International Trade, the Environment, and Networks: Building Relational Understandings of Global Environmental Problems

by

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DISSERTATION ABSTRACT

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Title: International Trade, the Environment, and Networks: Building Relational Understandings of Global Environmental Problems

This dissertation uses social network analysis to integrate the relationality of nation-states more fully into quantitative macro-environmental sociology. Specifically, I am interested in the following questions: How can social network analysis help develop more relational understandings of global environmental problems? And, how does global trade network position and integration provide meaningful contexts for better understanding relationships between domestic economic and technological factors and emissions? I answer these questions by conducting empirical investigations of case studies such as global end-of-life vessel exchanges; global crude oil extraction, trade position, and oil-related emissions; and the effects of global economic integration for renewable energy effectiveness in reducing emissions.

I argue that methodological approaches incorporating network methods have important substantive implications for macro-environmental sociological questions. For ecologically unequal exchange theory, use of network simulations shifts the focus from value of commodities exchange to tie centralization, potentially a useful approach for understanding the global organization of disposal-side trade relations, which may involve only a few sites. Moreover, and perhaps more importantly, operationalizing the theory using network methods to classify countries based on trade position emphasizes extractive sites through trade relationships, more in line with the underlying theoretical foci relative to conventional approaches emphasizing national income bifurcations and export intensity to high income nations. For research on the

economy-environment relationship, I depart from the vast majority of work that focuses on domestic measures, most significantly economic development. By employing network methods, a relational measure of international trade integration is produced, centering the research design not on the expansionary tendencies of capital, but rather on national integration into its global expansion. In this way, a novel conceptualization is applied to the question of the circumstances or contexts in which renewable energies reduce emissions. The use of network methods innovates research designs within quantitative macro-environmental sociology, more fully integrating the relationality of nation-states in the global economy and expanding the research space to ask questions surrounding how national positionality in trade networks modifies the effect of social, economic, and technological factors on environmental change.

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CHAPTER I: INTRODUCTION

This dissertation engages questions pertaining to major topics in environmental sociology. Namely, how can social network analysis help develop more relational understandings of global environmental problems? And, how does global trade network position and integration provide meaningful contexts for better understanding relationships between domestic economic and technological factors and emissions? I investigate these questions in several empirical settings: the global ship scrapping industry; global crude oil trade position and oil extractive dependence; and global trade integration and national renewable energy consumption. In general, I argue that sociological assessments of ecologically unequal exchange specifically, and quantitative macro-environmental sociology more generally, would benefit from fuller incorporation of network methods, especially as it relates to national positionality in trade networks.

For over four decades, macro-environmental sociological research has shed insight into how modes of economic activity, technological innovation, and the international structure of nations shape environmental outcomes. Several debates and questions animate the subfield, such as: What factors contextualize the relationship between technological innovation and environmental change? How does economic dependence on resource extraction influence resource consumption and environmental degradation? And, how does the international structure of nations shape environmental outcomes cross-nationally? A variety of theoretical perspectives inform empirical research that seeks to address these questions. Treadmill of production theory and related ecological Marxist traditions draw attention to the irreconcilability between the capitalist system's insatiable need for economic growth on a planet with finite natural resources (Foster 1999; O'Connor 1998; Schnaiberg 1980). Ecological modernization theory highlights the practical pro-environmental changes that can take place within our current economic setting, including but not limited to institutional reform toward environmental ends, technological innovation, and global exchange of environmental information and practices, all of which function to (potentially) “green” the economy (Mol 2001; Mol and Sonnenfeld 2000). While ecological Marxist traditions and ecological modernization theory understand the relationship between economic development and environmental degradation to be largely influenced by domestic factors within countries, ecologically unequal exchange theory holds that relations between nations through international trade linkages (among others) promote particular development and degradation trajectories depending upon a nation’s position in the world-system (Bunker 1984; Hornborg 2019; Jorgenson 2006).

My research broaches several of these questions, stemming from a simple observation: states are connected to each other via international trade. This observation is central to a variety of social scientific traditions (Chase-Dunn 1998; Galeano 1973; Giddens 2003; Wallerstein 2011). However, the methodological intimation from this observation is rarely incorporated in studies on cross-national environmental outcomes within sociology, as national income bifurcations tend to be employed over national trade position/integration (e.g., Jorgenson 2006). My dissertation project uses network methods, whose main focus is the relationality between actors, to more closely pay attention to interactions between states in the global economy, and the attendant implications for debates and questions fundamental to the subfield of environmental sociology.

Environmental Sociology: Longstanding Debates, New Approaches

The origin of environmental sociology is well-documented (e.g., Gramling and Freudenburg 1996; York and Dunlap 2019), sketched by the foundational work of Catton and Dunlap (1978) situating the social world within its broader ecological context and underscoring the importance of investigating the complexities and implications of bidirectional society-nature relations. The subfield has drawn attention to a variety of issues, including but not limited to how economic development and technological advances produce and/or mitigate environmental harm, uneven exposure to environmental harms and involvement in environmental decision-making along economic, racial/ethnic, and gendered lines, and ways of understanding how environmental trajectories are shaped by the global economy.

Scholarly work on the human drivers of environmental change tends to focus on dynamics within nations that contribute to or mitigate environmental degradation. Treadmill of production theory focuses on how, within a capitalist economic system, business interests and shareholder activity are geared toward economic growth and expansion, without consideration of the social and environmental costs of doing so. Business operations adopt more capital-intensive equipment through time, resulting in more chemical use and pollution to accelerate production, increase profits, and decrease labor costs (Schnaiberg 1980). Explicitly, treadmill of production theory conceptualizes a warehouse model of the environment, where resources are taken from it ("withdrawals") and pollution is added to it ("additions") as a consequence of industrial activity (Schnaiberg and Gould 1994). Empirical research in the tradition uses economic development as a proxy to capture the relative extent to which geographic units (e.g., countries; counties) are participating in the "treadmill," in other words, pursuing economic growth for its own sake without a consideration of the social and environmental consequences of such activity (e.g., Jorgenson and Clark 2012; York, Rosa, and Dietz 2003).

In contrast to treadmill of production theory, ecological modernization theorists seek to address ways in which sustainability can be achieved within the prevailing economic structure.

As Mol (2002) argues, ecological modernization is about “the centripetal movement of ecological interests, ideas and considerations in social practices and institutional developments” (93). Through an ecological rationality, institutions and markets can be structured toward environmental ends: adjusting the “rules of the game” to include and privilege environmental interests may quell some of the more detrimental tendencies of economic growth (Mol 2002; Spaargaren and Mol 1992). Drawing on the technological optimism of Joseph Huber (Mol and Sonnenfeld 2000:4) and the capacity for reflexivity within modernization processes (Beck, Giddens, and Lash 1994), ecological modernization ultimately contends that institutional changes, technological advances, and the diffusion of ecologically conscious worldviews may produce beneficial outcomes in a modernizing world (Mol 2002). Moreover, globalization may encourage the spread of pro-environmental practices, such as the transfer of technologies and ecologically responsible regulations cross-nationally (Mol 2001). In the empirical literature, ecological modernization is often operationalized as an environmental Kuznets curve, or an inverse-U shaped relationship between economic development and environmental harm (Stern 2004). In other words, as nations modernize and reach economic maturity, ecological considerations become built into economic expansion and governance, thus resulting in a diminishing ecological impact.

Juxtaposed to treadmill of production and ecological modernization theories, ecologically unequal exchange theory understands the environmental conditions of nations as the product of relations between nations historically and contemporaneously. Bunker’s (1984, 1985) foundational work on the Amazon Basin and its extractive export economies in timber and rubber to meet demands from the world system grounds the theoretical anchor in inequitable flows of energy and matter from state to state. Bunker (1984) maintains that the expansion of extractive activity to meet specific commodity needs is connected to the construction of built infrastructures to support that extraction, which subsequently constricts developmental pathways, intensifies economic reliance on extraction, and increases environmental degradation. While the theoretical underpinning of ecologically unequal exchange focuses on how the international structure of nations in particular commodity trades influences related environmental degradation in extractive export zones, empirical research in sociology largely examines how trading from lower income nations to high income nations increases degradation in the former (Jorgenson 2006, 2012; Shandra, Shor, and London 2009).

Quantitative research on the cross-national drivers of environmental change is strongly influenced by the stochastic impacts by regression on population, affluence, and technology (STIRPAT) approach to socio-environmental modeling (Dietz and Rosa 1994, 1997; York, Rosa, and Dietz 2003). Derived from the earlier IPAT (impacts by population, affluence, and technology) accounting-based method (Ehrlich and Holdren 1972), the STIRPAT approach enables hypothesis testing, easier interpretability, and a multiplicative relationship between variables (York, Rosa, and Dietz 2003). A significant body of research uses this general framework to study research questions pertaining to the human drivers of environmental change. Empirical work on ecologically unequal exchange, for example, uses the modeling framework to analyze the extent to which trade to high income nations contributes to environmental harm in lower income countries (Jorgenson 2006; Shandra, Shor, and London 2009). Greiner and McGee (2018) show how position in the world-system modifies the economic growth-carbon emissions relationship, showing that semi-peripheral nations, in their quest for modernization and development, tend to have a more consistent positive association relative to core and periphery nations. Others use the framework to better understand how issues such as technological innovation, domestic inequality, and economic growth interact to influence carbon dioxide emissions on national scale (McGee and Greiner 2019; Thombs 2017; York and McGee 2017). However, generally, research in this vein has yet to incorporate network analyses to better conceptualize how countries fit into the global economy, despite being prominently theorized in the subfield (Bunker 1985; Downey 2015; McMichael 2008).

Primarily, my interests lie at the intersection of social network analysis, international trade, and environmental change. While a large body of work examines domestic factors that contribute to or ameliorate environmental problems, fundamental debates and questions in environmental sociology could more extensively employ social network methods to situate and conceptualize nations' place in the global economy. As such, there is a limited body of research examining how oft-studied domestic processes (e.g., resource extraction; renewable energy implementation) interact with a country's position in the global economy to produce particular environmental outcomes. I use network techniques to understand and conceptualize how nations fit into specific commodity trades and the global economy as a whole. I then see how these trade positions modify the effect of more conventionally studied factors, such as resource extraction and renewable energy consumption, on carbon dioxide emissions.

Social Network Analysis, International Trade, and the Environment: Theoretical and Empirical Considerations

Research at the intersection of international trade and the environment critically assesses stratification in global markets and yet, to a large extent, does not sufficiently capture relationality between nations methodologically. The theoretical underpinnings of ecologically unequal exchange, an approach commonly used when investigating the environmental implications of international trade within environmental sociology, emphasize the uneven relationships between colonized or exploited sites of resource extraction and the beneficiary consumer of those resources: "different regional levels of development result from the interaction between changing world demand for specific commodities and the local reorganization of modes of production and extraction in response to new or changing market opportunities and pressures" (Bunker 1984:1019). In other words, developmental levels of countries and regions are directly related to their relationships with other countries, particularly pertaining to the types of commodities exported and the associated forms of productive activity to enable those exports.

The prevailing methodological schema for analyzing ecologically unequal exchange, however, does not locate sites of resource extraction inductively in trade networks, instead opting for a formulation that samples lower income nations and assesses how relatively more trading to high income or more-developed nations contributes to related forms of environmental harm (Jorgenson 2006, 2012; Noble 2017; Shandra, Shor, and London 2009). While this form of analysis has shed considerable insight into how international economic stratification shapes environmental outcomes in lower income nations, it does not capture the relational nature of ecologically unequal exchange. Focusing on national income classifications privileges bifurcations of affluence and international economic stratification but fails to consider a nation's position in the trade network, and thus the central exporters or importers to the trade network as a whole. Resource frontiers are not identified nor are the domestic consequences of serving as a resource frontier assessed. As such, methodological innovations that explicitly consider whether a country functions as a resource frontier or a consumer is imperative to the literature on ecologically unequal exchange.

In parallel, world-systems theory and related analyses of global capitalism, despite being an important forebearer to theoretical traditions like ecologically unequal exchange and part of the general neo-Marxist orientation that grounded early environmental sociological research (Downey 2015; York and Dunlap 2019), is rarely emphasized in macro-environmental sociological research methodologies. World-systems theory understands the global economy as consisting of three zones: the core, periphery, and semi-periphery. The core enjoys the benefits of historical imperialism, has high-technology production and sophisticated manufacturing; the periphery suffers from legacies of colonization and generally engages in resource extraction and simple manufacturing processes; and the semi-periphery acts as an intermediary zone that is rapidly industrializing but still not as developed or powerful on the international stage as the core (Wallerstein 2004). A wealth of research examines international trade networks (at least in part) to understand the global economy in world-systems terms (Clark and Beckfield 2009; Mahutga 2006; Mahutga and Smith 2011; Snyder and Kick 1979), using a variety of network techniques known as blockmodels.

Blockmodels are a general suite of social network approaches that analyze what positions actors occupy in the network at large. There are two fundamental dimensions that blockmodels address: "identifying social positions as collections of actors who are similar in their relations with others, and modeling social roles as systems of relations among actors or among positions" (Faust and Wasserman 1992:6). Two commonly used blockmodeling techniques are structural and regular equivalence. Structural equivalence identifies actors in a network that share the same types of ties with the same actors (Faust and Wasserman 1992). To illustrate, consider a hypothetical international aid network, where the U.S. gives assistance to France and Belgium and Canada gives aid to the U.K. and Spain. France and Belgium, and the U.K. and Spain have structural equivalence in that they have the same type of relation to the *same actors*: Each country pair (France and Belgium; U.K. and Spain) has a tie to the same donor country (the U.S.; Canada). Given the rather stringent nature of structural equivalence, a more generalized approach is regular equivalence, considering the extent to which actors in a network share the same types of ties to other actors that occupy the *same role or position* (White and Reitz 1983). To demonstrate the difference from structural equivalence, donors and donees across groups would have regular equivalence (they occupy the same position/role), but not structural equivalence (they do not share ties with the donor/donees): France, Belgium, the U.K., and Spain are all donees, and therefore are regularly equivalent in that they occupy the same role, but are not all structurally equivalent, as they do not all receive aid from the same source.

In analyzing international trade relations, it is important to consider how roles in the global economy are conceptualized in the case at hand. Ecologically unequal exchange theory is, at times, concerned with specific commodity trades and how resource frontiers in the global economy may suffer social, economic, and environmental costs from supplying the world system (Bunker 1984; Hornborg 2019). Put in network terms, identifying countries in commodity trade networks that consistently send a large quantity of extracted resources would be ideal to empirically capture which countries serve as resource frontiers. Given regular equivalence's focus on social roles/positions in networks, it is well-suited to evaluate such trade networks. Setting minimum dollar benchmarks is commonly performed in the research area (Clark and Beckfield 2009; Jorgenson et al. 2022) to ensure that regular equivalence procedures and related techniques are conducted over meaningful trade ties. I contend that using regular equivalence procedures over benchmarked binary trade networks for specific extraction-related commodities enables an inductive approach to assess countries' positions in trade, a conceptual and methodological improvement over the prevailing trade metrics (e.g., Jorgenson 2006) and high income/lower income bifurcation of data.

A wealth of research uses social network analysis to shed light on the structure of the global economy. Several studies use all trade flows and network approaches to construct world-systems typologies consistent with its theorized three-tiered system (Clark and Beckfield 2009; Snyder and Kick 1979). Other studies, perhaps more in line with world-systems emphasis on relations between production processes (Wallerstein 2004), disaggregate trade data to assess which modalities of economic activity take place in which nations and how these zones relate to each other (Mahutga 2006; Mahutga and Smith 2011). Analyses using all trade flows and not disaggregating into commodity types more accurately could be considered as capturing relative integration in the global economy in that countries more central to global trade are perhaps more important for the functioning of global capitalism. In this way, the use of aggregated trade data may be better suited toward understanding which nations are more central to the global economy, while the use of disaggregated trade data may more closely attend to the theoretical underpinnings of world-systems analysis that highlight relations of production globally.

Network methods, including but not limited to positional analyses such as regular equivalence, would benefit the subarea of the cross-national drivers of environmental change within environmental sociology by more closely attending to the relational nature of international trade. Conceptualizing nations as part of larger positions in commodity-specific trade networks more closely adheres to theoretical traditions such as ecologically unequal exchange. Constructing measures of global economic integration via international trade flows that are consistent with the years being investigated more accurately depicts the status of nations during that time frame relative to studies that use typologies constructed elsewhere that only include part of the data's timespan (e.g., Greiner and McGee 2018).

Of course, I am not the first to apply network methods to important questions in quantitative macro-environmental sociology. In particular, Christina Prell and Colleagues' work examines how world-system position influences cross-national pollution burdens and wealth accumulation as a consequence of U.S. consumption (Prell et al., 2014) and how integration in trade networks in total, and as importers and exporters, influences sulfur dioxide emissions and wealth through trade (Prell 2016) and carbon exchanges (Prell and Sun 2015). My dissertation builds on and departs from this work as it seeks to classify countries categorically in positional (e.g., import-oriented; export-oriented) or central (e.g., most integrated; least integrated) terms, and to see how these contexts modifies the effect of domestic factors on emissions.

Dissertation Agenda

The domestic factors that influence degradation and emissions, especially those derived from STIRPAT, have been well-analyzed. Yet, in environmental sociology, appreciation for the international structure of nations and global economic networks have just begun to be explored in the context of how they modify the effect of these factors on environmental change. Moreover, work on global environmental inequality typically examines extraction, production, and consumption linkages, perhaps occluding how end-of-life commodities fit into our understanding of the ways in which global economic inequality shapes environmental change. My dissertation project seeks to further research on international trade and the environment in sociology by using social network analysis to descriptively assess disposal-side trade relationships and to place countries into relative positions in the global economy. Below I summarize the research plan for each chapter to follow in this project.

The second chapter of this dissertation project empirically assesses the transboundary movement in end-of-life vessels. While environmental social scientists have provided valuable case studies in the political economic context of ship recycling and the environmental impacts in recycling hubs (Demaria 2010; Frey 2015), I employ data from NGO Shipbreaking Platform to describe trends in ship ownership, flag state, and destination countries, and use network simulations to establish the preferential status of a few hubs of recycling, suggesting that the global shipping industry relies upon a few sites for waste disposal. Attention is also paid to the role of national economic growth in the expansion and entrenchment of the ship recycling sector in certain economies, as needs for steel enable built infrastructure projects.

The third chapter provides a novel methodological schema for empirically assessing ecologically unequal exchange theory. Jorgenson (2006) pioneered an operationalization of the theory via the construction of "weighted export flows" to capture the relative extent to which a lower income country exports to wealthy nations. Subsequent empirical work uses similar methods to address ecologically unequal exchange, with several important refinements (e.g., Jorgenson, Austin, and Dick 2009; Noble 2017). Bunker (1985) theorizes unequal ecological exchange as a process whereby the world economy relies upon certain sites for specific resource extraction, in so doing fostering a built infrastructure and economic dependence on that extraction, resulting in a lack of economic diversification and increased environmental costs. Analyzing the global crude oil trade, I use network methods to place countries into positions as export-oriented, import-oriented, or well-integrated in the global oil trade network. Using these positions, I explore whether export-oriented nations have intensified oil-based emissions as a consequence of extractive oil dependence relative to other oil trade orientations. I argue that this method more closely adheres to the theoretical underpinnings of ecologically unequal exchange theory in that it captures both international (trade position) and national (extractive dependence) dimensions of the theory, and that it inductively locates extractive export economies as opposed to *a priori* assuming that lower income nations serve as those sites.

The fourth chapter draws attention to how integration in the global economy shapes the extent to which renewable energy consumption reduces carbon dioxide emissions. The drive for growth within our economic system has shown to produce paradoxical relationships between renewable energies and emissions (e.g., Thombs 2017; York and McGee 2017). Yet, in the context of integration in the global economy, one might expect more central countries to serve as diffusion sites for green energies and technologies, and thus have more emissions reductions from renewable energy consumption (e.g., Mol 2002). On the other hand, countries more central to the global economy may be more entangled within global capitalism, and thus in infrastructures, lifestyles, and systems that necessitate fossil fuel usage (Malm 2016). I use network methods to place countries into positions in the global economy using total commodity trade data and see whether national integration in international trade modifies the effect of renewable energy consumption on emissions. Acknowledging the global dimensions of capitalism may illuminate logics of capital that sole focus on growth and expansion tendencies occlude.

The final chapter concludes with the empirical contributions this dissertation project makes to the field of environmental sociology in general, and research in the subarea of cross-national drivers of environmental change in particular. I highlight the promise and benefits of using social network analysis to understand national positionality in the global economy, and how this more closely pays attention to some of the theoretical expectations in environmental sociology relative to current operationalizations.

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CHAPTER II: SHIPBREAKING AND ECOLOGICALLY UNEQUAL EXCHANGE: TRADE DYNAMICS AND NETWORKS OF END-OF-LIFE VESSELS

Abstract

Ship breaking is the practice of dismantling end-of-life vessels for metals and other valuable materials. In the process, workers in the ship breaking industry endure serious, and sometimes fatal, accidents, as well as exposure to an array of hazardous materials. Sociological theories of global environmental inequality, such as ecologically unequal exchange, posit that international trade relationships satisfy the natural resource consumption demands of high-income nations while contributing to socioenvironmental harm in lower-income nations. Ongoing work on framing and conceptualizing waste as resources questions the assumed linearity of theories like ecologically unequal exchange. Instead, this body of research promotes reuse and recycling of end-of-use commodities as essential for a more sustainable commodity lifecycle. I analyze the global trade in used ships to illuminate how these insights are not mutually exclusive, as inequality, recycling (in this case, ship breaking), economic development, and socioenvironmental harm intersect in trade. I use data from NGO Shipbreaking Platform from 2014-2020. This research suggests that inequality may endure in sustainability strategies, as the benefits and costs embedded in commodity lifespans are unevenly distributed cross-nationally.

Introduction

Ship breaking, or the practice of dismantling vessels at end of use for scrap metals, has occupational health consequences as many workers in nations such as India and Bangladesh endure accidents that cause injuries and death according to journalistic accounts (Taylor 2014; Vidal 2017). While valuable materials, such as steel, are extracted during the dismantling process, so too are hazardous materials, including asbestos and oil (Islam and Hossain 1986; Zhijie 1988). The adverse occupational and environmental health implications of the industry due to environmental hazard exposure, lack of safety equipment, and poor working conditions are well documented in natural science literatures (Hossain et al. 2016; Neser et al. 2008; Wu et al. 2015). Environmental social science situates ship breaking yards into a global political economic context, analyzing how powerful nations export their used ships to "waste frontiers" like Alang-Sosiya, India and Chittagong (Chattogram), Bangladesh (Frey 2015), representing not only an externalization of ecological costs but also "accumulation by contamination" (Demaria 2010). Yet, associations between imported waste and economic development (e.g., Bai and Givens 2021) complicate the treatment of hazardous waste trades as solely an example of environmental injustice. As such, in this chapter I ask: how do exogenous national attributes (e.g., national income status) and endogenous network tendencies shape the global organization of ship scrapping?

