

# Renewable Energy as a Panacea?

Examining Ecological Modernization and Ecologically Unequal Exchange Processes  
in Global Wind and Solar Power Systems

A Sociology Undergraduate Honours Thesis

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## Abstract

In this study I examine ecological modernization (EM) and ecologically unequal exchange (EUE) effects surrounding solar-panel and wind-turbine systems. EUE effects are analyzed by examining the material composition of these technologies, the top extractors of these materials, and socio-environmental disruption resulting from this extraction. Meanwhile, EM effects are analyzed in the examined countries by reviewing installed capacity for solar-panels and wind-turbines, as well as policy and regulatory arrangements that support implementation of these technologies. The results are used to assess the relationship between EM and EUE processes and the uses of EM and EUE theories, and to posit whether renewable energy implementation, and EM more broadly, without fundamental socioeconomic restructuring, is a sufficient path to sustainability. A trend was found, whereby developing countries tend to suffer the most socio-environmental disruption from material extraction for solar-panels and wind-turbines while exhibiting lower implementation of these technologies, and developed countries show opposite effects. This indicates that EUE effects constitute global solar-panel and wind-turbine systems, and that developed countries displace socio-environmental disruption from energy innovation onto developing countries. Critically assessing sustainable development and EM within the capitalist system, I conclude that universal sustainability is not possible within such a framework, and that instead a global non-growth, steady-state socio-economic framework is required, in which the costs and benefits of utilizing natural resources are distributed equitably.

**Keywords:** Solar-panels; wind-turbines; ecologically unequal exchange; ecological modernization; sustainability.

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## Introduction

Achieving sustainability is becoming a growing issue in light of the present and future threats of environmental and socioeconomic disruption imposed by climate change, resource depletion, and pollution. Theoretical and political approaches to sustainability efforts are varied, though one of the most prevalent strategies - that of technological innovation - is central to the theory of ecological modernization (Mol 1997; Mol and Sonnenfeld 2000). Proponents of this theory argue that, in order to achieve sustainability goals, incremental changes to socioeconomic and political structures are needed alongside technological advancements (Mol and Sonnenfeld 2000). However, such theorists maintain that the greening of technology is pivotal for sustainability (Huber 2008). Technological innovation as a means of achieving sustainability is perhaps most prevalent in global efforts to avert climate change by reducing carbon emissions. This strategy involves increasing the efficiency of technologies that are powered by fossil fuels, or replacing the use of fossil fuels with renewable energy technologies - such as solar-panels and wind-turbines.

The method employed in this study is partially built upon those utilized by Bonds and Downey (2012), where ecologically unequal exchange effects were found to result from ecological modernization processes. Bonds and Downey were looking to see whether environmental and social disruption occurred in peripheral or semi-peripheral nations as a result of technological innovations that were adopted in core nations as a means to decrease their carbon emissions. Specifically, they examined the greening of technologies in the automobile industry, analyzing the environmental and social effects that the adoption of catalytic converters, bio-fuels, and hybrid cars had on the countries that extracted raw materials for those technologies. They found that varying socially and environmentally destructive outcomes resulted from extensive resource extraction for these industries. These outcomes included deforestation, contamination of water sources, the creation of ecological dead zones, dispossession and displacement of people from their land, and threats and violence against those who resisted this disruption - resulting in arrests, beatings, torture, rape, and in some cases, killings. In effect, the adoption of efficient automobile technologies in core nations resulted in a displacement of environmental disruption from the core to peripheral and semi-peripheral nations - in many cases, causing social disruption as well.

Relationships between core and peripheral nations such as those described by Bonds and Downey are captured within the scope of ecologically unequal exchange theory. Put succinctly, this theory posits that the high position that core nations occupy on the global ladder - in terms of economic, military, and political power - enables them to secure unfair trade deals with those nations lower on the ladder. As a result, the latter are coerced into engaging in extensive resource extraction industries, which are less economically reliable than the industries in core nations and lead to more environmental and social disruption (Gellert, Frey, and Dahms 2017; Jorgenson 2016a; Jorgenson 2010). As well, the periphery is seen to act as a sink for the waste products of core nations, and in some cases, more environmentally destructive and economically exploitative manufacturing industries - compared to core nations - are relocated to the periphery (Jorgenson, Dick, and Mahutga 2007). Jorgenson (2016a: 6) describes the ecologically unequal exchange process as "[constituting] the obtainment of

natural capital... and the usurpation of sink-capacity... [by core countries] to the detriment of [peripheral] countries." Essentially, the core receives a disproportionate share of the positive consequences of the utilization of natural capital, while the periphery receives a disproportionate share of the negative consequences.

The idea that an unequal relationship exists between core and peripheral nations, and that environmental harms are displaced from the former to the latter, creates points of contention between the theories of ecological modernization and ecologically unequal exchange. The conception within ecological modernization theory that technological innovation can achieve sustainability ultimately assumes that greening of technology is universally beneficial (Mol 1997; Huber 2008). Additionally, and related to this - as will be discussed in the following section - ecological modernization theory promotes the view that sustainability can be achieved while preserving the current socioeconomic framework. The evidence that Bonds and Downey (2012) present regarding the displacement of environmental disruption from core to periphery due to the adoption of green technology stands against the views of ecological modernization, including the idea that technological innovation should be the core avenue to sustainability, the notion that technological development is universally beneficial, and, to some extent, the conception that sustainability can be achieved while preserving the status quo. Given the growing global movement to transition from fossil fuel to renewable energy sources, it would be prudent to investigate whether similar ecologically unequal exchange relationships exist surrounding the industries of solar-panels and wind-turbines, or whether ecological modernization more aptly describes the proliferation of these technologies. My aim in this honours thesis, therefore, is to analyze the socioeconomic and environmental outcomes of the adoption of solar-panels and wind-turbines; specifically, to examine how these outcomes are distributed between nations that are involved in the material extraction for and usage of these technologies. The lenses of ecological modernization theory and of ecologically unequal exchange will be utilized in this endeavor. This investigation seeks to answer the research question:

Are the environmental and social outcomes of the proliferation of solar-panels and wind-turbines best described by ecological modernization or ecologically unequal exchange theories, or some combination of both?

Contained within this research question are two sub-questions:

- a) What are the strengths and limitations of the theories of ecological modernization and ecologically unequal exchange in conceptualizing the environmental and social outcomes of the proliferation of solar-panels and wind-turbines?
- b) Do the environmental and social outcomes of the proliferation of solar panels and wind turbines lend credence to the idea that technological innovation and incremental changes to social and political systems are a sufficient path towards sustainability, or do they suggest that more fundamental socioeconomic and political restructuring may need to take place?

The following section provides a literature review for both ecological modernization and ecologically unequal exchange theories, upon which the methods for this research project are based.

## Literature Review

### Ecological Modernization

As discussed, the idea that technological innovation can achieve sustainability is the core component of ecological modernization theory (Huber 2008). However, Mol and Sonnenfeld (2000) state that other important avenues to achieving sustainability via ecological modernization include: market dynamics and economic agents; transformations in the role of the nation-state to a more decentralized and less top-down role in environmental and economic governance; a shift in the role and ideology of social movements to having more of a say in environmental and economic decision-making, and placing less of an emphasis on anti-systemic ideologies; and an increased prevalence of environmental concerns and ethics in ideology and practice.

