ASSESSING ENERGY POLICY FOR SUSTAINABILITY OUTCOMES:
A COMPARATIVE STUDY OF DIFFERENT REGULATORY MARKET STRUCTURES ACROSS NORTH AMERICA

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Abstract

Our modern world runs on electricity, and electricity is often produced using fossil fuel sources that contribute to global climate change. In a world with increasingly ambitious climate goals, it is vital to understand the relationship of energy markets where electricity is bought and sold and the renewable energy policies that exist to reduce fossil fuel generation. This thesis compares policies implemented in the continental US and Canada to explore potential relationships between renewable energy policies and energy market types (regulated markets vs. restructured markets) based on outcomes for reduced CO_2 emissions, increased renewable generation, and decreased fossil fuel generation. This research uses statistical techniques to explore said relationships including OLS regression and multi-variate analysis of variance. This research contributes to Energy Policy and Sustainability literature with various findings, such as results showing there are no significant statistical differences between energy market types for impacts on renewable energy policy effectiveness. Findings are limited by the exploratory nature of this research and highlight the need for further study into the effectiveness of renewable energy policies.

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Glossary

Agency Theory – The relationship where company executives act as agents on behalf of shareholders.

Biomass Generation – The burning of biological waste materials for electrical station fuel. Including but not limited to landfill and waste wood products.

Cap and Trade – See Emissions Trading Scheme

Capacity Market – A form of restructured energy market where generators are compensated for how much generation they make available to the grid, regardless of if said generation is utilized by customers.

Carbon Tax – A form of indirect climate regulation. Polluters are charged a fee based on the amount of carbon dioxide released to the air.

Canada Energy Regulator (CER) – The Canadian federal energy regulator.

Clearing Price – The price electricity is sold at, after the merit order is determined and demand is met. All firms that sold electricity are compensated at the price of the last unit of electricity sold.

CO2 – Carbon Dioxide. Formed from combustion, CO2 in the atmosphere acts as a greenhouse gas by reflecting heat energy back towards earth's surface.

Coal & Coke Generation – Uses coal and coal byproducts for fuel for electrical generation stations. Usually by burning coal to heat water into steam, then using the steam in turbines. Coal is a fossil fuel that releases CO2 along with other pollutants when burned.

Converse error – AKA Affirming the Consequent. When a true statement is used to assume the converse statement. Exists in the logical form $P \rightarrow Q, Q \therefore P$. E.g. If I have my umbrella, it is raining. It is raining therefore I have my umbrella.

COP26 – AKA the Glasgow Climate Change Conference. The 2021 United Nations Climate Change conference where nations recommitted to limit global temperature to 1.5 ℃ by 2100.

Cost of Service Regulation – When firms are compensated based off the cost to perform a service, including an approved profit margin.

Cournot Competition – An economic model of competition where companies compete on the quantity of a homogeneous output produced individually and independently, rather than competing on price. Price is determined by the supply provided by the competing firms.

Energy Market – The market in which electricity is bought and sold from generators to consumers. Each market is under the jurisdiction of a legislative authority, usually a state or provincial government. The number of intermediary firms between the generator and consumer can vary.

Energy-only Market – A form of restructured energy market where generators are compensated by selling electricity to a system operator. The price is bought using a merit order, with all firms that sold being compensated at the clearing price.

ERCOT – The Energy Reliability Council of Texas. The Regional Transmission Organization and System Operator for the Texas Interconnection.

Emissions Trading Scheme (ETS) – A form of indirect regulation where polluters have a maximum amount of CO2 they can emit. Any excess emissions require purchasing a carbon offset or other stipulated certificate. Certificates are created by designated organizations. The organizations are often non-polluting firms such as wind or solar generators.

Federal Energy Regulatory Commission (FERC) – The American federal energy regulator.

Feed-in Tariff (FIT) – A form of direct energy regulation. An additional cost on charged to electrical generators based off the type of electricity provided to the grid. Can be used to artificially increase the cost of fossil fuels by charging coal and natural gas generators more using the FIT.

Gross Domestic Product (GDP) – The monetary value of the goods produced and services provided by a region within a specific time period. Used to measure economic size, growth, and activity.

Geothermal Generation – Using the natural heat of the earth's core to generate electricity. Usually by forcing water in pipes deep underground to boil, then using the resulting steam in turbines.

Gigawatts – Unit of power. Equivalent to one billion watts. Describes electrical energy

Greenhouse gas (GHG) – A gas that, once in the atmosphere, reflects the earths heat back towards the surface. Can be conceptualized as a blanket around the earth. Notable greenhouse gases include CO2 and Chlorofluorocarbons (CFCs)

Hydroelectric Generation – Using water to generate electricity. Usually by dams using gravity to force water through turbines.

Installed Capacity – The measure of electrical generation available in a region from all the built and working electrical generation plants.

Interconnection – A synchronized region in an electrical grid where all AC power lines are connected together. North America has five interconnects. The Western interconnection, the Eastern interconnection, the Texas interconnection, The Quebec interconnection, and the Alaska interconnection.

Independent System Operator (ISO) – The organization that manages and operates the infrastructure in an electrical grid. Usually does not include the generation stations and is limited to a single state or province.

Megatonne (Mt) – Unit of weight. Equivalent to one billion kilograms. Used to determine amount of GHGs released from generation stations.

Megawatt Hours (MWh) – Unit of energy over time. Used to describe the amount of electrical energy sustained for one hour. Equivalent to 3.6 megajoules.

Merit Order – A ranking of the available energy sources for purchase. A standard is used to determine merit so electrical sources can be ranked in order of most desirable to least. Most commonly used merit is price, cheapest to most expensive.

Natural Gas Generation – Uses natural gas (methane) for fuel to generate electricity. Usually methane is burned to boil water into steam for use in turbines. Natural gas is a fossil fuel that releases CO_2 when burned.

Nuclear Generation – Uses radioactive elements to generate electricity. Radioactivity releases energy in the form of heat. Usually used to boil water into steam for turbines.

OPEC – the Organization of Petroleum Exporting Countries. Contains thirteen member countries and accounts for 44% of global oil production. Member countries will often collude to restrict supply and keep prices of oil inflated.

Paris Agreement – AKA the Paris Climate Accord. The 2015 United Nations Climate Change conference where nations committed to limit global temperature to well below 2 ℃ by 2100.

Performance Based Regulation (PBR) – A form of regulation where firms are compensated by meeting performance targets, rather than using cost of service regulation.

Petroleum Generation – Uses petroleum products to generate electricity. Petroleum products include crude oil, heavy and light fuel oils, diesel fuel, and gasoline. Usually the petroleum product is burned to boil water into steam for use in turbines. Used instead of coal or natural gas when infrastructure for fuel deliveries, such as pipelines or rail, do not exist. Petroleum products are fossil fuels that releases CO_2 when burned.

Parts per Million (PPM) – A measure similar to percentage. Used to indicate how many parts of air are CO_2.

Public Utility Commission (PUC) – A regulatory body which regulated public utilities including electrical utilities.

R&D – Research and Development

Regulated Market – An energy market which has not been restructured to include a wholesale market for electricity.

Restructured Market – AKA deregulated market. An energy market which has been changed to allow for generators to compete on price in a wholesale market.

Return on Investment (ROI) – A metric to determine the expected return and profitability of a monetary investment.

Renewable Portfolio Standard (RPS) – A form of direct energy policy. Outlines some minimum amount of renewable generation an electrical generator must own.

Regional Transmission Organization (RTO) – Similar to an ISO. An organization that operates an electrical grid to ensure cooperation and reliability. Often spans multiple jurisdictions, covering many states and provinces in each RTO.

Sustainable Development Goal (SDG) – A collection of 17 United Nations goals acting as a blueprint for global equity and future sustainability.

Solar Generation – Uses the power of the sun to generate electricity. Usually photovoltaic cells that generate power when exposed to radiation from the sun. Can also be a collection of mirrors which concentrate the sun's heat energy to boil water into steam.

Wind Generation – Uses the power of the wind to generate electricity. Usually uses large wind turbines.

Chapter 1: Introduction

Our world stands on the precipice of global climate catastrophe. The delicate ecosystem that maintains the earth's global climate has continued to destabilize (Dijkstra, Westerman, & Harris, 2011; Earles, North, & Hurteau, 2014). Global climate changes, driven by increasing temperatures, have led to a dramatic increase in extreme weather and disastrous events (Lindsey & Dahlman, 2020). The primary cause of our changing climate is the release of greenhouse gases (GHGs) into the atmosphere (IPCC, 2014). Sixty years ago, carbon dioxide (CO2), the primary GHG, had an atmospheric concentration around 300 parts per million (ppm) (IPCC, 2014). Atmospheric levels of CO2 now reside above 400ppm and within cities can reach levels of 500ppm (IPCC, 2014; Lindsey, 2020). The targets within the Paris Climate Accord, an agreement to reduce global temperature rise to below 2 degrees Celsius by 2100 through the reduction of GHG emissions, are not being met by member countries. Even when governments met in November of 2021 at the COP26 summit to reaffirm the Paris Agreement and commit to the more ambitious goal of 1.5 degrees of temperature rise, doubt remains as to when targets for CO_2 reduction will be met considering countries were struggling with the previous targets (Sommer, 2021). There is uncertainty about the commitment of countries to fight the climate crisis, with the United States leaving and rejoining the Paris agreement within the span of a year (Stracqualursi & Kann, 2021). We have known about anthropogenic climate change for the better part of a century, yet governments remain unsure about the path forward (Carey, 2008).