Ecologically unequal exchange theory is commonly used to contextualize case studies of global environmental inequality in a political economic framework. Broadly, research on ecologically unequal exchange emphasizes that serial underdevelopment may not only be understood as uneven economic transfers (Emmanuel 1972), but also in an ecological sense as "unbalanced flows of energy and matter" (Bunker 1984:1018). The theory links modes of economic activity to the construction of built infrastructures to support that activity, influencing potential developmental pathways. Empirical work overwhelmingly addresses extractive economic activity in the Global South and the "vertical flow" of resources to the Global North, especially how primary sector trade exports (e.g., forestry; agriculture) to high-income nations contribute to deforestation in lower-income nations (Jorgenson 2006; Jorgenson, Austin, and

Dick 2009; Noble 2017; Shandra, Leckband, and London 2009). However, it is also important to examine how transboundary flows on the disposal-side of commodity lifespans are shaped by domestic economic development and the global political economic system. While prior work has attended to the dynamics of unequal exchange within the context of extraction-consumption exchanges, less has examined trades in hazardous waste at end-of-use. A notable exception is R. Scott Frey's work dealing with disposal-side trade in the world system, examining how powerful nations accumulate wealth and dispose of "anti-wealth" (i.e., waste) from and to lower-income countries on topics such as e-waste and ship breaking (Frey 1994, 2012, 2015). Recent quantitative work focuses on trades in wastes, specifically trades in plastic waste and e-waste (Bai and Givens 2021; Theis 2021). This chapter builds on research on ecologically unequal exchange by focusing on the practice of ship breaking, extending prior environmental social science work that examined specific import centers (Demaria 2010; Frey 2015) by analyzing the industry's global context. Specifically, I descriptively assess the main countries involved as owners, destinations, and flag states (countries responsible for regulatory compliance), and explore whether high-income nations use their advantageous position in global context to dump their end-of-life vessels on lower-income nations.

Methodologically, quantitative research typically measures associations between relative trades of a given commodity type to high-income nations and a measure of environmental degradation (e.g., Jorgenson 2006; Shandra et al. 2009). Refinements using this methodology have specified trade flows and/or forms of degradation (Jorgenson, Austin, and Dick 2009; Noble 2017) and trades to particular high-income nations (Huang 2018) and semi-peripheral nations (Shandra, Restivo, and Sommer 2019, 2020). Recently, heightened attention has been placed on what contributes to the formation of trade ties (Sommer 2020; Theis 2021) and the volume of exports and imports (Bai and Givens 2021). While social network analysis is used commonly in assessments of international trade structure (Snyder and Kick 1979; Nemeth and Smith 1985; Clark and Beckfield 2009; Mahutga and Smith 2011), it has only recently been adopted in analyses of ecologically unequal exchange (see Prell and Sun 2015; Prell et al. 2014; Sommer 2020, Vesia, Mahutga, and Bui 2023). This chapter uses descriptive analysis of trade flows and social network analysis to highlight key linkages in the trade and the role of flag states in perpetuating global environmental inequality. In so doing, I provide quantitative support for qualitative case study evidence suggesting inequities in the ship breaking industry (Demaria 2010; Frey 2015) and depart from other descriptive quantitative work (Wan et al. 2021) by anchoring the research design and aims in ecologically unequal exchange. Empirically, I contribute to the literature by (1) focusing on flows of end-of-life vessels, a hazardous waste and (2) using network analysis to highlight trade concentration. These analyses form the basis for my larger argument articulating how socioenvironmental inequalities coincide with the need for valuable materials (namely steel) and economic development in a few destination countries, and for understanding how generally benign environmental practices, such as materials recovery and recycling, may still involve severe localized costs.

This research was conducted using data from NGO Shipbreaking Platform (2021), a non-governmental organization bringing attention to the human rights and environmental consequences of shipbreaking and pushing for more environmentally sound dismantling processes. Given that public data on ship scrapping is difficult to obtain, I use NGO Shipbreaking Platform's data, despite potential shortcomings from using data from non-governmental sources. I summarize important, exogenous features of the trade, including beneficial owner nations, flag states, and destination countries. Then, I compare network simulations to observed ship scrapping networks to show the extent to which the trade is centralized to a few ownership and destination countries, capturing endogenous tendencies of owner-destination networks. This research investigates end-of-life vessel trade to further understand how recycling used materials, economic development, and the unequal world-system intersect.

Ecologically Unequal Exchange

The sociological theory of ecologically unequal exchange is derived from political economic theories of serial underdevelopment and dependency (Amin 1976) and world systems theory (Wallerstein 2004). Ecologically unequal exchange provides an environmental elaboration on earlier notions of unequal exchange emphasizing uneven trade relations in the international division of labor (Emmanuel 1972). Bunker (1984) is widely credited with developing unequal ecological exchange, using the Amazon basin as a case study to highlight how extractive export economic modalities in the region extracted rubber and timber, contributing to deforestation and fostering serial underdevelopment in response to world system demands.

Investigations in the research area also tend to focus on extractive economic activities and their consequences for environmental health. The "vertical flow" of resources from lower-income to high-income countries has consistently been shown to be linked to environmental degradation in the former (e.g., Jorgenson 2006; Noble 2017; Shandra et al. 2009). Relative exports to high-income nations of cocoa (Noble 2017), agricultural and forestry commodities (Jorgenson, Austin, and Dick 2009; Shandra et al. 2009; Shandra, Leckband, and London 2009), and mining in lower-income nations with repressive governance (Sommer, Shandra, and Coburn 2019) have been found to be associated with deforestation in lower-income countries. Indeed, high-income nations enjoy monetary benefits from uneven trade in ecological and labor terms, while lower-income countries serve as resource providers and suffer trade deficits (Dorninger et al. 2021), showing the unequal use of lower-income nations' environmental space (Rice 2007).

Developments in ecologically unequal exchange research shift the focus to the role of semi-peripheral countries, using social network analysis, and focusing on disposal-side commodity flows. Semi-peripheral countries, while functioning as sites of extraction for core nations, are able to leverage their advantageous position in the global economic structure relative to peripheral nations in ecological terms. For example, low- and middle-income countries trading more agricultural exports (Shandra, Restivo, and Sommer 2019) and forestry exports (Shandra, Restivo, and Sommer 2020) to China and more palm exports to India (Sommer, Restivo, and Shandra 2020) are associated with increased deforestation in the former. Focusing on how rapidly industrializing nations influence environmental harm in other low- and middle-income nations has proved useful for understanding the role intermediary positions in the world system play in perpetuating global environmental inequities. Yet, it may also be worth considering how processes encouraging economic development may incentivize imports to certain lower-income nations, despite the environmental consequences (Bai and Givens 2021; Pellow 2007; Theis 2021).

Network approaches to ecologically unequal exchange embed countries in trading relations. Sommer (2020) uses network analysis to show shifts in the forestry export network, as semi-peripheral countries play an increasingly important role over time, emphasizing the social connectedness of trade in environmental context. Prell (2016) shows how integration in the global trade network influences how much sulfur dioxide and wealth embodied in trade is experienced by countries. Similarly, Prell and Sun (2015) demonstrate that being more central to the global trade network and being an important importer is associated with having more carbon-intensive trade activity. In other words, the hierarchical structure of the political economic system fosters positions in trade networks which entrench exploitative relationships.

While the vast majority of empirical work in the field looks at extraction/production-consumption trade relationships, some have looked at disposal-side relationships. Frey critically investigated hazardous waste trades, such as e-waste (Frey 2012) and end-of-life vessels (Frey 2015), from a world-systems perspective, explicitly bringing disposal-side trade relations into theorization of unequal exchange. Frey (2015) emphasized that it is not only the "vertical flow" of resources from the periphery to the core (accumulation of wealth), but also the displacement of "anti-wealth," or hazardous wastes and production, from the core to the periphery (see Hornborg 2019 for a recent theoretical investigation), that constitutes ecologically unequal exchange. In other words, it is a relational process that (re)produces economic and environmental costs and benefits unevenly through the world-system and across commodity lifecycles.

End-of-Life Commodities as a Waste or Resource?

A growing number of studies in the literature on discarded commodity trades examine whether they are better understood as wastes or resources. The methodological and theoretical approaches regarding commodity lifespans often assume linearity (that commodities move along from extraction to production, consumption, and then disposal with no circularity), despite reuse and recycling of valuable materials being prevalent in the global production network (Lepawsky and Mather 2011). These processes allow for the extraction of valuable materials from end-of-lifespan commodities, especially materials that may be more depleted due to use by high-income nations. Evidence from empirical studies shows that popular understandings and media accounts of waste trades tell only part of the story, as the harvesting of used materials is a significant economic activity for some lower-income nations (Gregson and Crang 2015).

Yet, the discourse of discarded commodities as "resources" instead of "wastes" can also be analyzed as a tactic to reframe hazardous waste trades from global environmental injustice to part of a sustainable development effort (Lucier and Gareau 2015). In short, there are varying perspectives on whether discarded commodity trades represent sources of economic development and sustainable extraction or a global environmental inequality. In total, there is mixed evidence for a strictly "resource" or "waste" perspective on discarded commodity trades, perhaps highlighting that the need to recover used materials from high-income nations represents the troublesome reality of economic development for lower-income nations in an unequal world-system, and that ecological and human health consequences of recycling discarded commodities may co-occur with economic development.

Breaking Ships: Economy, Health, and Environment

Since comprehensive reviews of the process of ship breaking have already been outlined (e.g., Buerk 2006; Demaria 2010), here I briefly highlight relevant issues for materials recovery, economic development, and hazardous and unsafe labor conditions. At ship breaking yards in Bangladesh, India, and Pakistan, vessels are typically "beached" on shore. Beaching is the practice of grounding end-of-life vessels so that laborers can tear them apart. The disassembly process involves a variety of tools such as blow torches and hammers, as parts are dismantled and then removed by cranes and iron ropes (Demaria 2010; Taylor 2014). It is labor-intensive, and there is significant room for occupational injuries simply due to the nature of the work itself. There is additional harm due to the hazardous materials in ships such as asbestos, often used as insulation between walls near engine rooms and sold for repurposing in local communities (ILO 2021; NGO Shipbreaking Platform 2021), as well as heavy metals and oil (Islam and Hossain 1986; Zhijie 1988). Lack of proper safety equipment and training for workers and insufficient hazardous waste inventory by ship owners contributes to unsafe conditions for laborers in the industry and residents nearby (ILO 2021; NGO Shipbreaking Platform 2021).

Ship breaking is shaped by contingencies of economic development and includes environmental and human health consequences for those involved in the disassembly process. In other waste trades, such as electronic waste, modernization projects influence the extent to which nations import wastes as a means toward valuable materials collection (Pellow 2007). Parallel dynamics are visible in the trade in end-of-life vessels, which are primarily recycled to recover metals, namely steel. Materials recovery is a significant economic activity in some nations, particularly in the ship breaking industry, where up to 95 percent of a vessel can be recycled (Sujauddin et al. 2015). Indeed, given the opportunity for recycling, some have analyzed ship breaking as part of a circular economy, analyzing global environmental gains over localized costs (Rahman and Kim 2020).

In large part due to cheaper labor costs, less expensive (and less safe) methods of recycling, a high continental shelf enabling intertidal cutting and disassembly, and the need for materials recovery due to rapid urbanization, Bangladesh, India, and Pakistan are known as primary destinations for ship recycling (Sarraf et al. 2010). In this way, ship recycling provides an important function in national and local economies, as needed employment, metals, and other resources are generated that support construction efforts and therefore urbanization. To be concrete, materials recovery from the ship breaking industry in Bangladesh met more than one-third of the national demand for finished steel products in 2010 (Sujauddin et al. 2017), half of national steel production, and one-fourth of steel consumption in 2008 (Sarraf et al. 2010). Meanwhile, the industry in Pakistan contributes roughly fifteen percent to production and ten percent to consumption of steel in 2008 (Sarraf et al. 2010). India’s 2019 Recycling of Ships Act enabled its accession to the Hong Kong Convention (HKC), an international agreement that will regulate ship breaking globally when entered into force on June 26, 2025. This development brought HKC closer to being in force and signaled a willingness to invest in more environmentally sound recycling practices and equipment and encouraging more formal sector ship scrapping (e.g., Seetharaman and Katiyar 2019; Singh 2021). The industry in Bangladesh, India, and Pakistan is integral to overall economic activity, and supports modernization efforts.

While recycling may be of economic benefit for some nations, it is also indicative of an unequal world system whereby ship owners can externalize the human health and ecological costs of waste management to ship breaking destinations who must recycle the used goods of others for the purposes of materials recovery. The recycling of used goods entails significant damages to human and ecosystem health. For example, increased cancer incidence was detected among Taiwanese shipbreaking workers, especially for those who are responsible for cutting metals with torches (Wu et al. 2015). Additionally, ship breaking is one of the most dangerous industries in the world, with many fatalities resulting from poorly supervised working conditions, lack of safety training, and risks of explosions/fires (ILO 2021). Researchers have found that soil near shipbreaking yards have higher levels of heavy metals relative to other sites (Hossain et al. 2021), and even more soil contamination relative to industrial ones (Rahman et al. 2019). Air quality near significant shipbreaking yards in Alang-Sosiya, India (Basha et al. 2007) and Chittagong, Bangladesh (Nost et al. 2015) suffers as well. Coastal environments are perhaps most at risk from this activity, since ships are often beached on-shore and torn apart there (Barua et al. 2018). Shipbreaking activity adversely impacts local air, water, and soil quality, deteriorating local ecosystem health.

High-income countries such as Greece, Japan, Singapore, Hong Kong, Germany, South Korea, Norway, and the United States top the list of the world's leading ship owning nations, along with China, a rapidly industrializing nation (Wan et al. 2021). Beneficial owners of ships own the vessel commercially, and benefit/lose from its financial gains/losses. These nations may own the most ships, in other words, be the country of beneficial ownership, but are not necessarily responsible for regulatory compliance. These countries will often engage in practices to avoid international or national regulations, including flagging a near end-of-life vessel to another state, termed a "flag of convenience" (Frey 2015; NGO Shipbreaking Platform 2021). The flag state is the jurisdiction under whose regulations a vessel is registered and is responsible for regulatory compliance.

Often, flag states are tax havens (Galaz et al. 2018) or black/grey listed by the Paris Memorandum of Understanding, an international organization composed of North Atlantic nations (North American and coastal European countries) that track deficiencies in vessels and regulatory compliance (Paris MoU 2022). Black or grey listed flags mean that inspections of those flagged vessels typically have more deficiencies than expected (Paris MoU 2022). In short, the country of the beneficial owner who profits from vessels may not be the country responsible for regulatory compliance (the flag state), to avoid taxes and regulation. Not only do ship owners use flags of convenience, but when ships are at their end-of-life owners also seek out third parties, or cash buyers of scrap, to circumvent regulation and avoid direct contact with ship scrappers (Demaria 2010; NGO Shipbreaking Platform 2021).

Given the potential for local environmental hazards, global environmental benefits, occupational issues, and economic feasibility of ship recycling, international conventions have been adopted to regulate ship recycling and transboundary transfers of end-of-life vessels. The

International Maritime Organization's Hong Kong Convention (HKC), adopted in 2009 and entering into force in June 2025, addresses occupational and environmental concerns by mandating an inventory of hazardous materials (including volume and location) on-board, a ship recycling plan at each scrapping site, identifying worker training procedures, safety precautions, and environmental monitoring; the flag state is responsible for adherence to each measure (IMO 2009). The European Union's Ship Recycling Regulation (SRR), applied in late 2014, exceeds the measures adopted in HKC, requiring maintenance of an inventory of hazardous materials and ship recycling plan for each vessel to be scrapped. Additionally, a list of approved sites that were evaluated for sound occupational and environmental procedures and practices is provided for EU-flagged vessels; notably, recycling yards featuring the beaching method are excluded, such as those in India, Bangladesh, and Pakistan (European Commission 2023). While these international regulatory schemas stress the need for safe labor and sound environmental practices, placing the regulatory onus on flag states may function to perpetuate many of the troublesome practices in the ship scrapping industry.

According to ecologically unequal exchange theory, high-income nations use their advantageous position within the world-system to offshore environmentally harmful economic activity onto lower-income countries. Despite international environmental law designed to curb the transboundary movement of hazardous materials, enforcement in the realm of ship breaking is quite difficult due to complications concerning flag states and cash buyers, as well as verifying whether vessels are actually being sent to be scrapped or simply repaired (e.g., Alam and Faruque 2014). Ecologically unequal exchange theory and the challenges of enforcing and monitoring end-of-life vessels trade motivate the analytical objectives for the remainder of this chapter. First, I ascertain the central countries participating as ship owners and destinations for ship scrapping. Additionally, I consider the role of flag states, particularly the extent to which high-income nations use black/grey listed flags or tax havens when dumping end-of-life vessels onto the shores of lower-income nations for scrapping purposes. Finally, I compare observed owner-destination networks to simulated networks to identify characteristics consistent with network concepts.

Data and Methods

The data for this study was collected from NGO Shipbreaking Platform (2021). Annual lists are published every year that include ships scrapped worldwide. Information in the lists includes ship name, International Maritime Organization (IMO) number, beneficial owner, beneficial owner country, gross tonnage, year built, flag state, registered owner, registered owner country, and place of scrapping. Complete data regarding gross tonnage is available from 2014 onwards, and therefore I analyze these data from 2014-2020.

To describe trends in ship breaking, I establish leading countries in terms of destination countries, beneficial owners of vessels, and flag states by gross tonnage over time. Others have demonstrated the utility of visualizing the relationship between country of ship ownership, flag states, and destination countries using alluvial plots (e.g., NGO Shipbreaking Platform 2021; Wan et al. 2021). Likewise, I use alluvial plots to assess the extent to which tax haven or black/grey listed flag states are used by income classification. Alluvial plots were first developed to assess change over time within and across network clusters (Rosvall and Bergstrom 2010). Here, I first categorize beneficial owner states as high-income or lower-income (upper middle, lower middle, and low income) in the first year of the time period (2014). Second, I categorize flag states as black/grey listed based on inspections from 2018-2020 (Paris MoU 2022), a tax haven (Galaz et al. 2018), or another flag state. Some states are both black/grey listed and tax havens, in which case they were categorized as black/grey listed as that categorization is more germane to the topic at hand. I limit the destination countries to the five that make up the vast majority of ships scrapped globally in terms of gross tonnage. Effectively, this results in a visualization that shows flows from national income classification to flag state status to destination country, assessing my argument as to whether high-income nations employ “flags of convenience” more often than lower-income nations. The alluvial plot includes scrapped vessels that are owned, flagged, and/or recycled by the same state. Wan et al. (2021) perform a similar descriptive analysis with ship scrappage over time, main destination countries, and the extent to which major beneficial owner nations use tax havens as flags. I share similar aims but use updated data from NGO Shipbreaking Platform, focusing on the differentials between high-income and lower-income use of black/grey listed flags and tax havens in their dumping of end-of-life vessels.

Lastly, I conduct network analyses to see whether transboundary flows of end-of-life vessels are more or less centralized than expected by chance. These simulations exclude recycled ships that are owned and recycled in the same state. Network simulation methods evaluate how characteristics of the observed network differ from what we might expected from simulated networks specified to produce certain network tendencies (e.g., degree distributions; transitivity) (Fredrickson and Chen 2019). Specifically, I examine in- and out-degree centralization, which captures how concentrated import and export ties are to a few, important nodes (in this case, countries). I simulate 1,000 Erdos-Renyi and Scale Free networks. In so doing, I determine how the observed network of beneficial owner countries to destination countries compares to networks characterized by random chance tie generation and preferential attachment to select nodes, respectively (Barabasi and Albert 1999; Erdos and Renyi 1960). Erdos-Renyi simulations involve the generation of random networks that have a preset number of nodes and edges. For each year I input the number of nodes and edges in the ship breaking network, enabling a comparison between the observed network and what can be expected by random networks of the same density. Given that prior research indicates that ship recycling may be concentrated in a few nations, I also simulate scale free networks that I specify as following a linear power law distribution for in-degree. I report the average simulated in- and out-degree centralization with error bars representing two standard deviations from the mean (capturing roughly 95% of the simulated possibilities), as well as the observed in- and out-degree centralization score. This is designed to establish, relative to random networks, the extent to which ties are centralized along export and import lines in the ship breaking network, approximating canonical methods of hypothesis testing.

Results

Table 1 lists the major destination countries by gross tonnage. Throughout 2014-2020, there are five major ship breaking nations: Bangladesh, India, Pakistan, Turkey, and China. Over 97% of all shipbreaking takes place in these nations across the time period. Between 70%-80% of shipbreaking occurs in Bangladesh, India, and Pakistan specifically, where the beaching method of ship disposal is used, and particularly unsafe working conditions and environmentally harmful practices are pervasive. Bangladesh is the world leader in gross tonnage scrapped across the time period, except for 2014 where India scrapped more; in every other year, India recycled the second most gross tonnage. Pakistan, China, and Turkey alternate between being the third, fourth, and fifth recyclers of ships, although in sum Pakistan recycles far more than China, who in turn recycles far more than Turkey. Consistent with prior research (Wan et al. 2021), a few destination states in South Asia scrap the vast majority of ships in gross tonnage.

Table 1. Top Five Destination Countries by Gross Tonnage, 2014-2020.