Similarly, Christoff (1996) discusses three main orientations of ecological modernization theory. First, the pursuit of technological innovation that occurs as a result of market dynamics and the pursuit of profit, resulting in beneficial environmental outcomes without fundamental changes to the socioeconomic framework. Second, changes in policy and policy discourse that accommodate the importance of the environment and sustainability, while managing sustainability goals within pre-existing socioeconomic and political institutions. And third, the internalization of the environment into the socioeconomic framework.

It seems that the characteristics of ecological modernization discussed by Mol (2000) and Christoff (1996) serve to act as supports for the central tenant of achieving sustainability through technological innovation. Another common thread in the characteristics of ecological modernization theory is the assertion that sustainability can be achieved while preserving the current socioeconomic order (Coffey and Marston 2013). This is appealing to policy-planners, governments, corporations, elites, and perhaps much of the industrialized world, because it is an extension of the idea of sustainable development: the view that sustainability can be achieved alongside the pursuit of societal and economic growth (WCED 1987).

These aspects of ecological modernization ensure that it fits well within the existing framework of neoliberalism. When the main characteristics of neoliberalism are compared alongside those of ecological modernization - as outlined above - this can be seen quite plainly. These characteristics include: privatization of state or socially-owned, or environmental, goods and services; marketization or commodification; state deregulation in social and environmental spheres; state reregulation favouring privatization and commodification; marketization of remaining state services; encouragement of non-governmental and community groups and services in the absence of state or privatized services; and limited reliance of individuals and communities on the state and state services (Castree 2010).

As well, the view that neoliberalism is ultimately beneficial to all is echoed in the idea that technological innovation is universally beneficial. On the one hand, neoliberal doctrine posits that socioeconomic reform - mainly through market deregulation - favouring the pursuit of profit by the society's most wealthy, will result in a 'trickle-down' effect, where some of this wealth is transferred to the masses (Portes 1997). On the other hand, the idea within ecological modernization that the greening of technology - alongside supporting socioeconomic reforms - will be sufficient to achieve sustainability utilizes a non-critical lens of socioeconomic relations, as it assumes that proliferating green technologies within the current socioeconomic system will be of benefit to all.

From a sociological viewpoint, neoliberalism and ecological modernization fall under a structural functionalist lens, as they seek to explain and preserve the stability of society by means of reforming, rather than fundamentally altering, pre-existing socioeconomic structures. As mentioned, a critical view does not enter into the equation here. In this way, the theories of ecological modernization and ecologically unequal exchange stand in contrast to one another.

### Ecologically Unequal Exchange

Unlike ecological modernization theory, ecologically unequal exchange is less prescriptive, and focuses more on description. That being said, some prescriptive elements do exist in the literature, which will be discussed at the end of this sub-section.

As discussed in the introduction, the theory of ecologically unequal exchange seeks to explain the unequal positions of core and peripheral nations as the result of a self-reinforcing system that makes it so that the more powerful core nations maintain their positions by taking a disproportionate share of the benefits of the development of natural capital, while displacing to the periphery a disproportionate share of the negative outcomes of this development.

The process of ecologically unequal exchange is further extenuated through the means by which peripheral nations seek to attract foreign investment. Due to their lower position on the global ladder, these nations often seek to encourage the movement of capital into their borders by means of less stringent environmental and labor laws, and sometimes by lowering taxes (Leonard 1988; McMichael 2008). As well, Roberts and Parks (2007) argue that these pressures make it so that these nations are less likely to ratify international environmental treaties.

Ecologically unequal exchange is essentially an extension of the world systems theory that was developed by Immanuel Wallerstein. Wallerstein (2004) posits that the world system, not the nation-state, should be the primary unit of macro social analysis, and explains the differing positions of core, semi-peripheral, and peripheral nations within the world system as resulting from exploitation of the periphery by the core. This occurs through a continuous redistribution of surplus value from the former to the latter, by means of unfair trade relationships that coerce peripheral nations into extensive resource extraction industries, while core nations more readily engage in manufacturing and service industries, which create more surplus value.

World systems theory on its own does not consider the distribution of environmental disruption that occurs as a result of these structures, or how this disruption may serve to reinforce the system. However, it does explain that the increased profitability found in core nations serves to reinforce their place at the top of the global ladder. Ecologically unequal exchange theory explains the structure of the world system as an expression of the same fundamental processes of exploitation, and deepens world systems theory by adding details regarding the ways in which these power structures maintain themselves: by facilitating the cooptation of natural capital in the periphery to the core, and the displacement of environmental disruption to the periphery.

Thus, ecologically unequal exchange is rooted in critical theory, as it deems structure and change in the world as resulting from exploitative relationships between the more and less powerful. Emanating from this view are the prescriptive elements of ecologically unequal exchange. First, the concept of ecological debt stems from the idea that an 'ecological subsidy' has consistently been paid from peripheral to core nations, where this subsidy, stemming from colonial times, takes the form of the ecologically unequal exchange relationship that maintains the power of core nations relative to peripheral nations. Ecological debt is rooted in the idea of environmental justice, though on a global - rather than national or regional - scale, where proper orchestration of justice in this case would mean a reversal of this ecological subsidy, resulting in a more equal distribution of wealth and power between core and periphery, and a fair distribution of the advantages and disadvantages of the development of natural capital (Warlenius, Pierce, and Ramasar 2014).

Second, weaker prescriptive elements of ecologically unequal exchange stem from the idea in the literature that the presence of international organizations and civil society groups, in general and within peripheral nations, can help to encourage and to set norms for more stringent environmental and labor regulations. In doing so, these organizations help to stem some of the symptoms of ecologically unequal exchange relationships (Jorgenson 2016b; Jorgenson 2010). I call this prescriptive element weak in comparison to those encouraged by the concept of ecological debt because they only serve to alleviate some of the symptoms of ecologically unequal exchange, whereas the reversal of ecological debt could, in theory, solve the problem itself. Nevertheless, these weak prescriptive elements are more likely to occur than a total reversal of ecologically unequal exchange relationships.

## Methods

The methods for this research project are built upon those used by Bonds and Downey (2012) in their analysis of whether 'green' technologies contribute to ecologically unequal exchange in the world system. They look for cases where green technologies that are commercially available in core nations are manufactured using raw materials that are extracted from peripheral or semi-peripheral nations, and where social or environmental disruption occurs in the latter as a result. Their methods involved choosing three different technologies as case studies, and determining which natural resources are used in the manufacture of their chosen technologies and where those resources are extracted. Subsequently, they searched for cases of social and

environmental disruption in or around the locations in which those resources are extracted. Once they determined the extraction locations of their chosen minerals (by unspecified means) they used news stories to search for evidence of ecologically unequal exchange effects. Here, they used the websites 'LexisNexis' (lexisnexis.ca), 'Mines and Communities' (minesandcommunities.org) and 'Mining Watch' (miningwatch.ca) for their searches.

The countries that I assessed for evidence of ecological modernization and ecologically unequal exchange consisted of the top three global extractors of the three materials I selected from those that are used to produce solar-panels and wind-turbines. Using a life cycle analysis as a starting point, I found the top three extractive countries for three minerals each for solar-panels and wind-turbines. Ecologically unequal exchange and ecological modernization effects were then examined in each of these countries.

