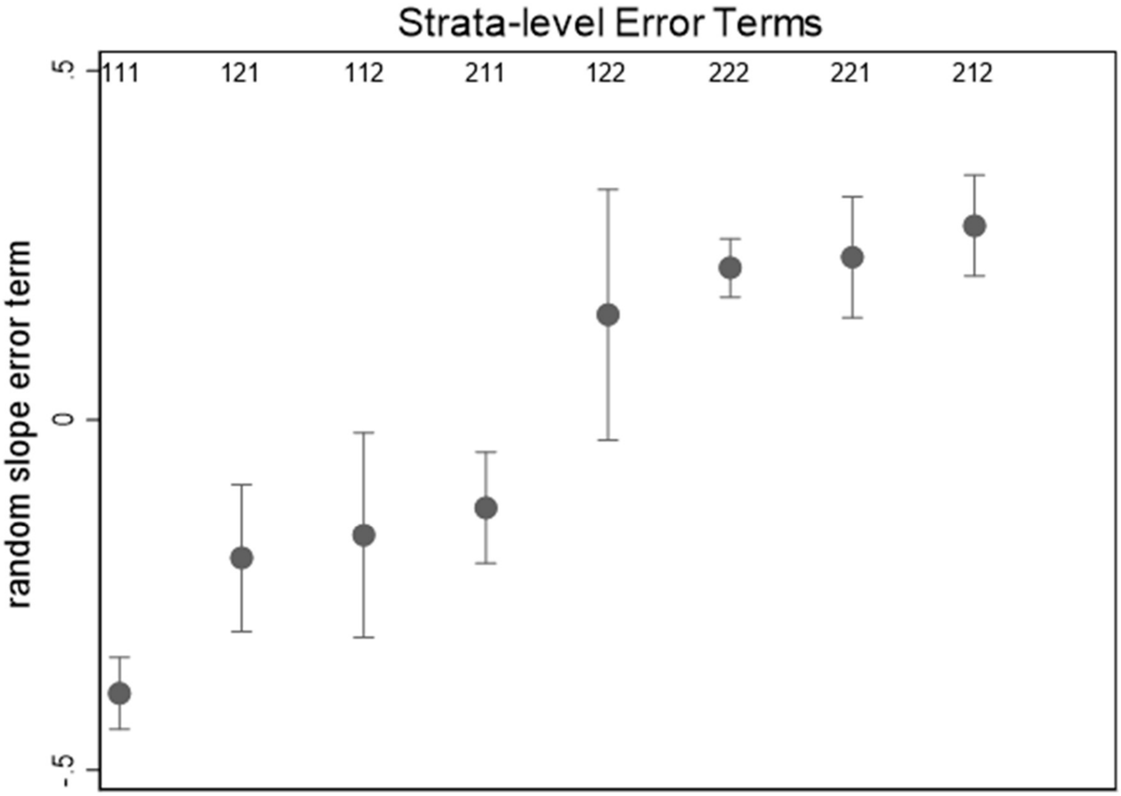

Figure 2: A caterpillar plot of strata, labeled at the top of the graph. The y-axis is the random slope error term, m_{1j}. Zero marks no difference from the grand mean estimate of the coefficient for GDP per capita. Confidence intervals are at the 95% level.

Looking at the caterpillar plot, Figure #, there seem to be three distinct groupings of strata. The first is stratum 111 on its own, representing nations with no/settler colonial history, below median gender inequality, and below median income inequality. It has the most negative error term resulting in a near-zero estimated coefficient for GDP per capita (see Figure #). The second group of strata are 121, 112, 211, given that the confidence intervals for these three strata overlap but are mostly distinct from other strata. The third group consists of strata 222, 221, and 212. I would also add stratum 122 into this group given its overlapping confident interval most overlaps with this third group, though it should be noted that the confidence interval for 122 and 112 do overlap at their tips. These groups can be further split by the zero on the y-axis, where the first two groupings I describe lie below zero, suggesting these strata have estimated coefficients below the overall average for the analytical dataset, while the last group is above zero, suggesting they have estimated coefficients above the overall average.

At first glance it seems that these groups are at progressive levels of inequality such that the first group, stratum 111, is the least unequal while the third group (strata 222, 221, and 212) are the most unequal. However, there is not a perfect gradient suggesting that there may be qualitative differences between these strata. Most notable is the distinct jump from stratum 111 to all other strata, but even from the next closest stratum. This suggests that having no/settler colonial history, and below median gender and income inequality is associated with decoupling between economic growth compared to all other nations.

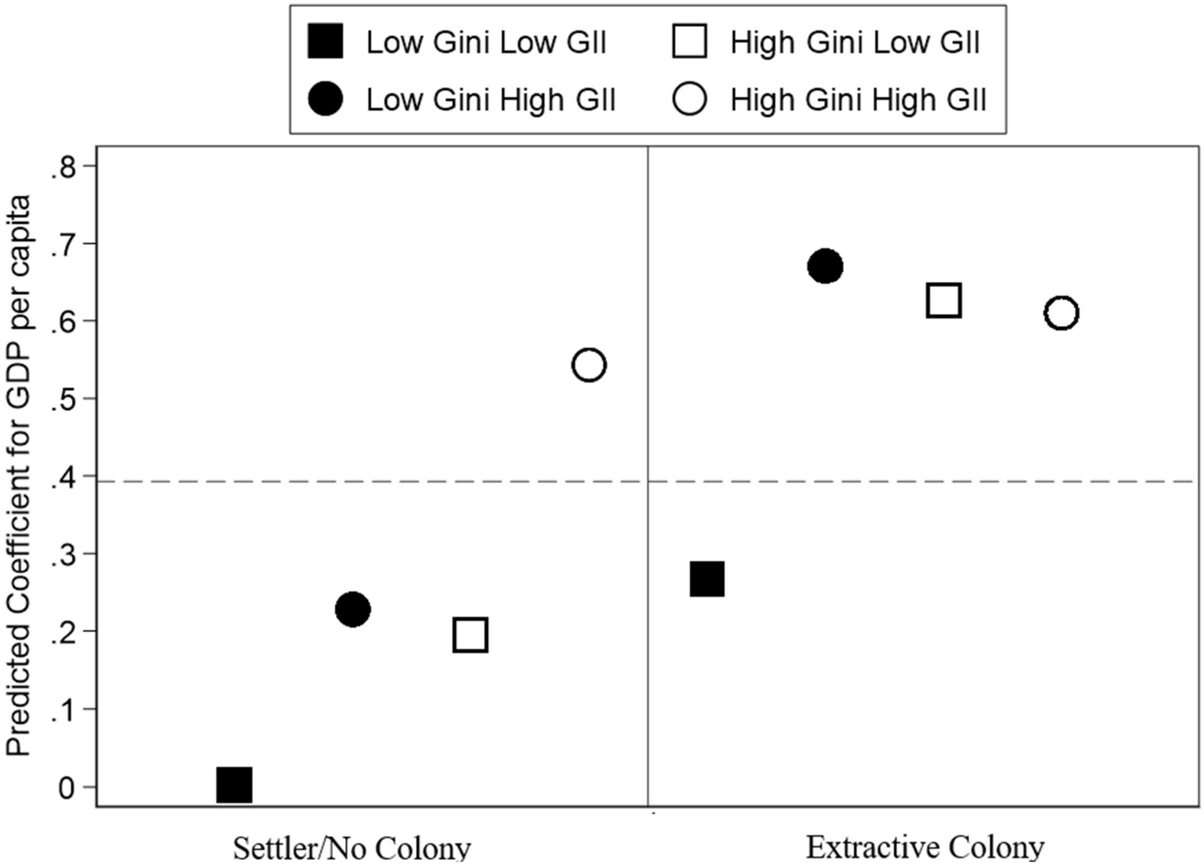

Figure 3: Displayed are the estimated coefficients for GDP per capita by strata in a more visual comparison of strata. Shaded markers designate nation-years with Gini coefficients below the median (35.48503), while unshaded indicate nation-years with Gini coefficients above the median. Squares indicate nation-years with GII values below the median (0.331) while circles indicate nation-years with GII values above the median. The left side of the figure are strata for nations which have never experienced colonization, including colonizer nations, and settler colonial states, while the right indicates nations which have experienced extractive colonization. The horizontal dashed line represents the grand mean estimate across all nation-years for the elasticity relationship between GDP per capita and carbon emissions.

It is difficult to resist additive logics when discussion the strata and their groupings. Figure 3 provides a more visual presentation of the estimated coefficient for GDP per capita for the respective strata, beyond a ranked caterpillar plot. Of the strata with estimated coefficients above the grand mean for all nation-years, three have above-median gender inequality and three have extractive colonial histories. Comparing shaded-square to shaded-square, and other shading-shape pairs is a comparison of similar contexts with the intervention of colonial history. Though stratum

122 has a wide confidence interval, all of these shading-shape pairs follow the pattern of those with extractive colonial histories have a higher estimated coefficient for GDP per capita relative to the corresponding strata with no/settler colonial history.

Furthermore, differences in estimated coefficients between strata is not straightforwardly a story of affluence, where less inequality is expected in nations with more affluence, given the broad range of GDP per capita in each of the stratum with the estimated coefficients closest to zero: 111, 121, 112, and 211 (see Figure 1 for distributions).

To assess the relative additive effects versus multiplicative effects, I return to the random intercept models described at the top of this section to examine the PCV and the inclusion of additive effects in the random slope model. The PCV between the null random intercept model and the same model with the addition of categorical GII, Gini, and colonial variables is 99.99% ($\frac{0.5713- \ .27\times 10^{-14}}{0.5713}\times 100$). This indicates that the variation in national carbon dioxide emissions is almost entirely from additive effects of gender inequality, income inequality, and colonial history. I note that when controls are included in addition to the additive effects, GDP per capita, urbanization, and age dependency ratio, the PCV is 97.7% ($\frac{0.5713-0.0131499}{0.5713}\times 100$). This suggests that there is a small portion (100-PCV or 2.3%) of the variation of national CO_2 emissions, controlling for known social structural and demographic covariates, which is attributable to multiplicative effects.