The United Nations (UN) suggests that reducing CO_2 emissions is a direct way to combat climate change and promote a sustainable future through both the Paris Agreement and the

Sustainable Development Goal (SDG) for Climate Action (SDG #13). The two largest contributors to carbon emissions in the United States are transportation and electricity generation (EPA, 2020). Therefore, there are two key paths to achieving the emission reduction targets of SDG #13 and the Paris Agreement: reducing emissions from transportation and reducing emissions from energy generation. The UN SDG #7 recommends that reliable and sustainable energy is vital for a better future. Currently, the generation of electricity accounts for 1.8 billion metric tons of CO_2 annually, with approximately two thirds resulting from the burning of fossil fuels such as coal and natural gas (EPA, 2020). While existing modes of transportation are a major contributor to total emissions, new technologies such as electric vehicles have the potential to radically shift the balance of emissions. New transportation technologies have the potential to put new load on existing electricity generation and increase emissions from energy production in an attempt to reduce emissions from transportation (GITT ISATT, 2019).

There are plenty of new technologies in electricity to reduce CO_2 emissions; solar and wind power to name a couple. Even with advancements in renewable technology, the numbers show that coal is still a significant portion of the total generation today (EPA, 2020). What are the barriers that exist to cleaner generation, and are there ways to accelerate adoption through incentives? The institution of electrical production and consumption is guided, by definition, by both internal and external actors and pressures. Firms respond to renewable energy policies such as Feed-in Tariffs and other policy pressures that governments and regulators employ. How firms respond to individual policies has been researched by various sources (Chaton & Guillerminet, 2013; Haas et al., 2011; Ritzenhofen, Birge, & Spinler, 2016). For example, existing research (Alagappan, Orans, & Woo, 2011) suggests that government polices such as Feed-in

Tariffs will lead to an increase in renewable energy adoption. However, the ability to meet carbon reduction outcomes in a timely manner is disputed (Carley & Andrews, 2012).

Energy markets traditionally exist as vertically integrated monopolies in highly regulated regions, however some regions deregulated the markets, restructuring the market to decouple transmission and distribution so electricity can be sold wholesale (Prentis, 2015). The same research that disputes the ability to meet carbon reductions also suggests that the energy market type (regulated or restructured) that firms inhabit does not act as an influencing factor for renewable energy adoption (Alagappan et al., 2011). However, there is conflicting research that contends that restructured markets (See Glossary) have reduced investment in renewables (Carley, 2009). This tension in the literature remains unresolved and speaks to the complexity of energy market and policy interactions. It is plainly evident that different energy market types, whether it is traditionally regulated or restructured, require different regulations and policies to operate. A policy to mitigate market power exercises in a restructured market cannot be implemented in a regulated market where market power cannot be exercised. Thus, market-based policies require alignment with market factors. To extend that logic, environmental policies should require this same alignment. That is, policies for promoting adoption in renewable technology should show some differences in effectiveness when implemented in a regulated market vs a restructured market, as the two market types differ in how investment decisions are determined. To this end, this thesis seeks to explore the complex relationship between the different types of electricity markets and the adoption of renewable technologies in response to different renewable energy policy decision.

1.1 Objectives and Research Questions

The objective of this research is to explore the relationship between energy markets, energy policy and the effect both have on the adoption of renewable technology. Better understanding about how energy markets and renewable energy policies increase renewable generation can directly lead to lowered CO_2 emissions through the better implementation of polices. To better understand energy markets and energy polices with the end objective of reducing carbon emissions, the research questions are:

Question 1a: Which set of renewable energy policies are more effective for decreasing emissions from energy generation?

Question 1b: Which set of renewable energy policies are more effective for increasing adoption of renewable energy technologies?

Question 2: Do energy markets (regulated or restructured) facilitate renewable energy policies for increasing adoption of renewable energy technologies?

1.2 Significance and Originality of the Research Contribution

With climate experts saying that some effects of climate change are likely irreversible and immediate action is required to prevent further climate damage, it is clear that research focused on sustained climate action is invaluable (Lindsey & Dahlman, 2020). To date, existing research into climate action through increasing investment in renewable energy has focused on two areas, (1) the efficacy of clean technologies to reduce carbon emissions (Baker, 2008; Costello, 2014; Milstein & Tishler, 2011; Pehl et al., 2017) and (2) the effectiveness of different policy mechanisms to influence the adoption of such technologies (Alagappan et al., 2011; Brown, 2018b; Brown & Eckert, 2018; Can Sener, 2017; Haas et al., 2011; G. Holburn, Lui, & Morand, 2010; Palmer & Burtraw, 2005; Ritzenhofen et al., 2016). One study examined the effects of market type on the adoption of renewable energy, finding that market deregulation is related to lower renewable investment (Carley, 2009), but another study found a competing conclusion, claiming markets are not an influence on the adoption of renewable technology (Alagappan et al., 2011). Importantly, however, both studies do not consider the market type of primary concern to study, seeking to explain instead the effectiveness of policies on the outcomes of renewable energy adoption. Also of note, both articles are dated with respect to understanding of climate action as progress in renewable energy policies have been made in the past ten years since the publication of both articles.

This thesis intends to directly address this tension in the literature through exploring answers to the research questions using an inductive research design. As a result of answering the research questions, this thesis will contribute to energy policy literature by furthering the understanding of the interaction (if any) between renewable energy policies and energy markets. The insight provided by this research is intended to help policy makers make more informed decisions about how policies perform when enacted for climate change action.

1.3 Practical Implications

Electricity, being essential to our society's operation, has a dominating hold on our way of life. This fundamental aspect of our modern society requires a closer analysis, of how we both generate and use electricity due in part to the scale of production required to keep our society operating. Current estimates put total electricity generation capacity (also known as installed capacity) at over 1000 gigawatts (GW) of power in the US and 145 GW in Canada (EIA, 2020a; Statistics Canada, 2019). For perspective, that is enough power for approximately one trillion household lightbulbs. As previously stated, 61% of electricity in the United States is still generated using coal and natural gas (EIA, 2020a). This equals 1.8 billion metric tonnes of CO_2, contributing over one sixth of the US total CO_2 emissions (EIA, 2020a). Additionally, the Biden administration has outlined ambitious targets to have 100% clean energy by 2035 (Muyskens & Eilperin, 2020). The magnitude of emissions, combined with the goals of carbon reduction in electricity generation, makes analysing the methods to move away from fossil fuels and towards sustainable generation of particular importance to reducing the effects of climate change.

The UN lists seventeen interconnected SDGs as a blueprint for a sustainable future. Two of those goals (SDG #7 and SDG #13) are directly related to analysing energy initiatives. SDG #7: Affordable and Clean Energy, suggests increasing the share of renewables as a direct path to achieving its targets, while SDG #13: Climate Action focuses on urgent action to combat climate change, indicating that the Paris Agreement, in direct response to climate change, is meant to reduce GHG emissions (United Nations, 2020). This research will provide policy makers with practical information on which policies to implement to fight climate change through the reduction of electricity-related emissions.

1.4 Thesis Overview

This thesis is organized as follows. In the following chapter, Chapter 2, I conduct a review of the energy policy and energy market research literature. In Chapter 3, I explicate the method that will be used to conduct this research. Chapter 4 contains the results of this exploration into market policy and market-based methods of climate related regulation. This thesis then closes with Chapter 5 discussing the implications of the findings as well as directions for future research.

Chapter 2: Literature Review

2.1 Chapter Intro

This chapter is intended to show the current literature relating to the positive and negative sustainability outcomes within regulated and restructured markets to better understand how policies are enacted in each market type. Regulated markets have less published research analysing effectiveness, but compelling research into both the positive and negative effects of this market type still exists. Restructured markets, in contrast, have a vast array of economics and policy literature focused on the operations of wholesale energy markets. With the increased focus comes increased scrutiny, as there is more work critical of the outcomes of liberalizing the operations of energy markets. Apart from this are the renewable energy policies that influence the electric utilities to adopt renewable generation technologies, including but not limited to, Feed-in Tariffs (FITs), carbon pricing, and Renewable Portfolio Standards (RPSs). The later sections of this literature review will cover the specific research on the effectiveness of these factors to modify organizations' behaviour and how each are implemented in regulated and restructured markets.

2.1.1 Existing Groundwork

This thesis is primarily concerned with exploring the contrasting viewpoints of two articles. The first article, *What drives renewable energy development*, reviews developed energy markets to determine what metrics play a statistically significant role in renewable investment (Alagappan et al., 2011). Using market structure, FITs, transmission planning, and transmission interconnection cost as potential drivers, Alagappan et al. (2011) analyse the effectiveness of each method by comparing each region's percentage of install capacity to suggest that market type does not play a significant role in influencing sustainability outcomes, but the use of FITs do. However, this article does not posit why market type does not impact the effectiveness of renewable energy policies such as FITs.

The second article, *State renewable energy electricity policies: an empirical evaluation of effectiveness*, explores the implementation of policies such as Renewable Portfolio Standards (RPS) and factors such as GDP and electricity use in a fixed effect variable decomposition regression to determine the impact of each factor on renewable investment and installed capacity share (Carley, 2009). One of the effects is deregulation (also called restructuring in other articles) and is found to have a contradicting result from Alagappan et al. (2011).

In searching for further literature that focuses on the effects of market restructuring on the moderation or promotion of emissions reductions or renewable energy investments only one other article analysed these interactions. In which, the author also laments the lack of research into the area of markets as a factor for renewable energy development (Baldwin & Tang, 2021). The conclusions from Baldwin and Tang (2021) include the same tension between Carley (2009) and Alagappan et al. (2011), in that markets are not a primary driver when compared to policies such as RPSs, but also lack investments in renewable generation without additional regulations.