The analysis and discussion involves a cross-comparison of ecological modernization effects between the core, semi-peripheral, and peripheral countries in the dataset. In this study, countries were categorized as peripheral, semi-peripheral, or core, based on a list in the appendix of Chase-Dunn et al. (2000). Countries were classified in this list according to a multi-variate model developed by Terlouw (1993), in which z-scores were developed from averaging the z-scores of variables measuring the stability of trade relations, gross domestic product per capita or gross national product per capita (depending on availability of data), military manpower, military expenditure, and the number of embassies and diplomats sent and received, for each country. These variables reflect the economic, political, and military dimensions of power relations in the world system.

Subsequently, conclusions are drawn as to the relationship between ecological modernization and ecologically unequal exchange processes in the world-system surrounding the implementation of solar-panels and wind-turbines, the strengths and weaknesses of each of these theories in this context, and whether this study lends credence to the idea that changes within the status quo or more fundamental changes are the most appropriate path towards sustainability.

The structure of the methods for this study and the sources utilized at each stage of the methods are summarized in table 1, below. These methods and sources are discussed in more detail in the following subsections.

*Table 1: Summary of Research Methods and Data Sources*

Section of Study		Data Sources (Solar-Panels)	Data Sources (Wind-Turbines)
Life Cycle Analysis	Mineral composition of technologies	<ul style="list-style-type: none"> <li>• Muhovich (2010)</li> <li>• The Solar Company (2016).</li> <li>• De Gree (2016)</li> <li>• Gerbinet et al. (2014)</li> <li>• IRENA (2016)</li> <li>• Renewable energy corporation (2017)</li> </ul>	<ul style="list-style-type: none"> <li>• Hodder (2010)</li> <li>• Walker (2013)</li> <li>• Smoucha et al. (2016)</li> <li>• Northwest Mining Association (n.d.)</li> <li>• Courtice (2012)</li> <li>• SETIS (2016)</li> <li>• Goggin (2016)</li> </ul>
	Top mineral extractors	Locations:	Locations:

		<ul style="list-style-type: none"> <li>• Muhovich (2010)</li> <li>• Shaw (2017a)</li> <li>• Padhy (2017a)</li> <li>• Statista (2014)</li> </ul>	<ul style="list-style-type: none"> <li>• Hodder (2010)</li> <li>• Shaw (2017b)</li> <li>• Padhy (2017b)</li> <li>• Padhy (2017c)</li> </ul>
	Production of technologies (locations, methods, technologies)	Methods/technologies: <ul style="list-style-type: none"> <li>• Renewable energy corporation (2017)</li> <li>• The Solar Company (2016)</li> <li>• SVTC (2009)</li> </ul> Locations: <ul style="list-style-type: none"> <li>• Colville (2017)</li> </ul>	Methods/technologies: <ul style="list-style-type: none"> <li>• Walker (2013)</li> <li>• Dvorak (2015)</li> </ul> Locations: <ul style="list-style-type: none"> <li>• Statista (2017)</li> <li>• SETIS (2016)</li> </ul>
	Use of technologies	<ul style="list-style-type: none"> <li>• IRENA (2017)</li> </ul>	<ul style="list-style-type: none"> <li>• IRENA (2017)</li> <li>• GWEC (2016)</li> </ul>
	End-of-life of technologies (locations, uses, technologies used to extract use)	<ul style="list-style-type: none"> <li>• Larsen (2009)</li> <li>• Desai and Nelson (2017)</li> <li>• IRENA (2016)</li> </ul>	<ul style="list-style-type: none"> <li>• Andersen (2015)</li> </ul>
	Maintenance of technologies	Materials and timeframes: <ul style="list-style-type: none"> <li>• Elsheref (2016)</li> </ul>	Materials and timeframes: <ul style="list-style-type: none"> <li>• Andersen (2015)</li> </ul>
<b>Analytical Framework</b>	Definition of states as core, semi-peripheral, or peripheral	<ul style="list-style-type: none"> <li>• Chase-Dunn et al. (2000)</li> <li>• Terlouw (1993)</li> </ul>	
<b>Evidence for Ecologically Unequal Exchange Effects</b>	Environmental and/or socio-economic disruption	<ul style="list-style-type: none"> <li>• Mines and Communities (2018) (Homepage &gt; search)</li> <li>• Mining Watch (2018) (Homepage &gt; search)</li> <li>• Google (2018)</li> </ul>	
<b>Evidence for Ecological Modernization Effects</b>	Total installed generation capacity for renewables (MW in 2016)	<ul style="list-style-type: none"> <li>• International Renewable Energy Agency (IRENA) (2017) (Our work &gt; data and statistics &gt; capacity and generation)</li> </ul>	
	Policies supporting renewable energy/discouraging fossil fuels	<ul style="list-style-type: none"> <li>• International Renewable Energy Agency (IRENA) (2017) (Our work &gt; policies and measures)</li> </ul>	

### Methods and Rationale for Modified Life Cycle Analysis of Solar-Panels and Wind-Turbines

The methods of this research project were essentially divided into two main stages. In the first stage, I conducted a modified type of life cycle analysis, where I utilized internet sources and scientific literature to create an overview of the life cycle of solar panels and wind turbines, including an outline of the stages of extraction, usage, maintenance, and end-of-life. This life cycle analysis focused mainly on the extraction and usage stages, the former being used to gain an understanding of the material composition of solar-panels and wind-turbines, followed by determining the top three countries of origin for the materials found in these technologies (based on total amounts extracted in 2016 for each respective mineral, or in 2015 if 2016 data was not available). The maintenance and end-of-life sections are combined, and include information regarding the parts that most often need to be replaced in solar-panels and wind-

turbines and the average lifespan of those parts, as well as any information regarding where solar-panels and wind-turbines - and the parts that need to be replaced in them - go at the end of their life span, what they are used for, and the processes and technologies utilized to extract this use.

### Testing for Ecologically Unequal Exchange Effects

Testing for ecologically unequal exchange effects involved looking for evidence of social and environmental disturbance resulting from industrial mining processes in the top three extracting countries for each respective mineral. Only effects reported as occurring during or after 2005 were included in this analysis, in the interests of space and time.

Evidence for ecologically unequal exchange was demonstrated in this study by the presence of environmental or social disruption in the countries engaged in the resource extraction process for solar-panel and wind-turbine industries, where this disruption occurred as a result of mining industries designed to extract the mineral that is being focused on in each case. Specifically, factors I used or looked for as evidence here included deforestation; pollution of water, land or air; creation of ecological dead-zones; dispossession or displacement of people from their land; threats and violence against protestors of the respective extractive industries; arrests or detentions; beatings and injuries; torture; rape and sexual assault; killings; (attempts at) media suppression; labelling of protestors or activists as terrorists; protests in response to corporate violation of socioeconomic benefit agreements; pollution or exploitation of sacred cultural or religious sites; unlawful occupation of states or territories by state-owned industries; exile or diasporas of Indigenous peoples due to unlawful occupations; child labour; contractions of sickness or disease due to exposure to pollution from mines; and distortion of impact tests via collusion between environmentalists and industry. The methods listed in this paragraph are essentially the same as those utilized by Bonds and Downey (2012). As mentioned, the sources they used were LexisNexis, Mining Watch, and Mines and Communities. Most of the data in this stage of the project was found via Mines and Communities, though I supplemented this with news stories from MiningWatch and the Google search engine.