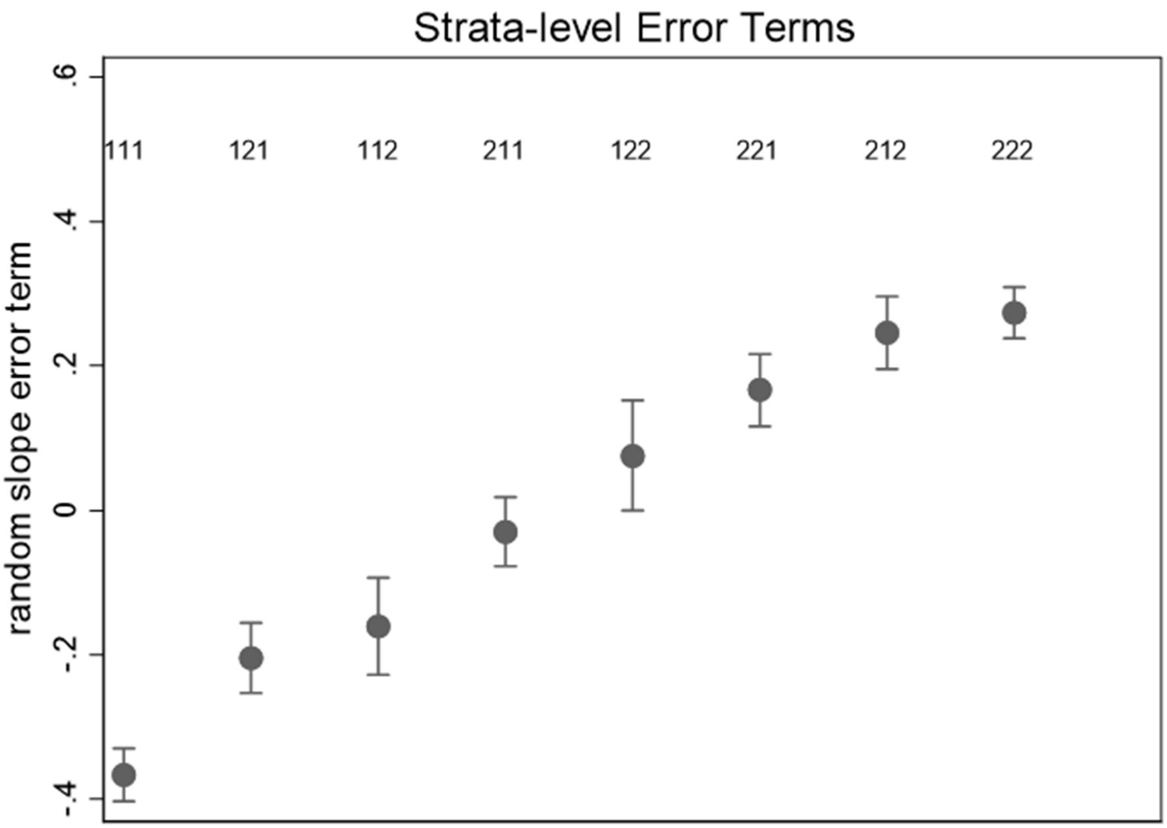

Figure 4: A caterpillar plot of a random slopes model including the additive effects of GII, Gini, and colonial history in addition to controls. Strata labels are at the top of the figure. Confidence intervals are at the 95% level.

Figure 4 is a caterpillar plot for a random slope model identical to the model which produced Figure 2, but it includes categorical variables for GII, Gini, and colonization in addition to control variables. The error terms are drawn closer towards zero, displaying a smaller range in error terms as well as narrower confidence interval bars. Additionally, there is a smoother gradient between strata, and while most strata are in the same relative positions, stratum 222 is now ranked 8th, with the largest estimated coefficient for GDP per capita. This suggests economic growth is most tightly coupled with carbon dioxide emissions in nations with extractive colonial history, above median gender inequality, and above median income inequality.

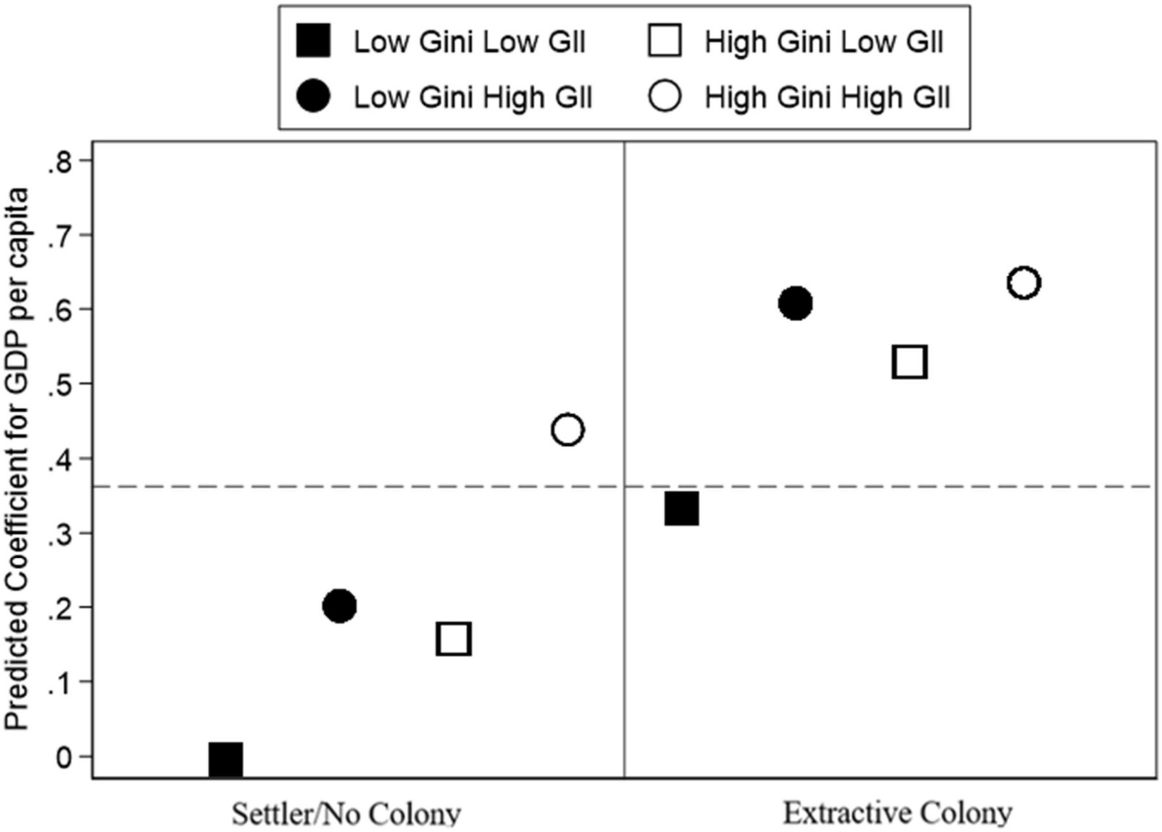

Figure 5: Displayed are the estimated coefficients for GDP per capita by strata in a more visual comparison of strata. This Figure is analogous to Figure 3 but represents results from a random slope model including both controls and main effects of categorical GII, Gini, and colonization.

Turning attention to Figure 5 demonstrates a more intuitively visual representation of this gradient, which seems to suggest, alongside the PCV analysis, that apart from the main effects of dimensions of inequality, there is some small amount of additional influence of qualitative differences in nations with increasing levels of multidimensional inequality.

Conclusion

My findings suggest that a significant portion of the variability in carbon emissions can be explained by the shared historicized characteristics of nations in the form of income inequality, gender inequality, and colonial history. These landscapes of inequality may belie shared national histories, particularly in the colonial context, or perhaps divergent histories as nations arrive at states of inequality, though these states may share contemporaneous characteristics explaining the observable clustering based on these characteristics.

Furthermore, most of the effects of these dimensions of inequality seem to be additive, and a small portion multiplicative. In other words, the dynamics of gender inequality, income inequality, and colonial history are likely best examined independently rather than conjointly as intertwined systems of inequality. While there is a good theoretical reason to think of these inequalities are fundamentally intertwined, their connections to carbon emissions seems more siloed.

This methodological approach is an additional tool to address empirical questions of interest to environmental sociology. Here, I employ a three-level multilevel model structure to focus on the parsing of variance terms and to approach interactional relationships from a different angle. Some methodological limitations of this approach are the underlying assumptions around sampling for multilevel models, which assumes clustering groups are samples of all possible, in this case, nations. While this is a more viable assumption for examinations of other geographic units, like census tracts or neighborhoods, it is a somewhat more difficult assumption for nations. However, with clearly theoretically motivated examinations, multilevel models can provide diverse and helpful tools to add to the methodological pluralism that is a strength of sociology as a broader discipline.

Intersectionality as a theoretical tradition and methodological intervention informed this study in fruitful ways. Testing for multiplicative dimensions of inequality in the context of being a moderating force between economic growth and carbon emissions can shed light on the ways in which social inequality connects with decoupling. These results suggest that approaches towards decoupling rely upon addressing specific mechanisms perpetuating gender inequality, income inequality, and legacies and the ongoing nature of colonialism.

Future work might examine other configurations of strata, including different measures of the dimensions of inequality examined here. For example, the components comprising the GII could be examined separately, and alternative measures for income inequality, like wealth controlled by the top tenth percentile of a domestic population, could be used in lieu of the Gini coefficient. These examinations would give a clearer picture of the dynamics examined in the exploratory study.

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Chapter 3: Cheap and abundant for whom? A history of industry and electricity in the Pacific Northwest

Abstract

Previous research has found that additions of low-carbon fuels do not necessarily replace fossil fuels at a 1:1 ratio at the global level and can even be associated with increased fossil fuel use. Understanding the mechanisms behind this observation, particularly in the electricity sector, is critical for mitigating ongoing climate crisis and remains under researched. This paper is a historical analysis of hydroelectricity in the U.S.'s Pacific Northwest and provides a case study of the political economy of a low-carbon fuel in a region which has experience expansive growth in the economy, electricity generation, and fossil fuel use. While growth is often framed as natural in retrospect, and growth in supply said to follow growth in demand, I demonstrate how the state via the Bonneville Power Administration (BPA) directly facilitated growth in both electricity supply and demand in the region. At the end of this process, fossil fuel consumption in the region went from negligible to half total power consumption in Washington and wind farms have at times been paid by the BPA not to produce electricity. The region is farther now from a 'sustainable' future not necessarily due to a lack of technological advancement, but rather due to neoliberal regulatory regimes and our commitment to commodifying even 'uncooperative' commodities like electricity.

Key words: displacement paradox; hydroelectricity; energy transition

Introduction

The Pacific Northwest is a place of contradictions. Electricity has defined the region since the 1930s, but has transformed from a symbol of utopia, to key to defense production, to menace to wildlife, to keystone of regional understandings and action against climate change. With abundant, cheap, and reliable electricity, the region was to transform from a 'last frontier' occupied by loggers, farmers, and miners to a new industrial center, and eventually to a new utopia of sleek tech giants and towering Nature flourishing side-by-side.

This chapter traces the origins of hydroelectricity in the Pacific Northwest, as well as the major industrial electrical consumers often described as drawn to the region due to federally subsidized energy. By following the changes in core power customers and regulatory agencies in the region, I demonstrate how the demand and supply of electricity in the region are co-produced and reflect upon the implications for the installation of non-fossil fuel energies. While electrification is presented as a path towards a more sustainable future and decarbonization (IPCC 2022), electricity is also used to mask the persistence of fossil fuels by acting as a purifying intermediary between fossil fuels (i.e. natural gas) and end-users. Tracing this history troubles the idea of hydroelectricity, or any low-carbon energy, as 'sustainable' in a context of capitalist accumulation, and troubles the cultural representations of the Pacific Northwest as purified from its extractive past.