The literature covered herein constructs the argument about why the market types are substantially different and complex, and thus why the understudied interactions of market type should be expected to affect the effectiveness of renewable energy polices.

2.2 Regulated Markets

2.2.1 Summary

Most energy markets exist as vertically integrated natural monopolies regulated directly by governments, known as a regulated market. Not all regulated markets have exactly the same characteristics, such as containing a single entity operating or the system operator being a public company. In general, markets have a sole government owned company operating over a significant time period (Prentis, 2015). Regardless of the ownership type of the companies, said companies are subject to direct regulation from government legislative bodies and/or a regulating body called a public utility commission (Dodds & Lesser, 1994; Melody, 2016). Regulated markets are the most common and the traditional method for the generation and distribution of electricity (Bradley, 2011; IER, 2014).

2.2.2 Negative Consequences of Regulated Markets

First and foremost, a commonly claimed consequence of regulated markets is that they are inefficient since the need for innovation is hampered by a lack of competition and responsiveness (Csereklyei & Stern, 2018; Delmas, Russo, & Montes-Sancho, 2007; Shao, Hu, Cao, Yang, & Guan, 2020). This is a fair criticism; if incentives do not exist or are not introduced for market responsiveness then those markets can be considered inefficient. Compelling trends in research show that monopoly markets can exhibit over-capacity in their installed generation, which is probably the most tangible form of inefficiency (Gencer, Larsen, & van Ackere, 2020). Keppler (2017) and Melody (2016) would both argue that public utility commissions (PUC) exist as a way to push for innovation and prevent stagnation in regulated markets. By using the institutional powers of a PUC, regulated markets can induce and subsidise desired change or can institute barriers and punish undesired behaviours to coerce or incentivise actions of utilities under the jurisdiction of said PUC (Dodds & Lesser, 1994; Keppler, 2017; Melody, 2016). However, if incentives are not present, this can lead to reduced investment in energy or an increase in costs associated with a lack of efficient business practices (Keppler, 2017; Melody, 2016). The previously mentioned authors, in conjunction with Mukhopadhyay and Hastak (2016), argue that PUCs play a vital role in creating the incentives that promote innovation and efficiency in energy markets, which implies the contrapositive; a lack of PUC intervention can lead to a market of stagnation.

On the topic of PUCs and regulation, a problem exists when the regulatory authority of a PUC is superseded by government. A primary and valid concern is when governments supersede the independence of the regulating PUC and use electrical monopoly utilities as political tools (G. Holburn et al., 2010; G. L. F. Holburn, 2012). The reliance of traditional regulated markets on a PUC for effective operation means that the effects of government intervention can be more pronounced than in competitive markets, primarily because of the legislative power of the government and the PUC over corporations. This is the idea of regulatory risk, and the contextual factors make Canadian markets more susceptible to it (G. L. F. Holburn, 2012). Restructured markets, with many utility companies, are more insulated from regulatory risk and from being used as political tools. Interventions such as rate caps can interfere with the cost of recovery for a monopoly entity if the cap is set below the cost of service. This will mean that the companies affected will bear unreasonable financial burdens, often leading to cost cutting or accruing large amounts of debt (McCandless, 2016). A clear example of government intervention leading to inefficiency and negative consequences is the case of BCHydro under the provincial Liberal government. In an effort to maintain public favour by keeping rates low, the British Columbia Utilities Commission (BCUC) was legislated to prevent BCHydro from increasing rates, with any shortfall in revenue being placed in a debt deferment account, against normal accounting standards (McCandless, 2016). As a result, BCHydro was unable to recover costs and the deferment account grew during the years that the legislation was in place. (McCandless, 2016). By the time a new government was elected and removed the obstructive legislation, the debt deferment account amassed a substantial balance of 5.5 billion dollars, which required the new the government to use the tax base to cover 1.1 billion dollars to prevent a massive increase in the price of electricity (Government of British Columbia, 2019; Meissner, 2019).

On regulatory intervention, many authors argue that intervention in markets can hide vital market signals and impede market performance. Most notably, Simshauser (2014b) argues that regulatory mechanisms such as price caps and policy decision are at the heart of market failure (Simshauser, 2014a). In his paper *When does Electricity Price Cap Regulation Become Distortionary?* Simshauser (2014b) states that regulators are incapable of estimating fair market prices for price caps. That is to say that regulators cannot know fair market price better than a fair competitive market. Thus, introduced regulation will likely bring along some form of market failure (Simshauser, 2014a, 2014b).

A final, powerful claim against the use of regulated markets is self-sabotaging behaviours. If a firm is compensated based on the cost of service, there may not be incentives to reduce costs, or even times when a firm is incentivised to increase costs resulting in increased compensation (Brown & Sappington, 2021; Sappington & Weisman, 2021). The articles by Sappington and Weisman (2005) and Brown and Sappington (2021) establish that some vertically integrated firms, such as those found in traditional regulated markets, can self-sabotage upstream production to purposefully hurt downstream competitors, and this is especially problematic when products cannot be differentiated; such is the case with electricity. A prominent example is found in the article by Daniel, Sattler, Massie, and Jacobs (2020) that shows that regulated markets that trade with restructured markets are susceptible to this form of self-sabotage due to regulatory effects. This example is explained as such: Regulated utilities are compensated based on cost of service, so incurred costs can be passed along to rate payers, whereas wholesale markets are compensated at marginal cost. This disparity allows for coal plants in regulated markets to be 'self-committed' and turn on generation out of merit order.

This means that coal can jump the line and any costs incurred from selling this electricity below marginal cost are covered by the cost-of-service regulation. Any Regional Transmission Organization (RTO) that trades with regions are susceptible to this, but the Midcontinent Independent System Operator (MISO) region is particularly noted as experiencing this form of self-sabotage (Daniel et al., 2020). So, while this is a negative thing in general because there is a mechanism for regulated utilities to interfere in competitive markets to the detriment of other firms, from an environmental impact perspective, this is particularly bad due to the unnecessary use of coal generation.

2.2.3 Research Refuting the Negative Consequences of Regulated Markets

The above negative consequences seem to indicate that regulated markets are at a disadvantage to respond to the climate crisis due to the effects described above, such as self-sabotage, or a lack of responsiveness (Daniel et al., 2020; Shao et al., 2020). However, policy mechanisms do exist to mitigate undesirable side-effects or to amplify positive environmental outcomes of regulated markets.

One such mechanism is Performance-Based Regulation (PBR). Performance Based Regulation is a paradigm shift away from the traditional cost of service model that has existed in the monopoly regulated market (Sappington & Weisman, 2021). PBR seeks to tie utility compensation to benchmarks rather than a flat compensation on costs in order to spur an incentive for increased operating efficiency (Sappington & Weisman, 2021). When properly implemented, Sappington and Weisman (2021) would argue that by using external industry benchmarks along with other configuration options for PBR, a utility that outperforms the benchmark by finding a previously undiscovered efficiency can then receive compensation where previously none existed. PBR has clear benefits, but complexity and industry pushback have resulted in slow adoption (Sappington & Weisman, 2021). BC Hydro, for example, opposes the implementation of PBR, using the excuse that “BC Hydro does not have a mandate to maximize profits, which can dull the additional “carrot” incentive that PBR attempts to provide” (BC Hydro, 2019, p. 1080). Whether this is legitimate concern about the efficacy of PBR in publicly owned utilities, or a company justifying a culture of compensated stagnation, is left up to the reader.

Countering the idea that free markets are more efficient and effective, many articles indicate that restructured markets fail to perform at the level of regulated markets. In the article by Frame, Hannon, Bell, and McArthur (2018), using the authors definition of innovation, restructured markets are found to be under suggested targets. In tandem, research and development (R&D) spending in restructured markets is about 18% lower than before restructuring (Dooley, 1998). Concurrently, as with R&D spending, so too is reliability spending under desired targets. Prentis (2014) notes that deregulated markets are not meeting the Federal Energy Regulatory Commission (FERC) required targets for reliability investments. An example of the consequences of an under-reliable grid is the 2003 North-East Blackout, and more recently, the 2021 Texas ERCOT blackout (Stevens, 2021; Van Doren & Taylor, 2004). These articles signal underperformance in deregulated markets, calling into question the established belief that free markets result in efficiency and innovation (Dooley, 1998; Prentis, 2014; Van Doren & Taylor, 2004). One explanation for these results comes from critics of Agency Theory, who explain that a focus on shareholder profits and value tends to incentivise cost cutting to realize short term gains, which comes at the expense of long-term investments

(Bower & Paine, 2017). Therefore, it could be argued the perceived ‘bloat’ of a regulated entity is utilities spending in necessary areas for reliability and R&D in a dictated fashion, and when given the chance, utilities will cut vital investment areas to favour a bottom line (Prentis, 2014, 2015).

Some research also indicates that regulated markets have a stronger ability to respond to consumer demands. Fremeth, Holburn, and Spiller (2014) find that the strength of a PUC in regulated markets can have extra-societal benefits outside of keeping energy costs low. The article indicates that PUCs allow for amplified consumer advocacy leading to and lower residential rates to the amount of 7.9 million USD and a consequential loss of profits for utilities (Fremeth et al., 2014). It can then be argued that increased consumer advocacy supports the idea that regulated markets have the ability to externalize concepts of legitimacy. That is to say that implementing a legal framework for consumer advocacy transfers institutional power from governments to the consumer advocates. Utilities regard these stakeholders as having higher actual or perceived power, and this leads to increased regulatory compliancy and corporate citizenship. A concrete example of this is increased climate disclosures (Kraft, 2017). When analysing the effectiveness of frameworks that promote carbon reduction, increased climate disclosures and more regulatory compliance align with this goal, and the takeaway from the arguments listed in this section indicate that regulated markets have tools to combat the climate crisis.