Given the range of ecologically unequal exchange effects, I found it analytically helpful to group them into three categories based on both the extent of environmental and socio-economic impacts, and the extent to which these impacts are acknowledged by those impacted. I categorized the effects as ranging from strong, to moderate, to weak. I define “weak” effects as those occurring in countries where pollution took place but no people or communities were reported as protesting or being affected or harmed by the pollution. I define “moderate” effects as those occurring in countries where pollution took place and where protests were reported, or where industry actions harmed people or communities indirectly by means of damaging their means of subsistence, by polluting their sacred cultural or religious sites, by labelling individuals as terrorists, by suppressing information, or by displacing people or communities from their traditional lands, but where no direct harm was reported as being inflicted upon people or communities. I define “strong” effects as those occurring in countries

in which pollution took place and individuals or communities were directly harmed due to the pollution or due to their protests of the disruption caused by the respective industry. These strong effects included such outcomes as killings, torture, injuries, arrests, illness and disease from pollution, child labour, or sexual assault.

### Testing for Ecological Modernization Effects

As discussed in the literature review, ecological modernization can include greening of technology as well as incremental changes to socioeconomic and political structures to bring about positive environmental outcomes without compromising economic gains. Since technology is the core focus of ecological modernization theory, the first place to look for ecological modernization effects is the usage stage of solar-panels and wind-turbines. Therefore, the first form of evidence used for ecological modernization was total installed megawatt capacity in 2016 for wind-turbines or solar-panels, depending on whether the country in question was a top extractor for a mineral used for the former or the latter. The second form of evidence consisted of policies to encourage the implementation of wind-turbines or solar-panels and discourage fossil fuel use. These policy innovations consisted of regulatory instruments, such as laws, acts, or renewable energy targets; education or advice on renewable energy implementation; research and development plans or projects; economic instruments, such as renewable energy auctions, market mechanisms, tax relief, renewable energy credits, grants or subsidies, and investments in renewable energy infrastructure; policies or strategic policy frameworks for renewable energies; information provision on renewable energies; or the creation of institutions intended to encourage the implementation of solar-panels or wind-turbines.

The number of policies was compared between countries, as well as their variety. Here, variety was compared by assigning each country a number out of seven, according to how many types of policy innovations were found in that country, according to the types listed above. The jurisdictional area-of-effect was also examined for these institutional innovations, which could include national, regional/state/provincial, or municipal areas. This factor was included in the analysis because, presumably, countries with institutional innovations that cover a wider variety of scales would be more effective at promoting renewable energy implementation. This factor was analyzed by assigning each country a number out of three, depending on how many scales were covered by the policies in that country.

In this analysis, the policies listed do not add up to the total number for the country, as some policies are listed by IRENA as embodying more than one category. As well, installed megawatt capacity and institutional innovations were only examined for the technology that the material was analyzed for, though there are some countries that are the top producers of minerals for both technologies, in which case, ecological modernization findings are listed separately between the solar-panels and wind-turbines sections.

I searched for these ecological modernization measures on a database on the International Renewable Energy Agency (IRENA) website. 2016 was the latest measurement that IRENA provided for installed megawatt capacity, hence why I used that year. As well, the

categories I utilized as policies for solar-panels or wind-turbines were the categories that IRENA listed in their database.

## Findings

### Solar-Panels

#### Material Composition

Muhovich (2010) provided most of the information I found regarding the material composition of solar panels, though I cross-checked and supplemented this with information from The Solar Company (2016), De Gree (2016), IRENA (2016), Gerbinet et al. (2014), and the Renewable Energy Corporation (2017).

Solar-panels can be composed of arsenic, bauxite (aluminum), boron, butryl, cadmium, coal, copper, gallium, indium, molybdenum, lead, phosphate, selenium, silica (silicon dioxide), and titanium (titanium dioxide, also known as rutile). Out of these materials, I examined copper, phosphate, and titanium, because, based on the sources cited in the previous paragraph, these elements seem more likely to be used in all types of solar panels. The types of solar-panel I examined include crystalline silicon photovoltaics and thin layer photovoltaics. Crystalline silicon class panels - which are the most commonly used class - include a range of models that all utilize silicon, and thin layer panels, a more recently developed class that has a more heterogeneous range of models, uses a range of different materials across different model types (Gerbinet et al. 2014).

#### Top Extraction Locations of Copper, Phosphate, and Titanium

Muhovich (2010) provides information regarding the main extraction locations (by amounts mined) for copper, phosphate, and titanium dioxide (rutile). I cross-checked and updated this information with data from Padhy (2017a) for copper, Shaw (2017a) for phosphate, and Statista (2014) for titanium. As of 2016, the top copper extractors are Chile, Peru, and China; and the top phosphate producers are China, Morocco, and the United States. As of 2014, the top titanium producers are China, Australia, and South Africa.

#### End-of-Life and Maintenance

The life span of a solar panel is on average about 25-30 years. The battery is the main component within solar panels that needs replacing. The life span of a solar panel battery tends to be 6-12 years, so the battery will need to be replaced approximately 2-5 times in the life of a solar panel (Elsheref 2016).

## Material Extraction and Ecologically Unequal Exchange Effects

Table 2 (below) summarizes the ecologically unequal exchange effects found for the top three extractors of materials for both solar-panels and wind-turbines, as well as the aggregate summaries of these effects within the core, semi-periphery, and periphery. Where multiple minerals are noted in a row, their ecologically unequal exchange effects are noted for each in the order listed.

*Table 2: Ecologically Unequal Exchange Effects Found Within the Top 3 Extractors of Minerals for Solar-Panels and Wind-Turbines, and Aggregate Effects for Core, Semi-Periphery, and Periphery*

	Country	Mineral	Ecologically Unequal Exchange Effects	
Core	Canada (wind)	Cobalt	Weak	Moderate, Weak, Not found
	USA (solar)	Phosphate	Moderate	
	USA (wind)	Molybdenum	Not found	
Semi-Periphery	Aus. (solar)	Titanium	Not found	Strong, Moderate, Not found
	Aus.(wind)	Zinc	Moderate	
	China (solar)	Copper, phosphate, titanium	Strong, strong, not found	
	China (wind)	Molybdenum, zinc, cobalt	Not found, strong, not found	
	S. Africa (solar)	Titanium	Strong	
Periphery	Chile (solar)	Copper	Moderate	Strong, Moderate, Weak
	Chile (wind)	Molybdenum	Weak	
	DRC (wind)	Cobalt	Strong	
	Morocco (solar)	Phosphate	Strong	
	Peru (solar)	Copper	Strong	
	Peru (wind)	Zinc	Moderate	

Regarding solar-panel materials; for copper, strong evidence of ecologically unequal exchange was found in Peru and China, and moderate evidence in Chile. In Chile, this involved ongoing contamination of local water supplies by mining operations (MAC 2016a), which in one case (Jamasmie 2016) led to a temporary evacuation of an Indigenous community from their land. In Peru, evidence included attempts at media suppression (Hill 2015) - which in one case (MAC 2017; Moore 2016), involved the temporary detainment of Canadian film-makers for screening a movie intended to spread information to locals about unethical practices of a local copper mine. Additional evidence consisted of violations of socioeconomic benefit agreements by mining companies (MAC 2014; MAC 2017), killings (MAC 2016a; Chaps 2013; Hill 2015; Moore 2009; Cobain 2009), attacks and injuries (McCrae 2015; Chaps 2013; Hill 2015; The Associated Press 2013; Moore 2009; Cobain 2009), arrests or detention (Hill 2015; Moore 2009; Cobain 2009) sexual assault, and torture (Cobain 2009) of mine protestors, as well as labelling

of protestors as terrorists by state government (Hill 2015; MAC 2008), pollution (Chaps 2013), displacement of locals from their traditional lands (Neuman 2013), and the arrest of a mayor who was acting as a figurehead of local mine protests (Chaps 2013). In China, evidence consisted of attacks and injuries, detaining or arresting, and threatening mine protestors (Radio Free Asia 2014), polluting land and damaging agriculture (Radio Free Asia 2014; China Radio International 2011), polluting waterways and damaging fish-stocks (China Radio International 2011; AFP 2010), polluting sacred cultural and religious sites (Radio Free Asia 2014), and severe health impacts from pollution, such as organ diseases and cancer (China Radio International 2011).