Below is a history of dam building and tightening control of a river, the immediate expansion of this system to support the reliability of fluctuating water flows for electricity generation, the rise and fall of the aluminum industry, and the growth of increasingly concentrated electricity use in the form of the encroachment of server farms in the region since 2005. This history highlights the paradoxes of energy diversification given and exemplified by electricity's unique relationship as a commodity to the state, regulation, and capital accumulation.

These characteristics delineate a set of mechanisms behind the displacement paradox and the observed lack of replacement of fossil fuels with the additions of alternatives. As we look toward present changes and future plans to address carbon emissions through an expansion of low-carbon energy capacity, understanding existing low-carbon energies in a capitalist, fossil-fuel dominated nation is critical for understand what social, regulatory, and organizational challenges may arise given that this is not just a technical problem.

The Displacement Paradox the Persistence of Fossil Fuels

The displacement paradox describes observations of the introduction of new technologies intended as substitutes for existing technologies not replacing incumbents at a 1:1 ratio (York

2006). New technologies may thus contribute to the growth in overall consumption, increasing the material impact of our economies. There is even evidence that the introduction of new technologies may increase not just overall consumption, but also the consumption of the incumbent technologies. This has been illustrated in the case of the introduction of petroleum products in the context of whaling (York 2017). Whales were routinely hunted and killed, and their bodies used for industrial and household purposes for lighting and lubrication. Petroleum products have now replaced whale products in these processes, but this transition did not happen immediately. For a time, even more whales were killed than before petroleum products were introduced, in part due to the role of petroleum in fueling more powerful vessels and techniques for whale-killing. Therefore, the introduction of a substitute technology (petroleum) increased the consumption of an incumbent technology (whales).

This is a critical illustration of mechanisms behind the displacement paradox, particularly in highlighting the role of capitalist accumulation in the use of a new technology to continue hunting of whales. However, research observing the displacement paradox has widely focused on electricity and energy use more broadly. New installations of low-carbon power have not been observed to replace fossil fuels at even near a 1:1 ratio (York 2012), natural gas may not be reducing carbon emissions, though it is intended as a substitute for 'dirtier' fossil fuels (Greiner, York, and McGee 2018), added renewable energy capacity may be replacing nuclear energy rather than fossil fuels (Greiner, York, and McGee 2022). This paper presents a specific case of the displacement paradox and reveals how these observations can come to be in a specific place in the context of electricity and energy use.

Furthermore, the displacement paradox calls into question how we define energy transitions. Absolute (energy) consumption, rather than proportions of consumption from various fuels, is what matters for critical emissions outcomes we care about when addressing climate mitigation (York and Bell 2019). Entangled in this perceptual and definitional issue are underlying schema of how scholars and policy makers are conceptualizing historical and technological change. Therefore, historical analyses which carefully trace processes reflected in the observation of the displacement paradox in aggregated, cross-national quantitative work can reassess dominant orientations to historical change vis-à-vis climate change mitigation efforts. Below I discuss critical theoretical frameworks structuring where I turn my analytical attention for this case, and includes metabolic rift, raw materialism, electricity capital, and fossil capitalism.

The problems of ecological rift are often envisioned as having technological solutions driven by market mechanisms, which will eventually dematerialize the economy (Mol 2002). As this chapter demonstrates, there may be the appearance of dematerialization when industries shift such that electricity can be used at ever greater quantities in places where the relevant mineral commodities are already assembled (i.e., data centers, induction stoves), thus hiding away the material impacts of both minerals and energy.

Marx's metabolic rift, as described by John Bellamy Foster, highlights the linkages within socio-ecological cycles cracked or broken by capital's imperative for accumulation. Metabolic rift is first described via primary accumulation and the antagonism between town and country, whereby food and fibers are grown in the country but consumed in towns (Foster 1999). This relationship creates accumulated waste in towns and countrysides bereft of these wastes to use as fertilizer. Rifts are addressed in times of crisis with technological fixes, i.e. synthetic fertilizer, seemingly never towards repair but to shift rupturing relations to new sectors, new spaces, or new modalities (Clark and York 2008).

Previous scholars have spent time exploring the socioecological dynamics and mechanization of river system development in the region. For example, Richard White describes the Columbia as an organic machine, altered by human intervention and technology but maintaining “its natural, it’s ‘unmade’ qualities” (White 1995:5). He presents an image of continuity, with the underlying materiality of thermodynamics to link the labor of the river and human work. This emphasis in continuity does not align in every way with a metabolic rift approach, the latter of which focuses analytically on shifts in cyclical processes, but nor do I see these frameworks as incompatible when addressing the history of the Pacific Northwest.

Raw materialism, or new historical materialism, emphasizes the control over the extraction, processing, and consumption of raw materials as a systemic characteristic of capital accumulation and a capitalistic world-system (Bunker and Ciccantell 2005; Gellert and Ciccantell 2020). This framework emphasizes the specific characteristics of un- or less-processed commodities as ‘raw’ inputs to a productive process, such as including electricity, as well as the associated transportation capacities in analyses to examine the material basis of power and inequality (Gellert and Ciccantell 2020). While applications of raw materialism to energy studies have emphasized the dual movement of economies of scale and ‘diseconomies of space,’ the case of electricity generation through hydroelectric dams presents an interesting point of comparison. Whereas coal and other ‘stock’ fuels, discussed further below, certainly operate on economies of scale, these economies of scale correspond to increased transportation and extraction costs often leading to investment into transport infrastructure, spreading the logic of economies of scale.

After the period of construction of transmission lines, the dams on the Columbia do not experience increasing costs of transportation of electricity as a commodity to end users. However, the Columbia River system still reflects these dynamics of the transformation of the Pacific

Northwest region in service to the United States' hegemonic ascent. The dams themselves were in part a technological solution to the diseconomies of space of other industries, such as agriculture and mining, by allowing for sea-going shipping vessels to reach as far inland as Idaho via barges and the built locks and dams. This demonstrates the tendency suggested by discussion of raw materialism for the tensions of economies of scale and diseconomies of space to result in the expanding scale of capitalistic integration and capital investment (Gellert and Ciccantell 2020). It is telling that the advent of megadam projects in the United States are closely intertwined with war, defense production, and fertilizer (i.e. Muscle Shoals, see Hager 2021). Production for the military provided the first retroactive justification of industrial development in the Pacific Northwest, but it was just a temporary one, leaving the region's power administrators to tempt wartime industries to remain by other means.

Dematerialization, Fossil and Electricity Capitals

Data have been lauded as a key feature of dematerialization of the economy, an a commodity nearly as important as labor and capital to the future of capital accumulation (Taffel 2021). Extractive and exploitative metaphors abound with data—data mining, cryptomining, and data colonialism. 'Raw data' is framed as a critical raw material for a digital or platform economy, sometimes in parallel to fossil fuels as the most critical material input to the present modes of accumulation (Taffel 2021). While this is a salient point, in order to connect data infrastructure to the continuity of the environmental and social harm of capital accumulation, I favor the framework of electricity capital to bridge the dynamics of aluminum and data centers in relation to grid and generation infrastructure.

Electricity has been conceptualized as a core fraction of capital alongside industrial, commercial, or financial capital, whereby private accumulation of capital is facilitated by electricity provision, largely subsidized by public investment (Luke and Huber 2022). While framing electricity capital as a fraction of capital may distract in some cases from fundamental capitalist relations, here I employ the term to better understand “the political and technical forces that drive changes in energy provision” (Luke and Huber 2022:6). The scale and expense of energy infrastructure as fixed capital points to the importance of externalizing costs onto the state and intertwining finance and eletricity in such ways that it is difficult for capitalist institutions to walk away from such investments. In the context of a fossil-fueled world, these fixed costs and financialization of energy contribute to path-dependency and block efforts to decarbonize (Labban 2010; Luke and Huber 2022).

However, what if the fixed capital was a low-carbon energy source, like hydroelectricity? Similar dynamics of fixed capital, financialization, and state investment persist, and the ways in which hydroelectricity fits well into capital accumulation and crisis are highlighted in this chapter. In addition to the continuity of these patterns, the history I trace below outlines how hydroelectricity, shifting industrial power customers, and the material and regulatory dynamics of the electricity grid in the Pacific Northwest contributed to the expansion of production through the provision of electricity, the increased use of fossil fuels in the region, and the intensified commodification of electricity in an attempt to tame material qualities of electricity that make it an “uncooperative commodity” (Bakker 2003).

Malm defines fossil capital as “self-expanding value passing through the metamorphosis of fossil fuels into CO_2” (Malm 2016:290). One might replace metamorphosis with metabolism. Malm further traces the rise of fossil fuel use in the industrialization of England in the early 1800s, highlighting the critical property of coal in service of capital: that it was a stock. Stock fuels can be stockpiled, transported to end-users and locations, and need not be tied to their geographic and geologic origins. Water wheels, used in tandem with coal to power the burgeoning textile manufactures at the time, employed a 'flow,' the flow of water. Flows cannot be moved, stockpiled, and are temporally and spatially specific. Malm emphasizes that the stock character of coal allowed emerging capitalists to centralize factories in urban areas otherwise convenient for their commerce and to better control labor through reserves of labor in cities.

The advent of electricity changed these dynamics, but the saliency of stocks and flows of power continues. For example, climate change mitigation plans emphasize power storage to approximate the stockpiling of stock energies in the application of flow energies, solar and wind, at a scale necessary to power contemporary society. Hydroelectricity transformed the use of waterpower, alongside long-distance electricity transmission, into a fuel which looks quite a bit more like a stock than a flow. In fact, some have suggested pumped storage, where electricity is used to pump water back up into a reservoir to drop through a dam's turbines again, as a strategy to store solar and wind energy for nights or climatically inopportune times (i.e., Penn et al. 2018).

I draw further from the history of this early mix of waterpower and coal. Growth is usually naturalized and justified after the fact. In Malm's example, there is a myth that the English production system was running out of land and/or was up against the limits of waterpower in production. However, this was not actually the case. This argument is often arrived at after the fact, by describing that a Europe without fossil fuels would need 2.7 times the land mass it currently has to maintain its level of production. Well, it is because we began down a path of production that makes it so, not that fossil fuels solved a land or energy scarcity problem in the past. Challenging a Malthusian approach to technological development, Malm writes:

> "If technologies are developed when—and only when—people plunge into poverty because procreation has run riot on a narrow resource base, if the Industrial Revolution was a response to such a crisis and coal struck upon as the solution, then technological development should have

petered out thereafter, the use of fossil fuels stagnating at the new 'ecological equilibrium" (Malm 2016:261).

There are other explanations for technological change and the dynamics of hydroelectricity. Previous literature on waterpower and hydroelectricity highlights the guiding role of social power in the development of these technologies (Graf 1999; Reisner 1993; Swyngedouw 2015). Hydroelectricity and other mega water projects have been framed as a nationalistic and nation-building endeavor, expanding territorial control and state power, and solidifying bureaucratic and technocratic regimes (Mukerji 2009; Swyngedouw 2015). This is certainly true of the Pacific Northwest, as well as broader water development within the United States.