Destination	2014		2015		2016		2017		2018		2019		2020		Total
	GT	%	GT	%	GT	%	GT	%	GT	%	GT	%	GT	%	GT
Bangladesh	5,615,841	24.75	6,774,950	33.22	9,553,930	34.80	6,568,227	31.73	7,936,186	42.01	7,849,569	58.08	6,496,774	42.19	50,795,477
India	6,715,484	29.60	4,523,347	22.18	8,220,191	29.94	5,980,514	28.89	4,918,647	26.04	3,665,963	27.13	4,515,973	29.33	38,540,119
Pakistan	4,401,977	19.40	3,731,532	18.30	6,035,228	21.98	4,070,498	19.67	4,215,117	22.31	285,189	2.11	2,256,705	14.66	24,996,246
China	4,350,574	19.17	4,148,851	20.34	2,547,938	9.28	2,296,190	11.09	424,032	2.24	304,320	2.25	216,010	1.40	14,287,915
Turkey	975,266	4.30	1,083,104	5.31	1,004,335	3.66	1,380,955	6.67	962,986	5.10	1,169,163	8.65	1,624,568	10.55	8,200,377
Total		97.22		99.34		99.66		98.06		97.70		98.22		98.13	

Table 2 describes beneficial owner countries by gross tonnage. Compared to ship breaking destinations, beneficial owner nations are more dispersed. The top ten beneficial owner nations (including unknown owners), make up between 50%-70% of ships scrapped from 2014-2020. All countries on this list own large fleets of vessels, and most are high-income nations from East Asia, Europe, and North America. Greece, South Korea, and Japan are among the top beneficial owner nations with fairly stable shares of gross tonnage scrapped every year. Meanwhile, Germany's sending of ships to be scrapped fluctuates more, peaking in 2016 and declining thereafter. While China is a major beneficial owner, a significant amount of their gross tonnage is scrapped domestically. The United States, Hong Kong, and Singapore are also major beneficial owner nations. There are also a high number of owners from unknown countries. Lastly, and consistent with Wan et al. (2021), it is important to note that India's gross tonnage may be overestimated, since owners of end-of-life ships sometimes sell ships to local third-party corporations to shirk regulations.

Table 2. Top Ten Beneficial Owner Countries for Ship Breaking by Gross Tonnage, 2014-2020.

BO Country	2014		2015		2016		2017		2018		2019		2020		Total
	GT	%	GT	%	GT	%	GT	%	GT	%	GT	%	GT	%	GT
Greece	2,663,318	11.74	3,179,960	15.59	4,026,886	14.67	2,144,155	10.36	3,660,655	19.38	1,612,106	11.93	1,803,597	11.71	19,090,677
China	4,961,253	21.87	4,043,432	19.82	3,441,007	12.53	2,178,602	10.53	357,307	1.89	672,298	4.97	890,850	5.79	16,544,749
Korea (South)	1,657,095	7.30	1,454,887	7.13	1,737,198	6.33	1,974,249	9.54	2,005,072	10.61	1,352,986	10.01	2,420,027	15.72	12,601,514
Germany	1,492,785	6.58	1,121,161	5.50	3,796,390	13.83	2,158,334	10.43	1,163,952	6.16	335,398	2.48	367,010	2.38	10,435,030
Japan	681,210	3.00	1,008,632	4.95	1,512,278	5.51	621,755	3.00	408,209	2.16	964,135	7.13	1,178,403	7.65	6,374,622
USA	798,893	3.52	709,963	3.48	675,766	2.46	433,307	2.09	2,048,840	10.85	857,830	6.35	708,536	4.60	6,233,135
Hong Kong	1,097,958	4.84	1,342,856	6.58	1,166,938	4.25	527,835	2.55	51,959	0.28	296,609	2.19	865,063	5.62	5,349,218
Singapore	1,311,599	5.78	295,353	1.45	776,487	2.83	310,806	1.50	718,581	3.80	536,245	3.97	940,108	6.11	4,889,179
Unknown	397,636	1.75	523,460	2.57	898,112	3.27	524,128	2.53	669,260	3.54	435,375	3.22	192,974	1.25	3,640,945
India	315,404	1.39	427,523	2.10	460,559	1.68	685,699	3.31	907,575	4.80	429,556	3.18	225,273	1.46	3,451,589
Percentage of Total		67.77		69.17		67.35		55.85		63.48		55.44		62.29	

Table 3 outlines the main flag states by gross tonnage, ordered by total gross tonnage. It appears that a flag state being known as a tax haven or black/grey listed for deficient operation contributed heavily to being on this list, as nine of the ten top flag states for scrapped vessels are black/grey listed and/or are tax havens. Panama, Liberia, the Marshall Islands, Hong Kong, and the Bahamas are all leading flag states for scrapped ships, perhaps due to their status as tax havens (Galaz et al. 2018). Additionally, the flags of Palau, Comoros, St. Kitts & Nevis, and South Korea are prevalent in the ship scrapping industry. These flags are on the black or grey list published by the Paris Memorandum of Understanding, signaling deficient operations during inspection (Paris MoU 2022). China is also a commonly used flag, largely due to the volume of vessels that are owned and scrapped in-state, fostering an intra-national circular economy in ship recycling (Steuer, Staudner, and Ramusch 2021). The prominence of tax havens and black/grey listed flag states indicates the need on behalf of beneficial owner countries to be as economically viable as possible and to avoid international regulations, regardless of localized environmental costs.

Table 3. Top Ten Flag States for Ship Breaking by Gross Tonnage, 2014-2020.

Flag State	2014		2015		2016		2017		2018		2019		2020		Total
	GT	%	GT	%	GT	%	GT	%	GT	%	GT	%	GT	%	GT
Panama	5,440,860	23.98	2,904,332	14.24	5,773,017	21.03	2,380,334	11.50	1,621,278	8.58	2,410,843	17.84	3,092,130	20.08	23,622,794
Liberia	2,514,979	11.08	2,388,001	11.71	4,208,461	15.33	2,738,760	13.23	1,539,168	8.15	505,791	3.74	2,218,528	14.41	16,113,688
Palau	98,922	0.44	348,944	1.71	1,517,900	5.53	2,289,699	11.06	6,205,829	32.85	3,691,143	27.31	665,861	4.32	14,818,298
Comoros	1,328,586	5.86	1,307,588	6.41	2,111,929	7.69	3,178,150	15.35	3,035,169	16.07	2,089,619	15.46	1,625,806	10.56	14,676,847
St Kitts & Nevis	1,933,013	8.52	1,595,350	7.82	1,836,971	6.69	1,914,628	9.25	1,540,009	8.15	758,228	5.61	1,451,939	9.43	11,030,138
China	2,275,412	10.03	2,520,910	12.36	1,051,302	3.83	570,409	2.76	50,125	0.27	300,388	2.22	203,109	1.32	6,971,655
Marshall Islands	811,604	3.58	1,096,486	5.38	1,143,376	4.16	1,044,258	5.05	681,418	3.61	264,296	1.96	1,499,841	9.74	6,541,279
Hong Kong	825,654	3.64	1,114,502	5.46	1,069,864	3.90	914,354	4.42	18,975	0.10	45,859	0.34	753,849	4.90	4,743,057
Korea (South)	344,558	1.52	898,509	4.41	1,128,509	4.11	734,080	3.55	614,903	3.25	257,714	1.91	231,080	1.50	4,209,353
Bahamas	476,588	2.10	741,463	3.64	416,358	1.52	276,624	1.34	110,969	0.59	357,983	2.65	516,018	3.35	2,896,003
Total		70.74		73.13		73.79		77.50		81.61		79.04		79.61	

Figure 1 shows the extent to which beneficial owners from high-income countries use black/grey listed or tax haven flag states when dumping ships onto the shores of Bangladesh, Pakistan, India, China, and Turkey. About 51% of the gross tonnage of high-income ships are flagged in a tax haven, while 42% are flagged in a black/grey listed state. Meanwhile, about 35% of the gross tonnage of lower-income countries' ships are black/grey listed flag states and 35% are flagged in a tax haven. Beneficial owners from lower-income countries are much more likely to be flagged in other countries (30%) relative to their high-income counterparts (7%). Countries that have an unknown beneficial owner or were not categorized in terms of their national income in 2014 had similar flag state use patterns as high-income nations, with tax havens (48%) and black/grey listed flags (43%) far outweighing other flags (9%). Moreover, the destination countries receive the majority of their vessel gross tonnage through black/grey listed states and tax havens. Bangladesh (44%; 49%), India (49%; 43%), Pakistan (48%; 46%), and Turkey (45%; 34%) receive most of their used vessels from tax havens and black/grey listed flag states, respectively. Meanwhile, China receives most of their vessels through other flag states (56%) and tax havens (42%), unlike the other major destination countries, largely because roughly half (48%) of their gross tonnage carries China as a flag state.

Figure 1. Income Status – Flag State Status – Destination Linkages, 2014-2020.

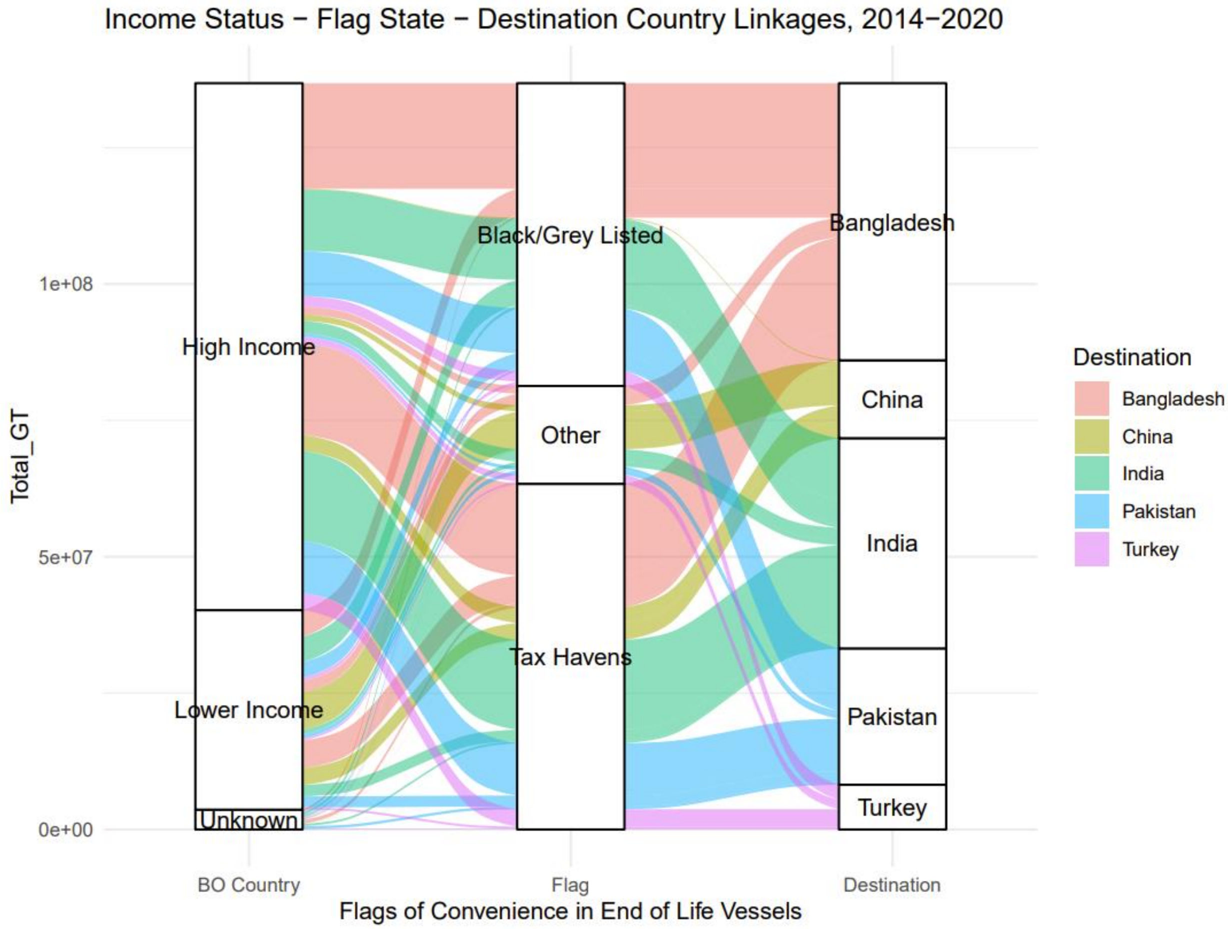


Figure 2 shows the in-degree centralization scores (concentration of end-of-life vessel ties to a few destinations) by year relative to Erdos-Renyi and Scale Free simulated networks. As we can see, across 2014-2020, observed in-degree centralization is higher than that expected by chance in constant probability and power law distribution random graphs. Thus, we can conclude that ship breaking is more centralized into a few countries in terms of incoming ties (not only total gross tonnage) than expected by random simulations of Erdos-Renyi and scale free graphs. There may be preferential processes at work that encourage more ties to a few sites of ship scrapping, consistent with expectations of ecologically unequal exchange theory and the observed economic realities of the ship scrapping industry.

Figure 2. Simulated vs Observed In-Degree Centralization, 2014-2020.

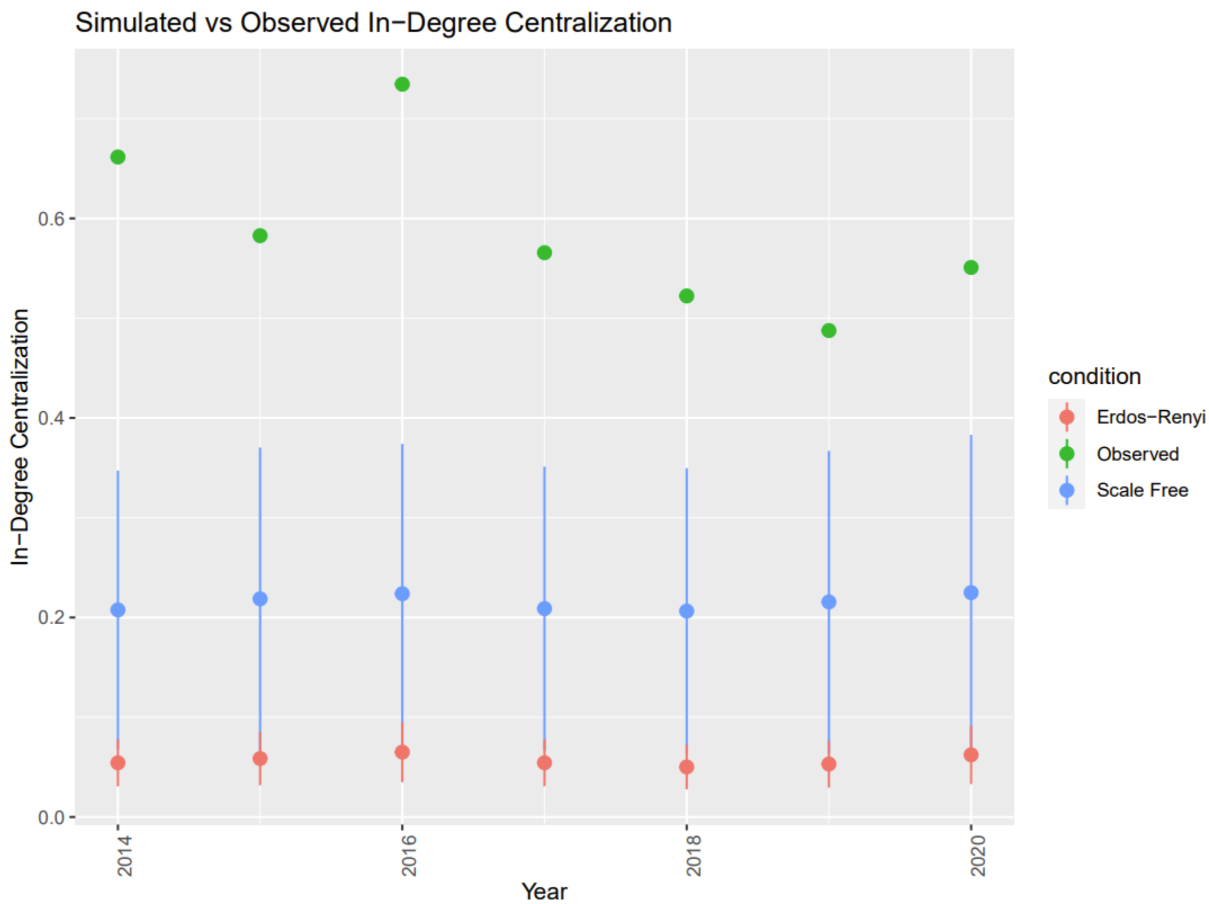
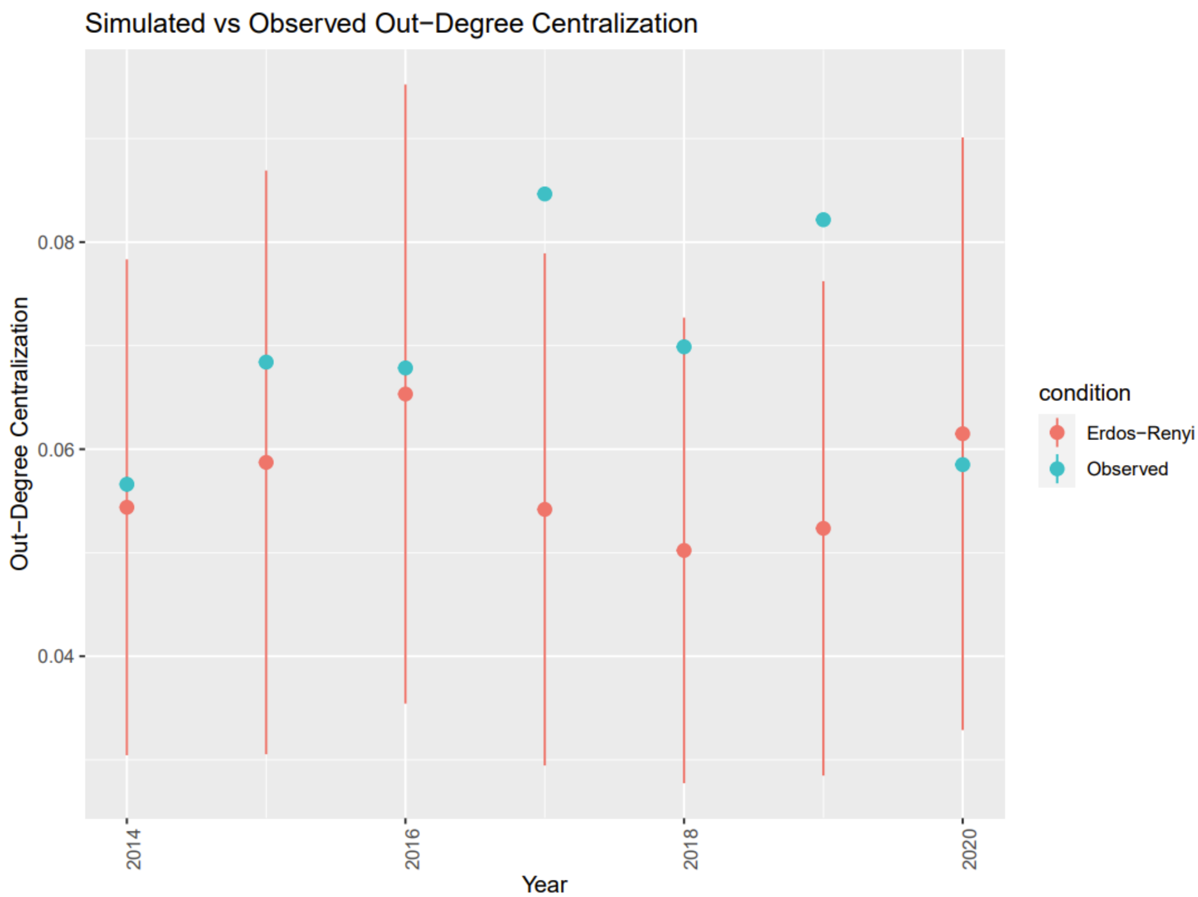


Figure 3 shows the observed out-degree centralization (concentration of end-of-life vessel ties from a few destinations) relative to simulated Erdos-Renyi graphs. For most years, observed out-degree centralization is within the bounds of what is expected by Erdos-Renyi graphs, with the exception of 2017 and 2019. Thus, for most years the distribution of export ties among nations conforms to what is expected given the density of the graph, and suggests much more dispersion relative to in-degree centralization. In this case, the relative dispersion of outgoing ties may be connected to the preferential processes attached to the concentration of incoming ties: many more countries own ships than scrap vessels, therefore fostering a network with centralization of incoming ties and dispersion of outgoing ties.

Figure 3. Simulated vs Observed Out-Degree Centralization, 2014-2020.



Conclusion

This chapter aimed to describe beneficial owner nations, flag states, and destinations regarding ship scrapping, and the relations between them. From 2014-2020, Bangladesh, India, Pakistan, Turkey, and China scrap the vast majority of ships in the world in terms of gross tonnage, totaling over 97% of scrapped ship tonnage for each year. Meanwhile, Greece, China, South

Korea, Germany, and Japan were the countries of beneficial ownership of the most gross tonnage of end-of-life vessels. Ship breaking is centralized in a few nations while ship ownership is dispersed across wealthy nations in Europe, East Asia, and the United States. The observed in-degree, or number of import relationships, centralization is greater than that expected of simulated scale free networks and given network density. However, observed out-degree, or number of export relationships, centralization is consistent with what is expected given network density for most years. In other words, the number of ties concentrated into a few destination countries is larger than expected even by networks designed to capture power law in-degree distributions, while the number of ties concentrated into a few beneficial owner nations conforms to what is expected given the density of the graph for most years. Flag states for end-of-life vessels are predominantly tax havens or black/grey listed, an avenue through which beneficial owners from wealthy nations can avoid regulation and dispose of their vessels in lower-income nations.

This analysis contributes to the literature on ecologically unequal exchange. Most empirical research emphasizes the “vertical flow” of resources from lower-income nations to high-income countries (e.g., Jorgenson 2006; Shandra, Leckband, and London 2009). In this case study of end-of-life vessels, a disposal-side exchange relation, I find that beneficial owners from high-income countries send most of the tonnage of end-of-life vessels, and that destination countries are lower-income nations, particularly in South Asia. High-income nations use tax haven and black/grey listed flag states more when dumping end-of-life vessels onto the shores of destination countries as measured by gross tonnage, consistent with ecologically unequal exchange theory: high-income nations use their advantageous position in the world system to avoid international and national regulations concerning ship recycling.

Given the accumulation of capital and technology in the Global North (Hornborg 2019), it is unsurprising that industrialized nations in Europe, the United States, and East Asia are important beneficial owner nations of end-of-life vessels. Concentrated importation in India, Bangladesh, Pakistan, China, and Turkey indicates the need for metals that cannot be extracted due to over-extraction or lack of access (e.g., Sujauddin et al. 2017). That rapidly industrializing nations rely on discarded materials from the Global North to secure access to needed metals is an issue of global economic and environmental inequality, as ship breaking is associated with a host of human and ecological health issues (Hossain et al. 2021; Rahman et al. 2019; Wu et al. 2015).