For phosphate, strong evidence was found in China and Morocco, and moderate evidence in the USA by comparison. In China, this consisted of threats towards (Fang 2013); and arrests of (Fang 2013; Environmental Justice Atlas 2015) mine protestors, water pollution (Fang 2013; Environmental Justice Atlas 2015), land pollution (Environmental Justice Atlas 2015), and cancer resulting from exposure to mine pollutants (Fang 2013; Environmental Justice Atlas 2015). In Morocco, this included unlawful occupation of the Western Sahara region, exploitation of the phosphate resources there, displacement of the local people from their lands (Wilton 2013), imprisonment (Friends of MiningWatch 2016), and torture, injuries, and threats (Campbell 2015) to the Indigenous people who protested the Moroccan exploitation. In the USA, evidence consisted only of water pollution (Miller 2009; Pugh 2017).

For titanium, no evidence of ecologically unequal exchange effects was found in China or Australia, though strong evidence was found in South Africa. These included attacks, injuries, and threats to protestors of a local mine, and the assassination of an anti-mining activist leader (MAC 2016b; Clarke 2016).

### Usage and Ecological Modernization Effects

Table 3 (below) summarizes the ecological modernization effects found in the top three extractors of materials for both solar-panels and wind-turbines.

In 2016, installed megawatt (MW) capacity for electricity generation from solar-panels was 1,603 in Chile; 96 in Peru; 77,788 in China; 21.87 in Morocco; 32,954 in the USA; 5,202 in Australia; and 1,549 in South Africa.

At present, Chile has 9 policies supporting solar-panel implementation; consisting of 5 regulatory instruments, 1 educational instrument, 1 research and development plan, 5 economic instruments, and 1 strategic policy framework. All of Chile's policies are being enacted at the national level.

Peru currently has 12 policies supporting solar-panels; consisting of 4 regulatory instruments, 9 economic instruments, and 3 strategic policy frameworks. All of Peru's policies are being enacted at the national level.

China currently has 59 policies supporting solar-panels; consisting of 24 regulatory instruments, 2 educational instruments, 6 research and development projects, 22 economic

instruments, 25 strategic policy frameworks, 1 informational provisioning system, and 5 created institutions. China has 56 policies being enacted at the national level, 2 at the state or provincial level, and 1 at the municipal level.

Table 3: Ecological Modernization Effects Within Examined Core, Semi-Peripheral, and Peripheral Countries, With Averages for Each Categorization

	Country	Number of Policies		Variety of Policies (/7)		Scales Covered by Policies (/3)		Installed Energy Capacity 2016 (MW)	
Core	Canada (wind)	21	30.3	5	6.3	2	2.3	11,900	42,055.3
	USA (solar)	37		7		3		32,954	
	USA (wind)	33		7		2		81,312	
Semi-Periphery	Aus. (solar)	17	28.2	6	6.2	3	2.4	5,202	47,569.8
	Aus. (wind)	14		6		2		4,327	
	China (solar)	59		7		3		77,788	
	China (wind)	41		7		3		148,983	
	S. Africa (solar)	10		5		1		1,549	
Periphery	Chile (solar)	9	8.7	5	3.8	1	1	1,603	543.1
	Chile (wind)	9		5		1		1,298	
	DRC (wind)	3		2		1		0	
	Morocco (solar)	7		5		1		21.87	
	Peru (solar)	12		3		1		96	
	Peru (wind)	12		3		1		239.7	

Morocco currently has 7 policies supporting solar-panels; including 3 regulatory instruments, 1 research and development project, 3 economic instruments, 2 strategic policy frameworks, and 4 created institutions. All of Morocco's policies are being enacted at the national level.

The USA currently has 32 policies supporting solar-panels; including 10 regulatory instruments, 8 educational instruments, 5 research and development projects, 21 economic instruments, 8 strategic policy frameworks, 6 informational provisioning systems, and 3 created institutions. The USA has 22 policies being enacted at the national level, 15 at the state level, and 1 at the municipal level.

Australia currently has 17 policies supporting solar-panels; including 4 regulatory instruments, 1 educational instrument, 4 research and development projects, 8 economic instruments, 2 strategic policy frameworks, and 1 created institution. Australia has 12 policies being enacted at the national level, 5 at the state or provincial level, and 1 at the municipal level.

South Africa currently has 10 policies supporting solar-panels; including 2 regulatory instruments, 1 educational instrument, 1 research and development project, 4 economic instruments and 7 strategic policy frameworks. All South Africa's instruments are being enacted at the national level.

## Wind-Turbines

### Material Composition

Hodder (2010) provided the majority of the information I found regarding the material composition of wind turbines, though I cross-checked and supplemented this data with information from Walker (2013), the Northwest Mining Association (n.d.), Courtice (2012), SETIS (2016), and Goggin (2016).

Models of wind turbines, and, by extension, the materials they are composed of, appear to be more homogeneous than is the case with solar panels. Wind turbines can be composed of rock aggregates, bauxite, clay or shale, coal, cobalt, copper, gypsum, zinc, iron, silica sand, limestone, and molybdenum. Out of these materials, I examined cobalt, zinc, and molybdenum, as they are resources that are less common and seem to be used less extensively in production than those that compose the concrete, cement, and steel parts of the wind turbine (such as rock aggregates, clay, silica, limestone, coal, and iron). As such, they should presumably be able to provide more direct evidence of ecologically unequal exchange effects because less countries extract these resources, and a smaller variety of products are manufactured with them. Moreover, I chose to examine materials that are different than those which I examined in solar panels, so as to provide a wider range of data.

### Top Extraction Locations of Molybdenum, Zinc, and Cobalt

Hodder (2010) provides information regarding the main extraction locations (by amounts mined) for molybdenum, zinc, and cobalt. I cross-checked and updated this information with data from Shaw (2017b) for molybdenum, Padhy (2017b) for zinc, and Padhy (2017c) for cobalt. As of 2016, the top molybdenum extractors are China, the United States, and Chile; the top zinc extractors are China, Peru, and Australia; and the top cobalt extractors are the Congo (DRC), China, and Canada.