The Pacific Northwest certainly grew on hydroelectricity, and for a very short time, exclusively. However, the region now uses a significant amount of fossil fuels alongside hydroelectricity. The power produced by the first large-scale dams in the region, Bonneville and the Grand Coulee, was disparaged as power in the middle of nowhere, far from the industrial centers of the east. It is not through inexorable an inevitable growth that the Pacific Northwest transformed, but rather through militarism and the deepening commodification of electricity.

Below I engage with secondary and primary histories of the region and its energy infrastructure to pull out key moments of change. I focused particularly on moments of expansion of generation capacity and drew upon retrospective histories as well as contemporary writings. The Bonneville Power Administration, alongside its grid management responsibilities, produces official histories I drew from to emphasize the BPA's public narrative describing the need for expanding generation capacity and river system management. Lastly, I drew upon political-economic theory outlined above to tell a theory-driven story about how fossil fuels can and do expand alongside their alternatives.

Foundations of hydroelectricity in the Pacific Northwest: Why Federal dams?

Scholars who had addressed river basin management and the multiple uses of dams often cite irrigation, flood management, navigation, and power all as important purposes of dams. In fact, without all of the interests involved in these uses, some argue that large dam projects would not get funded or supported by a political and territorial coalition. What is missing from this formulation is where the power is going. Larger industrial customers for the electricity produced by dams are key actors in the network of actors in these coalitions. Data centers and other tech customers have becoming increasingly powerful actors in river basin management, replacing aluminum smelters as the primary industrial customers of public power in the region (Levenda and Grabowski 2022).

I begin here with the impetus for the construction of the Columbia River system of dams and electricity generation. The centrality of regulation is somewhat unique for electricity, where the state plays a significant role in directing fixed capital investment and carves paths for capital accumulation from electricity provision (Luke and Huber 2022). This began with the federal government establishing jurisdiction over the development of waterways.

The Reclamation Act was passed in 1902, the same year as John Wesley Powell died. It essentially put the federal government in charge of all future irrigation projects in the west, which naturally included dam development. It was funded by the sale of federally owned land in the region, unlike future funding schemes. Worster describes this as one of the beginnings of Western water regimes, with the trinity of features of Western water control: technology, centralized planning, and concentrated economic and political power (Worster 1994). He notes that this comes at the expense of effective local and democratic decision making.

Dams have been built in the United States since the 1880s, for irrigation, flood control, navigation, and even electricity, with the earliest electricity-generating example at Niagara Falls in 1896 (Bakke 2016). However, most of these early examples of large dam projects were funded by private or municipal interests, as in Appleton, Wisconsin, where a wealthy citizen bought and installed an Edison dynamo generating electricity from the Fox River. Why was the federal government not involved in these early efforts, and how did it come to be that the federal government became the main and centralized source of large public works projects? The origins lay earlier than the New Deal.

In 1913, two Constitutional amendments provided the means and motivation for federal involvement in public works. The 16th amendment to the Constitution was adopted on February 25, 1913, and allowed the federal government to receive income in the form of a national income tax. The 17th amendment to the Constitution was adopted May 21, 1913, and provided that Senators are appointed by direct elections rather than by state legislatures, making them more responsive to public opinion. Furthermore, the brief American war mobilization for WWI featured prominent hydroelectric projects, desired for nitrate production, demonstrated the viability and challenges of this form of energy (Hager 2021).

The New Deal

Though plans for a dam at the site of the Grand Coulee date to the 1920s and even the 1890s, no viable financing plan preceded the New Deal. As with likely all western water projects and western infrastructure projects, there was robust contestation of every large project and every dollar allocated. Plans to dam the Columbia were met with particular consternation by some, as the PNW was often described as land with no people. F.D.R. in turn made great pains to link the monumental endeavor to manufacturing in the east, particularly of steel. Additionally, this link illustrates F.D.R.'s greater vision of public works as a path towards tighter integration of regional manufacturing and an acceleration of production that precedes the Second World War. For example, F.D.R. spoke to an audience at the Grand Coulee construction site on October 2, 1937: "…we must also remember that one half of the total cost of this dam is paid to the factories east of the Mississippi River. In other words, it is putting to work in the steel centers and other great manufacturing centers of the east thousands of people in making the materials that go into the dam" (Roosevelt 1937:2)

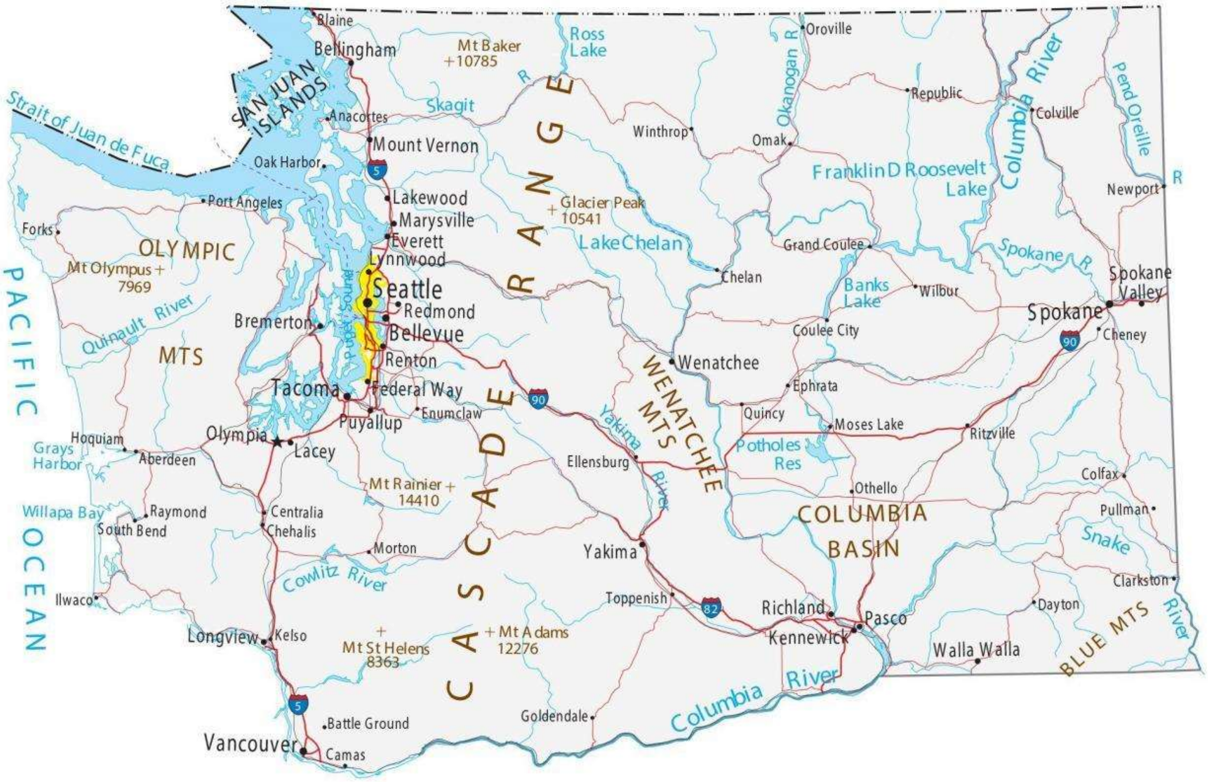

Figure 1: A map of Washington state including major rivers, cities, and roads (GISGeography 2023)

The Pacific Northwest was seen as a last *terrus nullus*, and a final frontier even in the twentieth century. Though the region's economy long relied on extractive industries such as timber and fishing, this image of pure Nature and boundless resources persisted. It persists still, transformed into the purity of sustainability and progressiveness in the Silicon Forest. However, at the time of the building of Bonneville and the Grand Coulee, F.D.R. continued to justify the expenditure in diverse ways, including as an irrigation project to open up fertile land to Americans suffering from the Dust Bowl and 'overcrowding' in the east. He spoke to a crowed in Spokane in October of 1937:

> "There are parts of this Nation that are not as favored as the Northwest. Mistakes have been made. They have cut off their timber. Their land is played cut, or they plowed up prairie land which is now blowing away. I am thinking about those people as well as you people. You have got room for them here in the Northwest where they can make homes, where they can live happily and prosperously" (Roosevelt 1937: 994).

In 1925, in response to the Federal Water Power Act and growing national calls for energy development, Congress commissioned what is known as the 308 Report, ordering the Army Corps of Engineers to survey the Columbia River for waterpower potential (Norwood 1981; Willingham 1987). The report, ordered to appease hydro boosters but unlikely to be funded, benefited from being completed in 1933, amidst the Great Depression and a federal government hungry for labor-intensive projects (Norwood 1981; Springer 1976).

The Bonneville Dam, 42 miles east of Portland, began producing power in 1938, and the Grand Coulee, 85 miles west of Spokane in 1940 (Stein 2007). The Bonneville Dam was built by the Army Corps of Engineers and the Grand Coulee was built by the Bureau of Reclamation. These two agencies were often in opposition and competition during the dam building boom in the U.S., and each envisioned administering the power from their respective dams independently from one another. However, Congress decided a centralized planning authority was needed, even if they could not agree on whether it should be as comprehensive and autonomous as the Tennessee Valley Authority. The Army Corps of Engineers, the Bureau of Reclamation and private utilities companies vehemently opposed a “Columbia River Authority,” and so the BPA was created as a stopgap originally intended to be temporary (Voeltz 1962). The Bonneville Power Administration (BPA) was created to build and administer the transmission of power from federal dams, starting with Bonneville and the Grand Coulee, as well as find markets for that power. Given different regulatory and political environments, Washington was the only state in the region to develop a large number of public utility districts. Oregon, Idaho, and Montana are all dominated by private utilities, and are more similar to the rest of the country.

The BPA was originally seen as a temporary measure before the establishment of a more comprehensive Columbia Valley Authority modeled on the Tennessee Valley Authority (TVA), but this never came to pass (Pope 2008). Richard White called the BPA “a public agency that exists to transmit electricity to markets and to create markets to which it can transmit electricity,” and an overall failure to achieve the utopian vision of hydroelectric development in the Pacific Northwest (White 1995:62). It cannot own generation facilities directly but facilitates generation as the transmission authority. While public or investor-owned (private) utilities sell power the BPA transmits to residential customers, the BPA can sell directly to large industrial users, known as Direct Service Industries (DSIs) (Pope 2008:11). The agency was further mandated to facilitate the widest possible use of electricity through building transmission lines, increasing generation capacity, and creating markets for that electricity.

While the BPA is unique in some of its mandates, its organizational focus on transmission foreshadows the de/reregulation of utilities nation-wide starting in the 1970s. While the BPA managed federal dams in the region and transmitted electricity generated by those dams, they also transmitted electricity generated from other sources. Given the constraints of the electrical grid, this regulatory environment cultivated a focus on selling electricity such that the increasing commodification of electricity became necessary for the organization's survival.