In summation, it is known how the factors of regulated markets, such as organizational inertia and regulatory intervention, affect the adoption of renewable energy technology for generation (Kim, 2013; Simshauser, 2014a). It is, however, unknown how these factors moderate the effectiveness of renewable technology promoting policies.

2.3 Restructured Markets

2.3.1 Summary

Some energy markets have seen forms of deregulation that changed the structure of said market. These markets are most commonly referred to as restructured markets, but are also known as deregulated markets (EIA, 2020a; Prentis, 2015). These markets were restructured to allow for electric generators to compete separately to sell electricity to the grid, which a grid operator will then transmit and distribute to consumers. The rationale for a government to liberalize and reduce regulations on electric generators is that it will incentivise competition to lower costs. While this is a commonly accepted explanation, an additional reason for restructuring energy markets is that it facilitates trade (Billette de Villemeur & Pineau, 2010, 2012). Regions fraught with high electricity prices have an incentive to lower costs, and one method of doing so is to purchase electricity from regions where electricity is cheaper. Facilitate the trade of electricity from low cost to high cost regions requires regulated bilateral trade agreements, as stipulated by FERC (FERC, 2020). The alternative is a liberalized electricity market where electricity can be bought and sold on a wholesale market. This comes combined with the ‘bonus’ of competitive markets also potentially reducing prices (Cicala, 2017).

2.3.2 Negative Consequences of Restructured Markets

Restructured Markets are not without issues and unintended side effects. Research clearly shows that restructured markets are often fraught with market failures. Both Prentis (2015) and Simshauser (2014a); (2014b) come to the same conclusion that in their restructured markets, the US and Australia respectively, the regions had higher costs of electricity. Other authors also support the claim that restructured regions have higher prevailing costs (Billette de Villemeur & Pineau, 2010). It would seem that the aim of restructuring to reduce costs to levels equal to that of other regions has been unsuccessful.

Returning to the topic of trade: restructured markets do succeed at removing barriers to inter-regional trade (trade across state or provincial borders). Research shows, however, that trade between regions, especially trade between market types, has unintended consequences (Billette de Villemeur & Pineau, 2010, 2012). First, trade from a regulated region to a restructured region will benefit the regulated jurisdiction due to the difference in average cost vs marginal cost of producing energy (Billette de Villemeur & Pineau, 2012). Regulated regions with lower electricity costs are compensated at average cost, while the market price in restructured regions is set at marginal cost, which is usually higher. This will incentivise trade across the border in one direction, as intended, but becomes problematic in two respects. First, trade is limited by the proportion of the load that can be shed in the case of transmission failure (AESO, 2013). For example, if the intertie between the regions were to give out, then the importer could sustain major damage as the local grid demand could not be met by local grid supply. Second, increased trade from regulated markets to restructured markets increases consumption in the importing region. This will have environmental effects as increased consumption leads to a wealth transfer and increased pollution, among other environmental effects (Billette de Villemeur & Pineau, 2010). So, while the increase in trade may be economically beneficial in the short-term, if the goal is to reduce carbon emissions, then increased trade is not a positive effect. The wealth transfer involved means that the environmental effects of increased trade and lower energy cost cannot be offset by the increase to economic activity, as wealth that once could be used to offset carbon emissions is transferred out of a region.

Restructured markets also appear to have a higher sensitivity to generation methods that have short Return on Investment (ROI) periods as well as low generation costs. A study conducted by Csereklyei and Stern (2018) found that deregulated US states had a higher preference for investment in natural gas generation that coincided with periods of low natural gas prices. This finding is replicated in the British energy market, where low natural gas prices also resulted in increased natural gas generation (Safarzynska & van den Bergh, 2011). It can be inferred that this sensitivity is caused by a need to satisfy returns for investors in the private competing companies. Csereklyei and Stern (2018) also inferred that companies in deregulated markets are more responsive to market conditions, stemming from the need to return a profit. This results in strong pressures to invest in natural gas technologies. If the goal is to move away from coal as a generation backbone, restructured markets are succeeding, but if the goal is to go to zero emissions generation, then restructured markets are failing to achieve this.

Delmas et al. (2007) add context to the topic of how restructured markets are locked into carbon generation. Firms that were privatised incumbents, i.e., they were once government owned but got privatised at the time of restructuring, exhibit path-dependence, a form of organizational inertia. That is, these incumbents are burdened by their existing resources and are unable to divest from coal generation into other forms such as natural gas and must remain reliant on coal to remain in the competitive space. This might explain why coal generation still exists even in markets that have been restructured.

Delmas et al. (2007) also support the idea that deregulated markets promote responsiveness, with their conclusions hypothesising that differentiation in generation, such as investment in green technology, is a direct result of attempts for strategic differentiation. However, these findings are directly refuted by Kim (2013), who states that the data used to conclude that restructured markets promote investment in renewables as differentiation is hardly robust. Kim (2013) further reinforces the idea that firms exhibit path-dependence. Firms with more carbon-based generation are less likely to invest in renewables, and it falls on non-incumbent firms, the independent power producers (IPPs), to invest in renewables within restructured markets.

Electricity is an essential service, and as a consequence, many governments place price caps on electricity to protect low-income households and to prevent large spikes in demand from drastically impacting electricity price. The results of the caps can vary (Simshauser, 2014b), but one result is supply shortage as companies refuse to sell electricity which leads to a blackout, as was the case in California during the early 2000s (Puller, 2007). California had other issues present as well. Market power can be at an imbalance if markets are not implemented correctly (Singh & Chauhan, 2011; Van Doren & Taylor, 2004). This market power can prevail when one firm controls too much generation and can control the market price, or if firms collude on price. Liberalized markets are meant to form Cournot competition, where homogeneous products are sold by non-cooperating firms. Each firm is theoretically supposed to choose a production amount based off the current price in secret. Then all the firms post these offers simultaneously, and profit is awarded starting with the lowest cost firm and moving on upward in price until demand is met. Cooperation between firms in a Cournot competition leads to a market failure and is best seen with the largest energy cartel, OPEC, which sells oil and petroleum and can determine the price of oil globally, usually choosing to restrict supply to keep prices artificially high.

As a result of perceived dissatisfaction from the effects above, governments will often intervene under the assumption of correcting a market failure or protecting consumers from high prices (Keppler, 2017; Prentis, 2015; Puller, 2007; Simshauser, 2014a, 2014b). The perceived needs for government intervention may differ, but a common reason is that liberalized energy markets in an Energy-only configuration can have an artificially limited supply at times of low demand. To restate, firms wish to sell electricity at a high price and will withhold generation until the cost of production can be met by the cost of sale, this will lead to an underutilization of installed capacity. This means that in times when the market goes from low price to high price, a delay in available generation will exist as the price will need to increase first before generators are willing to ramp up dormant plants. This situation is marked by low supply and extreme prices as any firm selling to match the required demand can ask of the market any price under threat of a black out (Hurlbut, Rogas, & Oren, 2004). This problem is exacerbated by the existence of the market clearing price. If a firm uses ‘hockey stick pricing’ (pricing all but the last 1% of generation reasonably) then the market clearing price will be an order of magnitude more than the sum of all the prices sold (Hurlbut et al., 2004). Equivalent to striking a lottery, if firms can manage to charge a desperate market an extreme price, then extreme profit results. This hockey stick pricing occurred during the 2021 Texas ERCOT outage, with one energy CEO quoted as saying, the week was “like hitting the jackpot” (Domonoske, 2021). This is a problem that exists because energy-only markets tend to have less supply available to meet peak demand, and when supply runs out, logically competition fails (Brown, 2018b; Hurlbut et al., 2004). There exists concurring research that shows restructured markets can have lower investment in generation (Brown, 2018a; Dooley, 1998), fail to meet required grid investment levels (Prentis, 2014), and have lower than potential innovation (Frame et al., 2018).

2.3.3 Research Refuting the Negative Consequences of Restructuring

As with the section covering the negative effects of regulated markets, the research above points to lots of actual and potential negative side effects of restructured markets. The paper *Imperfect Markets versus Imperfect Regulation* by Cicala (2017) explains that the mere existence of market failure is not justification for dismantling the entire system if outcomes are still desirable. It is a fair argument to make that the gross improvement of specified goals should justify a certain number of imperfect trade-offs. As described by Cicala (2017), the response to market failure should not be an immediate cancellation of the welfare benefits gained from free competitive markets. Extending the argument to this analysis, the existence of market failure and possibility of short-term increase of CO_2 emissions in restructured markets should not negate positive benefits from the investment in renewable generation mixed with the potential for future reductions in emissions.