### End-of-Life and Maintenance

Andersen (2015) discusses the ability to reuse or recycle wind turbines and their component parts at the end of their life span, as well as the parts that most commonly fail or need to be replaced. Common replacement or maintenance parts include the gearbox, rotor blades, and the generator. Andersen states that the average recyclability of wind turbines is calculated to be approximately 80%, where the majority of non-recyclable material is found in the rotor blades. In Sweden, the metals, such as steel, copper, and aluminum tend to be sold as scrap for recycling, whereas the cables and electronic equipment are usually delivered to recycling companies that separate their component parts into metals for recycling, plastics, for combustion and energy production, and unusable toxic materials for disposal. Concerning the rotor blades, the plastics and organic material can be incinerated to produce electricity via heat, but the methods for recycling the composite material from the blades are varied and more challenging. These composites can either be ground down to have the copper sifted out and the remaining materials used as filler in products such as artificial wood, cement, or asphalt; cut

into small enough pieces so that they may be incinerated for heat production, albeit with the production of a high amount of ash that has to be sent to a landfill; processed via pyrolysis, which produces a gas that can be burned for electricity, and fibres that can be reused; or sent to a landfill - though this last option is said to be banned in many countries, including Sweden, due to the high organic content in these rotor blades. Andersen states that no industrial-scale recycling facilities currently exist for rotor blades.

#### Material Extraction and Ecologically Unequal Exchange Effects

A summary of ecologically unequal exchange effects in the top three extracting countries for wind-turbine minerals is provided by table 2, in the solar-panels section above.

For molybdenum, no evidence of ecologically unequal exchange effects was found in China or the United States; though weak effects were found in Chile, which consisted of water pollution - though no communities protested or were reported to be affected (Jamasmie 2016).

For zinc, strong effects were found in China, and moderate effects were found in Peru and Australia. In China, evidence consisted of cultural leaders and anti-mining activists who were reported as missing, where locals suggested that they were arrested. Additionally, pollution of sacred cultural and religious sites was found in China (Kang Lim 2007). In Peru, evidence included displacement of local people from their traditional lands, pollution of land, water, and air, and collusion between environmentalists and mining companies to distort mining impact test results (Bajak 2014). In Australia, evidence consisted of water and air pollution resulting in contamination of fisheries and cattle (Bardon 2015; Bardon 2016).

For cobalt, no evidence was found in China, weak effects were found in Canada, and strong effects were found in the Congo. In Canada, evidence consisted of water pollution, though no protests were reported, and no people or communities were reported as being affected (Ashley 2008). In the Congo, pollution contaminated local crops, fisheries, and communities (MAC 2016c), and there were ongoing cases of mines employing child laborers (as young as seven years old), and violence, extortion, intimidation, as well as reports of other unspecified human rights abuses against mine employees (Kelly 2016).

#### Usage and Ecological Modernization Effects

A summary of ecological modernization effects in the top three extracting countries for wind-turbine minerals is provided by table 3, in the solar-panels section above.

In 2016, installed megawatt (MW) capacity for electricity generation from wind-turbines was 148,983 in China; 81,312 in the USA; 1,298 in Chile; 239.7 in Peru; 4,327 in Australia; and 11,900 in Canada. As of 2016, the Congo still had no wind-turbine installations.

At present, China has 41 policies supporting the implementation of wind-turbines; including 18 regulatory instruments, 1 educational instrument, 5 research and development projects, 15 economic instruments, 21 strategic policy frameworks, 1 informational provisioning

system, and 3 created institutions. China has 38 policies being enacted at the national level, 2 at the state or provincial level, and 1 at the municipal level.

The USA currently has 33 policies supporting wind-turbines; including 11 regulatory instruments, 9 educational instruments, 5 research and development projects, 13 economic instruments, 7 strategic policy frameworks, 6 informational provisioning systems, and 2 created institutions. The USA has 21 policies being enacted at the national level, and 12 at the state level.

Chile currently has 9 policies supporting wind-turbines; consisting of 5 regulatory instruments, 1 educational instrument, 1 research and development plan, 5 economic instruments, and 1 strategic policy framework. All of Chile's policies are being enacted at the national level.

Peru currently has 12 policies supporting wind-turbines; consisting of 4 regulatory instruments, 9 economic instruments, and 3 strategic policy frameworks. All of Peru's policies are being enacted at the national level.

Australia has 14 policies supporting wind-turbines; including 5 regulatory instruments, 1 educational instrument, 4 research and development projects, 5 economic instruments, 2 strategic policy frameworks, and 1 created institution. Australia has 11 policies being enacted at the national level and 3 at the state or provincial level.

The Congo has 3 policies supporting wind-turbines, consisting of 2 regulatory instruments and 1 educational instrument. All the Congo's policies are being enacted at the national level.

Canada currently has 21 policies supporting wind-turbines; including 6 regulatory instruments, 2 research and development projects, 16 economic instruments, 6 strategic policy frameworks and 1 created institution. Canada has 6 policies being enacted at the national level and 15 at the provincial level.

## Discussion

When considering ecologically unequal exchange and ecological modernization, there does seem to be a connection between their strength and the relative economic and political power of countries. Though every country examined was found to have some extent of ecologically unequal exchange effects, it is telling that no effects were found for specific minerals only in semi-peripheral countries (i.e. China, Australia) and core countries (i.e. USA), while no strong effects were found in the core countries (i.e. USA and Canada).

Additionally, as table 4 (below) shows, the ecological modernization effects tested for show that countries with the weakest effects tend to be in the periphery, while those with the strongest are in the core and semi-periphery. Peripheral countries (i.e. Peru and Chile) had the lowest installed capacity for electricity generation from solar panels in 2016, and were at the bottom of the list as well for capacity for electricity generation from wind-turbines in 2016,

where they were above only the Congo - another peripheral country, which had zero capacity in 2016. Meanwhile, peripheral countries consistently had the least number of policies supporting renewable energy implementation, both for solar-panels (i.e. Morocco and Chile) and wind-turbines (i.e. the Congo and Chile, and Peru). As well, all peripheral countries only adopted policies for renewables on a national scale and had much less variety in terms of the types of policies they adopted compared to semi-peripheral and peripheral countries.

*Table 4: Ecologically Unequal Exchange Effects Examined Alongside Ecological Modernization Effects in Examined Core, Semi-Peripheral, and Peripheral Countries*

	Average Number of Policies Per Country	Average Variety of Policies per Country (/7)	Average Number of Scales Covered per Country (/3)	Average State Installed Energy Capacity 2016 (MW)	Aggregate Ecologically Unequal Exchange Effects
Core	30.3	6.3	2.3	42,055.3	Moderate, Weak, Not found
Semi-Periphery	28.2	6.2	2.4	47,569.8	Strong, Moderate, Not Found
Periphery	8.7	3.8	1	543.1	Strong, Moderate, Weak

It is perhaps no surprise that China reported the most ecologically unequal exchange effects, as it was the world's top producer of four out of the six minerals examined, and was in the top three producers for all six. However, China also had the most installed capacity in 2016 for both solar-panels and wind-turbines, and the most policies for both solar-panels and wind turbines; and though most of these policies were enacted at the national scale, it had policies at all three scales for both technologies.

The fact that core and semi-peripheral countries utilize the most renewable energy technologies and have the most policies for these technologies out of the countries examined means that they are exerting great pressure to expand extractive industries within the top extracting countries. Thus, it appears that, at least in terms of renewable energy generation, strong ecological modernization effects in core and semi-peripheral countries increase the prevalence of ecologically unequal exchange effects, meaning that countries higher up on the global socio-economic ladder displace socio-environmental disruption onto countries lower on the ladder.