The BPA was a much more precarious agency than the TVA at the time, and starting in 1939, it had to actively cultivate a base of power demand in the region. It worked to build an aluminum industry in the region, alongside F.D.R.'s charismatic support, to "fulfill its mandated mission and to ensure its institutional future with needed revenue and political support" (Stein 2007:3). These revenues were needed to pay back the federal government for the dam construction, and the agency faced sharp questioning for low revenues in the late 1930s as anti-New Deal congress members became more vocal (Stein 2007). Furthermore, unlike the TVA, the BPA submitted all their revenues to the federal Treasury and rely on congressional appropriations for operating and building funds. The BPA identified the light metals industry as a suitable industry to cultivate in the region, with aluminum as the most desirable of these industries, and the agency funneled any opportunity for federal loans, tax breaks, employment, and other incentives to draw aluminum manufacturers (Stein 2007). Therefore, the arrival of the aluminum industry in the Pacific Northwest preceded WWII due to the institutional and transmission related needs of the BPA, not the demands of war-time production or simply the promise of cheap, abundant electricity.

WWII, Defense Production, and Aluminum

FDR is said to have invited the Aluminum Company of America (ALCOA) and Reynolds Metals himself to the region to use the electricity in aluminum smelting, and to provide employment in the region (Voller 2010). The links between hydroelectricity and aluminum were already well established, and it was an industry with predictable, large demands for electricity. This predictable electricity demand would solve the BPAs need for a reliable base load demand and would justify the agency's continued administration of federal power which took enormous expenditures of political will to create. The arrival of aluminum in the Pacific Northwest was crafted by the federal government and the BPA, as outlined below, calling to question the simplified narrative of abundant supply naturalistically attracting demand.

The process of producing aluminum is a multistep one. First, bauxite must be mined as raw ore for making aluminum. Second, the bauxite must be refined into alumina. Third, alumina (aluminum oxide) must be electrolytically reduced to aluminum, sometimes called pig aluminum. Then, the pig aluminum needs to be fabricated into the particular alloys and forms needed for specific industrial uses before being manufactured into its final form (Anon n.d.-a; Engle 1944). The third step of producing aluminum from alumina is the most electricity-intensive step and is the reason aluminum refinement facilities are often located in places with cheap electricity. These facilities are associated globally with large-scale hydroelectricity. For example, Norsk Hydro is now one of the world's largest aluminum producers in the world, and describes itself as both an aluminum and renewable energy (especially hydro) corporation owned in part by the Norwegian government, a nation with large hydroelectricity and oil industries (Anon n.d.-e).

Within the United States, there were limited reserves of bauxite mainly in Arkansas, with some additional deposits in Alabama and Georgia, which is why Alcoa had placed several refinement facilities in that region. However, "[r]eserves of high grade bauxite are limited and the United States will enter the postwar era practically a have-not nation for this essential raw material of aluminum" (Engle 1944:254). The growth of aluminum as a desired material skyrocketed during and after WWII, and the U.S.'s deposits of bauxite were quickly depleted. The top net exporters of bauxite in 2022 were Guinea, Australia, Indonesia, China, and Brazil, however the U.S. sources imported bauxite from a somewhat different set of nations reflecting lasting imperialist relationships with the Western Hemisphere: in 2022, 62% of U.S. bauxite imports were from

Jamaica, 13% from Brazil, and 8% from Guyana (Ciccantell 1999; Ciccantell and Bunker 2005; McCoy 1992; Merrill 2022).

News articles published during the initial dam-building era in the Pacific Northwest lauded the magnetic power of hydropower to draw new industries to the region. One article proclaims, "Northwest Draws 1st Aluminum Reduction Plant West of Mississippi With Lowest Industrial Power Rate in The United States" (Staff Writer 1940). At the time, it took 8-12 kwh to produce a pound of aluminum, as well as nine pounds of raw material, almost all of which was sourced from outside the region or even outside of the country. The wholesale cost of power from Bonneville and the Grand Coulee at this point was about 0.2 cents a kWh, the lowest cost in the nation (Voller 2010).

The alumina for the first "aluminum reduction plant west of the Mississippi" in Vancouver, WA needed transporting from Mobile, Alabama or East St. Louis, Illinois, a costly distance for refinement (Staff Writer 1940). While engineers and chemists associated with the U.S.'s growing hydroelectric dam-building agencies claimed to be developing refinement processes for aluminum-bearing clays of the PNW into a new raw material, including the BPA building transmission lines to Utah to utilize raw materials there, bauxite was and remains the most common raw ore for aluminum refinement (Staff Writer 1940; Stein 2007). Additionally, the energy intensity of aluminum refinement could only become more intense with increasing impurity.

Aluminum was a relatively minor metal in comparison to steel before WWII, and while steel and copper production still greatly overshadowed aluminum production during the war, its lightweight durability and thus suitability to planes and ships made it a critical material starting during WWII (Stein 2007). During WWII in 1943, aluminum ate up 60% of all the electricity the BPA sold (White 1995). To meet wartime production needs, the federally funded Defense Plant

Corporation (DPC) built aluminum-reduction plants in Troutdale, OR; Mead, near Spokane; and in Tacoma, WA. They also built the rolling mill in Trentwood. Once the war was over, the DPC leased the aluminum-reduction plants to Kaiser Aluminum and Chemical Corporation, which later bought the plants. This was with the state's intention of fostering "competitive conditions within the primary aluminum industry" (Voller 2010:11). The rolling mill was eventually sold to Reynolds Metals. The BPA and DPC worked together to bring new corporations into the domestic aluminum industry to weaken Alcoa's monopoly and diversify Direct Service Industries (Stein 2007).

After WWII, the Pacific Northwest had a larger portion (30-35% of the national total) of aluminum production of any region in the country apart from the Southeast (Engle 1944). Five out of 16 aluminum reduction plant in the U.S. in 1944 were in the Pacific Northwest, none of which existed in 1939. Of these plants, Alcoa and Reynolds Metal each owned one, and the federal government built and owned the other three. A growing issue was transportation: "Just as iron ore is taken to coal, so bauxite is taken to a source of electrical energy […] The deciding factor is transportation" (Engle 1944:254). During the war, ships carrying bauxite from the Caribbean were sometimes attacked, but even without this threat it was a distant and expensive source of raw materials. The BPA's solution to the issue of transportation, in order to continue their cultivation of the aluminum industry in the region, was to support vertical integration of the aluminum industry in the Pacific Northwest (Stein 2007).

At the time, there was a single facility in the region to convert pig aluminum to specific alloys and shapes for industrial use in Trentwood, Washington, near Spokane. Though this is only one facility, it represented 25% of total rolling mill capacity in the U.S. as of 1944 and was connected via the Columbia River locks and dams to international shipping (Engle 1944:255).

Besides a budding aircraft industry and shipyards in Seattle and Portland, few aluminum consumer products were manufactured in the PNW at that time. The BPA brokered a favorable regional freight rate specifically for aluminum products from the Interstate Commerce Commission in 1946, continuing to take major public steps to retain the aluminum industry in the region (Stein 2007). They went far and above their mandate to transmit power, massively investing in preserving and growing power demand.

The BPA were ultimately unsuccessful in assisting aluminum companies vertically integrate in the region. No other rolling miss or user of pig aluminum was built besides the mill in Trentwood. Further attractiveness of the Pacific Northwest involved plans to ship bauxite from the Caribbean more systematically in order to take advantage of the region's electricity (Engle 1944:258). By 1952, only about two percent of the pig aluminum was used in the Pacific Northwest by small foundries, about seven percent was used by Alcoa in the region in Vancouver, WA, and about 30 percent was sent to the rolling mill in Trentwood, WA (Herman 1952). But by the 1970s, the smelters in the Pacific Northwest still accounted for 40% of U.S. smelting capacity, and 6-7% of global capacity (NWCouncil). The industrial load allowed the BPA to gain political legitimacy and aided their arguments for greater congressional appropriations for building power and transmission capacity.

Full River Control, Expanding Dams for Navigation and Generation

In August of 1805, Lewis and Clark began their navigation of the Snake and Columbia rivers. Their impressions of the west, at least retrospectively, are used as the first traces of the 'need' for engineering intervention for the purposes of capital, navigation, in this region. As one BPA historian wrote,"[t]he Lewis and Clark Journals began the record which led to building Bonneville Dam to drown the dangerous Cascades, The Dalles Dam to permit river traffic over

Celilo Falls, and six more dams to extend barge navigation to Lewiston, Idaho." (Norwood 1981:9-10). This expansion of development on the river seems to be an inevitable progression if industry and people were moving to the region only for the abundant, cheap electricity such that demand began to exceed supply. However, this expansion was justified by the cultivated presence of the aluminum industry in the region, used by the BPA to justify further appropriations from Congress. Further justification, reinforcing the expansionist regime, is part of the more complicated interconnections between administrative imperatives of the BPA, non-energy dam functions such as flood control, and the material properties of generating electricity through dams.

Seventy-three percent of the waterflow on the Columbia flows during the six spring and summer months (White 1995). While this matches the needs of irrigated agriculture well, such variation in power generation is a management nightmare for the BPA as the manager of electricity transmission in the region. Deep dips and high peaks in electricity demand are certainly issues for grid managers everywhere, but the same dips and peaks in energy *supply* compound these difficulties. While some have attributed the proliferation of electrical home appliances and the cultivation of night-time consumers of electricity to the need to even out electricity demand throughout a 24-hour cycle, developing consistent electricity supply has been equally transformative (Bakke 2016; White 1995).

The Bonneville Dam is a run-of-the-river dam, meaning there is no real control of the flow of the river at that dam site, rather dam managers simply allow the river to flow through turbines to produce power or over the dam if no excess power can be introduced to the grid. The Grand Coulee dam, on the other hand, has storage capacity in the form of a large reservoir, and can release water at variable rates through the turbines to meet electricity demand. This capacity also increases the generation capacity of all dams between the Grand Coulee and the mouth of the Snake River

(White 1995). FDR noted this at a speech at the Grand Coulee construction site in 1934, "The Chief Engineer here was telling me a few minutes ago that the eventual completion of this dam [Grand Coulee] is going to mean the doubling of potential power of every site on the Columbia River between here and the mouth of the Snake, and that is a lot of power" (Roosevelt 1934). Therefore, increasing the storage capacity across the river system increases the power generation potential across the entire system, including for existing dams.

Alongside increased generation capacity in a river system, storage dams also help prevent flooding, which was a key concern in many river basins in the U.S. where hydropower developed The flooding of Vanport, Oregon in 1948 and droughts during Korean War production in 1951 and 1952 sparked and fueled discussion of river-system management and need for more power, which just 20 years before had been described as power "no one wanted" (White 1995:58). Outlining the history of utopian vision of the abundant, cheap electricity damming the Columbia would provide, White writes, "[t]he social ends electricity was meant to achieve, so clear in the 1930s, largely vanished from the discussion of development. Electricity had become an end in itself" (72). This seems due both to the difficulty of administering a grid with variable supply and demand of power, as well as to the BPA's commitments of 'cheap and abundant' energy to industries cajoled into expanding into the region.