Seeking to address this argument brings forth the literature which sheds light on the potential for restructured markets to incentivise renewable energy generation (Ben-Moshe & Rubin, 2015; Can Sener, 2017; Kim, 2013; Rivard & Yatchew, 2016; Wagner, 2016; Woo et al., 2014). Though there is literature that argues against this point (Kim, 2013), the favourable literature is quite clear that restructured markets can use policy mechanisms that incentivise investment in wind energy (Can Sener, 2017; Woo et al., 2014). Rivard and Yatchew (2016) show that using FITs, Ontario's restructured market completely eliminated coal and tripled the installed capacity for wind, and this agrees with the findings in Wagner (2016); which also found that FITs promote wind investment. Ben-Moshe and Rubin (2015) found that wind energy in a restructured market can lower wholesale cost and mitigate the market power of generators, both of which are positive outcomes for restructured markets. Findings in the above-mentioned articles provide evidence that restructured markets can promote wind energy investment, using FITs as a policy mechanism, and that there are unique benefits of wind energy in such markets. In addition, while not an optimal outcome, natural gas technologies have contributed to a significant drop in CO_2 output when compared to coal (EIA, 2020a; Pehl et al., 2017). The research indicates that restructured markets excel at increasing natural gas investment (Csereklyei & Stern, 2018; Delmas et al., 2007; Kim, 2013; Safarzynska & van den Bergh, 2011; Woo et al., 2014).

As discussed in the previous section, 2.3.2 Negative Consequences of Restructured Markets, restructured markets can exhibit security of supply issues during high demand: "In an energy-only market, electricity generators are compensated for the energy services they provide in hourly markets. This scarcity pricing is the primary instrument to motivate capacity investment in order to facilitate competition in hourly energy markets and ensure a reliable supply of electricity" (Hogan, 2005 as cited in Brown, 2018a, p.2). If prices are kept too low to meet fluctuating demand, or other externalities occur like a fluctuating oil and gas price, then shortages and extreme price spikes can occur (Hurlbut et al., 2004). Investors also face uncertainty in markets when zero marginal cost renewable generation can threaten capacity investments (Brown, 2018a). This can be mitigated by a strategy called a Capacity market. Capacity markets help ensure a reliable supply of electricity by ensuring firms are compensated for providing potential generation to the grid rather than actual generation sold. Capacity markets can also be used as a policy mechanism to motivate carbon reduction strategies. This outcome will be discussed more at the end of this chapter. Primarily, Capacity markets ensure that needed investment in generation capacity is met by compensating generators for the energy they could supply using capacity payment contracts (Arango & Larsen, 2011; Brown, 2018a, 2018b; Keppler, 2017). Capacity markets can also be used as a policy mechanism to increase investment in green generation by compensating desired generation preferentially over fossil fuel generation.

In summary, restructured markets can have negative effects from firms exercising market power over the essential utility of electricity and increasing investment in fossil fuel generation. However, these effects can be mitigated using policy mechanisms. Restructured markets can also use market forces to respond to immediate problems successfully, such as removing coal generation in favour of better alternatives. So, while it is understood how restructured markets affect the adoption of renewable energy technologies, it is unknown how the factors of restructured markets, such as market signals, interact with policies to promote the adoption of renewable energy technology. Therefore, it is unknown how restructured markets moderate renewable energy policies.

2.4 Policy Mechanisms That Influence Renewable Technology Adoption

The above literature should be compelling evidence that the two market types are substantially different and complex and require different regulations and policies that prevent different negative effects. Therefore, it is reasonable to extend the understanding that distinct market types require distinct policies, and specifically distinct renewable energy policies. With the above understanding that the two market types are substantially different, it is time to determine what policy knobs and levers are available to each market that affect renewable technology adoption. Because of the above variances, the policies listed herein are suggested to have different abilities to affect the adoption of renewable energy technologies depending on the barriers imposed by the market type. The following section provides a brief explanation of each policy.

The first policy is Feed-in Tariffs (FITs). FITs are widely discussed in the energy policy literature because of the ease of implementation and expedience of success (Alagappan et al., 2011; Brown & Eckert, 2018; Haas et al., 2011; Ritzenhofen et al., 2016). A FIT is a form of price-driven regulation on generation (Haas et al., 2011). It is a guaranteed compensation amount for electricity generated. In practice, this means that firms will receive a monetary incentive for provide renewable energy to the grid even if the cost of electricity is low, thus overcoming cost barriers to investment in renewables. The side-effect of FITs is that they are seen to shift the cost of renewable energy on to the rate payer as opposed to the tax base (Chaton &

Guillerminet, 2013; Haas et al., 2011; Rivard & Yatchew, 2016). FITs come in two variations as outlined by Brown and Eckert (2018): fixed FITs and premium FITs. Premium FITs are also referred to as market premia by Haas et al. (2011). Fixed FITs are compensation that is a fixed flat amount per unit generated, while premium FITs compensate a fixed amount on top of the current market price for electricity, or a premium on the market: a veritable market premia (Brown & Eckert, 2018; Haas et al., 2011; Wagner, 2016). FITs have been historically used due to the ease of implementation and consistent results (Haas et al., 2011). As previously stated, Rivard and Yatchew (2016) found that FITs, as Ontario's renewable energy policy, were important to Ontario's decarbonization. The differences between fixed and premium FITs are outlined in the article by Brown and Eckert (2018); premium FITs exacerbate existing market power exercises, while fixed FITs do not allow for a 'more valuable' renewable that is desired by a market to prevail. For markets with high competition and low market power issues, premium FITs allow market forces to promote more welfare enhancing and desirable renewables. A note on premium versus fixed FITs is that both policy options are available to restructured markets, but premium FITs are not available to traditional regulated markets because there is not a spot market (wholesale market) for electricity. Since traditional regulated markets operate, in general, on cost of service, any FIT is a fixed FIT. This distinction could prove instrumental in any differences exhibited by the different market types, especially considering the fact that little research looks specifically at the difference between fixed and premium FITs, and none of the research this thesis found compares across market types.

The second policy to be discussed are Renewable Portfolio Standards (RPSs). A Renewable Portfolio Standard is a form of quantity performance driven regulation (Haas et al., 2011). RPSs are policies used to dictate a minimum amount of renewable energy procurement for affected industries. For example, they may require electric suppliers to have an energy portfolio that contains a certain amount of renewable energy available to their customers (EIA, 2019). The specific implementations can differ, but in general RPSs stipulate that a certain percentage of electricity must be procured from a renewable source. This is often tracked using a tradeable certificate. For example, a wind farm that generates 1MW of electricity would receive a certificate proving they generated 1MW cleanly. The wind farm could hold on to the certificate to meet an RPS requirement or sell the certificate on to a different business which then could use the certificate to meet their own RPS requirement. The logic is that new certificates are created by renewable companies which can sell the certificates as an additional incentive; certificates then leave the commodity market when they are counted for an RPS (EIA, 2019). It is important to note that the certificates are separate from the actual energy being traded. The efficacy of RPSs are considered in Haas et al. (2011) and Ritzenhofen et al. (2016). Both find that RPSs are correlated with higher renewables adoption. Ritzenhofen et al. (2016) in particular mentions that RPSs, due to the complexity of implementation, have higher costs to implement but have robust and continuous results for improving renewable adoption.

The previous two strategies are considered direct regulatory polices, with the opposite being indirect polices such as tax charges and credits (Haas et al., 2011) or emission trading schemes (ETS). These indirect policies have wider implications for policies as a whole because carbon taxes affect other institutional sectors, such as oil and gas. As such, indirect regulatory strategies have different implications and justifications for implementation. The effect on the electricity sector has been noted by Palmer and Burtraw (2005), Goulder and Schein (2013) and

Chaton and Guillerminet (2013). First, carbon pricing is usually a tax placed on activities that emit CO_2, thus making polluting more costly. Brown, Eckert, and Eckert (2018) find that carbon pricing does lead to fuel switching away from coal generation because the carbon price reduced the profitability of coal as a fuel. An ETS, also called Cap-and-Trade, seeks to limit emissions output, where similar to an RPS that trades Renewable Energy Certificates (REC), ETSs trade carbon offsets as a way to compensate against emissions. Tax credits are seen as more flexible and interoperable with existing regulations but can also be interpreted as unfavourable to those affected (Goulder & Schein, 2013). An ETS, on the other hand, can be beneficial when compared to an RPS because it can be more cost-effective and used in wider contexts (Palmer & Burtraw, 2005). Both carbon taxes and Emissions Trading Schemes are better than FITs, because FITs preferentially treat new market entrants, and both can be beneficial at reducing carbon emissions (Chaton & Guillerminet, 2013).

Chapter 3: Methods

This thesis project aims to explore how the market structure of energy markets interacts with sustainable policies implemented by governments and regulators. To this end, the present study examined the impacts of different policy factors and mechanisms on carbon emissions as moderated by market type. This analysis was conducted through three statistical analyses. First, this study constructed a regression model to establish the strength of the relationship between CO_2 emissions and generation technology use. Second, since the data is time series data, it was analysed using a repeated measure analysis of variance (ANOVA) to develop an understanding of the relationship of the independent variables to CO_2 emissions and generation technology across the multiple years of data. And lastly, a Multivariate Analysis of Variance (MANOVA) was used to examine the interconnected relationship of regulated and restructured markets with the use of renewable energy policies, and how each relation affects emissions and generation technology. Each step included additional controls described in each subsection further into this chapter.

The regions analysed are the energy markets in Canada and the United States, sub-divided into market regions based on state and provincial borders. Regions are broken up along these geographical boundaries because the regulatory authority of energy market types, whether said market is restructured or not, exists at the state and provincial level. The data was collected from government data repositories; examples include, but are not limited to, the Energy Information Administration's (EIA) Energy-Related CO_2 Emissions data set (EIA, 2020c) and Canada's official greenhouse gas inventory (Environment and Climate Change Canada, 2020). The data was analysed using the programming and scripting language Python implementing the Scipy.stats software module, as well as IBM SPSS.