### Relationships Between Ecological Modernization and Ecologically Unequal Exchange Processes

In answer to the main research question, it seems that both ecologically unequal exchange and ecological modernization processes can be used to describe the social and environmental outcomes of the proliferation of solar-panels and wind-turbines in the world system. Evidence for the former can be found in that less or weaker ecologically unequal exchange effects are found in the core countries, and in the lack of core countries that were examined in this study, as peripheral or semi-peripheral countries tended to be greater extractors of minerals for solar-panels and wind-turbines; as well as in the fact that many moderate and strong effects are

found in the peripheral and semi-peripheral countries. Evidence for the latter can be found in that countries with higher rates and a wider range of policies in support of renewable energy implementation also have a higher installed capacity for electricity generation. Additionally, the data shows that the peripheral and semi-peripheral countries that have the weakest ecological modernization effects also have a higher incidence of ecologically unequal exchange effects, suggesting that there are less ecological modernization processes taking place in those countries that would protect against (the negative impacts of) high rates of resource extraction.

### Assessing the Strengths, Weaknesses, and Uses of Ecological Modernization and Ecologically Unequal Exchange Theories

Responding to the first sub research question, it appears that the strengths of an ecological modernization lens lies in its ability to examine phenomena within individual countries, and to connect the implementation of green technologies to political and regulatory efforts to secure this implementation. As is shown in table 3, countries with the greatest number and diversity of policies and regulations designed to encourage the use of solar-panels or wind-turbines and to discourage the use of fossil fuels, also tend to have the highest generative capacity for those respective technologies, and vice versa. However, the weakness of an ecological modernization perspective is that, alone, it cannot explain why certain countries have higher incidences of ecological modernization effects while others have less. This weakness in analytical capability appears to be remedied when examining ecological modernization effects alongside ecologically unequal exchange processes.

An ecologically unequal exchange lens, due to it being an extension of world systems theory, allows for analysis of processes that occur between nations, or within the world system. As mentioned, this scope makes it easier to assess why ecological modernization effects are stronger in some countries and not others – because of the balance of power between these countries in the world system. As was found in this research project, countries with stronger incidences of ecologically unequal exchange effects tend to have weaker ecological modernization effects. These countries tended to be peripheral or semi-peripheral, meaning that they occupy a weaker power position on the global ladder within the world system than countries that were found to have strong ecological modernization effects and weak ecological modernization effects. The latter tended to consist of core countries, who dominate the world system and those countries further down the ladder. Here, the ecologically unequal exchange lens can be used, to surmise that the weaker position of the peripheral and semi-peripheral countries within the world system means that the most socially and environmentally disruptive industries (i.e. extractive industries) tend to be displaced there from more powerful countries. In order to make room for these damaging extractive industries, it is often the case that these less powerful countries have less stringent social and environmental regulations (Leonard 1988; McMichael 2008). Since such regulations are a form of ecological modernization, this notion may explain why these countries tended to have weaker ecological modernization effects in terms of implementing renewable energy technologies.

Though the strength of ecologically unequal exchange theory lies in its broad scope, this can also be a weakness. Since this theory conducts analysis at the level of the world system, assessing the presence of its processes has the potential to become very complex compared to ecological modernization analyses, and examining ecologically unequal exchange effects cannot, in effect, be done by examining countries in isolation: these effects must be compared between countries of varying power to see whether the distribution of the costs and benefits of the utilization of natural capital are distributed equally. As such, the analytical capability of the ecologically unequal exchange lens in this study was amplified when combined with the ecological modernization lens. For examining each together allows for a relatively easy assessment of the benefits and costs of the utilization of natural capital in each country, where the benefits consist of the implementation of renewable energy technologies, and the costs, of the disruptive extraction of minerals that are used in the production of those technologies.

### Implications for Sustainability

The tendency for lower implementation of solar-panels and wind-turbines in the countries that suffer the most consequences as a result of extracting minerals for these technologies implies that pursuing global sustainability via ecological modernization alone will not be a successful endeavor. As discussed, the prevalence of social and environmental damages in the periphery from extractive processes is due in large part to the weaker position of these countries within the world system. This power imbalance spells a limited number of economic options for such countries, meaning that they tend to lower their social and environmental regulations to expand these options. However, a weak regulatory climate means that such countries have less ability to encourage and implement the use of renewable energy technologies, and less capacity to discourage fossil fuel use. When viewed in this way, in the context of a transition to renewable energy, the question becomes not only *whether* sustainability can be achieved, but *who* can achieve it. In the case of this study, with the exception of China, it is the most powerful countries: those who utilize the most renewable energy, yet suffer the least consequences from its use. The theory of ecologically unequal exchange posits that social and environmental harms are displaced from core to periphery in the world system, and this study affirms this to be the case in the context of the adoption of solar-panels and wind-turbines. Within a world system based upon inequality, where the benefits and costs of the utilization of natural capital (e.g. the minerals used to produce solar-panels and wind-turbines) are distributed unevenly, universal sustainability appears to be unattainable.

Therefore, these findings suggest that universal sustainability could only be achieved if the world system operated in such a way that costs and benefits were distributed equally. Since their unequal distribution appears to stem from a fundamental power imbalance between core and periphery, which allows the exploitation of the latter and its resources by the former, rebalancing this power could lead to relationships based around 'ecologically equal exchange'. Since a great part of the current power imbalance stems from large economic debts in the periphery, owed to core countries or their affiliated international agencies (such as the International Monetary Fund), one such method of rebalancing power could begin to be undertaken through so-called ecological debt. According to the theory of ecological debt, which

is closely related to ecologically unequal exchange theory, the unequal distribution of costs and benefits between nations perpetuates itself, as extractive industries, undertaken more within the periphery, are more environmentally and socially disruptive than the more prevalent manufacturing and service economies in the core. The weak position of peripheral countries essentially coerces them into extractive industries, and interferes with their development, via a combination of relatively low profits and high environmental and social disruption (Warlenius, Pierce, and Ramasar 2014). As such, recognizing this ecological debt would essentially mean a rebalancing of power, via economic debts owed to the periphery by the core, and a more equalized distribution of the costs and benefits of the utilization of natural capital.

Following from this, the first step to achieving universal sustainability would be in rebalancing power between the core and periphery. This would involve redistribution of money and of the costs and benefits of the utilization of natural capital. However, this would be problematic, given that current rates of resource consumption and pollution surpass the carrying capacity of the Earth to regenerate those resources and assimilate that pollution. As of 2017, global society would require approximately '1.7 Earths' to sustain current levels of consumption and pollution (Global Footprint Network 2017). Given that global rates of consumption and pollution increase every year, this number will only continue to grow.

Ecologically unequal exchange theory offers an explanation as to why these unsustainable levels of consumption are not more easily recognized: because the places where the most consumption happens, the most powerful countries, are where the consequences of that disruption are displaced. If global ecological debt forgiveness were to be enacted, the fact that we are overshooting Earth's carrying capacity would become much more apparent everywhere.

The treadmill production theory of Schnaiberg (1980) posits that, since capitalist society is sustained by growth, such a society inevitably depends upon ever-increasing resource inputs. The increasing overshoot of global society beyond Earth's carrying capacity can thus be attributed to the growth ethos that is fundamental to capitalism. I argue that, though global fulfillment of ecological debt and an equalized distribution of costs and benefits would lead to more just and equalized power relations, it would in effect make the unsustainability of a growth-oriented society that much more obvious, as well as more necessary. This is because the consequences of over-consumption and overshoot would become much more acute across the world, rather than concentrated mostly in the periphery.