The Columbia River Treaty of 1964 addressed the need for smoothing the power production peaks and troughs by increasing storage at the only sites still available at that time along the main trunk of the Columbia – in Canada. The Treaty outlined three storage dam projects which would hold large reservoirs of water to be released as power-producing dams in the U.S. needed, increasing the generation capacity of existing dams on the Columbia at that time by an entire Grand Coulee dam (White 1995). The BPA managed this increased network and began selling excess power to California through a new electrical grid intertie authorized the same year. Thus, both supply (new storage dams) and demand (intertie with California) were expanded together in response to demand supported by federal power and the BPA and the material constraints of natural cycles on the predictability of power supply.

The metabolic rift in ecological cycles caused by the construction of enormous dams and the guiding logic of river system control underpin the history of the region and cannot be ignored. Increased river control leads to increased electricity generation, as well as an expansion and deepening of ecological and social rifts associated with large-scale hydro. Furthermore, the urban-rural divide at the crux of metabolic rift is an important thread throughout the industrialization of the region, culminating in the current proliferation of data centers in the region.

Table 1: Key Legislation and Public Reports

Title	Abbr.	Year	Jurisdiction	Key Intervention
The Columbia River and Minor Tributaries	308 Report	1933	Federal	Army Corps of Engineers ordered by Congress in 1925 to survey the Columbia River to address debate about hydroelectric development in the region. Submitted in 1933, and background of Great Depression made the development more politically attractive than initially thought.
Bonneville Project Act		1937	Federal	Created the Bonneville Power Administration to market and transmit power from federal dams, with a mandate to sell to public power consumers first.
Columbia River Treaty		1964	International	Agreement to build storage dams in the upper Columbia (in Canada) to increase electricity generation capacity in the entire river system. U.S. to offer half of additional capacity and/or payments back to Canada.
Public Utility Regulatory Policy Act	PURPA	1978	Federal	Requires utilities to purchase electricity from qualified independent producers.
The Pacific Northwest Electric Power Planning and Conservation Act	Northwest Power Act	1980	Federal	Established a regional planning council joining OR, WA, ID, and MT. Established long-term power contracts for aluminum companies.
Electric Utility Restructuring Act (AB 1890)		1996	State - California	Went into effect in 1998. Deregulated wholesale electricity markets in California leading to West Coast Energy Crisis of 2000-2001.

Electricity, Expansion, and the Pacific Northwest

"In the century just past, the region and electricity grew up together, and electricity was both a cause and a result of the growth" (Norwood 1981:12).

While the origins of hydroelectricity in the Pacific Northwest were not initially intended to replace incumbent energies or lead to a low-carbon economy, the vast hydroelectric capacity in the region has subsequently been presented as the cornerstone of the region's plans for sustainability. However, the material and regulatory interactions of the hydroelectric system directly led to the expansion of fossil fuel use in Washington as outlined in this section. Furthermore, these same logics are active obstacles to the growth of additional low-carbon energies in the region, specifically wind.

There are a few important features of electricity and electricity transmission which are key for understanding the management hurdles this commodity provides. Like water, electricity has specific material characteristics which make it difficult to commodify, following Karen Bakker's discussion of "uncooperative commodities" (Bakker 2003). First, electricity is a flow (more accurately a field) and it is difficult and expensive to store in any meaningful quantity. Second, it is used (by aluminum factories, by our home appliances) near instantaneously as generation, so data on and modeling of demand is critical for utility managers in order for them to plan generation rate and capacity. One way they accomplish this is through understanding load factors.

A load factor is the ratio of the average amount of electricity demanded in a given period of time to the peak demand in that period. A higher load factor means the difference between average demand and peak load is not that great, and a low load factor means invested capital in high generation capacity will frequently be idle during non-peak demand. One strategy to achieve a high load factor is through interconnections and diversification of uses drawing from the grid, i.e., between suburban residential areas and commercial or industrial customers.

The capital intensiveness of generation influences power system planning, and hydroelectricity is particularly capital-intensive. As a result, built dams cost more or less as much when idle than when producing electricity. This fixed capital cost suggests that large dams like those on the Columbia should be used for supplying the base load, which is the core electricity demand expected throughout normal service times (Pope 2008). However, the ease of varying the flow of water in rate and volume through storage dams allows for a versatility in power production which also makes hydro dams good for addressing variable or peak demand. A certain amount of hydropower will always be part of firm power for the BPA given the Columbia continues to flow; firm power is the power utilities know they can always reliably supply. Additionally, after the 1980s and 1990s the BPA is reluctant to allow water to flow over the region's dams and bypassing the turbines, due to the harm this practice has on salmon and other fish populations in the region and the BPA's legal responsibility under the Northwest Power Act to protect wildlife.

These material properties of electricity are fundamental to and reinforced by the grid as the system of interconnected electricity transmission lines. These lines are managed by different transmission authorities by region, with interconnections needing interagency cooperation to manage generation and demand. Before the 1970s, utilities in the United States were mostly vertically integrated, owning and operating generating facilities, transmission lines, and distribution and delivery of electricity to households (Bakke 2016; Pope 2008). However, deregulation of the utilities sector, long protected due to the labeling of the electricity industry as a "natural monopoly" with unique challenges and potential for public goods, compelled utilities to purchase power from any qualified power producer including private and household producers. The Public Utility Regulatory Policy Act (PURPA), passed in 1978, complicated the task of utility managers to integrate their own generation capacity as well as the capacity of independent producers. It set the stage for individualized decarbonization efforts like rooftop solar, as well as further capital accumulation the provision of electricity, deepening the commodification of electricity capital through deregulation. This change has corresponded with additional creative financing and the financialization of major power-consumer firms as well as the agencies themselves. The combination of deregulation and new financing schemes complicated the BPA's ability to meet their mandate.

In 1969 the Joint Power Planning Council set up a ten-year $7 billion program involving regional utilities and the BPA, the latter of which would broker the power from three nuclear reactors planned by the Washington Public Power Supply System (WPPSS, pronounced 'whoops') (White 1995:81). Droughts in 1972-1973 and 1976, combined with the oil crisis, had pushed the BPA to seek out ways to supply more power. Therefore, in 1976 even more extreme power forecasts added two additional nuclear reactors. That year, over 40% of Bonneville's firm power went to Direct Service Industries, which were mostly aluminum (Pope 2008). Because the expansion of the Columbia River System was more or less complete, with no real room to expand hydroelectric generation, the BPA sought to establish a system of thermal power plants which would work in tandem with the hydroelectric system. These thermal power plants would replace hydroelectricity as the base load of power in the region, while the dams supplied electricity in times of excess demand.

This is in part due to the constraints of generating electricity with thermal powerplants versus dams in the context of our current grid system. Thermal plants, nuclear-based or fossil fuel-based, cannot be turned on and off at the flip of a switch but take time to come on and offline, and doing so is costly (Bakke 2016; Smil 2017). Hydroelectric dams, however, can release water at the will of an operator if they have storage capacity and climatic conditions align. Therefore, given a system with extensive thermal power plants in tandem with hydroelectric dams, the management decision which makes most sense is one which addresses known demand, the baseload, with thermal power and using the hydro dams to top off supply to address variable demand.

However, building nuclear power plants proved ruinously more costly than anticipated by a factor of at least five, and of the five planned plants, only Plant #2 at Hanford was completed and came online in 1984 (Pope 2008). The failure of the project led to WPPSS to default on its bonds, the largest municipal bond default in American history. Because the BPA also assumed risk in the plan as the conduit of the nuclear electricity to end users, the fiasco contributed to a sixfold rate increase of BPA power from 1979 to 1983. However, even in the aftermath of this financial disaster, the BPA was calling for more funds for more energy. In 1981, a BPA historian wrote,

> "In the Pacific Northwest the electric public utility responsibility was for a long time met almost exclusively by harnessing water power – a renewable resource. The next phase was to add thermal power resources based on a coal and nuclear fuel. As the need for more power supplies increased, the direction of policy turned to energy conservation and toward all available forms of renewable resources, but as yet the results have been slow and the outlook is for shortages" (Norwood 1981:12)

Thought of as "natural monopolies," utilities were regulated to support the reduced costs of monopolies being passed on to the consumer. As 'natural monopolies,' utilities and power generation was thought to be best planned with economies of scale in mind -- intense capital investment in construction and low operating costs over the lifetime of infrastructure (Pope 2008). Hydroelectricity in the Pacific Northwest seemed to corroborate this rule, and as such nuclear seemed like a viable path to build upon and beyond the capacities of the Columbia. Additionally, given this logic, nuclear power plants were also being proposed at sizes otherwise not seen in existing nuclear plants. While the smallest new plant proposed in the United States between 1963 and 1967 was to have a capacity of 400 megawatts, the largest operating plant in that same time frame had a capacity of 200 megawatts (Pope 2008). The logic of natural monopolies lured planning agencies into larger and larger projects, which outstripped the financial and technocratic resources available, leading to the collapse of WPPSS.

In 1980, the Pacific Northwest Electric Power Planning and Conservation Act (Northwest Power Act) was passed. It established the Northwest Power and Conservation Council, directed to propose and adopt a regional energy conservation and electric power plan alongside a concerted program to protect and enhance fish and wildlife on the Columbia, including mitigating the effect of power production on such wildlife. It represents regions in Washington, Oregon, Idaho, and Montana.

Another consequence of the Northwest Power Act was long-term power contracts for aluminum companies, in an attempt to address the impact of BPA rate increases due to drought and WPPSS. Though rates went up again somewhat, aluminum companies were able to lock these rates in long-term contracts (NWCouncil). By 1984, the BPA had a *power surplus* and enormous debt after their participation in the failed attempt to exponentially grow power production in the region. As in other times of power surplus or public deficit, the BPA relied on selling more power to their largest industrial user, the aluminum industry. They temporarily offered a reduced rate to aluminum companies, who were struggling to compete with smelters in Canada and Brazil using even cheaper, newer installations of hydroelectricity (Ciccantell 1999; White 1995). However, by 1996, the aluminum industries were in decline even with set long-term rate contracts (Levenda and Grabowski 2022).