This research also highlights how economic development fits into hazardous waste trades. Rapidly industrializing nations in Asia prioritize the economic benefits of importing hazardous wastes, namely for purposes of employment and materials recovery (e.g., Pellow 2007). This strategy for materials access as a method for economic development highlights an unequal world system, where historically core nations (e.g., Germany, the United States, Japan) possess large-scale ship building enterprises for both war and cargo purposes (Bunker and Ciccantell 1995), while major destinations of end-of-life vessels bear the occupational and ecological costs associated with ship breaking. Like importation of plastic waste (Bai and Givens 2021), it appears that importing end-of-life ships may be a developmental strategy, as needed materials recovery occurs, especially in the steel industry (Sarraf et al 2010; Sujauddin et al. 2017). Thus, while ecologically unequal, ship scrapping serves an important economic function in a small set of industrializing nations, providing valuable metals such as steel for local and national economies.

Recycling and materials recovery are important, pro-environmental practices. Globally, recycling ships enables the reuse of steel and other valuable materials, thereby lessening the need for extraction of metals and associated environmental impacts (Rahman and Kim 2020). The main destination countries (Bangladesh, India, and Pakistan) use the “beaching” method of ship recycling, involving very risky labor practices and severe, localized environmental costs and human health issues (Hossain et al. 2021; Rahman et al. 2019). Recent legislation in the European Union, the Ship Recycling Regulation (SRR), mandates that EU-flagged vessels are scrapped at approved shipyards (which use safer, non-beaching techniques, and are located in the E.U., Norway, Turkey, and the U.S.), maintain an inventory of hazardous materials, and restricts the amount of sulfur in vessels (European Commission 2023). While EU regulation may be well-intentioned, the use of “flags of convenience” hinders the efficacy of EU policies to curb EU-owned ships being sent to lower-income countries since the regulatory onus is on flag states (Moncayo 2016).

As the proliferation of foreign flag states, and in particular “flags of convenience,” enables an international law regime which places the onus on the recycling states (e.g., SRR) (Moncayo 2016), international legal principles that emphasize the need for owner countries to be responsible for recycling or providing aid to current destinations to upgrade their recycling infrastructures is necessary (Yujuico 2014). Current and pending regulations (e.g., SRR; HKC) focus on flag states and recycling states, the entities least able to comply with international regulations. Increased regulatory emphasis on beneficial owners of vessels will likely yield sounder environmental and labor practices, and thus more consistency with principles of environmental justice (Puthucherril 2010). Analyzing the dynamics of beneficial owner-destination linkages shows that high-income nations use tax havens and black/grey listed flag states to circumvent international regulatory schemes, further stressing the need to reexamine how transboundary flows of end-of-life vessels are regulated, and to push for more aggressive measures (e.g., aid to recycling sites in India, Bangladesh, and Pakistan) to ensure safe and environmentally sound practices in destination sites.

Future research on ecologically unequal exchange should continue to examine hazardous waste trades. Recent work has emphasized that hazardous waste trades do not necessarily fit into simple narratives of powerful, core nations dumping onto poor nations, as these trades are often coupled with developmental projects. Yet, the reality of ship scrapping highlights that high-income nations enjoy the benefits of ship ownership while Bangladesh, India, Pakistan, Turkey, and China bear the occupational and environmental costs of ship dismantling. Of course, this study provides a conservative estimate of the trade, as hazardous waste trade data is likely underreported due to its illicit nature. Future work should continue to examine hazardous waste trades using innovative methods, including but not limited to social network analysis, historical-comparative analysis, and geographic approaches, to highlight the relationality of global environmental inequality.

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CHAPTER III: OIL, EXTRACTION, AND EMISSIONS: A NETWORK APPROACH TO ECOLOGICALLY UNEQUAL EXCHANGE

Abstract

Empirical research on ecologically unequal exchange conventionally operationalizes the theory through national income bifurcations and testing whether intensified exports to more-developed countries contributes to environmental harm in lower income nations. In this chapter, I analyze the case of global crude oil trade to see if ecologically unequal exchange dynamics are present. Using network methods, I develop a novel method to assess ecologically unequal exchange, categorizing countries into positions in the global crude oil trade network through regular equivalence. Then, I conduct a series of multilevel models to investigate whether economic dependence on oil extraction contributes to related emissions differentially across trade positions. I find that crude oil export-oriented economies tend to experience increased related emissions with increases in extractive dependence relative to other-positioned economies. I close by highlighting the implications of this study for research design and methodology in the research area.

Introduction

Since resources, such as oil reserves, are disparately allocated globally, international markets are essential to sustain energy use and economic development. Research across disciplines illuminates how countries import raw materials from elsewhere to externalize potential environmental costs associated with extraction (e.g., Behrens et al. 2007; Dorninger et al. 2021; Jorgenson 2006). In the context of climate change, much attention is placed on reliance of the global economy on several oil-rich nations for the purposes of petroleum consumption, fostering domestic politics around “energy security” (Colgan 2021). While analyses often place the onus of climate change on oil consumers on the international market – and rightfully so – less focus is placed on oil exporters and how the expansion of their extractive dependence to fuel global consumption may influence emissions. This chapter uses social network analysis and multilevel modeling to (1) place countries into positions in the global crude oil trade network and (2) assess the extent to which national positionality in that network modifies the influence of oil extractive dependence on related carbon dioxide emissions.

Environmental social scientists often analyze the ways in which processes of economic globalization contribute to global environmental change. Some study the implications of international trade for climate change, including how policy can curtail the ecological consequences of international trade (Weber and Peters 2009), how environmental inequality is embedded in the world-system via trade (Bunker 1985; Roberts and Parks 2006), and how trade openness influences emissions (Antweiler, Copeland, and Taylor 2001; Thombs 2018). The theory of ecologically unequal exchange highlights how environmentally-extractive regimes in the Global South support consumption and heightened technological innovation in the Global North (Bunker 1985; Hornborg 2019). As the theory is related to world-systems analysis, it tends to focus on how relations of extraction, production, consumption, and disposal are geographically heterogenous, resulting in uneven environmental costs and economics gains cross-nationally (Dorninger et al. 2021; Wallerstein 2004). Empirical examinations tend to focus on the adverse ecological consequences for lower-income nations when they trade larger shares of their raw materials and natural resources to high-income nations (e.g., Jorgenson 2006; Shandra et al. 2009). Broadly speaking, these studies examine how intensity of trade to rich nations contributes to environmental degradation in lower-income countries.

Given the necessity to transition away from fossil fuels to build a just sustainable future, it is important to consider how global energy trades influence emissions. Countries that may not have domestic access to fossil fuels rely on international trade for energy purposes, in the process placing increased demand on extractive export hubs. Several studies examine how trade-openness in petroleum-exporting countries influences consumption-based carbon emissions (Hasanov, Liddle, and Mikayilov 2018; Khan et al. 2020) or how energy trade measures influence territorial-based carbon emissions (Zhang et al. 2020) and sulfur dioxide emissions (Zhong et al. 2019). The role of countries as oil exporters is a meaningful context to understand environmental problems because of the consequences of expanded extraction to meet global energy demands.

Scholarship on natural resource dependence emphasizes that relative position in trade structure influences the extent of environmental impacts. For example, natural resource dependency partially explains how least central nations in the natural resource exchange network fuels greater emissions because of economic development (Vesia, Mahutga, and Bui 2023). Using a sample of Gulf Cooperation Council nations, Mahmood and Furqan (2021) find a positive and significant association between oil rents and carbon emissions. Through the lens of ecologically unequal exchange theory, oil export economies expand extraction to meet the demands of the world-system. These demands may also incur increased reliance on oil rents (difference between the value and cost of oil production) for economic development. The aim of expanding extraction increases the likelihood that measures such as weakening environmental protections and deploying riskier extraction techniques will be used, thereby intensifying pollution and emissions. Moreover, these effects occur in a network context as countries compete with and emulate similarly situated countries.

Social network analysis has yielded considerable insight into the social organization of international trade in general (e.g., Snyder and Kick 1979; Smith and White 1992; Mahutga and Smith 2011; Zhou 2020) and international energy trade in particular (e.g., Fracasso, Nguyen, and Schiavo 2018; Kitamura and Managi 2017). Scholars assessing how international trade contributes to environmental problems have recently used network approaches to conceptualize how position and integration in particular trade networks influences environmental change (Prell and Sun 2015; Prell et al. 2014; Sommer 2020; Vesia, Mahutga, and Bui 2023). While prior sociological work on the ecological implications of international trade has predominately used share of trade to high-income nations or trade-openness as key measures, this study focuses on how the context of export- and import-position in the global crude oil trade network modifies the influence of oil extractive dependence on related carbon dioxide emissions. My analytical strategy contributes to prior literature in two ways. First, it orients scholarly focus to relational measures of trade over share of economic output or share to high-income nations. Second, it assesses resource dependence in the context of trade position, examining how the international structure of nations may shape the effect of resource extraction on degradation. Consistent with ecologically unequal exchange theory, I expect that crude oil export-oriented economies will have higher oil-based carbon dioxide emissions than other types of economies because of extractive dependence due to the oil export-oriented economies' position as a resource frontier in the world-system (e.g., Bunker 1985).

Literature Review

International Trade and Environmental Harm

Global inequality manifests in environmental problems through international trade relations. Stephen Bunker (1985), for example, analyzed how extractive economic modalities in the

Brazilian Amazon, from rubber to timber, satisfied the demand from the world-system while producing serial underdevelopment in the region. The construction of infrastructures for extraction constrains developmental pathways and entrenches certain types of economic activity in peripheral countries. Ecologically unequal exchange theory, an ecological derivation of Marxian theory, views unequal exchange as “unbalanced flows of energy and matter from extractive peripheries to the productive core” (Bunker 1984:1018). At its core, this theoretical outlook explains how and why there are disparities in countries’ environmental quality through a relational and zero-sum understanding of natural resource extraction and consumption on a global scale (Hornborg 2009). In other words, this perspective centers on how nations are connected through international trade relationships in the analysis of global environmental inequality.

Across a variety of environmental social science disciplines, there is broad empirical support for ecologically unequal exchange theory (e.g., Dorninger et al. 2021; Frey, Gellert, and Dahms 2019). In the sociological literature, Jorgenson (2006) proposed a way to test the theory, finding an association between “weighted export flows” of all commodities and deforestation in lower-income nations. A number of studies in the research area find support for an association between agricultural and/or forestry exports to high-income nations and deforestation in lower-income nations (Jorgenson 2006; Shandra, Leckband, and London 2009). The consumption-degradation paradox thus arises, as lower-income nations that are rich in natural resources export these materials to high-income nations, suffering from the environmental harms associated with extraction but not enjoying the social benefits of their consumption (Jorgenson, Austin, and Dick 2009). Recent work shows that trade openness has intensified emissions for lower-income nations relative to high-income countries over time, suggesting that emissions-intensive industries are moving to the former (Thombs 2018). Put simply, the research area is concerned with the "inequitable appropriation of environmental space" (Rice 2007:1369) within the global organization of extraction, production, consumption, and disposal.

There have been several important refinements and nuances introduced in the research area, including specifying commodities that are linked to environmental degradation or natural resource consumption. For example, Shandra et al. (2009) show that increased primary sector flows increase threatened mammal populations (mammal species with relatively low populations) in lower-income nations. Shandra, Leckband, and London (2009) show that lower-income nations with increased forestry exports to high-income nations face higher levels of deforestation. Jorgenson, Austin, and Dick (2009) demonstrate that increased primary sector flows to high-income nations increase deforestation and decreases agricultural natural resource consumption. Noble (2017) examines cocoa exports, showing that specialization in cocoa production is linked to deforestation in lower-income nations. Identifying specific commodity flows and connecting them to related forms of degradation adds nuance and refinement to our understanding of ecologically unequal exchange.

Attention has also been paid to how rapidly industrializing nations contribute to environmental change in lower-income countries. Semi-peripheral nations, such as China and India, are also able to leverage their position in the world-system to externalize the ecological costs of their natural resource consumption. For example, intensified mining, forestry, and agricultural exports to China increases forest loss in lower-income nations (Shandra, Restivo, and Sommer 2019, 2020; Sommer, Restivo, and Shandra 2021). In parallel, more palm exports to India are also associated with an increase forest loss in lower -income nations (Sommer, Restivo, and Shandra 2020). The exploitation of lower-income nations' natural resources is not exclusive to high-income countries, as rapidly industrializing nations with relative power also utilize their advantageous position in trade to externalize environmental costs.

The reasons that natural resource export-oriented countries experience intensified environmental damage are plentiful. First, uneven positions of trade may result in export-oriented countries forgoing environmental protections (e.g., regulations) for economic development (Tester 2020). Second, there is evidence that there has been a “tilt” in global production, as the most environmentally harmful processes of extraction and production have moved to lower-income nations (Thombs 2018). Third, specializing in natural resource exports suppresses economic diversification in exports (Harding and Venables 2016) and foreign direct investment in non-resource related matters (Poelhekke and van der Ploeg 2013), incentivizing further extraction. Thus, for nations positioned as exporters in resource trade networks (e.g., oil), we may expect intensified associations between extractive dependence and environmental degradation relative to other-positioned economies.

International Trade, Social Networks, and Environmental Change

While ecologically unequal exchange theory draws attention to the relational nature of global environmental inequality, most quantitative assessments in the research area use intensity of exports to high-income nations or related measures as the key explanatory mechanism (Jorgenson 2006; Shandra et al. 2009), or share of exports to rapidly industrializing countries, namely China and India, to highlight the adverse implications of South-South trading (Shandra, Restivo, and Sommer 2019, 2020). Fortunately, a large body of research uses social network analysis, a methodological approach that centers relationality, to analyze and understand the organization of global trade.

Historical and ongoing colonial and neocolonial relationships shape the international structure of nations (e.g., Wallerstein 2004). Today, the global economic structure is visible through international trade relationships. Given the relational nature of trade (there is an exporter and importer), social network analysis is a key methodological tool to make sense of its organization. A wealth of studies employ social network analysis to place countries into positions in the global economy or to determine which nations are most central to international trade structure (e.g., Snyder and Kick 1979; Clark and Beckfield 2009; Mahutga and Smith 2011). Central to this literature is world-systems analysis (Wallerstein 2004), which postulates a three-tiered hierarchy of the global economy. Core nations tend to produce and export sophisticated technological and capital-intensive commodities; peripheral nations tend to produce and export raw materials and agricultural/extractive commodities; semi-peripheral nations tend to perform a mix of these types of economic activities.

Network approaches explore the international structure of nations by assessing flows of commodity types across national groupings, consistent with world-systems propositions. Nemeth and Smith (1985) use structural equivalence to assess trade data from 1970 and group both commodities and countries. Structural equivalence groups countries based on their pattern of ties so that countries with the *exact same* connections to identical others are blocked together. This early work finds a group of core countries with productive industries and a group of peripheral countries with extractive industries, "consistent with descriptions of the mechanisms of unequal exchange suggested by theories stressing imperialism and dependency relations" (Nemeth and Smith 1985:529). Smith and White (1992) extend this line of research by adopting regular equivalence, a less stringent approach than structural equivalence, grouping countries according to relationships with *similar* others, or those with the same role in the network. Examining how trade positions change over time, Smith and White (1992) find that the core group expanded through time to include modernized European countries. Again, capital-intensive manufacturing exports were associated with the core, while peripheral countries produced agricultural goods for export.

Later research more closely considers world economic system changes. The transfer of less profitable and efficient manufacturing from the core to the semi-periphery adds a low value-added/high value-added distinction to the already-established capital-intensive/raw material binary in the global division of labor (Mahutga 2006). In short, the institutionalization of free trade agreements and the rise of neo-liberal policies enabled lower costs for international production, at the same time industrializing non-core nations while preserving hierarchical relations. However, while inequality persists, rapidly industrializing nations exhibit some convergence with core nations in their productive capacities while diverging from peripheral nations (Mahutga and Smith 2011). These network studies analyze the world economic system through consideration of types of commodity flows across countries in similar positions.

While ecologically unequal exchange theory explicitly theorizes a relational structure of nations (e.g., Bunker 1984; Hornborg 2019), empirical work only recently has begun to integrate this methodologically (Jorgenson et al. 2022; Prell and Sun 2015; Sommer 2020; Theis 2021). Specifically, network methods have been used to establish how position and integration in international trade and investment networks influences environmental degradation. For example, countries more central to trade tend to benefit more economically from the United States' consumption while those less central tend to endure more pollution (Prell et al. 2014). Sommer (2020) observed shifts in the forestry exchange network and predicted forest export ties, finding that economic development and forestry rents decreases export ties, while forest area increases export ties. In the natural resource exchange network, Vesia, Mahutga, and Bui (2023) show that less central countries in the natural resource exchange network experience greater carbon dioxide emissions in their development pathways due in part to dependence on natural resource extraction. Moreover, countries more central to the foreign direct investment network tend to emit more carbon dioxide, especially for Global South countries, as the Global North offshores its environmental inefficient and harmful industries to the former (Jorgenson et al. 2022).

While the above studies mostly examine overall centrality, it is important to consider how positionality in trade networks influences environmental outcomes, as much theoretical and empirical work explores how these types of trade relationships may have differential impacts (e.g., Bunker 1984; McMichael 2008). A few network studies in the cross-national literature on environmental degradation have paid attention to differences between import- and export-integration. For example, countries more central to global trade network structure and more integrated as importers tend to experience increased net inflows of carbon dioxide embodied in international trade (Prell and Sun 2015). Similarly, countries more central to global trade experience increased production-based sulfur dioxide emissions, while more central countries and countries more integral as importers experience increased consumption-based sulfur dioxide emissions (Prell 2016).

Ecologically unequal exchange theory contends that extraction expands in export-oriented economies due to world-system demands, contributing to environmental degradation and serial underdevelopment. While prior work has largely focused on agricultural and forestry exports, given the exigent nature of the climate crisis, I turn to the international trade in crude oil to see how unequal exchange dynamics play out in a global energy trade.

The Case of International Oil Trade

Since the early 1900s fossil fuels have predominated global energy consumption, with oil being the most-consumed fuel source since the 1950s (York and Bell 2019), corresponding with the Great Acceleration (Angus 2016). Given the well-evidenced connection between fossil fuel use and climate change, it is integral to understand the social organization of global energy trade and how this organization influences emissions. Countries without domestic oil access may rely on international trade for oil or oil-intensive finished products. However, these dynamics also produce environmental inequity problems, as extraction of oil and the production of oil-intensive goods produces pollution and emissions (e.g., Meng et al. 2018; Oviasuyi and Uwadiae 2010).

The heterogeneous global supply of oil reserves fosters international markets in oil. Given their oil-rich nature, former Soviet states and nations in Africa and the Middle East largely supply countries in North America, Europe, and East Asia (Zhang, Ji, and Fan 2015). However, North American imports are concentrated in one nation (the U.S.), while European and Asian-Pacific imports tend to be more dispersed, suggested heightened competition between countries from 2000 to 2011 (Zhang, Ji, and Fan 2015). The largest markets in the global economy also import the most oil: the United States and China are the largest net importers of oil embodied in trade (oil used in commodities) and oil, respectively (Wu and Chen 2019). Globalization and increasing trading relations between regions has led to a more robust global oil network, but also poses heightened potential for systemic risk, as intensified interdependence may diffuse national/regional disturbances (e.g., Ji and Fan 2016; Ji, Zhang, and Fan 2014). In short, the geographic zones of oil extraction and consumption are disparate, and intensified global demand has fostered a more interdependent but delicate market that is heavily reliant on a few oil-extraction export hubs.

Research on the “oil curse” explores how oil-rich nations may not experience levels of economic development that might be expected given their resource abundance (e.g., Bridge and Le Billon 2013; Ross 2012). Oil-rich nations often nationalize oil industries, providing governmental revenues that ease reliance on taxes and therefore contribute to less democratic regimes and intense income inequality (Bridge and Le Billon 2013; Ross 2012). Additionally, the well-studied “Dutch Disease” can arise, where extraction and exportation of a resource, like oil, can suppress other sectors of the economy due in part to increased valuation of the currency (e.g., Corden 1984). Of course, the dynamics of the “oil curse” are also implicated by the structure of the global economy. Oil extraction and consumption often occur in different spaces: the reliance of the world-system on oil exporting countries encourages the expansion of oil extraction. In turn, the seeming abundance of oil may encourage the construction of infrastructures that are more or less exclusively reliant on its use. Efforts to expand extraction are shaped in large part by relative position in the international structure of trade.

In intensive oil exporting countries, total exports and imports per capita have a negative and positive association with consumption-based carbon dioxide emissions, respectively (Hasanov, Liddle, and Mikayilov 2018; Khan et al. 2020), consistent with expectations from the consumption-degradation paradox that posits that extractive export economies experience suppressed natural resource consumption in their supplying of global markets (Jorgenson, Austin, and Dick 2009). Zhang et al. (2020) construct a variety of trade metrics from global energy trade (combined coal, crude oil, and natural gas), and find differential impacts from trade integration based on whether a country is more- or less-developed. Focusing on domestic extractive dependence in export countries, a few studies find positive associations between oil rents and emissions using regional samples of nations (e.g., Gulf Cooperation Council nations;

OPEC nations) (Mahmood and Furqan 2021; Mahmood and Saqib 2022). In the context of the U.S., intensifying extractive dependence contributes to climate change and lessened social well-being (Thombs 2022).

While useful, these studies do not situate economies into trade positions, in line with ecologically unequal exchange's emphasis on extractive export economies (Bunker 1984). Network methods enable an inductive identification of the positions that actors occupy in relation to one another, in this case, major exporters in global oil trade.

Hypotheses

Ecologically unequal exchange theory and research draws attention to the ways in which the exploitation and exportation of natural resources contributes to environmental degradation in lower-income nations (e.g., Bunker 1984; Hornborg 2019; Jorgenson 2006). Scholarship on natural resource dependency highlights social and ecological harms from extractive expansion, including but not limited to heightened emissions (e.g., Freudenburg 1992; Mahmood and Furqan 2021; Thombs 2022). Social network analysis of international trade can unveil the roles/positions nations play in the global economy.

In sum, prior work on international trade points to the importance of social network analysis in understanding inequality in the world system, while work on ecologically unequal exchange highlights how environmental inequality is embedded in the world system. I build on recent work that connects ecologically unequal exchange and social networks by focusing on the crude oil trade network and oil-based carbon emissions. To do so, I conduct regular equivalence analysis in the global crude oil trade to place countries into relative positions in the trade network. Regular equivalence techniques are used to identify which actors (in this case, countries) occupy the same social role (White and Reitz 1983). This network measure of international trade is more consistent with the theoretical expectations of ecologically unequal exchange theory, which posits that more powerful countries utilize their advantageous positions in the world-system to gain access to natural resources from less powerful nations (e.g., Bunker 1984). As opposed to conventional measures of ecologically unequal exchange (e.g., share of exports to high-income countries), this approach considers whether countries are relied upon as resource frontiers or exploit the "environmental space" (Rice 2007) of other countries.