3.1 Data Collection

The data for this study has been collected primarily from two sources. Canadian data was obtained via open.canada.ca. Greenhouse Gas emissions data was assembled by Environment and Climate Change Canada (Environment and Climate Change Canada, 2020). Energy supply by province was assembled by Canada's Energy Regulator via their 2019 *Canada's Energy Future* report (Canada Energy Regulator, 2019). All this data has been obtained and used via the Open Government Licence.

American data was obtained from the U.S Energy Information Administration provided to the public domain for use. Emissions data contained emissions by each generation type by state and was found on the EIA website (EIA, 2020c). Net generation by state was also obtained via the EIA website obtained from their annual generation report (EIA, 2020b).

3.2 Variables

3.2.1 Dependent Variables

This thesis examined two dependent variables to analyse the effect of the independent variables: Generation technology used and emissions in CO_2 equivalent emissions from electricity production. The use of generation technology is to test across the separate market regions to find a link between current technologies employed and current policy factors. Emissions for electrical generation was analysed because the focus of this thesis is combatting climate change through reducing emissions related to the generation of electricity, and as such, the analysis of emissions contextualizes when changes in technology do not equate to changes in emissions.

3.2.1.1 Generation technology variables

Generation technology (e.g., solar, wind, natural gas) per megawatt hour (MWh) is a proxy for determining adoption by firms in each type of renewable technology, as other research has done (Rivard & Yatchew, 2016). This study, in analysing multiple markets of various size uses not only the actual technology use in MWh but also percentage of total generation. Using the percentage of total generation in each region allows for the study of larger markets with more generation capacity against smaller markets, while actual generation in MWh is used to show actual adoption in each technology. The data is constructed based on the composite of installed capacity of technologies used and employed capacity of technologies used and was obtained from government and firm websites of the relevant regions (BC Hydro, 2016; Canada Energy Regulator, 2016; US Department of Energy, 2016). The differences are determined by the different reporting standards between the US and Canada. The earliest data for Canada is 2005 and continues until 2019. The US data was downsized to match this timeframe. Some of the analysis used the percent change in technology from 2005 until 2019 to examine which regions switched from one technology to another. The technologies are reported as Wind, Nuclear, Solar, Petroleum, Natural Gas, "Hydro / Wave / Tidal", Coal & Coke, and "Biomass / Geothermal / Other". Most are straight forward, Hydro / Wave / Tidal refers to any water-based generation such as hydroelectric dams or pumped hydro, and Biomass / Geothermal / Other is the catch-all category for any technology that does not fit into any other.

Please refer to the **Error! Reference source not found.** for specific definitions. For the purposes of this research, hydroelectric, wind and solar are considered renewable generation technologies, whereas coal and natural gas are not.

3.2.1.2 Emissions variable

Emissions per region is reported in Megatonnes (Mt) of equivalent CO2 emissions. The time frame is from 1990 until 2017 for the US, and 1990 until 2018 in Canada. The Canadian data was trimmed to match the US data. The use of emissions as an outcome is to illustrate how the policies and market type interact first through generation technology choice and then the generation technology affects emissions. This two-step relation means that not every increase in renewables reduces emissions. This is shown in more detail in Chapter 4: Results

3.2.2 Independent Variables

The independent variables for this thesis consist of six discrete categorical variables. Alagappan et al. (2011) reviews renewable energy development in 14 markets to assess the impact of market type and the use of Feed-in Tariffs on renewable technology adoption. Using Alagappan et al. (2011) as starting point, this analysis will have the first variable as market type (regulated and restructured). As an extension to Alagappan et al. (2011), this analysis includes Feed-in Tariffs (FITs), Renewable Portfolio Standards (RPSs), and Emission Trading Schemes (ETSs). Additionally, this thesis analyses the impact of the various combinations of these policies on the adoption of renewable generation technology.

3.2.2.1 Market type

Market type is split into the two categories of regulated and restructured markets as defined in earlier sections of this thesis. States and provinces that previously removed the traditional monopoly structure and implemented some form of wholesale or retail competition fall into the restructured category. This information is obtained from Prentis (2015).

3.2.2.2 Renewable portfolio standards

RPSs are a policy mechanism shown to be effective at influencing firm behaviour to promote investment in renewables (Ritzenhofen et al., 2016). To measure the effect on the dependent variables, this is included as a categorical variable (implemented or not implemented). This information was collected from either the relevant provincial legislation for Canadian provinces, or from the EIA for states in the US. The use of RPSs were also broken down into four subcategories consistent with EIA reporting (EIA, 2019). First is a traditional RPS, next is an Alternative Energy Portfolio Standard (APS), which is less strict by allowing for some carbon generation sources to be included (EIA, 2019; R. H. Williams, 2014). Third is a Clean Energy Standard (CES), which is more restrictive than an RPS (Carley, 2012; EIA, 2019). And last is an RPS Goal, which is a voluntary measure, not a mandatory one (EIA, 2019). For each analysis, RPS was analysed first as the aggregate group “Any RPS”, and then analysed as the four subtypes.

3.2.2.3 Feed-in tariffs

FITs are another promising policy mechanism for increasing investment in and adoption of renewable generation (Alagappan et al., 2011; Brown & Eckert, 2018; Ritzenhofen et al., 2016). Brown and Eckert (2018) identify a difference in the efficacy of premium rate and fixed rate FITs. Ideally, this would have resulted in FITs being separated into three categories (not employed, premium FITs, and fixed FITs). However, due to the lack of data availability within North America about the use of premium FITs, this study was not able to differentiate between premium and fixed rate FITs.

3.2.2.4 Indirect polices

As discussed in Chapter 3: Methods, both tax credits and emission trading schemes (ETS) have been shown to have a positive effect on reducing CO_2 emissions (Goulder & Schein, 2013; Palmer & Burtraw, 2005). This study builds on the work of Alagappan et al. (2011) by including these relevant policy variables into its analysis. A dummy variable was created for the variable use of tax credits (i.e., 1=yes, 0=no) and for use of ETS (i.e., 1=yes and 0=no). The inclusion of these two variables is also necessary to increase the robustness of the analysis by preventing potential confounding variables from affecting the results.

3.2.3 Control Variables

To control for potential confounding effects, there are a number of control variables added to the model to attempt to limit any confounding effects in the data.

Certain regions may have distinct resource endowments which favour certain renewable technologies, such as coastal regions having access to develop offshore wind. To control for this, a control group was used that separates states and provinces into one of three regions; Coastal, such that the region is connected to ocean. Mountainous, if that region is connected to either the Cordilleras (Rocky Mountains) or the Appalachian ranges. Lastly, Plains, for the remaining lowlands and great plains in central Canada and the US. This is informed from the geographical regions as described in the Encyclopedia Britannica (Schaetzl, Hoffman, Watson, & Zelinsky, 2021).

Since the EIA provides data and categorization for RPSs into four subtypes (EIA, 2019); as mentioned above in Section 3.2.2.2 Renewable portfolio standards, RPSs were separated into four subcategories. This was done to control for different efficacy levels among the four types.

The large sample size of states and provinces will be combining regions of varying economic size. Therefore, GDP was analysed during the regression analysis for any relation to technology choice or technology change. This was to determine if GDP explains technology shifts as a more substantial factor than policy choice. It would not be unreasonable to believe that large economies have excess capital to spend on new investments in generation technology, so determining the strength of the relationship between GDP and technology choice is important to control for such an extraneous effect outside the primary analysis.

Lastly, to control for the varying sizes of each region, population of each region was included as a control variable. In each step of the analysis, percentage of total generation was used as the base for the generation technology dependent variables. The data used was corrected on a per capita basis. Population data was obtained directly from census data (Statistics Canada, 2021; United States Census Bureau, 2021).

3.2.4 Data Dictionary

Table 0

Data Dictionary

Variable title	Variable type	data type	statistical test	RQ
CO_2 Emissions	Dependent	continuous	All	Q1a
Generation Technology	Dependent	categorical	All	Q1b
Market type	manipulated	categorical	RP Anova, Manova	Q2
renewable policy	manipulated	categorical	RP Anova, Manova	Q1
RPS Subtype	control	categorical	RP Anova, Manova	
geographic region	control	categorical	RP Anova, Manova	
GDP per capita	control	continuous	OLS	
Country	control	categorical	All	
Population	control	continuous	All	

3.3 Data Analysis

Data analysis was performed using the scripting and programming language Python and the software suite SPSS. The data tables will be obtained from the data repositories previously mentioned and analysed using primarily SPSS, but Python implementing the SciPy. Stats module was also used where indicated. The data was first categorized and described via descriptive statistics. Following this was the statistical analysis using a General Linear Model, including the regression, repeated measure ANOVA and MANOVA to analyse the effects of the policy and market factors.

3.3.1 Data Preparation

After data was collected from the respective data repositories, the emissions data and technology data were first normalized using Microsoft Excel, where each column name was unified between the US and Canada data. Next, the cases outside the chosen ranges for year and relevance were dropped from the data tables. This included limiting generation in MWh to just generation from utilities, excluding singular generators such as mining companies. Generation technology was also unified within the US data to match the Canada data, for example hydro generation was aggregated with pumped hydro. Where necessary, the values were then corrected based off of region population to create the per capita measure. Then, the data was then loaded into Python and the tables were concatenated between the regions.

Concurrently, all the categorical variables were loaded into an Excel table. This was then joined to the emissions and technology data frames using relational algebra and data managing module Pandas in Python. All the Python scripts used can be found in Appendix 1: Python Scripts.