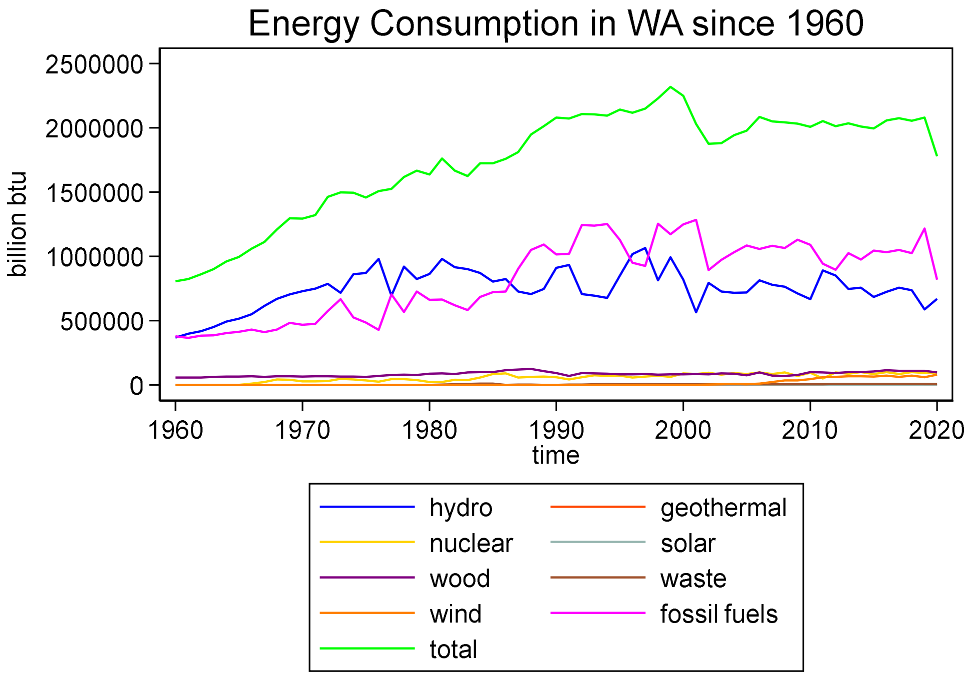

Figure 2: Total energy consumption for electricity generation by fuel in billion btus in Washington 1960-2020.

The BPA manages both federally produced hydroelectricity generation and a large amount of electricity transmission in the region. It is legally required to accept non-federal (including private) generated electricity "in a manner that is fair, non-preferential, and does not discriminate against non-federal sources" (Pearsall 2013:79). Though we can trace the rise of fossil fuel use in Washington state while hydropower remains relatively consistent (see Figure 2), there are important climatic and weather variables in the production of hydro power. In years of drought, there is less hydroelectricity capacity along the federal dam system on the Columbia – in years of heavy snowpack and rainfall, there is too much. Here, "too much" means something very specific – because the BPA is required to accept non-federal generated electricity onto its transmission lines, and only directly controls the generation of federal hydropower, then the only managerial choice available to the BPA in times of excess hydroelectricity (given that electricity must be used nearly simultaneously to generation) is to stop hydroelectric generation or pay private power producers to stop generating power. This has happened in the context of large snow-pack years and wind-power generation along the Columbia, and though wind generation corporations receive these payouts, it cultivates a discouraging outlook when these same corporations consider expanding their wind generation in the region (Pearsall 2013). Therefore, low-carbon energy sources are displacing each other in this scenario, rather than working together to displace fossil fuel use in the region.

Aluminum and BPA in Crisis

Between 1955 and 1971, five more aluminum plants were constructed in the wider Pacific Northwest. But by the end of 2009, only the Alcoa facilities at Wenatchee and Ferndale, WA, were in operation (Voller 2010:13). Voller attributes this to the increasing cost of electricity. Alcoa was contracted in a bulk power buying agreement with Chelan County Public Utility Commission, the same administrative unit dealing with the increase in Bitcoin mining in the county discussed below. After closing during the 2020 pandemic, Alcoa sold the Wenatchee facility to NYC private equity firm, Blue Wolf Capital, which was unsuccessful in renegotiating a wholesale rate from the BPA, which the BPA claims is due to their obligation to provide power to public customers first (Stang 2022).

The BPA rate increase between 1979 and 1983 due to the WPPSS fiasco was not received well by the aluminum industry (NWCouncil). The region's smelters, which were aging and lacked some modernized infrastructure included in new aluminum smelting construction globally, began to break long-term contracts with the BPA in order to access the wholesale power market, which included investor-owned (private) power companies. In response, the BPA reduced the quantity of power it supplied to the smelters, in 2000 to 40 percent or 1,425 MW, of the previously contracted amount (NWCouncil). This was also in part due to the West Coast Energy Crisis and drought conditions, pushing into the light the fraying relationship between the BPA and the aluminum industry.

The California or West Coast Energy Crisis of 2000-2001was the result of a confluence of problems, from California's deregulation of the wholesale electricity market, increased cost of natural gas, and a drought which reduced the hydroelectricity generation in the Pacific Northwest (Editorial Board 2001; Weare 2003). California Assembly Bill 1890, or the Electric Utility Industry Restructuring Act, deregulated electricity markets within California (Anon n.d.-c). The main provisions of the Act were allowing wholesale power customers to buy power in an open market rather than from districted power utilities, a creation of a state-wide transmission system operator, and the creation of a Power Exchange, intended to "operate like a commodities market where power producers will complete to sell their electricity generation in response to bids submitted by buyers" (Anon n.d.-c). These changes went into effect March 31, 1998. For the first year or two, the new system seemed to be working. However, by 2000, California was experiencing brown outs due to insufficient energy supply, as energy prices increased and power producers limited production or left the market all together.

The crisis drove the wholesale power prices renegotiated in the Northwest Power Act (1980) aluminum smelters now relied on up by factors of ten, twenty, or more, and by the summer of 2001 all ten PNW aluminum smelters were closed or idling production (NWCouncil). Both Alcoa and Golden Northwest Aluminum proposed building their own natural-gas plants in an effort to build an affordable power base for their operations in the region, but in negotiation with the BPA, discussions ended over issues of construction and power pricing (NWCouncil). Contemporary attempts to reopen the Ferndale, WA plant have leaned on the framing of the aluminum as "green," both in the sense of being powered by non-fossil fuels as well as the growing need for aluminum in electric vehicles and energy efficiency of conventional vehicles (Partlow and Mufson 2022). Though aluminum had been refined in the Pacific Northwest using hydroelectricity since 1939, firms now leverage their role in a capitalistic energy transition and climate mitigation to attempt to achieve the same public sponsorship that cajoled them into the region in the first place. However, there is an industry with a more spotless green image, which is more mobile and perceived as drawing more high-value jobs to the region: tech.

A Power Vacuum: A New Industrial Buyer

Data centers, including server farms, are among the world's largest consumers of electricity, composing of as much as two percent of the world's electricity use (Crawford 2021:43; Wang 2020:113). They are also a strategy for large technology corporations to reinvest capital into profitable activity, as these data centers are built with excess capacity intended for leasing by various companies. The arrivals of Google, Apple, Facebook, Microsoft, and Amazon data centers in the Pacific Northwest due to inexpensive electricity, water for cooling, cheap land, and "proximity to undersea networks" are "often accompanied by the promises of new jobs and a rhetoric of economic transition from forestry to data" (Levenda and Mahmoudi 2019:1). Thus, datacenters and cryptomining are but another set of industries drawn by cheap and abundant energy. However, as I trace below, there remains considerable interventions from the BPA and government agencies to entice these corporations to the region, rather than a naturalistic draw simply due to electricity prices.

The overwhelming basis of digital technologies overall and server farms in particular in fossil fuels is undeniable, and not reducible to electricity generation for end-use. Between 15% and 25% of the mass of most digital microelectronics are plastics derived from petrochemicals to serve as electrical and thermal insulators, their light-weight properties, and ease of casting specific parts (Taffel 2021). The number of diverse raw materials needed to produce electronics like the servers drawing from the Columbia requires enormous mining, transportation, and refinement operations in a global capitalist system overwhelmingly reliant on fossil fuels (Crawford 2021; Schinckus 2020; Taffel 2021). By 2030, as much as 21% of total global electricity demand will come from information and communication technologies, overwhelmingly from the infrastructure, extraction, and manufacturing upon which consumer electronics rely upon to function (Taffel 2021:8).

Though the complexity and intensity of material needs for electronics is mostly hidden from view in the Global North, as raw materialism suggests, this material intensity is reshaping global networks of exchange and power in support of continued capitalist expansion. In the Pacific Northwest, it must seem that the arrival of data centers in lieu of fading aluminum smelters is an economic and ecological improvement given the visual material intensity of aluminum by comparison. But as I detail further below, the data centers build upon the energy infrastructure and regulatory pathways paved by the BPA in partnership and support of aluminum.

Google opened its datacenter in the Pacific Northwest in 2006 at The Dalles in Oregon. Google’s website for this datacenter claims it chose The Dalles because it “has the right combination of energy infrastructure, developable land, and available workforce for the data center” (Anon n.d.-f). This was Google’s first server farm, built across the road from Northwest Aluminum’s idled smelting facility alongside the dam which drowned Celilo Falls (Strand 2008). While Northwest Aluminum employed 1,100 workers across the region at its peak capacity and used an average of 85 megawatts of power per facility, Google’s datacenter employees between 100 and 200 people while using about 103 megawatts of electricity (Strand 2008). Google only sited the facility in this location after securing a tax exemption, an assurance of cheap energy, and a city-built fiber-optic ring (Strand 2008). When the assurance of cheap energy was thrown in doubt by President George Bush's suggestion that the BPA be privatized under the Energy Policy Act of 2005, Google had a conference call with the BPA and Oregon Republican Representative Greg Walden, after which Walden publicly stated the privatization would not go through. In 2016, Google purchased 74 acres from Northwest Aluminum for future expansion of their data centers (Levenda and Mahmoudi 2019).

Twitter opened a data center in Sacramento to host its own servers, in a similar era as the server farm building along the Columbia. In the fall of 2022, this server was knocked offline due to extreme weather, and Twitter has since closed this data center in favor of renting server space from other data centers, possibly from Amazon, possibly from data centers along the Columbia (Marcelline 2022; O'Sullivan, Fung, and Lyngaas 2022). Some 40 to 60 percent of all traceable internet traffic can be attributed to rented server space, which is a strategy of big tech to diversifying profitable activity (Wang 2020:81). Amazon launched its first data center in Oregon along the Columbia in 2011 (Anon n.d.-d). Notably, Twitter was criticized for its lack of redundancy, which lead to the failure of the Sacramento data center affecting user access to Twitter (O'Sullivan et al. 2022). Redundancy may make for better data storage, communication, and information security, but it requires even more resources in line with the maximalism of the tech industry's approach to both software and hardware infrastructures (Crawford 2021).

Though many of these data centers are located in Oregon, where residential electricity is overwhelmingly sold by private utilities while Washington is majority public utilities, the BPA's ability to sell directly to large industrial users permits these datacenters to bypass private power utilities and access subsidized public hydropower. The dominance of public utilities in Washington is unique in the U.S., where as of 2022, 70% of residential electricity customers bought power from investor-owned (private) utilities (Luke and Huber 2022). Additionally, aluminum companies in the region were critiqued for bringing relatively few jobs in comparison to their energy consumption and broader environmental intensity, the maximum employment in Washington for the industry at its peak was about 11,000 workers (Herman 1952; Voller 2010). In comparison, each data center employs about 100-200 workers, meaning it would take 55 to 110 data centers to employ the same number of people as at the peak of the aluminum industry, though data centers are nearly equally as energy intensive (Anon n.d.-f; Strand 2008).