To assess how a nation's position in international trade contextualizes the impact of extractive expansion on degradation, I form the following hypotheses:

H1: For countries positioned as export-oriented in the crude oil trade network, increasing economic dependence on oil extraction will be associated with more oil-based carbon dioxide emissions.

H2: For non-export-oriented countries, increasing economic dependence on oil extraction will have a lesser impact on oil-based carbon dioxide emissions in the crude oil trade network relative to those positioned as export-oriented.

Data and Methods

All data, with the exception of the oil trade measures, were collected from the World Bank's World Development Indicators (World Bank 2022). Oil trade data was obtained by the UN COMTRADE database (U.N. n.d.) using commodity code "2709: Petroleum oils and oils obtained from bituminous minerals; crude," as other studies examining global crude oil trade have done (e.g., Kitamura and Managi 2017).[1] Reported imports were used for the purposes of

[1] For the purposes of this analysis, I consider trade relating to the Former USSR as that of the Russian Federation, the South Africa Customs Union as South Africa, the Yemen Arab Republic and People's Democratic Republic of Yemen as Yemen, Former Yugoslavia and Serbia and Montenegro as Serbia, the Former Federal Republic of Germany and the Former Democratic Republic of Germany as Germany, Belgium-Luxembourg as Belgium, and Former Sudan as Sudan. Excluding these countries from the multilevel model analysis does not substantively change the interaction effect results at the center of this chapter.

analysis, as these data are believed to be more accurate relative to reported exports (Kim and Shin 2002). Country-years are the unit of analysis.

Constructing National Positions in the Oil Trade Network

The construction of national positions in the oil trade network was performed using regular equivalence, a network method used to place nodes into social roles (White and Reitz 1983). While other approaches, such as structural equivalence, focus on ties with identical alters, regular equivalence emphasizes ties with similarly situated alters (nodes that occupy the same role): "Regular homomorphisms require that occupants of one role will be identically connected to some occupants of a 'counterpart' role" (White and Reitz 1983:197). I use oil trade from 1988-2016, the earliest and latest years data were available for the multilevel models in this analysis. As prior work has done (e.g., Clark and Beckfield 2009), I use a million U.S. dollars (current dollars) as a binary benchmark for inclusion in the analysis as a meaningful trade relationship. If a pair of countries has a meaningful trade connection by these terms for half or more of the years (more than 15 years) in the analysis, I include them in the regular equivalence computation. This approach considers both intensity and durability of trade relationships to effectively capture position in the trade network and yields 486 trade relationships between 100 nations.

To calculate regular equivalence for each pair of nations in the oil trade network, I use the REGE formula (White and Reitz 1983). In effect, this computation assesses how nodes relate to their partners, and then compares the relative extent to which this relation is equivalent to how other nodes relate to their partners. This procedure produces a matrix of similarities for each pair of nations from maximally dissimilar (0) to maximally similar (1) (see also Mahutga 2006).

Next, I perform a hierarchical cluster analysis – Ward's minimum variance – to group nations into common positions. Each nation is first placed in its own cluster, followed by an iterative procedure through which the most similar clusters are then joined. Ward's method seeks to minimize variance within groups by finding the lowest increase in sum of error squares at each iteration. I identify three groups partitioning the network due to the results of a Scree plot (see Figure S1 in Appendix A). This results in three distinct positions: an export-oriented group with no import ties, an import-oriented group with no export ties, and a well-integrated group with export and import ties. Table 4 shows which nations fall into which groups.

Dependent, Independent, and Control Variables

To evaluate the oil trade network relationship to environmental outcomes, I use carbon dioxide emissions in kilotons from domestic liquid fuel consumption (petroleum-derived fuels) as the dependent variable. The key independent variable is oil rents as a percentage of GDP, which I use as a proxy for economic dependence on oil extraction. The models feature a number of control variables. GDP per capita is an important and consistently positive predictor of emissions (e.g., York, Rosa, and Dietz 2003a, 2003b), and is in constant 2015 US dollars in this study. Urban population as a percentage of total population is a common proxy for urbanization, and research consistently finds that it is a positive determinant of an array of measures of environmental degradation (e.g., Al-mulali et al. 2013; York 2007). It is also important to control for the relative amount of industrialization in national economies, and thus value added from manufacturing as a percentage of total GDP is included in the models (Jorgenson 2012; York and McGee 2017). Age dependency ratio is included in the models to control for how the age structure of nations influences emissions (e.g., Liddle and Lung 2010). I include exports as a percentage of total GDP and imports as a percentage of total GDP to ensure that the effect of oil trade integration is not simply due to general openness as exporters and importers. All variables are level 1 and in natural logarithmic form, except for position in the trade network (level 2).

Multilevel Modeling Approach

Multilevel models are a methodological technique used when there is a hierarchical structure in data. In this analysis, I nest observations in countries. Multilevel models enable a parsing of the variation explained in the dependent variable by each level, in this case, at the year-level (level 1) and at the country-level (level 2). Multilevel modeling also adjusts the effect of each group (country) based on the number of observations it has compared to all observations, thus giving countries with more complete data more weight, and also limiting the influence of outlier/atypical cases on the results. Others have also highlighted these advantages over more conventional approaches (e.g., fixed effects regression techniques) in the research area (see Greiner and McGee 2018). I follow a similar rationale for conducting multilevel models, with the addition of their ability to include my categorical measure of crude oil trade position. Nevertheless, below I outline sensitivity checks that were conducted to ensure that the implications of these choices did not affect the results.

I construct a series of multilevel models to assess whether the effect of oil extractive dependency on oil-based emissions differs by position in the oil trade network. For the non-interaction models, I use random intercepts models that allow for the intercepts to vary by the nesting group (in this case, countries). To accomplish this, I first conduct a null model. Then, common variables in quantitative macro-sociology are included to see how the variation is partitioned between factors that change over time (level 1) and factors that do change over time (level 1). After, I include oil rents as a percentage of GDP and crude oil trade position. Finally, I model an interaction effect between oil trade network position and oil rents to see if trade position modifies the effect of oil extractive dependence on oil-based emissions. I use random coefficients models with oil rents varying by country in the interaction model set. The equation for the cross-level interaction model (Model 3 in the analysis) is below:

$$\text{Micro Model: } CO2OIL_{ti} = \beta_{0i}(x_{0ti}) + \beta_1(POP_{ti}) + \beta_2(GDPPC_{ti}) + \beta_3(GDPPC_{ti}^2) +$$

$$\beta_4(URBAN_{ti}) + \beta_5(AGERAT_{ti}) + \beta_{6i}(OILRENTS_{ti}) + e_{0ti}$$

$$\text{Macro Model: } \beta_{0i} = \beta_0 + \beta_7(INTEGRATED_i) + \beta_8(IMPORT_i) + \mu_{0i}$$

$$\beta_{6i} = \beta_6 + \beta_9(INTEGRATED_i) + \beta_{10}(IMPORT_i) + \mu_{6i}$$

$$\text{Level 2: } \begin{bmatrix} \mu_{0i} \\ \mu_{6i} \end{bmatrix} \sim N(0, \begin{bmatrix} \sigma_{u0}^2 & \square \\ 0 & \sigma_{u6}^2 \end{bmatrix})$$

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

Where $CO2OIL_{ti}$ is CO_2 emissions from liquid fuel consumption in natural logarithmic form for year t in country i; POP_{ti} captures the natural logarithmic form of population size for year t in country i; $GDPPC_{ti}$ is the natural logarithmic form of GDP per capita for year t in country i; $GDPPC_{ti}^2$ is the squared version of the natural logarithmic form of GDP per capita for year t in country i; $URBAN_{ti}$ represents the logged percent urban of total population for year t in country i; $AGERAT_{ti}$ is the logged age dependency ratio for year t in country i; $OILRENTS_{ti}$ represents the logged oil rents as a percentage of GDP for year t in country i; $INTEGRATED_i$ is the dichotomous measurement of country i being well-integrated in crude oil trade; $IMPORT_i$ is the dichotomous measurement of country i being import-oriented in crude oil trade; e_{0ti} represents the residual difference in CO_2 emissions from liquid fuel consumption for year t in country i; μ_{0i} is the difference in residual CO_2 emissions from liquid fuel consumption for country i when every explanatory variable is constant at zero; μ_{6i} represents the residual difference in CO_2 emissions from liquid fuel consumption for every one-unit increase in oil rents as a percentage of GDP for country i; σ_{u0}^2 is the between-country variance in CO_2 emissions from liquid fuel consumption (for models 3 and 4, this is only the case at the y-intercept); σ^2_{u6} represents the change in between-country variance in CO_2 emissions from liquid fuel consumption for every one-unit increase in oil rents as a percentage of GDP.

I also modeled the interaction effect using different assumptions within multilevel modeling (including time as a dummy variable) and using another standard technique in the literature (two-way fixed effect regression analysis with robust standard errors). I also added 0.01 to all values of oil rents since there were observations which were omitted due to the application of a natural logarithm to see if results were dependent upon data choices. These sensitivity checks resulted in substantively similar findings, showing support for the general finding across modeling assumptions and techniques (see Table S1 in Appendix A). I also modeled the data using different criteria for the regular equivalence computation, including 10– and 20-year benchmarks with the 1-million-dollar cutoff, and 10-, 15-, and 20-year benchmarks at the 25^{th} and 50^{th} percentiles of trade value. Again, results were substantively consistent with those reported here (see Table S2 in Appendix A).

Results

Regular Equivalence Analysis

Table 4 shows the results of the regular equivalence analysis on the crude oil trade network from 1988 to 2016 that are included in the multilevel models. Three groups were constructed: export-oriented economies that have meaningful and durable export crude oil ties, but no import ties; import-oriented that have durable and meaningful import crude oil ties, but no export ties; and well-integrated economies that have both export and import crude oil ties that are meaningful and durable. Export-oriented economies include many current and past member and observer states of the Organization of Petroleum Exporting Countries and Organization of Arab Petroleum

Exporting Countries: Algeria, Angola, Azerbaijan, Ecuador, Equatorial Guinea, Egypt, Gabon, Iran, Iraq, Kuwait, Libya, Mexico, Nigeria, Oman, Qatar, Republic of the Congo, Saudi Arabia, Sudan, Syria, and the United Arab Emirates.[2] Colombia, a major exporter in South America, is also part of the export-oriented position. While countries such as Guatemala, Democratic Republic of the Congo, and Mongolia may appear anomalous as they are not major crude oil exporters, they do have significant, durable export ties to the United States or China, and thus are positioned as export-oriented.

Import-oriented economies are geographically disparate and tend to have higher levels of economic development compared to export-oriented economies, with little to no access to domestic oil reserves. Several large economies are included in this position, including Japan, India, South Korea, France, and Spain. While a few countries in this position, like Lithuania and Greece, do export crude oil to some degree, none reach the criteria for inclusion as a meaningful and durable export tie.

Well-integrated crude oil economies tend to have access to oil domestically, are more developed economically, and are more integrated in regional and global trade networks in general. Many of the largest economies in the world occupy this position, such as the United States, China, Germany, the United Kingdom, Italy, Brazil, Canada, Russia, and Australia. While countries like the Slovak Republic and the Czech Republic may not export significant amounts of crude oil, both have significant and durable ties to Austria, and are thus positioned as well-integrated. While Argentina is predominantly a crude oil exporter, it does receive significant and durable ties from Bolivia and is therefore positioned as well-integrated from the regular

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[2] Venezuela, a member state of OPEC, is also an export-oriented economy from the regular equivalence analysis, however, is missing data for GDP per capita in constant 2015 USD, and thus is not listed here.

equivalence analysis. Economies in this position may be mostly net exporters or importers but are nonetheless part of this classification due to possessing meaningful, durable export and import ties with other economies.

In short, the results of the regular equivalence analysis placed countries into positions in the crude oil trade network. Export-oriented economies are mainly composed of current/former/observer states in international organizations related to petroleum exportation. Import-oriented economies tend to have little to no direct access to significant oil resources within their territories. Well-integrated economies tend to have access to oil resources and refining capacities and are generally more economically developed than the other positions.

Table 4. Countries Included in Multilevel Model Analyses by Oil Trade Position

Export-Oriented	Well-Integrated	Import-Oriented
Algeria	Argentina	Austria
Angola	Australia	Bangladesh
Azerbaijan	Brazil	Belarus
Bolivia	Cameroon	Chile
Colombia	Canada	Croatia
Congo, Dem. Rep.	China	France
Congo, Rep.	Cote d’Ivoire	Ghana
Ecuador	Czech Republic	Greece
Egypt, Arab Rep.	Denmark	Hungary
Equatorial Guinea	Germany	India
Gabon	Indonesia	Japan
Guatemala	Italy	Jordan
Iran, Islamic Rep.	Kazakhstan	Korea, Rep.
Iraq	Malaysia	Lithuania
Kuwait	Netherlands	Morocco
Table 4 Continued.		
Export-Oriented	Well-Integrated	Import-Oriented
Libya	New Zealand	Romania
Mexico	Norway	Senegal
Mongolia	Peru	Serbia
Nigeria	Philippines	South Africa

Oman	Poland	Spain
Papua New Guinea	Russian Federation	Sweden
Qatar	Slovak Republic	Turkiye
Saudi Arabia	Thailand	Ukraine
Sudan	Trinidad and Tobago	
Syrian Arab Republic	Tunisia	
Turkmenistan	United Kingdom	
United Arab Emirates	United States	
Vietnam		
Yemen, Rep.		

Multilevel Model Analysis

Table 5 shows the results of the multilevel model analysis of all nations in the oil trade network. The null model results suggest that nation-level factors that do not change over time explain the vast majority of variation in total carbon dioxide emissions from oil sources. The variance partition coefficient of the null model is 0.9628, indicating that 96.28 percent of the variation in oil-based emissions is explained at the national level, not factors within countries that change over time.

Model 1 includes common variables corresponding with prominent environmental sociological theory, such as human ecology and modernization processes. Population size and urban as a percentage of total population are positive and significant. Age dependency ratio is positive and non-significant. Model 1 shows evidence of an environmental Kuznets curve between GDP per capita and oil-based emissions, as the effect of GDP is positive but diminishes as GDP per capita increases. Model 2 includes oil rents as a percentage of GDP and oil trade position. Oil rents as a percentage of GDP is marginally negative and non-significant. Oil trade positive does not initially appear to influence oil-based emissions, as both well-integrated and import-oriented economies do not significantly differ from export-oriented economies. This may be somewhat unsurprising, as the extensive international market in crude oil enables consumption across positions. Interestingly, both Models 1 and 2 exhibit improvements in model fit via the results of likelihood ratio tests over the null model, yet they do not show significant improvements over each other. Models 1 and 2 also show that about 91 percent of the variation in oil-based emissions are attributable to nation-level factors that do not change over time. This suggests that, while the inclusion of time-variant factors within nations improves model fit, they explain significantly less of the variation in oil-based emissions compared to factors at the national level that do not change over time. Moreover, the inclusion of economic dependence on oil extraction and crude oil trade position do not significantly improve model fit, suggesting that, independently, these factors may not substantially explain variation in oil-based emissions.

Model 3 includes a random-coefficients specification for oil extractive dependence (oil rents / GDP) and a cross-level interaction between oil extractive dependence (level 1) and oil trade position (level 2). The control variables maintain their direction and significance from Model 2, with the exception of age dependency ratio which retained its substantively positive association but reached statistical significance. Of particular interest is the interaction effect. The export-oriented position is the reference group, so the main effect of oil rents captures that position's association with oil-based emissions. Consistent with H1, the coefficient is positive and significant: for export-oriented economies, a one percent increase in oil rents as a percentage of GDP is associated with 0.1 percent increase with oil-based emissions, net of control variables. Consistent with H2, the interaction effect between oil rents and the well-integrated position is negative and significant: relative to the export-oriented position, well-integrated economies exhibit a lessened slope by 0.15 percent. Similarly, and consistent with H2, the interaction effect between oil rents and the import-oriented position is negative and significant: relative to the export-oriented position, with a one percent increase in oil extractive dependence import-oriented economies exhibit 0.15 percent less oil-based emissions. In this model, the average marginal effect of oil extractive dependence is positive and significant for export-oriented economies, while for both well-integrated and import-oriented economies is negative and non-significant. Pairwise comparisons of the average marginal effects also indicate that the slopes of well-integrated and import-oriented economies do not significantly differ. These findings support the proposition of ecologically unequal exchange theory in general and my hypotheses in particular, as the oil export frontier experiences heightened oil-based emissions with expanded extraction to meet world-systems demand compared to other-positioned economies in the crude oil trade network.

Model 4 adds controls to assess whether the finding of the cross-level interaction is sensitive to changes in model specification. Percent imports and exports are added to the model to account for general tendencies of trade openness and percent manufacturing is added to account for the amount of economic output related to industrial activity, which tends to produce emissions. Accounting for these additional controls, the central findings of Model 3 hold. Export-oriented economies exhibit a positive and significant association between oil extractive dependence and oil-based emissions: for export-oriented economies, a one percent increase in oil extractive dependence is associated with a 0.19 percent increase in oil-based emissions, net of controls. Well-integrated and import-oriented economies exhibit a negative and significant association between oil extractive dependence and oil-based emissions compared to export-oriented economies. For well-integrated economies, a one percent increase in oil extractive dependence is associated with a 0.22 percent decrease in oil-based emissions relative to export-oriented economies. For import-oriented economies, a one percent increase in oil extractive dependence is associated with a 0.24 percent decrease in oil-based emissions relative to export-oriented economies. Again, the average marginal effect of oil rents for export-oriented economies is positive and significant, while for well-integrated and import-oriented economies it is negative and non-significant. More than Model 3, the findings from Model 4 suggest that, even while controlling for other explanatory mechanisms (general trade openness; manufacturing intensity), the cross-level interaction effects maintains its substantive and statistical significance: the crude oil export frontier, through the process of expanding extraction and molding their economies to meet world-system consumption needs, experiences increased oil-based emissions, while other-positioned economies experience relatively lessened emissions.

Table 5. Multilevel Model Results

Table 5. Multilevel Model Results												
	Null Model				Model 1				Model 2			
Fixed Effects			CI				CI				CI	
Variables	b	pvalue	lower	upper	b	pvalue	lower	upper	b	pvalue	lower	upper
Population (ln)					0.824	0.000	0.750	0.899	0.815	0.000	0.740	0.890
GDPPC (ln)					2.027	0.000	1.657	2.396	2.036	0.000	1.665	2.408
GDPPC (ln)2					-0.099	0.000	-0.120	-0.078	-0.100	0.000	-0.121	-0.078
Pct. Urban (ln)					0.449	0.000	0.279	0.619	0.454	0.000	0.284	0.624
Age Rat. (ln)					0.107	0.067	-0.007	0.220	0.099	0.088	-0.015	0.213
Oil Rents (ln)									-0.001	0.901	-0.014	0.013
Oil Trade Position												
Well-Integrated									0.317	0.110	-0.072	0.706
Import-Oriented									0.139	0.503	-0.268	0.546
Interaction Effects												
Well-Integrated x Oil Rents (ln)												
Import-Oriented x Oil Rents (ln)												
Pct. Imports (ln)												
Pct. Exports (ln)												
Manufacturing (ln)												
Constant	10.306	0.000	9.956	10.655	-15.836	0.000	-18.103	-13.570	-15.849	0.000	-18.114	-13.585
Random Effects												
Country	2.505		1.833	3.424	0.537		0.386	0.748	0.524		0.378	0.728
Observation	0.097		0.091	0.103	0.053		0.050	0.057	0.053		0.050	0.057
Oil Rents (ln)												
Number of Countries	79				79				79			
Number of Observations	2052				2052				2052			

Table 5 Continued. Multilevel Model Results												
	Model 3				Model 4							
Fixed Effects			CI				CI					
Variables	b	pvalue	lower	upper	b	pvalue	lower	upper				
Population (ln)	0.831	0.000	0.755	0.906	0.933	0.000	0.848	1.017				
GDPPC (ln)	2.014	0.000	1.644	2.384	1.014	0.000	0.587	1.440				
GDPPC (ln)2	-0.102	0.000	-0.123	-0.080	-0.047	0.000	-0.071	-0.023				
Pct. Urban (ln)	0.582	0.000	0.405	0.760	0.432	0.000	0.222	0.643				
Age Rat. (ln)	0.120	0.036	0.008	0.233	-0.031	0.630	-0.157	0.095				
Oil Rents (ln)	0.102	0.000	0.046	0.159	0.190	0.000	0.111	0.268				
Oil Trade Position												
Well-Integrated	0.585	0.003	0.199	0.970	0.661	0.003	0.223	1.098				
Import-Oriented	0.267	0.199	-0.141	0.675	0.391	0.092	-0.064	0.846				
Interaction Effects												
Well-Integrated x Oil Rents (ln)	-0.146	0.000	-0.224	-0.068	-0.218	0.000	-0.324	-0.113				
Import-Oriented x Oil Rents (ln)	-0.150	0.000	-0.232	-0.068	-0.238	0.000	-0.348	-0.129				
Pct. Imports (ln)					0.208	0.000	0.144	0.271				
Pct. Exports (ln)					-0.228	0.000	-0.287	-0.168				
Manufacturing (ln)					0.164	0.000	0.118	0.209				
Constant	-16.633	0.000	-18.932	-14.333	-13.193	0.000	-15.754	-10.631				
Random Effects												
Country	0.481		0.339	0.683	0.572		0.391	0.837				
Observation	0.046		0.043	0.049	0.036		0.033	0.038				
Oil Rents (ln)	0.016		0.009	0.028	0.030		0.018	0.050				
Number of Countries	79				76							
Number of Observations	2052				1748							

Conclusion

This study used social network analysis to build a novel approach to ecologically unequal exchange theory, largely through treating national positionality in a trade network as a meaningful context that shapes the relationship between extractive dependence and environmental harm. After countries were placed into positions (export-oriented; import-oriented; well-integrated) in the crude oil trade network, multilevel models were conducted to see whether this context changed the relationship between oil extractive dependence and oil-based emissions. There are several highlights from the results of this model set. First, the vast majority of variation of oil-based carbon emissions are explained by national level factors that do not change over time, consistent with findings on carbon emissions per capita (Greiner and McGee 2018). Second, crude oil trade position and oil extractive dependence may not strongly influence oil-based emissions independently. However, this may be expected, as trade itself allows nations to gain entrée to oil consumption. Thirdly, the interaction effect between these variables shows that well-integrated and import-oriented economies have lessened emissions as a consequence of oil extractive dependence compared to export-oriented countries, consistent with ecologically unequal exchange theory (H1 and H2). In short, countries that function as oil exporters in the global economy face increased related emissions with increases in economic dependence on extraction, as economic and energy diversification is likely suppressed.