3.3.2 Regression

The regression consisted of two models. The first model tested the relationship of each generation technology category to emissions. The second model tested the relationship of GDP in each region to the generation technology employed.

As previously mentioned, the first analysis conducted was a regression model to explore the links between emissions and generation technology and GDP and generation technology. First, regions were separated by country. Then, the regression model was created using, initially, the actual values for each technology in each year, with the outcome variable being emissions. Next, the same model was created except using the percentage of total generation, where the percentages were corrected based on population.

The second model was created using python to control for the relationship of GDP to each technology employed, both as actual generation and as percentage of total generation. An OLS regression was tested for each generation technology with any significant results indicating that the choice of that specific generation technology is significantly influenced by effects outside of policy decisions.

3.3.3 Repeated Measures ANOVA

The second analysis conducted was the repeated measure ANOVA to analyse the data as a time series from 1990 to 2018, exploring any links between policies and generation technologies. This was conducted in two parts. First, emissions were analysed year over year against the categorical variables. After emissions was analysed, the same procedure was conducted on each technology type, both as actual generation and percent generation, to determine which factors related to a choice in generation technology employed in the analysed regions.

3.3.4 MANOVA

The last step of the statistical analysis was the Multivariate ANOVA used to examine potential links between the policies and generation technology independent of time. First, emissions were analysed against the categorical variables in the base year 1990 and in the last year 2017. To analyse the combined effect of specific policy types in conjunction with restructuring, new dummy variables were constructed in SPSS and analysed. Concurrently, a T-test was conducted on emissions, using only regulated vs restructured in the year 2017 and country to control for difference between Canada and the US.

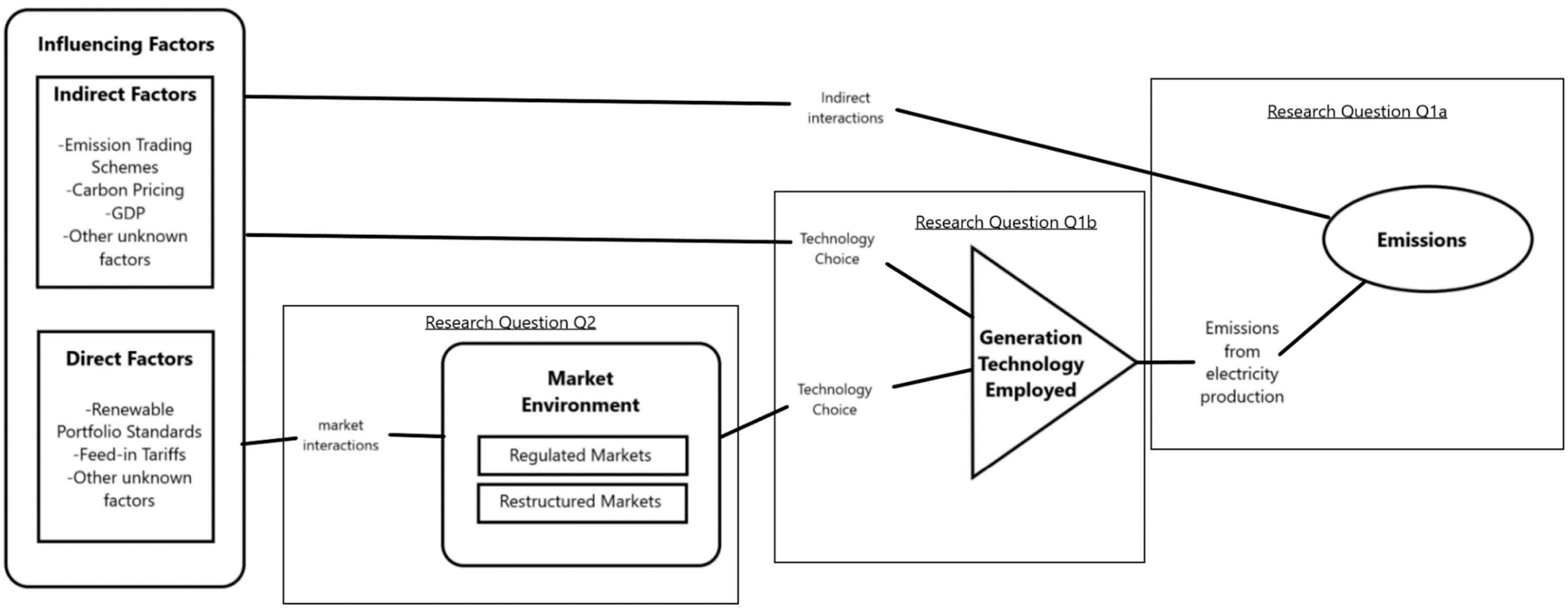
Next, technology actual and technology percentage were analysed against the categorical variables. All the same steps as above were replicated, including the dummy coding and the T-test. The chosen years were the base year of 2005, and the last year 2019.

Lastly, a key component of this study was to analyse the effect of policies and markets on technology changes. This is specifically targeting how policies and markets influence technology switching, or the change from one technology to another. To analyse this, the percentage change from 2005 until 2019 was calculated for each region and each technology. This was then analysed using the same steps described above. The results of the T-test in this case show the mean of the percentage change for regulated regions and restructured regions, allowing for a direct comparison of how each market type favoured certain technologies.

3.3.5 Diagram of Explored Interaction

Figure 1

Diagram of Explored Interactions in a Graphical Model



Chapter 4: Results

4.1 Descriptive Reporting

4.1.1 Independent Variable Reporting

Below in Figure 2 is a map of the restructured energy markets for the United States and Canada consistent with Prentis (2015). Restructured markets appear in yellow.

Figure 2

Map of Restructured Markets in North America

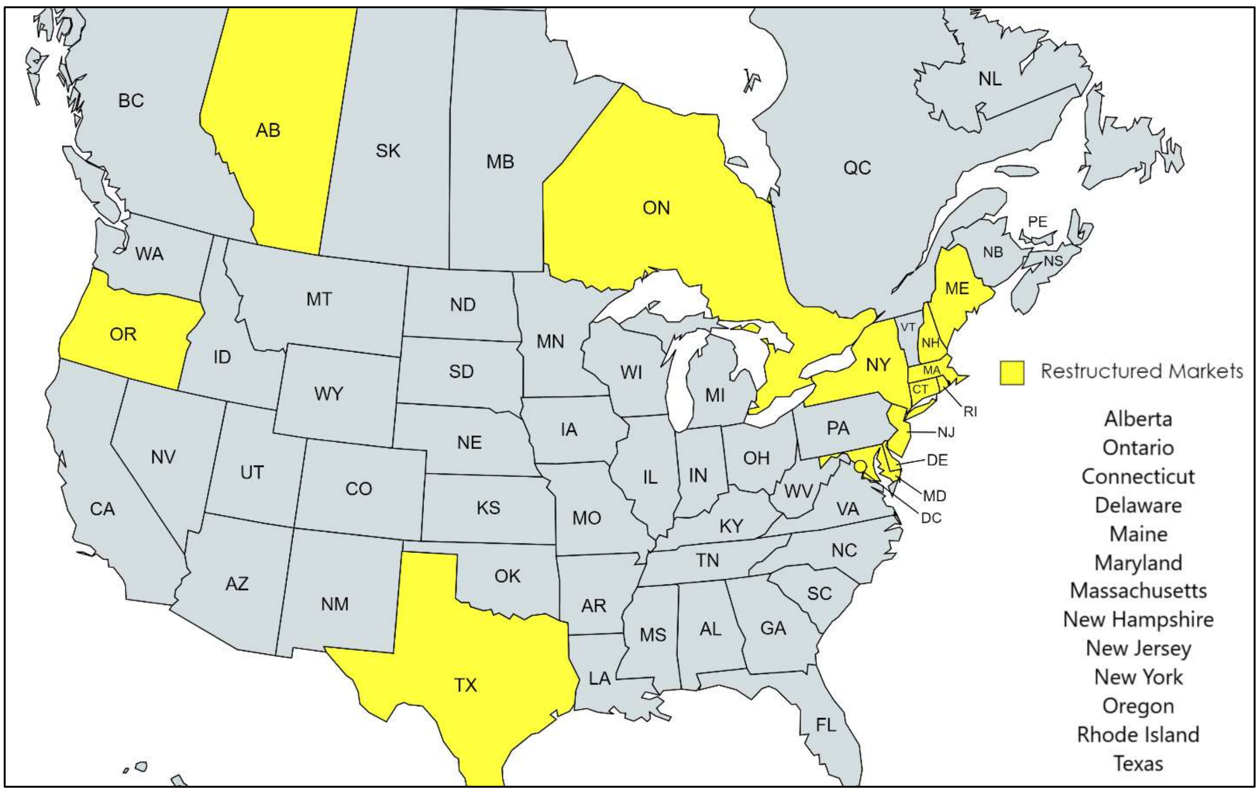


Table 1, 2, and 3 contain a full list of independent variable categorization. Table 1 shows a full list of regions employing an RPS as well as the RPS type employed. Table 2 contains a list of regions employing a FIT, again with the only Canadian province at the top and the six states below. Only two regions employed the use of carbon taxes prior to the 2018 federal Canadian carbon tax, those being British Columbia and Quebec. Table 3 contains the list of regions that are signed to either the Regional Greenhouse Gas Initiative (RGGI) or the Western Climate Initiative (WCI).