Data infrastructure, like much energy infrastructure, are often placed far from population centers. This has been described as a purposeful strategy towards amnesia or 'blindness,' obscuring the material nature of digital technology (Crawford 2021:45). While this is a salient implication of the remoteness of these infrastructures and may be a hinderance to direct political action and consciousness, there is a distinct foundation in the political economy of energy intensive industries which further explains the geographies of extraction.

Server farms, cryptomining, and other electricity-intensive industries tend to end up in areas of cheap power and public incentives. In the Pacific Northwest, this happens to be hydroelectricity. However, this is not the case in all places. In some places, in fact, in many places, that is likely to be fossil fuels. The industry growth and profit borne on the shoulders of public investment in hydroelectricity in the Pacific Northwest empowers these Big Tech corporations to expand in the ever-accelerating cycle of capitalist expansion. How clean is hydropower in this context?

Certainly, the enormous energy consumption of computational technologies, server farms, and cryptocurrency mining is a concern at a global level given the involved emissions and the scale at which they occur. However, there are also important direct and local effects of electricity-extractive industries which are changing the infrastructural geographies of the rural areas they occupy. While data centers leverage their corporate size to procure tax breaks, federal loans, and other forms of public assistance, they are mostly building on the existing infrastructure, including transmission lines, of vacated aluminum in the region. Cryptomining, however, tend to be smaller operations with similar needs but less corporate leverage. However, being a large energy consumer can be enough to leverage public investment in critical infrastructure, though there has been more over resistance from residents and local governments to cryptomining in general than against data centers.

Bitcoins are ‘mined’ through computational processing, an energy intensive process that becomes more intensive over time. Bitcoin, like other cryptocurrencies are based on the idea of “distributed consensus,” such that no one entity or authority holds a secret ledger of exchanges and balances. Therefore, the creation of new Bitcoin (of which there will be a finite quantity, unlike conventional fiat money), requires a computational process, of which the most intensive is awarded the newly mined Bitcoin. This calculation is called proof-of-work, and “it is based on the unique hash value associated with the transactions in each block, and it’s deliberately designed to tax computational resources by consuming as much electricity as possible” (Greenfield 2018:128).

The maximalism of this process encourages the most intense use of material resources in the form of electricity, as the days of mining Bitcoin on a home computer or DIY systems are over. There are now specialized mining hardware setups called application-specific integrated circuits, or ASICs, which are energy intensive both in computation and in cooling costs (128). This scale has driven mining operations to places, like Washington state, with low electricity costs.

Bitcoin and other cryptocurrency mining, unlike aluminum smelting facilities and to some extent unlike server farms, can be shut off more or less at will. This is a lucrative feature of these facilities. Though mining projects in some areas of the Pacific Northwest have forced investment in grid infrastructure and transmission lines, cryptomining facilities can be paid large sums of money by public utility companies to stop consuming power (or continue consuming power) to alleviate stress on the grid of too little or too much demand for electricity (Dance, Wallace, and Levitt 2023; Greenberg and Bugden 2019; Lally, Kay, and Thatcher 2019).

Through renting storage space to individual cloud computing customers or corporations like Twitter, or through the production of currency through the useless transformation of electricity, data centers and cryptomining represent the deepest commodification of the uncooperative commodity. These operations are still catered to by public utilities and the BPA due to the continued need for reliable base load customers. Their conversion of electricity to profit certainly still has complex, perhaps even more complex, material intermediaries in the form of servers and electronics than their aluminum predecessors, but this reality is obscured – and obscuring these connections is key to commodification.

Discussion and Conclusions

Industrial power customers were actively supported, enticed, and lured through public assistance to the Pacific Northwest, led by the BPA. By doing this, the BPA ensured a base of power demand, integral to their early survival as an institution, and maintained power supply under the existing grid infrastructure and financial regimes. This troubles the idea that cheap and abundant electricity alone lured the aluminum and tech industries to the region. Electricity generation, transmission, and growth is an end in its own right for the BPA and the region, ensuring revenues for the agency through electricity provision for private capital accumulation. These dynamics severely challenge the further integration of renewable energies in the region, will be exacerbated by climate change, and draw attention to the interlocking struggles for energy justice.

Climate change will have an impact on the variability and availability of hydroelectricity in the years to come. The BPA has already identified climate change signals in streamflow, snowpack, and temperatures in the region, and they predict wetter winters and drier summers, exacerbating the seasonal variation in hydroelectric capacity (Bonneville Power Administration 2022). This increase in variation will further underscore hydroelectricity as a variable, rather than base, source of power in the region, renewing the fuel mix logics above. Additionally, these climatic changes will also affect other regions with grid interties with the Pacific Northwest, notably the Southwest and California, where the hydroelectricity capacity will be severely affected by climate change in hydrological cycles (Voisin et al. 2020).

Given the shift of hydroelectricity to variable rather than base load power, the relationship between hydroelectricity and other fuels has changed moving forward. As wind electricity generation capacity began being installed in the Pacific Northwest in 2005, the BPA struggled to balance generation load with the new, variable renewable energy source. In the spring of 2011, there was a large snowmelt which led to an 'oversupply' of hydroelectricity, prompting the BPA to ask wind farm operators to curtail generation. The wind farm operators sued, citing the BPA's obligation to transmit power even from private generators, and a federal ruling mandated that the BPA pay those they ask to curtail production (van der Voo 2011). Some commentators in the region suggested the BPA try and curtail thermal generation and invest in power storage to integrate new renewable energy sources. Additionally, using excess hydropower in times of high water and oversupply is necessary to avoid further damaging fish populations from spilling water over the top of the dam (Anon n.d.-g).

Scholars addressing the growing permeation of AI tools into our lives call for greater democratized decision-making, as well as abstinence from applying these technologies into some areas of our lives, i.e., policing (Crawford 2021). Similarly, we need the control over energy infrastructure to be centered on collective decision making, rather than ostensibly public utilities beholden to private interests. Public understanding of utilities as monoliths unconcerned with energy equity and democratization resist efforts to implement technologies such as smart meters, intended to improve utility data of minute change sin energy use to better integrate variable energies (Kallman and Frickel 2019). This reveals a deeper gulf between people and the regulatory agencies with restructuring power. If the public were able to be as influential a block of electricity users via political power rather than simply energy intensity, utilities would be forced to recommit to their mandates to prioritize the public interest rather than private profit.

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Conclusion

This dissertation examines the relationship between low-carbon energies, fossil fuels, our system of production, and the social inequalities this production system has produced and shaped. These inequalities, critical for the continuance of our productive system, shape our attempts at social change including social change addressing climate crisis. Furthermore, this dissertation examines the narrative and reality of history, focusing on the ways in which we explain change and growth in the face of observable contradictions. This is particularly prevalent in the tracing of ecological and technological change.

In Chapter 1, I ask how the displacement of fossil fuels with low-carbon energies may vary based on a nation's position in the capitalist world-system. Previous research has observed no overall displacement of fossil fuels with their alternatives at the global level. I find that semiperiphery nations, the intermediary position in a three-tier world-system, seems to be displacing fossil fuels at a greater rate than core or periphery nations. I suggest this may be due to domestic elites acting in alignment with domestic interests and growth in an effort to disentangle from core-dominated global production and trade in fossil fuels. The world-systems position measure I use is a measure of global trade integration as a measure of relative (economic) power between nations. This paper was motivated by an interest in how historical inequalities between nations persists in our interrelationships and may be a barrier to nations addressing global climate change. An additional insight from this chapter is the lack of evidence for a difference between periphery and core nations. This is consistent with theories of dependence and unequal (ecological) exchange, where peripheries are sites of extraction which maintain the core, meanwhile undermining periphery nations' abilities to subvert dominant economic and ecological regimes.

In Chapter 2, I ask how the relationship between GDP per capita and carbon emissions may vary based on domestic landscapes of inequality. Previous research has found that economic inequality, gender inequality, and colonial histories all influence or mediate the relationship between economic growth and ecological outcomes. I suggest that these inequalities are not formed or shaped through independent social forces, but rather have related etiologies and therefore we may expect a combined effect. I create a combined measure of economic inequality, gender inequality, and colonial history, and found that there may be a small amount of combined effect of these landscapes of inequality on carbon emissions, as well as variation in the coupling of economic growth and carbon emissions by these characteristics.

In Chapter 3 I present a historical analysis of the energy system of the Pacific Northwest, tracing how a region shifted from a primarily low-carbon-fueled economy to consuming nearly equal proportions of hydroelectricity and fossil fuels while highlighting the current relatively large proportion of hydroelectricity as an accomplishment towards sustainability. I trace industrial users of power in the region from aluminum to data centers, and the efforts of government agencies to cultivate a regulatory environment to entice those industries to the region. This history challenges the idea cheap and abundant electricity is sufficient to 'draw' industry to the Pacific Northwest and highlights the ways in which this 'cheapness' is facilitated by state action. Furthermore, this story complicates the narrative that growth is a natural course for history and supply follows demand. These features illustrate some mechanisms behind the displacement paradox in this instance, where new substitutes for a particular commodity do not necessarily replace incumbent commodities and may even grow total consumption.

Like all work, there are things left out of this dissertation. Most glaringly, perhaps, is the omission of the role of the U.S. state as a settler colonial state in Chapter 3. Various state actors, including F.D.R., actively framed the Pacific Northwest as a 'last frontier.' Therefore, though there was 'no one' to use the electricity generation capacity being installed in the late 1930s, the project was labeled development of a frontier for white settlement, and development was a sufficient justification for the expenditure. If we return to the quote from F.D.R. from a speech he gave in Spokane in October of 1937:

> "There are parts of this Nation that are not as favored as the Northwest. Mistakes have been made. They have cut off their timber. Their land is played cut, or they plowed up prairie land which is now blowing away. I am thinking about those people as well as you people. You have got room for them here in the Northwest where they can make homes, where they can live happily and prosperously" (Roosevelt 1937: 994).

It is interesting that F.D.R. frames the Dust Bowl and other such results of intensive farming as 'mistakes,' here, as the retrospective explanation seems to focus on these events as ecological disasters and naturalizes them. However, as has been pointed out, these events pushing populations west are due to the connections between natural systems and social systems such as imperialism, settler colonialism and capitalism (Holleman 2017). Furthermore, dam building in the Pacific Northwest, exemplifies the rise of twentieth century technocratic management on the part of the federal government which is a feature critical for understanding the mechanisms of ongoing settler colonialism (i.e., Vinyeta 2022). I omitted these discussions given that I feel they constitute an entire paper-length chapter, thus I chose to focus more narrowly on the economistic dynamics of the electricity system in the region in Chapter 3.

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