Prior empirical work highlights the degradation-consumption paradox whereby powerful nations use their advantageous position to garner natural resources from less powerful nations, thus increasing consumption and decreasing degradation (e.g., Jorgenson, Austin, and Dick 2009). Historical and theoretical work emphasizes how demands from the world system encourage natural resource dependence, and subsequently underdevelopment, in export-oriented countries (see Bunker 1985). This chapter examined one of most traded commodities in the world, crude oil. Increasing economic dependence on oil extraction increases oil-based emissions in export-oriented countries but exhibits a more negative association for import-oriented and well-integrated countries.

This finding has several potential macro-explanatory mechanisms (that are not mutually exclusive). Extractive export-oriented economies are at an uneven position in trade relationships, and thus may enforce laxer environmental protections to intensify extraction (Tester 2020). More inefficient and environmental harmful extraction/production processes may be moving to export-oriented countries, a “tilt” in the transnational organization of production (Thombs 2018) fueled by foreign direct investment by wealthier nations, among other factors (e.g., Faber 2008; Jorgenson 2006). Moreover, extraction may intensify in export-oriented countries as natural resource export specialization may suppress export diversification (Harding and Venables 2016) and foreign direct investment in economic sectors unrelated to resource extraction (Poelhekke and van der Ploeg 2013). In short, international dimensions of trade and foreign direct investment may influence economic specialization, environmental protections, and extractive industry expansion within export-oriented countries.

Ross (2012) interrogates the well-studied “oil curse.” This thesis argues that natural resource endowed states suffer from poorer health, governance, and civil society outcomes due to a variety of factors. Ross (2012) finds that oil endowed states do not necessarily have worse outcomes relative to comparable counterparts, but merely do not enjoy the economic growth that might be expected given the abundance of resources available. This may be due to a variety of factors, but mainly that the nationalization of oil industries induces less democratic governmental institutions as intensified revenue eases governmental dependence on taxes and frees politicians from accountability. Moreover, there are uneven labor opportunities due to the booming oil sector that fosters gender disparities in employment opportunities, increases population size, and fosters some conditions for increased intra-national conflict (Ross 2012; Bridge and Le Billon 2013). Many of the struggles associated with the "oil curse" are related to oil extraction becoming a dominant feature of the economy to such a degree as to suppress other economic sectors. This study finds that increasing economic dependence on oil extraction increases oil-based emissions for export-oriented countries. Intuitively, we may expect that oil importers consume more oil as a consequence of international trade relations. I show that economic dependence on oil extraction also increases oil-based emissions within export-oriented countries. In this way, environmental problems may also be intimate by dynamics of the "oil curse."

This chapter also has theoretical and methodological implications for sociological research at the intersection of international trade and environmental outcomes. Bunker's (1985) formation of ecologically unequal exchange theory highlights that intra-national extraction and production processes organize around the needs of the world-system: "The ecological devastation of the Amazon started when the modes of extraction organized in response to world-system exchange opportunities focused on the single natural products for which there was greatest global demand" (250). While a variety of studies use measures that capture the relative intensity of exports of natural resources to high-income nations (e.g., Jorgenson 2006; Shandra 2009), recent studies use social network analysis to highlight the extent to which centrality in natural resource exchange (Vesia, Mahutga, and Bui 2023) and foreign direct investment (Jorgenson et al. 2022) influences emissions. This analysis contributes to the growing interest in using network methods to analyze the trade-environment relationship in environmental sociology. By using network methods, *a priori* assumptions that lower-income nations are resource frontiers are avoided, instead opting for an inductive identification of positions in the trade structure. As a consequence, a closer examination of how economic dependence on extraction influences associated forms of environmental harms is enabled. I contend that this approach more closely adheres to theoretical and historical work on unequal ecological exchange (e.g., Bunker 1985; Hornborg 2019) compared to empirical work that focuses on intensity of exports to high-income countries in two ways. First, it places nations into relative positions based on an evaluation of trade data as opposed to national income bifurcations that lack commodity-specific contexts. Second, it focuses on economic dependence on extraction, capturing both internal and external factors of the theoretical framework. This methodological schema employs network analysis to examine how the international structure of nations shapes the relationship between extractive dependence and related forms of environmental harm.

Future research should consider applying social network analysis to research at the intersection of natural resource extraction, international trade, and environmental harm. Several studies have already begun this work and have developed relational understandings of trade that emphasize the importance of centrality in trade networks. By parsing out positions as importers and/or exporters in trade networks, however, we can more closely attend to the theoretical expectations of ecologically unequal exchange and related theoretical traditions. Future research should consider how import- and export-position in trade networks influences environmental degradation to properly conceptualize the relational nature of trade.

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CHAPTER IV: DOES GLOBAL ECONOMIC INTEGRATION CHANGE THE RELATIONSHIP BETWEEN RENEWABLE ENERGY CONSUMPTION AND CO_2 EMISSIONS?

Abstract

Renewable energy technologies are an essential component of green energy futures. Significant environmental sociological attention has been paid to the role of renewables in reducing emissions, and the contexts and circumstances in which they are more or less effective. In this chapter, I address whether global economic integration modifies the effect of renewable energy consumption on carbon dioxide emissions. Through network and fixed-effect regression analyses, I find that countries least central to the global economy tend to experience additional reduced emissions from increased renewables consumption relative to most central countries. This implies that least central countries may not be embedded in the preexisting, global fossil fuel economy and infrastructures, and renewables function as a pathway toward providing energy resources.

Introduction

Renewable energy technologies play a central role in climate change policy and research. International and national government entities call for more investment and development of renewable energies to meet needed energy demands in a sustainable fashion to curb greenhouse gas emissions (e.g., IPCC 2011). President Biden, for example, campaigned on a clean energy and sustainable economy platform (Biden 2021). Considering the policy and practical import of renewable energy investment, it is critical to investigate how effective renewable energy consumption is in reducing emissions, and if there are certain circumstances or contexts in which it is more effective in reducing emissions.

The environmental sociological literature provides several perspectives regarding the role of renewable energy in addressing climate change. Ecological modernists advance that a “greening” of the economy can occur through institutional transformation and technological innovation toward environmental ends within a capitalist economic system (Mol and Spaargaren 2000). Conversely, ecological Marxist research on the ecological paradoxes of capitalism highlights that there are often unanticipated consequences to the implementation of eco-efficient production practices and renewable energies, such that gains in efficiency are outstripped by increases in use (York 2006) and that renewable energies are added to and do not necessarily replace fossil fuels (Thombs 2017; York and Bell 2019; York and McGee 2017). However, longstanding interest in these intra-national processes may occlude needed attention to relations between nations (Downey 2015; Mol and Spaargaren 2005) and their attendant environmental implications.

Theories of global environmental inequality draw attention to how the hierarchical structure of international trade promotes increased resource consumption in more powerful nations and more environmental harm in less powerful ones (Bunker 1984). Derived from world-systems analysis (Wallerstein 2004; Downey 2015), empirical work typically deals with how exportation of natural resources from lower income nations to high income nations increases environmental degradation (e.g., deforestation) in the former (Jorgenson 2006). Network analysts of international trade relations have yielded insights into the global organization of extraction, production, and consumption (e.g., Nemeth and Smith 1985; Mahutga 2006) and provided world-systems classifications based (at least in part) on transboundary commodities exchange (Clark and Beckfield 2009; Snyder and Kick 1979). Like others (Greiner and McGee 2018; Vesia, Mahutga, and Bui 2023), I argue that the international structure of nations is a salient context through which intra-national processes (such as renewable energy consumption) take place.

In this chapter, I use network methods to place countries into relative positions in the global economy based on international trade relationships. I then see how integration into the global economy changes the relationship between renewable energy consumption and carbon dioxide emissions. To accomplish this, I collect data from the International Monetary Fund's Direction of Trade Statistics (IMF 2022), World Bank's World Development Indicators (World Bank 2022), and Our World in Data (Ritchie and Roser 2022). Conducting a series of two-way fixed-effects regression models with robust standard errors, I assess whether more or less central nations in the global economy experience greater reductions in emissions from increased renewable energy consumption. With broader implications for informing longstanding debates in environmental sociology, the findings from this study suggest that the international structure of nations influences the relationship between renewable energy consumption and carbon dioxide emissions *within* nations.

Eco-Social Theory and Technological Innovation

International and national governmental entities stress the importance of investing in renewable energy technologies and decreasing fossil fuel dependence (Department of Energy 2022; UNEP 2022). Of course, the implementation of renewable energies is necessary to curb emissions and reduce fossil fuel use. However, eco-social theories differ in their interpretation of how effective increases in renewable energy development can be in mitigating emissions.

Ecological modernists argue that technological innovation and institutional transformation can reform capitalism toward more ecologically sustainable ends (Mol and Spaargaren 2000). This conclusion is reached in dialogue with earlier forms of ecological modernist thought, such as the work of Joseph Huber (Mol and Sonnenfeld 2000:4), which articulates how green technological innovation occurs through embracing the power of market actors and dynamics to engage in systems transformation (Huber 2004), and reflexive modernization, which highlights the tendency for "mature" economies to develop values and norms that are not exclusively associated with economic development and "progress" (Beck, Giddens, and Lash 1994). Analyses of technological innovation through renewable energy development and consumption typically show decreases in emissions (McGee and Greiner 2019; York and McGee 2017), while those operationalizing innovation through environmental patents show mixed results on environmental indices (Bugden 2022; Töbelmann and Wendler 2020). Adua, Clark, and Jorgenson (2022) show that increased income per capita is associated with implementation of energy efficiency policies and federal congressional voting at the U.S. state-level, while GDP per capita is not, showing some support for ecological modernization propositions. Meanwhile, Szasz (2023) tests whether an array of U.S. state-level policies are associated with reduced emissions, finding that cap and trade policies consistently reduce emissions within states over time. In essence, ecological modernization theory contends that, in post-industrial societies, eco-conscious values and norms can be embedded within the economic structure via political regulatory enforcement and environmental management of firms (Mol 2001; Mol and Spaargaren 2000).

Ecological Marxists tend to take a more pessimistic view of the relationship between technological innovation (often operationalized as renewable energy development or eco-efficiency) and emission reductions. The ecological paradoxes of capitalism, namely, the Jevons paradox and displacement paradox, occur within an economic system where the underlying logic is economic expansion and capital accumulation. The Jevons paradox occurs when gains from eco-efficiency are outstripped by increases in resource/energy use (Alcott et al. 2007; York and McGee 2016), a subset of the more general "rebound effect," which broadly discusses correlations between improvements in eco-efficiency and increases in usage (Greening, Greene, and Difiglio 2000; Sorrell 2007; Rajabi 2022). In other words, while the technological undergirding for extraction or energy use may have improved, this coincides with an increase in overall usage as a consequence. In parallel, the displacement paradox arises when we might expect increases in a green substitute to be associated with an equivalent decrease in the environmentally harmful technology or practice. However, a variety of studies have shown this supposition (or its concomitant effects) to be unfounded (McGee 2015; Thombs 2017; York 2012; York and McGee 2017), in part because energy usage (like the economy as a whole) is expanding. In this sense, renewable energies can serve as a complement and augmentation to existing energy usage as opposed to a replacement for them (York and Bell 2019).

In short, there are varying perspectives on how effective renewable energy technologies are in reducing emissions based on their engagement with political economic factors. Yet, each approach tends to focus on domestic factors (e.g., technological and economic development), indicating a need for consideration of how integration in the global economic system may also influence the extent to which ecologically beneficial technologies reduce emissions.

World-Systems Analysis, Economic Globalization, and Social Networks

World-systems analysis examines the international structure of nations. World-systems analysis posits that there is a tiered global political-economic system consisting of the core, periphery, and semi-periphery. Essentially, the core enjoys benefits from historical imperialism, sophisticated production practices, and raw materials and simple manufactured goods imports from the semi-periphery and periphery. In contrast, the periphery suffers from legacies of colonialism and ongoing neo-colonial relations, and from natural resource and simple manufactured goods exports to more advantageously positioned nations. Further, semi-peripheral nations occupy an intermediary position undergoing rapid industrialization, thus engaging in industrial activity both characteristic of the core and periphery (Wallerstein 2011). Within this framework, it is important to "remember that we are really talking of a relationship between production processes," in other words, that the geographical typologies of zones are not fixed and exist in relation to each other (Wallerstein 2004:28). In short, world-systems analysis examines how global capitalism promotes international stratification through differential economic activities in different parts of the world economy, as advantageously positioned nations (the core) use international trade to treat less advantageously positioned nations (the semi-periphery) as zones for unwanted (e.g., environmentally inefficient) or less profitable economic activities, or as frontiers for cheap labor and natural resources (the periphery) (Bunker 1984; Emmanuel 1972).

Built on the legacy of imperialism and colonialism, globalization has enabled the construction of the modern world-system through increased ease of transportation across nations and continents that allowed for the flow of information and commodities. Of course, globalization takes many forms, including (but not limited to) cultural, political, and economic diffusion of practices, ideas, policies, governance structures, and commodities. These processes are interlinked but are nonetheless important to delineate (Chase-Dunn 2006). Economic globalization can be understood as "greater integration in the organization of production, distribution, and consumption of commodities in the world economy" (Chase-Dunn 2006:83), made possible by improved (and lower cost) transportation systems (Hummels 2007) and neoliberal trade policies (Dreiling and Darves 2016). While economic globalization enables and allows for the capitalist world-system, conceptually these processes are not necessarily equivalent.

Social network analysis explores relationality between actors and the organization of complex social systems. For example, it has proven to be a useful tool to analyze and understand the global economy by illuminating how trade relationships link nation-states. The literature mainly assesses the global economic system in the tradition of world-systems analysis in two ways. First, studies examine aggregated trade data. An early study used structural equivalence, a blockmodeling method to establish which actors have equivalent relations with the same alters, to look at multiple nation-state interactions, including trade, treaties, military interventions, and diplomatic relations (Snyder and Kick 1979). Later work explicitly constructed a three-tiered classification system of the global economy, optimizing groupings based on density within blocks such that the core is maximally dense, the periphery is minimally dense, and the semi-periphery roughly equates to the density of the global trade network as a whole (Clark and Beckfield 2009; Clark 2012).

Second, studies examine trade linkages of several specific commodity types (e.g., sophisticated manufactured goods; extractive commodities) to establish which countries engage in specific economic activities, improving upon earlier work (Snyder and Kick 1979) by considering multiple commodity flows within trade relations and production processes. For example, sophisticated manufactured goods flow within the core and from the core to other strata while agricultural goods flow within the core and from the periphery to the core, consistent with world-systems expectations regarding the type of productive activity occurring in each zone (Nemeth and Smith 1985; Smith and White 1992). Longitudinal studies in this research area established that globalization encourages the maintenance of structural inequality within the global economy (Mahutga 2006). However, during the intense globalization of the late 20th Century, semi-peripheral nations underwent rapid economic development, indicative of a "convergence" of upper-tier zones in the world-system while simultaneously promoting a lack of growth in lower tiers (Mahutga and Smith 2011). Network studies of disaggregated trade data examine structural inequality in the world-system, as modalities of national economic activity (e.g., extraction; simple manufacturing; high-technological goods and automobiles) can be inferred from the trading of specific commodity types.

Fundamentally, world-systems analysis concerns relationships between modalities of economic activity on global scale. Exploring specific commodity linkages illuminates an international division of labor (e.g., Mahutga and Smith 2011), and thus engages with the theoretical foundations of world-systems analysis. Meanwhile, despite the fact that analyses may explicitly seek to establish world-systems classifications, the use of aggregated trade data belies its theoretical underpinnings: aggregated trade data determines generalized export/import linkages rather than relational production processes. Therefore, I suggest that network analyses of aggregated trade data capture groupings of nations by their integration into the global economy. Further, such analyses should understand that more integration could simply involve consistent and high-volume trade of specific commodity types (e.g., simple manufacturing goods; extraction-related commodities) rather than an advantageous position in the global economy. This acknowledgement explains the anomalous nature of a few nations into the core in these classification schemes (Thailand, Mexico, and Brazil in the core in the 1980s, as an example) (Clark and Beckfield 2009). In short, being more central to the global economy does not equate to being a "core" nation in the traditional sense of world-systems theory, as it is not possible to establish how that integration is situated in the organization of global capitalism and the commodity lifecycle.

However, categorizing nations by relative integration in the global economy still provides a useful analytic frame to understand the international structure of nations. I suggest that countries highly integrated in the global economy are more essential for the functioning of global capitalism, either as a supplier or as a consumer of resources. In general, less central nations export more of their goods to more central nations than they do to less central nations (e.g., Clark and Beckfield 2009; Clark 2012). Environmental sociologists use social network analysis, or the typologies provided by social network scholars to assess economy-environment linkages, among other domain foci. For example, Greiner and McGee (2018) find that semi-peripheral nations exhibit a relatively consistent relationship between economic development and emissions, while core and peripheral nations show an inversed U-shaped relationship (using typologies from Clark and Beckfield 2009 and Snyder and Kick 1979), consistent with expectations from an environmental Kuznets curve (Stern 2004). In terms of foreign investment, nations in the Global South that are more central to the global foreign direct investment network exhibit increased emissions relative to Global North nations, indicating the movement of energy inefficient and environmentally harmful industries to the Global South (Jorgenson et al. 2022). Countries least central to the natural resource exchange network endure more environmental costs as a consequence of economic development (Vesia, Mahutga, and Bui 2023), again consistent with ecologically-oriented world-systems frameworks that expect more powerful nations to externalize their environmentally-intensive activity to less powerful ones via international trade. While studies typically examine how the international structure of nations (via international trade or foreign direct investment) provides a useful context for analyzing relationships between economic development, international stratification, and the environment, I am interested in exploring how integration into the global economic system may influence the implementation of renewable energies and its efficacy in reducing emissions.

Global Economic Integration and Renewable Energy Implementation

While there is conceptual overlap between world-systems position and integration in the world economy, I suggest that these are better understood as distinct. More integrated nations may generally be more powerful than less integrated nations, but there is intra-group heterogeneity in that better integrated nations may be exploited for their natural resources and cheap labor more than less integrated nations. Thus, more integrated nations should be understood as more central for the functioning of global capitalism than holding power and influence over other countries in the global economy. There are varying perspectives as to how integration in the world economy influences environmental practices and degradation.

While ecological modernization theory is often operationalized at the nation-state level, Mol (2001) argues for an expansion of the theory to include processes of globalization. It is important to note that Mol acknowledges the unequal and detrimental effects globalization can incur on regional environments. Mol also suggests several potential benefits it can offer:

> Ecological concerns, motives and interests can be a driving force behind processes of globalization (in the economic, cultural, and political domains)… globalization processes can strengthen environmental reform and environmental consciousness. Globalization can trigger the harmonization of national environmental practices, regimes, and standards, produce new institutional arrangements at a supra-national level, transfer environmental technologies... and accelerate the exchange of environmental information around the world (Mol 2001:96).

The globalization of ecological modernization takes place, in part, through transboundary economic exchange, acting as a diffusion mechanism for environmental information and practices. Thus, we may expect globalization to encourage a homogenization of environmental practices and policies on an international scale (Mol 2001). Global economic relationships allow for the transfer of technologies and industrial policies that contribute to environmental improvement, especially in contemporary industrial centers throughout South and East Asia (Rock and Angel 2005). While there is cultural and political diffusion of pro-environmental activity as well (Mol, Spaargaren, and Sonnenfeld 2014), economic globalization is a tractable analytical framing for measuring the potential spread of beneficial technologies and approaches to environmental issues. As Mol (2001) suggests, "regional, originally economic institutions such as the European Union and to a lesser extent the North American Free Trade Agreement are probably of greater relevance for the future taming of transnational capitalism" (206), as these regions and their attendant regional governance structures increasingly integrate environmental reform. Under this light, we might expect countries most central to the world economy (such as some EU and NAFTA nations) to exhibit greener policies and more effective implementation of environmentally beneficial technologies, including renewable energy development, and for these practices to be the starting point for the diffusion of such innovations through trade networks to less central nations.

Critical environmental sociological work largely draws upon treadmill of production theory (Schnaiberg 1980) and other strands of ecological Marxism to argue that economic expansion outstrips gains from environmentally beneficial technologies (York 2006; Thombs 2017). From an ecological Marxist perspective, Andreas Malm (2016) outlines a historical analysis of the interlinked nature of capitalism and fossil fuel use. In the shift from muscle-power to machinery, technological advancement played a central role and was accompanied by new transportation forms and capital-intensive machinery that relied on fossil fuels (Huber 2009; Malm 2016). Malm (2016:22) elaborates the durability of the ensuing global fossil fuel economy:

> The fossil economy has the character of a totality, a distinguishable entity: a socio-ecological structure, in which a certain economic process and a certain form of energy are welded together... A person born today in Britain or China enters a preexisting fossil economy, which has long since assumed an existence of its own and confronts the newborn as an objective fact.

In other words, fossil fuels are so interwoven in the history of capitalist development that they serve as a social input: given the preexisting infrastructural system supporting fossil fuels, people and organizations are compelled to use them in their everyday lives and operations. The fossil economy is made possible in global terms by the international organization of natural resource extraction and consumption (Behrens et al. 2007). The mid-20th Century saw the formation of international organizations (e.g., WTO; United Nations) and international currency exchange agreements (e.g., Bretton Woods), paving the way for the establishment of a global order to be maintained via international economic exchange (Harvey 2005). Part of establishing and maintaining global order is the maintenance of and expanding entrée to energy sources, visible through the military actions of economic powers to secure access to oil fields, particularly the Middle East (Colgan 2021; Jorgenson et al. 2023). Countries most central to the global economy thus have vested interests in the fossil economy, as the built infrastructural capacity for its use already exists, and indeed, significant effort is directed toward the management of energy security. As such, we might expect that nations most central to the global economy will exhibit a less effective relationship between renewable energy consumption and emission reductions, as the preexisting infrastructure supporting fossil fuel use and expansionary logics of the economy encourages renewables acting as an addition to the energy supply, not a replacement for fossil fuels.

Hypotheses

In line with ecological modernization theory's emphasis on technological innovation and renewable energies, an abundance of research shows that, on the cross-national level, increases in renewable energy output and consumption is associated with a decrease in emissions (Hargrove, Sommer, and Shandra 2021; McGee and Greiner 2019; Thombs 2017; York and McGee 2017). Thus, I form the following hypothesis concerning ecological modernization through domestic processes:

H1: Across all nations, increasing renewable energy consumption as a percentage of total energy consumption will be associated with a decrease in carbon dioxide emissions, all else being equal.