Given this, the second step towards achieving universal sustainability would be to reduce levels of consumption and pollution to within that of Earth's carrying capacity, and to keep it below this threshold. Since the global capitalist economy is sustained by growth, it would be incapable of doing this, and a non-growth, steady-state economy would need to take its place (Czech 2013). Bringing the discussion back to solar-panels and wind-turbines, this research project suggests that the implementation of such technologies alone as a sustainable energy solution would be unsuccessful, as unequal power relations between nations obstruct the implementation of such technologies in the least powerful countries, while displacing the environmental harms of the core onto the periphery by concentrating extraction of the minerals for these technologies in the periphery. Averting both injustice and unsustainability,

therefore, would require both rebalancing these exploitative relationships, and transitioning to a steady-state society, so that the environmental and social consequences of extraction for solar-panels and wind turbines would not be at unsustainable levels.

## Conclusion

In the context of solar-panel and wind-turbine systems, ecologically unequal exchange effects were found to exist between (semi)peripheral and core countries, and peripheral and semi-peripheral countries. These effects are exacerbated in countries that are further down the global socio-economic ladder by ecological modernization effects in countries that are further up this ladder.

An exception must be made here for China, however, as it is a semi-peripheral country, yet has the highest incidences of both ecologically unequal exchange and ecological modernization effects, and is the highest producer of most of the minerals examined in this study. China's situation here could perhaps be explained by a strategy of implementing renewable energy systems through as a great of a reliance on its own resources as possible – that is, a push to get closer to energy independence that is supported by renewable energy technologies. However, more research would need to be put towards examining China's economic and energy policies for this to be confirmed.

The findings of this research project support the idea that achieving sustainability while maintaining the status quo may not be possible. That is, sustainability efforts that focus on the implementation of 'green' technologies, and political innovation as a means to this implementation, without taking into account both the unequal distribution of the costs and benefits of the utilization of natural capital, and the growth orientation that is fundamental to capitalism, appear to be short-sighted. In the case of this project, implementation of solar-panels and wind-turbines tended to be the most prevalent within countries that suffer the least environmental and socio-economic consequences from the extraction of materials for these technologies. This effectively means that efforts to increase sustainability in relatively powerful countries via renewable energy implementation exacerbates unsustainable practices in the relatively less powerful countries that extract the minerals for these technologies.

The results of this study serve as evidence that sustainability would be more effectively achieved within a non-growth society with equalized distribution of the costs and benefits of the utilization of natural capital. Using global solar-panel and wind-turbine systems as a case in point, destructive extraction of the resources for these technologies occurs in countries with the least implementation of solar and wind, implying that a global pursuit of sustainability should really be perceived as a displacement of unsustainability from core to periphery. Therefore, achieving true sustainability must occur in such a way that the sustainability of one country does not come at the expense of the unsustainability of another. However, equalized distribution of sustainability and unsustainability within contemporary capitalist consumer society would spell universal unsustainability, as continuous growth depends upon ever-increasing withdrawals of resources. Since the planet only contains and produces a finite

number of resources, a growth orientation is not feasible in the long-term - a fact that would become more transparent if unsustainable effects were distributed equally. A non-growth society with an environmental footprint below the threshold of the earth's carrying capacity is the answer to this.

In methodological and theoretical terms, this study advances understandings of the uses and limits of the theories of ecological modernization and ecologically unequal exchange, and the relationship between them. Though ecological modernization is an effective means of measuring sustainability efforts, both in technological implementation and political efforts to achieve this implementation, it is limited in its ability to explain why the presence or absence of such efforts occurs. The macro world-systems approach of ecologically unequal exchange assists with this, attributing such differences to imbalances of power between countries.

As well, the methods employed in this study show that analysis of ecologically unequal exchange effects can be strengthened by examining such processes alongside ecological modernization effects. Since ecologically unequal *exchange* surmises that a transaction of costs and benefits is taking place between countries, examining ecologically unequal exchange effects (i.e. costs) alongside ecological modernization effects (i.e. benefits) allows for a clearer picture of ecologically unequal exchange processes in the world system.

### Limitations and Suggestions for Further Research

Though no ecologically unequal exchange effects were found in China for cobalt, titanium, or molybdenum, in Australia for titanium, or in the USA for molybdenum, this does not mean that these effects are not present in these states for those industries. Seeing as though information suppression can be evidence of ecologically unequal exchange, this may be the case in these examples. Therefore, a limitation of studying ecologically unequal exchange is that by its very nature it can be hard to detect.

Additionally, though many more indicators of ecologically unequal exchange were found to be present for the minerals used in solar-panels, this may be partially because cobalt and molybdenum are classified as rare earth metals, meaning that they are mined in much lower quantities than other minerals. Therefore, there were essentially less data sources for cobalt and molybdenum, so ecologically unequal exchange effects were harder to detect for these minerals. In light of this, for subsequent studies of a similar nature, if there is a wide variety of possible minerals to choose from as objects of analysis, it may be wise to choose materials that are not rare earth metals.

A more substantive study of this nature could also look at pre-conditions for ecologically unequal exchange effects. These may include indebtedness of nations, weakened labour, social, or environmental regulations surrounding extraction industries, or end-of-life sites or facilities for solar-panels and wind-turbines or their component parts, as well as a relatively high raw-material-export-oriented GDP. These factors could be compared across countries in question and to ecologically unequal exchange and ecological modernization effects. Such a comparison

would provide a more detailed picture of ecologically unequal exchange processes in the world system.

As well, though my categorization of ecologically unequal exchange effects - into groupings of strong, moderate, or weak - assisted in analysis, some critics may argue that such hierarchical conceptions of environmental and social disruption are too anthropocentric – especially since the field of environmental sociology recognizes the interconnectedness of human and natural systems. In light of this, my categorizations may be somewhat limited in their ability to conceive of ecologically unequal exchange processes. However, I do not believe that these limitations are too debilitating in this context, as the theory of ecologically unequal exchange is rooted in world systems theory, of which the scope examines human power imbalances. Though these power imbalances are connected to environmental factors, hence why ecologically unequal exchange theory expands upon world systems theory, it still appears that human power imbalances are the driving force of these processes, and that the unequal distribution of ecological costs and benefits is a supporting mechanism for them. This being said, I think that my categorizations could carry more weight in terms of their explanatory and analytical potential if the labels were less hierarchical in terms of whether social or environmental impacts are more severe. In subsequent studies, attempts could be made to incorporate this.

Lastly, but perhaps most importantly, there exists the potential for the results of this study to be misconstrued as suggesting that renewable energy technologies are in fact unsustainable, where in actuality they indicate that such technologies are only sustainable under certain conditions: conditions that appear to be unlikely or impossible to attain from within the current socio-economic framework. As such, I have discussed the need to transition to a steady-state society with an equalized distribution of costs and benefits. However, a comparison between renewable energy technologies (e.g. solar-panels and wind-turbines) and fossil fuels (e.g. coal and oil) regarding the environmental and social impacts throughout their life-cycles would provide clarity when analyzing appropriate (and inappropriate) courses of action in pursuit of sustainability.

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