Globalization may have pro-environmental effects. Ecological modernists describe the potential benefits of a more connected world, including increased flow of environmental information, transfer of eco-efficient technologies, and the spreading of business practices and policies that promote environmentally beneficial outcomes (Mol, Spaargaren, and Sonnenfeld 2014). Countries most central to the global economy are expected to serve as the starting point for the diffusion of pro-environmental practices, policies, and technologies (Mol 2001). Thus, I form a second hypothesis corresponding to the globalization of ecological modernization:

H2: Increasing renewable energy consumption as a percentage of total energy consumption will be associated with decreased emissions in countries most integrated in the global economy relative to less integrated nations in the global economy, all else being equal.

Environmental sociologists exploring connections between economic development and potentially environmentally beneficial innovations frequently find paradoxes related to expected outcomes. Several studies (Thombs 2017; York and McGee 2017) find a paradox whereby increases in relative renewable energy use are simply additions to and not replacements for fossil fuels, unveiling that renewables may not act as the intended substitutes that they are so often portrayed as (York and Bell 2019). In the context of integration into global capitalism, we might expect that those countries that are least integrated in the global economy and thus not so entangled in fossil fuels and their related supporting infrastructural systems (e.g., Malm 2016) may have more effective implementation of renewable energies. Thus, I suggest a third hypothesis corresponding to ecological Marxist expectations:

H3: Increasing renewable energy consumption as a percentage of total energy consumption will be associated with increased emissions in countries most integrated in the global economy relative to less integrated nations in the global economy, all else being equal.

Data

I collected relational trade data for this analysis from the International Monetary Fund's Direction of Trade Statistics (IMF 2022). These data include imports to reporting countries, the counterpart (exporting) country, and the value of imports, cost, insurance, and freight in US dollars for every year from 1990 to 2019. Below I describe regular equivalence, a network approach to blockmodeling, which I used to place countries into relative positions in the global economy.

The dependent variable is carbon dioxide emissions from fossil fuel use and industrial activity, including the manufacturing of cement and steel, in tons (Our World in Data 2022). I collected independent variables from the World Bank's World Development Indicators (World Bank 2022). The variable of interest in the present study is renewable energy consumption as a percentage of total energy consumption, as other studies examining the mitigating effect of renewable energies on emissions have used (e.g., McGee and Greiner 2019; Thombs 2017). Since this measure has a non-insignificant amount of zero values, I add 0.01 to all values so that the variable can be in natural logarithmic form, consistent with the theoretical foundation of STIRPAT modeling (Dietz and Rosa 1994). When analyzing environmental degradation in general and emissions in particular, it is important to control for population dynamics and factors associated with modernization processes, such as economic development and urbanization (e.g., Rosa, and Dietz 2003). As such, I include total population size, GDP per capita in constant 2015 US dollars, percent of the population residing in urban areas, and age dependency ratio (ratio of those aged under 15 and over 64 to those aged 15 to 64). I also include the value added from manufacturing as a percentage of national GDP. Given that my interest is in international trade position, it is important to control for the effect of trade openness, and thus I include a control for value of trade (exports + imports) as a percentage of GDP. The variables above are available from 1990-2019. Following STIRPAT analysis (Dietz and Rosa 1994, 1997; York, Rosa, and Dietz 2003), all variables are in natural logarithmic form, with the exception of dummy variables for countries and years, and the constructed categorical variable capturing international trade integration. Thus, the models presented are elasticity models, where a one-percent change in the independent variable is associated with the reported coefficient percent change in the dependent variable.

Methods

Social Network Analysis of International Trade Relations

I use social network analysis to place countries into relative positions in the global economy based on international trade relationships. Using data from the thirty-year time period I describe above, I categorized countries based on whether their ties persisted for half (15) or more years at or above one-million USD.[3] These criteria select exporter-importer relationships that are significant and durable throughout the period of analysis. Then, I weighed the ties by the average dollar amount across all 30 years. Most approaches to studying the international structure of nations and its impact on the environment use binary ties (no weights) (Clark and Beckfield 2009; Jorgenson et al. 2022; Vesia, Mahutga, and Bui 2023). In contrast I use weighted ties to account for the intensity of trade relationships and to better operationalize global trade power.

Regular equivalence is a network approach that places nodes (countries, in my case) in the same group if they share similar tie structures and network neighborhood relations. White and Reitz (1983) provide a foundational, formal definition: "Regular equivalence yields groupings of points in which for every pair of persons in the equivalent position, *if one has a relation with a person in a second position, the other has an identical relation with a counterpart in that position*" (214, emphasis in original). Put simply, regular equivalence computations seek to determine how similar actors in a network are to one another based on whether they occupy similar roles in a given network structure. In the end, this process yields a matrix of similarities between nodes with values ranging from entirely dissimilar (0) to perfectly equivalent (1) (see also Mahutga 2006).

[3] For the purposes of this analysis, Belgium-Luxembourg was classified as Belgium, the USSR as Russia, Yugoslavia and Serbia and Montenegro as Serbia, and South Africa Common Customs Area as South Africa. If these countries are excluded from the regression analyses, the results are consistent with those presented here.

I used the FORTRAN subroutine of the REGE function available in R's blockmodeling package. I used Ward's (1963) method of hierarchical clustering to establish the partitions. This approach essentially treats the categorization of countries based on dissimilarities as a minimization of variance problem, providing groupings of nations based on their relative similarity of role in the network structure. Based on the results of a Scree plot (see Figure S2 in Appendix B), five groupings exhibited a parsimonious model for understanding global trade relationships. From these five groupings, I collapsed three groups that exhibited similar characteristics (in that they exhibit fewer trade relations) into one, least central group. Thus, I had three categorizations: a most central group, somewhat central group, and least central group. Table 6 provides a list of which countries belong to each group included in the regression analysis.

Table 6. Countries Included in the Regression Analysis by Global Economic Integration

Table 6. Countries by Global Economic Integration Included in the Regression Analysis			
Most Central	*Somewhat Central*	*Least Central*	
Australia	Algeria	Afghanistan	Mauritius
Austria	Angola	Albania	Moldova
Belgium	Argentina	Armenia	Mongolia
Brazil	Bangladesh	Azerbaijan	Mozambique
Canada	Belarus	Bahrain	Myanmar
China	Chile	Benin	Namibia
Czechia	Colombia	Bolivia	Nepal
France	Costa Rica	Bosnia and Herzegovina	Nicaragua
Germany	Croatia	Botswana	Niger
Hong Kong SAR, China	Denmark	Burkina Faso	North Macedonia
India	Dominican Republic	Burundi	Panama
Indonesia	Ecuador	Cambodia	Papua New Guinea
Ireland	Egypt, Arab Rep.	Cameroon	Paraguay
Italy	El Salvador	Central African Republic	Rwanda
Japan	Finland	Chad	Senegal

Korea, Rep.	Greece	Congo, Dem. Rep.	Sierra Leone
Malaysia	Guatemala	Congo, Rep.	Sri Lanka
Mexico	Honduras	Cote d'Ivoire	Sudan
Netherlands	Hungary	Cuba	Tajikistan
Poland	Iran, Islamic Rep.	Cyprus	Tanzania
Russian Federation	Iraq	Djibouti	Timor-Leste
Saudi Arabia	Israel	Equatorial Guinea	Togo
Singapore	Kazakhstan	Eritrea	Turkmenistan
Spain	Kuwait	Estonia	Uganda
Switzerland	Libya	Eswatini	Uruguay
Thailand	Lithuania	Ethiopia	Uzbekistan
United Arab Emirates	Morocco	Gabon	West Bank and Gaza
United Kingdom	New Zealand	Gambia, The	Yemen, Rep.
United States	Nigeria	Georgia	Zambia
Vietnam	Norway	Ghana	Zimbabwe
	Oman	Guinea	
	Pakistan	Guinea-Bissau	
	Peru	Haiti	
	Philippines	Jamaica	
	Portugal	Jordan	
	Qatar	Kenya	
	Romania	Kyrgyz Republic	
	Serbia	Lao PDR	
	Slovak Republic	Latvia	
	Slovenia	Lebanon	
	South Africa	Lesotho	
	Sweden	Liberia	
	Trinidad and Tobago	Madagascar	
	Tunisia	Malawi	
	Turkiye	Mali	
	Ukraine	Mauritania	

Regression Analysis

I conduct a series of fixed effects regression models with robust standard errors to test my hypotheses. Using STATA 17, I specify the xtreg, fe robust option and include dummy variables for years. By including fixed effects for panels and years, effects that vary across the temporal dimension but not across the panels (e.g., geographic characteristics) are controlled for, as well as factors that vary across panels but not the temporal dimension (e.g., international energy prices). The inclusion of robust standard errors adjusts for the clustering of residuals within panels.

Since research is analogous to a "garden of forking paths" (Gelman and Loken 2014), I conducted several sensitivity checks to assess the implications of my choices to methods and analytic strategy. I reran the analysis with a multilevel modeling approach that included dummy variables for years and robust standard errors to adjust for clustering of residuals within nations and to allow for the inclusion of the global economic integration categorical variable. I also reran the analysis but added 0.1 and 0.001 to renewable energy consumption to see if that data choice influenced the results (see Table S3 in Appendix B). In addition to my cut point of 15 years at one-million dollars in my analysis of international trade relations, I also conducted the regular equivalence analysis with cut points at 10 and 20 years at one-million dollars, weighted by average dollar amount. These analyses were consistent with the reported findings (see Table S4 in Appendix B).

The central purpose of this chapter is to determine whether the effectiveness of renewable energy consumption in reducing emissions differs by relative integration in the global economy. In Model 1, there is no interaction effect, and I include all variables except trade openness. This model is designed to show the aggregate effect of renewable energy consumption on emissions. In Model 2, I add a control for trade as a percentage of GDP. Model 3 repeats the structure of Model 1 with the inclusion of an interaction effect between international trade position and renewable energy consumption. Note that the main effects for international trade position are suppressed as it is perfectly correlated with the fixed effect for countries (Allison 2009). Finally, in Model 4, I again include total trade openness as a control variable to see if any effects shown in Model 3 may be accounted for by general trade openness.

Results

Table 7 reports the results of the fixed effects regression analyses that see whether world trade integration modifies the effect of renewable energy consumption on carbon dioxide emissions. Model 1 includes variables controlling for processes associated with modernization (e.g., economic development; industrialization; urbanization), population dynamics, and the variable of interest, renewable energy consumption. Consistent with prior work, population size and percent urban have position and significant associations with carbon dioxide emissions. GDP per capita exhibits an environmental Kuznets curve, with a positive and significant association for GDP per capita and a negative and significant association for its quadratic term. Age dependency ratio exhibits a negative and non-significant effect, whereas manufacturing as a percentage of GDP is positive and non-significant. Consistent with H1 and domestic factors associated with ecological modernization, renewable energy consumption exhibits a negative and significant association with carbon dioxide emissions. Specifically, a one percent increase in percentage of renewable energy consumption is associated with a .22 percent reduction in carbon dioxide emissions. Put simply, increasing renewable energy consumption tends to decrease carbon dioxide emissions, net of other factors.

Model 2 adds trade as a percentage of GDP into the model. Age dependency ratio becomes positive and non-significant in this model; all other independent variables retain their direction and significance status. Trade openness has a positive and non-significant effect on carbon dioxide emissions. In this model, a one percent increase in renewable energy consumption is associated with a .22 percent reduction in carbon dioxide emissions. Even whilst controlling for trade openness, this model also shows support for H1.

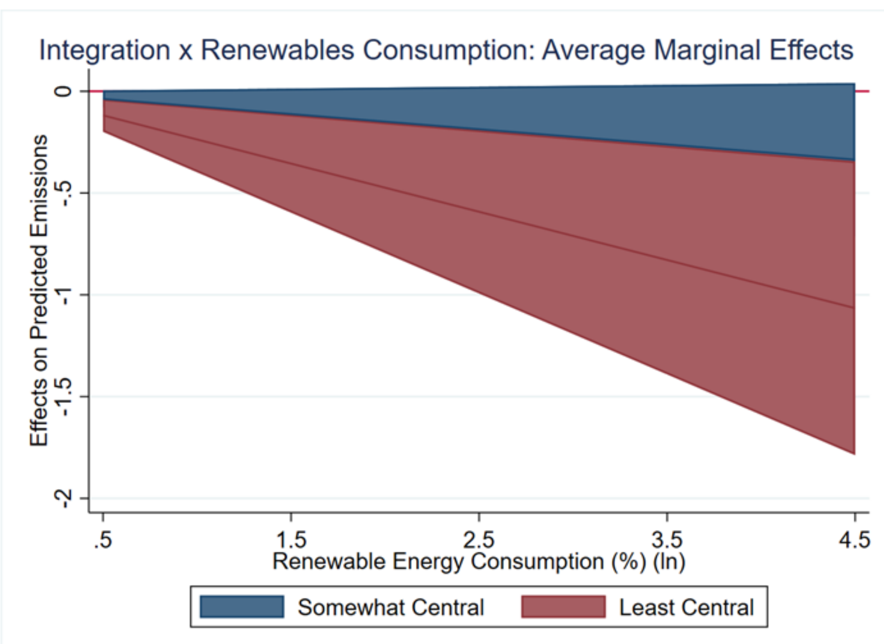
Table 7. Fixed-Effects Regression Results

Table 7. Fixed-Effects Regression Results												
	Model 1			Model 2			Model 3			Model 4		
Variables	b	P-Value	CI	b	P-Value	CI	b	P-Value	CI	b	P-Value	CI
Population (ln)	1.267	0.000	0.990, 1.545	1.247	0.000	0.953, 1.542	1.234	0.000	0.956, 1.512	1.230	0.000	0.941, 1.519
GDPPC (ln)	1.702	0.000	0.976, 2.428	1.901	0.000	1.140, 2.662	1.751	0.000	1.045, 2.457	1.970	0.000	1.227, 2.713
GDPPC (ln)2	-0.065	0.007	-0.112, -0.018	-0.079	0.001	-0.127, -0.031	-0.069	0.003	-0.115, -0.023	-0.084	0.001	-0.130, -0.037
Pct. Urban (ln)	0.630	0.012	0.141, 1.119	0.598	0.014	0.123, 1.074	0.632	0.010	0.153, 1.111	0.596	0.013	0.128, 1.064
Age Ratio (ln)	-0.028	0.838	-0.298, 0.242	0.013	0.919	-0.240, 0.266	-0.098	0.470	-0.364, 0.169	-0.054	0.662	-0.298, 0.190
Pct. Manu. (ln)	0.058	0.191	-0.029, 0.146	0.086	0.061	-0.004, 0.176	0.053	0.216	-0.031, 0.138	0.081	0.066	-0.005, 0.168
Pct. Renewables (ln)	-0.224	0.000	-0.288, -0.159	-0.220	0.000	-0.287, -0.152	-0.127	0.000	-0.194, -0.061	-0.131	0.000	-0.203, -0.059
Pct. Renewables (ln) x Somewhat Central							-0.075	0.083	-0.159, 0.010	-0.078	0.073	-0.164, 0.007
Pct. Renewables (ln) x Least Central							-0.237	0.004	-0.399, -0.075	-0.195	0.010	-0.341, -0.048
Pct. Trade (ln)				0.022	0.548	-0.050, 0.094				0.017	0.610	-0.050, 0.084
Observations	3940			3758			3940			3758		
Nations	152			148			152			148		

Models 3 and 4 assess the question at the center of this chapter: Does international trade integration modify the effect of renewable energy consumption on carbon dioxide emissions? Model 3 repeats the structure of Model 1 but includes an interaction effect between renewable energy consumption and world trade integration. The main effect of renewable energy consumption represents the slope for most central nations (the reference group). For most central nations, a one percent increase in percentage of renewable energy consumption is associated with a .13 percent reduction in carbon dioxide emissions. Relative to most central nations, somewhat central nations experience an increased reduction in their emissions (-.07%); however, this effect is non-significant ($p = 0.083$). These results are inconsistent with H2, but it is important to note that most central nations still exhibit a negative association between renewables consumption and emissions. Consistent with H3, relative to most central nations, least central nations exhibit a more negative relationship between renewable energy consumption and emissions. For least central countries, a one percent increase in renewable energy consumption is associated with an increased reduction in emissions of .24 percent relative to most central countries, on average. In other words, increasing renewable energy consumption in least central nations reduces emissions at a greater rate compared to most central nations, on average. Figure 4 shows the average marginal effects of the interaction between renewable energy consumption and world economy integration on carbon dioxide emissions. Across all values of renewable energy consumption, least central nations exhibit lessened emissions relative to most central countries.

Since my interests concern international trade, Model 4 integrates the trade openness control to ensure that the results from Model 3 are not explainable through another significant trade mechanism. All variables retain their direction and significance status from Model 2, with the exception of age dependency ratio, which becomes negative and non-significant. The main effect for most central nations remains negative and significant (p = 0.000). Similarly, somewhat central nations exhibit a more negative association compared to most central nations but remains non-significant (p = 0.073). Least central nations show a more negative relationship between renewable energy consumption and emissions relative to most central nations. These results are inconsistent with H2, but it is important to note that most central nations still exhibit a negative association between renewables consumption and emissions, even when controlling for trade openness. Consistent with H3, the model predicts that a one percent increase in renewable energy consumption is associated with an additional emissions reduction of .2 percent for least central nations relative to most central nations. Even adding a control for trade openness, in least central nations increasing renewable energy consumption decreases emissions more effectively than in most central nations, on average.

Figure 4. Effect of Renewable Energy Consumption by World Economy Integration on Carbon Emissions



Conclusion

This chapter sought to understand whether global economic integration changes the relationship between renewable energy consumption and carbon dioxide emissions. In this analysis, I used regular equivalence, a network method to determine which actors occupy similar roles in social organizations, to categorize nations by relative integration in the global economy. I then conducted a series of two-way fixed effect regression models with robust standard errors, specifying an interaction effect between renewable energy consumption and a categorical measure for global economic integration to see how the international structure of nations shapes the efficacy of renewable energy consumption in reducing emissions. I show that while countries with more renewable energy consumption tended to diminish emissions across all nations from 1990 to 2019, least central nations exhibited significantly greater reductions in carbon dioxide emissions with increases in renewable energy consumption relative to most central nations.

Prior work in the research area centers on economic development, efficiency, and income inequality within nations, yielding great insight into the many ways in which environmental issues are not only technical but also deeply political and economic (e.g., Greiner and McGee 2018; Thombs 2017; York and McGee 2017). Recent research draws more explicit attention to the world economic system. For example, the context of national position within the global economy (Greiner and McGee 2018) and natural resource trade in particular (Vesia, Mahutga, and Bui 2023) modifies the effect of economic development on emissions. Jorgenson et al. (2022) examine how centrality in the foreign direct investment network intensifies emissions for Global South nations relative to those in the Global North, consistent with expectations of ecologically unequal exchange. Yet, the role of world economic integration in influencing the effectiveness of renewable energies on emission reductions has not been fully explored.

Theories fundamental to central debates in environmental sociology discuss the role of renewable energies for environmental sustainability. Ecological modernists emphasize that environmental practices, policies, and technologies may be diffused in a globalizing world (Mol 2001), implying that trade powers are likely to transfer green technologies to less central countries. A variety of perspectives, including but not limited to ecological Marxism, contend that countries most central to the world economy may be most invested in fossil fuels and energy security (Colgan 2021; Malm 2016), suggesting that countries most central to global trade may use renewables as an augmentation to existing fossil fuel energy reserves and not as replacements for them (York and Bell 2019). Consistent with H3, I find that nations least central to the global economy experience relatively more emission reductions with increases in renewable energy consumption compared to most central nations. While critical environmental sociology often focuses on the implications of economic growth for renewable energy's role in reducing emissions (Thombs 2017; York and McGee 2017), my findings draw attention to how the global economy shapes renewables-emissions reduction pathways. In this way, my findings support critical environmental social science insights that highlight the role of fossil fuels in organizing the global economy (e.g., Huber 2009; Malm 2016). Most central nations likely have a built infrastructure to support production and consumption embedded in fossil fuel use, and thus construction of renewable energy infrastructures may serve to buttress rather than replace fossil fuels (York and Bell 2019). Nations least central to the global economy may also suffer from energy poverty (Sovacool 2012), lacking an entrenched fossil fuel energy infrastructure. McGee and Greiner (2019) argue that nations deploy renewable energies to meet energy needs in ways that interact with income inequality. I find that countries least central to the global economy may use renewable energies as a pathway toward expanding energy infrastructures, as they may not have access to preexisting fossil fuel systems in the same way that that more integrated nations do. In this way, the implementation of renewables represents more meaningful emissions reduction in least central countries, as extensive participation in the global economy implies investment in the entrenched fossil economy.

Future research should continue to explore how the international structure of nations may contextualize commonly studied linkages in environmental sociology. While I examine the relationship between renewable energy consumption and emissions, other commonly examined explanatory mechanisms, such as trade to high income nations, income inequality, gender inequality, and world polity integration, may also vary by relative integration in the global economy. Research on the cross-national drivers of environmental change should continue to use novel methods, including but not limited to networks, to explore new perspectives to longstanding debates in the subfield.

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CHAPTER V: CONCLUSION

Recapping Central Dissertation Findings

In this dissertation, I employed social network analysis to innovate research within quantitative macro-environmental sociology. The purpose of using social network analysis is to center the relationality of countries in the world economic system through international trade relationships. I used several network techniques to capture distinct elements of transboundary commodity exchange. Below, I review the central findings of each empirical chapter. Then, I discuss methodological and theoretical implications from this research project. I close by providing recommendations for future research.

Chapter 2 explored how the global ship scrapping industry is organized. Using data from NGO Shipbreaking Platform, I analyzed trends in major beneficial owner states, flag states, destination countries, and flows between them. To sum, a few countries (Bangladesh, India, Pakistan, Turkey, and China), serve as destinations for the vast majority of end-of-life vessels in gross tonnage. High income nations tend to use black/grey listed countries or tax havens as flag states when dumping end-of-life vessels onto the shores of these countries, largely in an effort to avoid international and national law regarding hazardous waste exchanges. I also conduct network simulations with the same density as observed annual end-of-life vessel exchange networks and with linear preferential attachment. The centralization of incoming end-of-life vessel ties to a few destination countries exceeds expectations of randomness (simulated networks based on same density) and preferential attachment across all years: preferential attachment processes thus may be at work in the end-of-life vessel exchange networks, as a few sites receive the vast majority of incoming ties. Conversely, outgoing ties largely conform to what is expected based on random network simulations with the same density: countries sending end-of-life vessels are relatively dispersed, with minimal centralization in (any set of) countries with outgoing ties. Given the political economy of the world-system and the need for construction materials in rapidly industrializing nations, a small set of countries scraps most of the world's vessels, setting the stage for perilous labor environments and localized environmental contamination to meet national economic and infrastructural needs.

Chapter 3 investigated the how the global crude oil trade and oil extractive dependence influences carbon dioxide emissions from liquid fuel (petroleum) consumption. I collect trade data from U.N. Comtrade for the years 1988-2016 using commodity code 2709 to specify crude oil and draw data from the World Bank's World Development Indicators concerning oil-based emissions, oil rents as a percentage of GDP, and controls for population dynamics, national affluence, and other economic and trade factors. First, I used a social network approach, regular equivalence, over the constructed binary trade network in crude oil to establish national positionality as export-oriented, import-oriented, or well-integrated. Then, a series of multilevel models were conducted to see whether crude oil trade position modifies the effect of oil extractive dependence on oil-based emissions. Export-oriented economies experience increased oil-based emissions as a consequence of intensified economic dependence on oil extraction relative to other-positioned economies. Thus, while we typically think of oil importation as the driver of consumption, I show that the heightened extraction that this fosters in export-oriented economies is associated with more emissions for those economies as well.

Chapter 4 asked whether global economic integration changes the relationship between renewable energy consumption and carbon dioxide emissions. To answer this question, I collected data from the Direction of Trade Statistics, World Bank's World Development Indicators, and Our World in Data. First, I conducted a regular equivalence analysis over weighted data to classify countries based on relative integration in the global economic system through international trade relationships. Then, I conducted a series of two-way fixed effects regression models with robust standard errors to adjust for clustering of residuals within panels. Specifying an interaction effect between renewable energy consumption and world economic integration, I found that least central nations experienced significantly more emission reductions as a consequence of renewable energy consumption relative to most central nations. National integration in the global economy, or a nation's relative importance to global capitalism, thus serves as a meaningful context through which renewable energy implementation is more or less effective in reducing emissions.

In what follows, I outline the central methodological and theoretical contributions that these analyses and findings make to macro-environmental sociology in general and research on global trade and the environment in particular.

Methodological and Theoretical Implications

This dissertation aimed at contributing to quantitative macro-environmental sociology. Specifically, it employed social network methodology to contribute to longstanding debates and innovate prominent research areas in global political ecology.

Perhaps most directly, this dissertation contributes to research on ecologically unequal exchange, a theory of global environmental injustice (Givens, Huang, and Jorgenson 2019). Bunker (1984) is often credited for developing the theory through his case study of the Brazilian Amazon. Increased global demand for rubber and timber encouraged local political elites to invest and implement infrastructures to support the extraction of those commodities. The construction of these infrastructures constricted future developmental pathways, restraining future trajectories of economic growth to those relating to resource extraction. In this way, extractive export economies can undergo "serial underdevelopment," as the path dependent nature of economic development entrenches regional or national geographies as resource frontiers for the world economy to exploit (Bunker 1984).

Later efforts further theorize ecologically unequal exchange in a more complete schema. Particularly, Hornborg's conceptualizations of ecologically unequal exchange as composed of flows of energy and biophysical resources (1998) in a zero-sum world where distributive inequities belie popular discourses toward sustainable development (2009) provide theoretical tethers for understanding how global environmental inequalities are a systemic product of the workings of the global economy. Gellert (2019) illuminates the impact and utility of Bunker's (1984) unequal ecological exchange for critical theories in environmental sociology, but also draws attention to the centrality of extractive peripheries, and thus extraction and exploitation, to theoretical and empirical work in the research area.

Quantitative operationalizations of ecologically unequal exchange are, for the most part, heavily influenced by Jorgenson's (2006) pioneering work finding an association between "weighted export flows," a weighted measured of national exports by import economy size, and deforestation in lower income countries. Subsequent studies emphasize that lower income countries with higher levels of agricultural, forestry, primary sector, and/or general commodity export intensity experience lessened resource consumption (Jorgenson, Austin, and Dick 2009), increased deforestation (Shandra, Leckband, and London 2009; Noble 2017; Jorgenson, Austin, and Dick 2009; Jorgenson, Dick, and Austin 2010), threatened mammal populations (Shandra et al. 2009), more water pollution (Shandra, Shor, and London 2009), increased carbon dioxide emissions (Jorgenson 2012), and intensified water footprint (Fitzgerald and Auerbach 2016). In short, using national income bifurcations to classify nations and seeing whether extraction-related exports contribute to environmental problems largely defines the research space, consistently finding empirical support for ecologically unequal exchange.

This dissertation contributes to research on ecologically unequal exchange largely in Chapters 2 and 3. Chapter 2 provided insights into the global organization of end-of-life vessel scrapping ownership, flag states, and destinations. Building on R. Scott Frey's work (2015) on the global political economy of end-of-life vessel destinations, as well as discard studies (e.g., Lepawsky 2015), I explore how discarded vessels serve an important function in destination economies, as they provide steel necessary for furthering industrialization and urbanization. At the same time, the centralization of gross tonnage of ships and incoming ties to Bangladesh, India, and Pakistan indicate the presence of an unequal world-system where secondhand materials from largely high income nations are used to spur growth in industrializing nations while inhering significant human and environmental health risks in the recycling process. While Frey (2015) notes that national steel demands play a significant role in the ship scrapping industry, the recycling and reuse of materials derived from end-of-life vessels implies that framing the issue as solely one of flows of "anti-wealth" is incomplete, as recovery efforts both supply important materials for economic growth and may produce global environmental benefits (Gregson and Crang 2015). I suggest that reforming regulatory apparatuses to place the onus on beneficial owner states may ease dangerous labor conditions and significant local pollution that results from end-of-life vessel recycling.

In Chapter 3, I form a novel approach to quantitatively assessing ecologically unequal exchange theory. While the conventional approach bifurcates nations based on income and treats trade intensity as the key explanatory mechanism (e.g., Jorgenson 2006), I contend that classifying countries based on trade position (e.g., export-oriented; import-oriented; well-integrated) and seeing whether this context modifies the effect of extractive dependence on environmental degradation better aligns with the underlying theory in several ways. First, it captures both the internal (extractive dependence) and external (international trade position) dimensions of ecologically unequal exchange. Second, by focusing on trade position, the key group being analyzed is the extraction sites (Bunker 1984; Gellert 2010), or the set of countries functioning as the resource frontier to meet the demands of the world-system. Third, by adopting social network methodology, it explicitly operationalizes the relational and endogenous nature of international trade relations and inductively locates countries in positions through the trade data at hand. I find that crude oil export-oriented economies with more economic dependence on oil extraction experience more oil-based emissions relative to other-positioned economies. In this way, the demand placed on oil-rich countries expands extraction such that energy and economic diversification may be suppressed and thus emissions increased. Global energy markets fuel emissions not only at the tail end (through importation and consumption) but also on the front end (through exportation and extraction). In sum, I suggest that bifurcating nations based on national positionality in trade networks better approximates the central stratifying mechanism implied by ecologically unequal exchange relative to income bifurcations. In so doing, we can explore and assess the multiple social, political, and economic factors that interact with national positionality to influence global environmental change.

Chapter 4 most directly contributes to the literature on potential decoupling of the economy from the environment, especially as it relates to renewable energies. Theories central to the development of environmental sociology, especially treadmill of production and ecological modernization, yield insights into to what extent technological innovations can resolve environmental issues. The ecological modernization perspective is relatively optimistic, essentially arguing that, given technological innovations, institutional transformation, and political reforms, economic development may be reconcilable with environmental sustainability (Mol and Spaargaren 2000). Meanwhile, treadmill of production theory contends that the growth imperative and expansionary tendencies of capital necessarily entail increased resource use and pollution (Schnaiberg 1980). Prior work in macro-environmental sociology focuses on decoupling of economic development from emissions through time (Jorgenson and Clark 2012), paradoxical associations between economic development, renewable energies, and emissions (Thombs 2017; York and McGee 2017), largely because total energy use from all sources is increasing (York and Bell 2019). These studies share a focus on operationalizing "the economy" through domestic measures of economic development and have contributed significantly to our understanding of trajectories of development and degradation within nations.

I emphasize the international structure of nations in the global economy through a network analysis of total commodity flows, classifying countries based on integration into global capitalism. Thus, my main focus is on how countries are positioned in world markets, a relational and transnational way of measuring how the economy may change the relationship between renewable energies and emissions. While ecological modernists argue that environmental values, consciousness, technologies, and policies are transferred cross-nationally in our globalized world (Mol 2003), others argue that the fossil economy is central to the functioning of capitalism (Malm 2016) and that the establishment of "energy security" involves securing geopolitical and economic interests among major politico-economic alliances (Colgan 2021). I found that countries least central to global capitalism experienced significantly lessened emissions as a consequence of renewable energy consumption relative to most central countries, consistent with critical eco-social theories and perspectives regarding the importance of fossil fuels to hegemonic power (Malm 2016; Colgan 2021). Sole focus on economic development occludes illuminating how the relationality of the global economy shapes important relationships in macro-environmental sociology (Greiner and McGee 2018; Vesia, Mahutga, and Bui 2023); in this case, the international structure of nations was shown to substantially shape how effective renewables are in reducing emissions, in part illustrating that narratives of "sustainable development," like development in general, lack a relational and exploitative appreciation of economic growth in an interdependent economic structure.

In sum, this dissertation emphasized the central intimation from a variety of major macro-social science traditions: that states are connected to each via international trade, and that these relationships are important to a variety of social phenomena (Chase-Dunn 1998; Giddens 2003; Wallerstein 2004). I employ a methodology that explicitly is organized around addressing relationality, social network analysis, to see how national positionality and integration in trade networks modifies the effect of factors relevant to longstanding environmental sociological issues, resource extraction and renewable energies, on emissions. In this way, I not only contribute to these questions, but also encourage novel approaches to assessing and analyzing them that, I argue, better align with the underlying theories at hand.

Final Remarks

Following contemplation and consideration of the findings presented here, it seems prudent to provide recommendations for future academic research. Perhaps unsurprisingly, I contend that social network analysis ought to be more fully embraced in macro-environmental sociology. While there certainly are studies that integrate it (Sommer 2020; Theis 2021; Jorgenson et al. 2022; Prell and Sun 2015; Vesia, Mahutga, and Bui 2023), there is considerable room for more extensive use of the methodology, broadening the scope of possible questions to ask and analyze in the research tradition. Primarily, position and role analysis has a long and rich legacy in the literature on understanding the organization of the global economy (Nemeth and Smith 1985; Smith and White 1992; Mahutga 2006; Mahutga and Smith 2011). In essence, these studies understand the organization of global capitalism by assessing which sets of countries export and import similar types of commodities (agricultural; manufacturing) (e.g., Nemeth and Smith 1985), that countries occupying the same role (exporting and importing similar commodity types) may change through time, and that the positions/roles may diverge or converge through time (Mahutga and Smith 2011). Particularly as prominent eco-social theories draw attention to the relevance of national positionality in trade networks in shaping the structure of domestic economies (Bunker 1984; Downey 2015), more research is needed that uses these positions in specific trade networks to better align method with theory. Relatedly, notions like the "Netherlands Fallacy," or the idea that production-related studies of environmental harm understate the significance of the impacts of consumption (e.g., Ehrlich and Holdren 1971), imply the need for not only consumption-related measures of environmental degradation (e.g., York, Rosa, and Dietz 2003; Jorgenson and Rice 2005; Clement, Pattison, and Habans 2017), but closer examination of how nationality positionality as production-oriented or consumption-oriented in given commodity exchanges may influence environmental outcomes. In short, given the theoretical primacy of resource extraction and exportation in ecologically unequal exchange, future work should bifurcate data based on a nation's positions in a given trade network. Position/role analysis provides a natural methodological tool for doing so.

Another method through which social networks are used to analyze the global economic structure is through analysis of all trade data and examining a core-periphery structure in the trade network. For example, several studies develop classification schemes for world-systems position based on coreness procedures and deductive categorization of countries into positions by intra-group density (Clark and Beckfield 2009; Clark 2012). In environmental sociology, Greiner and McGee (2018) use Clark and Beckfield's (2009) categorical scheme to see whether world-system position changes the relationship between economic development and carbon emissions, finding that semi-peripheral, rapidly industrializing nations experience increased emissions as a consequence of development relative to core nations, contextualizing longstanding debates in the subfield through a relational categorization of trade position. In parallel, Vesia, Mahutga, and Bui (2023) examine integration into the natural resource exchange network, highlighting how least central nations experience more emissions as a consequence of development relative to most central countries. Inclusion of national integration in trade networks, measured either categorically (as I and those mentioned above do) or continuously (Prell and Sun 2015; see Jorgenson et al. 2022 for an analysis of FDI flows) in analyses moves beyond assessments of the relationship between economic growth and emissions within nations over time, appreciates the relational dimensions of economic growth, and captures the importance of international markets for the structure of domestic economies. Measuring general integration in trade networks, or measured as import- and export-integration, may prove a fruitful avenue for contextualizing important findings and questions in the subfield, as well as a mechanism through which we can appreciate heterogeneity of findings across trade positions and groupings.

In general, this dissertation project used social network analysis to innovate research designs to prominent areas in environmental sociology. The goal is not to criticize prior work in these areas *per se*, but rather to promote social network analysis as a methodological tool that, I believe, has much to offer for quantitative cross-national research in environmental sociology. Of course, I am not the first to use network methods in this literature (e.g., Prell et al. 2014; Prell and Sun 2015; Sommer 2020; Vesia, Mahutga, and Bui 2023). These studies, as well as this dissertation, illuminate how countries are connected to each other through international trade, and that these connections are of methodological importance for quantitative macro-environmental sociology. My dissertation, alongside prior work, highlights that how countries are positioned in trade structures significantly changes the influence of important factors, like extractive dependence and renewable energy consumption, on environmental outcomes. Future environmental sociological research should more closely attend to national positionality in trade networks to better align methods with theory.

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APPENDIX A. CHAPTER III DIAGNOSTICS AND SENSITIVITY CHECKS

Figure S1. Scree Plot for Binary Crude Oil Trade Network, 1988-2016.

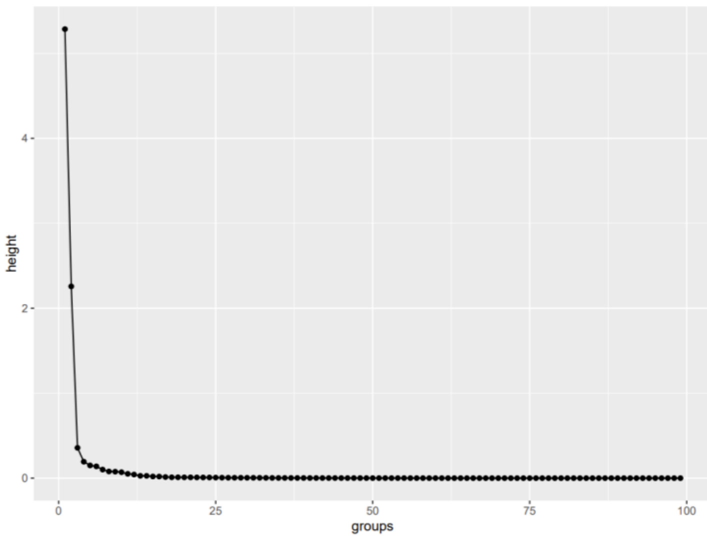

Table S1. Alternative Models for Chapter III with Same Regular Equivalence Procedure.

	Oil Rents + 0.01 Model		Time Dummy Model		FE Regression Model	
Variables	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
Population (ln)	0.832	0.000	1.085	0.000	1.141	0.002
GDPpc (ln)	2.078	0.000	0.562	0.016	0.497	0.594
GDPpc (ln)^2	-0.107	0.000	-0.014	0.326	-0.008	0.880
Pct. Urban (ln)	0.471	0.000	0.672	0.000	0.576	0.059
Age Ratio (ln)	-0.048	0.413	-0.096	0.141	-0.096	0.607
Oil Rents / GDP (ln)	0.171	0.000	0.159	0.000	0.095	0.000
Position						
Well-Int.	0.731	0.000	0.256	0.243		
Import-Oriented	0.243	0.255	0.125	0.578		
Interaction						
Well-Int. x Rents (ln)	-0.205	0.000	-0.191	0.000	-0.145	0.000
Import-Oriented x Rents (ln)	-0.252	0.000	-0.213	0.000	-0.123	0.001
Imports (ln)	0.206	0.000	0.220	0.000	0.179	0.048
Exports (ln)	-0.236	0.000	-0.223	0.000	-0.183	0.010
Pct. Manu. (ln)	0.168	0.000	0.131	0.000	0.143	0.041
Constant	-16.166	0.000	-14.764	0.000	-15.008	0.019
n	2,256		1,748		1,748	
Countries	93		76		76	

Table S2. Alternative Models for Chapter III with Different Regular Equivalence Procedures.

	1-Million, 10 Years Model		1-Million, 20 Years Model		25% of Value, 15 Years Model		50% of Value, 15 Years Model	
Variables	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
Population (ln)	0.898	0.000	0.932	0.000	0.932	0.000	0.971	0.000
GDPpc (ln)	1.092	0.000	2.147	0.000	1.051	0.000	0.913	0.000
GDPpc $(\ln)^2$	-0.053	0.000	-0.100	0.000	-0.050	0.000	-0.040	0.001
Pct. Urban (ln)	0.528	0.000	0.069	0.525	0.442	0.000	0.384	0.000
Age Ratio (ln)	-0.054	0.402	-0.063	0.320	-0.054	0.403	-0.009	0.888
Oil Rents / GDP (ln)	0.174	0.000	0.166	0.000	0.190	0.000	0.181	0.000
Well-Int.	0.697	0.001	0.764	0.000	0.654	0.003	0.637	0.015
Import-Oriented	0.380	0.131	0.245	0.246	0.341	0.156	0.168	0.451
Well-Int. x Rents (ln)	-0.213	0.000	-0.175	0.003	-0.224	0.000	-0.205	0.001
Import-Oriented x Rents (ln)	-0.223	0.000	-0.216	0.000	-0.245	0.000	-0.244	0.000
Imports (ln)	0.189	0.000	0.127	0.000	0.210	0.000	0.220	0.000
Exports (ln)	-0.206	0.000	-0.181	0.000	-0.230	0.000	-0.243	0.000
Pct. Manu. (ln)	0.138	0.000	0.135	0.000	0.161	0.000	0.201	0.000
Constant	-13.168	0.000	-17.120	0.000	-13.197	0.000	-13.325	0.000
n	1,858		1,522		1,770		1,659	
Countries	82		66		77		72	

APPENDIX B. CHAPTER IV DIAGNOSTICS AND SENSITIVITY CHECKS

Figure S2. Scree Plot for Weighted Global Trade Network, 1990-2019.

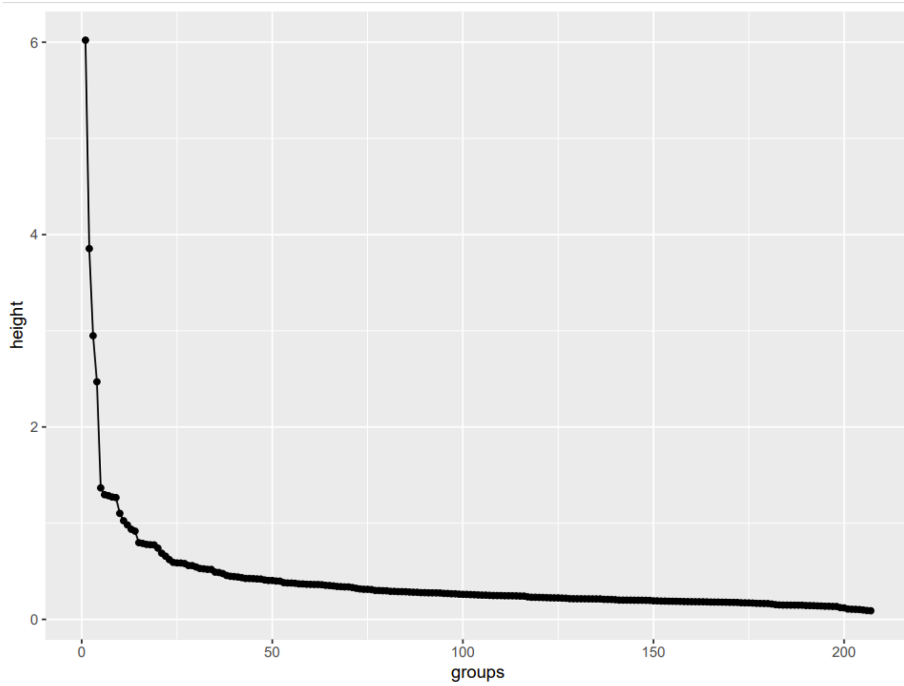

Table S3. Alternative Models for Chapter IV with Same Regular Equivalence Procedures.

	Multilevel Model		Renewables + .1		Renewables + .001	
Variables	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
Population (ln)	1.123	0.000	1.191	0.000	1.281	0.000
GDPpc (ln)	1.201	0.008	1.947	0.000	1.983	0.000
GDPpc $(\ln)^2$	-0.044	0.116	-0.083	0.000	-0.084	0.001
Pct Urban (ln)	0.479	0.027	0.585	0.013	0.611	0.012
Age Ratio (ln)	-0.046	0.751	-0.035	0.783	-0.072	0.557
Pct. Manu. (ln)	0.084	0.045	0.081	0.064	0.081	0.071
Renewables (ln)	-0.305	0.000	-0.154	0.000	-0.116	0.002
GEI						
Somewhat	0.238	0.472				
Least	2.435	0.000				
GEI x Renewables (ln)						
Somewhat	-0.050	0.529	-0.106	0.013	-0.031	0.577
Least	-0.699	0.000	-0.223	0.003	-0.153	0.091
Pct. Trade (ln)	0.016	0.621	0.023	0.514	0.011	0.738
n	3,758		3,758		3,758	
Countries	148		148		148	

Table S4. Alternative Models for Chapter IV with Different Regular Equivalence Procedures.

	10-year Model		20-year Model	
Variables	Coefficient	P-Value	Coefficient	P-Value
Population (ln)	1.230	0.000	1.226	0.000
GDPpc (ln)	1.970	0.000	1.976	0.000
GDPpc $(\ln)^2$	-0.084	0.001	-0.084	0.000
Pct Urban (ln)	0.596	0.013	0.594	0.013
Age Ratio (ln)	-0.054	0.662	-0.061	0.619
Pct. Manu. (ln)	0.081	0.066	0.081	0.068
Renewables (ln)	-0.131	0.000	-0.130	0.001
GEI x Renewables (ln)				
Somewhat	-0.078	0.073	-0.076	0.082
Least	-0.195	0.010	-0.206	0.008
Pct. Trade (ln)	0.017	0.610	0.015	0.643
n	3,758		3,745	
Countries	148		147	