Table 1

Regions With Renewable Portfolio Standards Listed With Associated Subtype

Region Name	RPS Type	Region Name	RPS Type
Arizona	RPS	New Hampshire	RPS
California	CES	New Jersey	RPS
Colorado	RPS	New Mexico	CES
Connecticut	RPS	New York	CES
Delaware	RPS	North Carolina	RPS
Illinois	CES	North Dakota	RPS Goal
Iowa	RPS	Oklahoma	RPS Goal
Kansas	RPS Goal	Oregon	RPS
Maine	RPS	Rhode Island	RPS
Maryland	RPS	South Carolina	RPS Goal
Massachusetts	CES	South Dakota	RPS Goal
Michigan	RPS	Texas	RPS
Minnesota	RPS	Vermont	RPS
Missouri	RPS	Virginia	RPS Goal
Montana	RPS	Washington	CES
Nevada	CES	Wisconsin	RPS
British Columbia	RPS	New Brunswick	RPS
Nova Scotia	RPS	Prince Edward Island	RPS

Note: Abbreviations are Renewable Portfolio Standard (RPS) and Clean Energy Standard (CES)

Table 2

Regions With Feed-in Tariffs

Region Name
California
Maine
Oregon
Rhode Island
Vermont
Washington
Ontario

Table 3

Regions Employing an Emissions Trading Scheme Separated by Initiative

Regions in the RGGI	Regions in the WCI
Connecticut	Nova Scotia
Delaware	Quebec
Maine	California
Maryland	
Massachusetts	
New Hampshire	
New Jersey	
New York	
Vermont	
Virginia	

Note: Abbreviations are Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI)

4.1.2 Descriptive Statistics

This section presents a summary of the descriptive statistics of the various regions with respect to generation capacity, emissions and technology employed. Table 4 shows a break down of the regions with the most generation by each type of technology as a percentage of total generation. As shown in Table 4, West Virginia is the top region for coal, Rhode Island for natural gas, Louisiana for petroleum, Ontario for nuclear, Manitoba for hydro, California for solar, Prince Edward Island for wind, and Nevada for other types of generation. Table 4 also shows that some technologies are employed only to a marginal amount, such as Louisiana generating the most power from petroleum, which nonetheless only provides 4% of the state's electricity. Solar and Other type generation can both be considered marginal generation technologies under the same logic.

Canadian provinces appear to favour one specific technology over a more balanced mix (See Table 4). For hydroelectric generation, Washington state has the highest utilization of hydro generation in the US, yet only generates 69% of its generation this way, as compared to most Canadian provinces with hydro usage above 90%. Table 4 also shows that technologies such as petroleum, other typed generation (biomass and geothermal), and to some extent solar, are not widely employed in any meaningful amount. The exception is California and Nevada, both of which employ greater than 10% solar generation on their respective grids. The low percentage for "Other" type generation shows that there is not much focus on technologies that do not fit existing generation paradigms for renewable energy; there is no room for technologies that are not wind or solar. Even if new technologies like geothermal and biomass generation are innovative and sustainable, utilization and investment remain low. The low percentage of petroleum generation is likely explained by the fact that petroleum is mostly used in small and isolated grids, such as the northern Canadian territories, which are not connected to the wider North American grid.

The mean and the median values of each technology category are presented in Table 5. Table 5 further highlights how some technologies are only employed marginally; for example, Petroleum, Solar, Wind, and Other all have means well below 10% of total generation. When the information from Table 5 is combined with Table 4, it illustrates how some regions grossly outperform others. For example, Prince Edward Island generates 99% of its energy using wind technology, whereas the next runner up, Kansas, generates below 40% using wind. These results also demonstrate the low adoption of other technologies, such as solar, which only achieves a maximum implementation of 14% in California while its mean adoption is less than two percent.

Table 4

Summary of Top Five Regions by Technology as a Share of Total Energy Production in the Region in 2018

Coal		Natural Gas		Petroleum		Nuclear		Hydro		Solar		Wind		Other	
Region	%	Region	%	Region	%	Region	%	Region	%	Region	%	Region	%	Region	%
West Virginia	92	Rhode Island	94	Louisiana	4	Ontario	60	Manitoba	97	California	14	Prince Edward Island	99	Nevada	9
Wyoming	86	Delaware	86	Nova Scotia	4	New Hampshire	59	Quebec	95	Nevada	12	Kansas	37	California	6
Kentucky	75	Massachusetts	78	Delaware	3	South Carolina	53	Newfoundland	95	Utah	6	Iowa	34	British Columbia	5
Missouri	74	Florida	70	Maine	2	Illinois	52	British Columbia	91	Vermont	5	Oklahoma	32	Nova Scotia	3
Indiana	68	Nevada	67	Massachusetts	2	Tennessee	44	Washington	69	Arizona	5	North Dakota	25	New Brunswick	3

Table 5

Summary of Average Technology Share in 2018

Coal		Natural Gas	Petroleum	Nuclear	Hydro	Solar	Wind	Other
Mean	25.98%	28.31%	0.55%	14.81%	16.30%	1.25%	8.66%	0.51%
Median	20.41%	25.48%	0.14%	8.63%	3.63%	0.12%	2.63%	0.00%

Shown in Table 6 are the regions with the most change in generation technology from 2005 until 2018, separated by each technology. The change is marked as a relative increase or decrease, rather than an absolute increase or decrease unless otherwise indicated. For example, if a region employed 50% coal generation in 2005, and 25% coal generation in 2018, the decrease would be a 50% relative reduction, not a 25% absolute reduction. Carbon based generation is shown with a negative sign denoting a percent decrease, while renewable generation shown with a positive denoting a percent increase. Delaware, New Mexico, Ohio, Nevada, and Georgia were the five regions that decommissioned the most coal and coke generation. While many regions showed an increase in natural gas generation, only seven regions decreased natural gas generation. The top five regions for reducing natural gas generation were Maine, New Hampshire, Ontario, Rhode Island, and British Columbia. Regions that showed the highest relative decrease in petroleum generation were New Brunswick, Florida, New York, Massachusetts, and Nova Scotia. Regions with the highest increase in nuclear generation were New Hampshire, Tennessee, New Brunswick, Ontario, and Maryland.

Regions with the highest increase in Hydro generation were Vermont, Maine, Montana, New York, and Ontario. Regions with the highest increase in Solar were California, Nevada, Utah, Vermont, and Arizona. Regions that increased wind generation the most were Kansas, Oklahoma, Iowa, North Dakota, and Maine. And lastly, the regions with the most increase in 'Other' types of generation like geothermal and biomass were Nevada, British Columbia, Utah, Nova Scotia, and Idaho.

Table 6 further illustrates that regions did not have any significant increases in 'Other' types of generation. What is also of note is that regions are, in general, not decreasing natural gas generation. This is likely explained by natural gas being the most direct replacement for coal generation. Table 6 also shows that wind generation appears to be favoured over solar generation in most regions.

Table 6

Summary of Top Regions by Technology Change from 2005 until 2019

Coal		Natural Gas		Petroleum		Nuclear		Hydro		Solar[a]		Wind		Other	
Region	%	Region	%	Region	%	Region	%	Region	%	Region	%	Region	%	Region	%
Delaware	-55	Maine	-24	New Brunswick	-24	New Hampshire	20	Vermont	37	California	14	Kansas	36	Nevada	6
New Mexico	-44	New Hampshire	-10	Florida	-16	Tennessee	16	Maine	7	Nevada	12	Oklahoma	30	British Columbia	1
Ohio	-40	Ontario	-5	New York	-15	New Brunswick	14	Montana	6	Utah	6	Iowa	30	Utah	0.65
Nevada	-39	Rhode Island	-5	Massachusetts	-13	Ontario	10	New York	5	Vermont	5	North Dakota	25	Nova Scotia	0.48
Georgia	-39	British Columbia	-2	Nova Scotia	-12	Maryland	6	Ontario	4	Arizona	5	Maine	21	Idaho	0.46

[a]Note: All columns use relative percentage change, except Solar which uses absolute increase

Table 7 shows the mean and median values of change from 2005 until 2018. The values shown can be contrasted against Table 6 to illustrate how successful certain regions have been at changing generation technology. Table 7 also identifies the general movement away from coal and towards natural gas, irrespective of policy usage or market type. Of note is how adoption of zero emission technologies is almost negligible.

Table 7

Summary of Average Technology Change for all Regions from 2005 until 2019

	Coal	Natural Gas	Petroleum	Nuclear	Hydro	Solar	Wind	Other
Mean	-18%	+13%	-4%	-1%	+1%	+1%	+7%	0%
Median	-16%	+7%	0%	0%	0%	0%	+2%	0%

4.2 Regression Models

4.2.1 Emissions by Technology Use

This section presents the regression results to show the link between generation technology employed and emissions from electrical generation. The results of this first test show a clear link between the use of carbon emitting generation technologies and the emissions from generation. While this is expected, what may not be expected is that there is not a statistically significant inverse relationship between increasing renewable technologies and lower emissions. This is unexpected as it highlights the possible existence of a converse error bias (i.e., Affirming the Consequent), where when proving one statement true, the contrapositive statement is assumed also true (Shafiei & Salim, 2014). In this case, just because reducing carbon-based generation reduces emissions does not mean that increasing zero carbon generation will also lead to emissions reductions, regardless of how that statement may intuitively feel. While some research claims to find a strong link between renewables and reduction of CO_2 emissions, this section would seem to contradict any direct causal relationship (Shafiei & Salim, 2014).

Table 8 shows the resulting R-squared values of the four regression models with Table 9 showing coefficients and significance. Figure 3 and Figure 4 show the correlation matrices for Canada and the USA respectively. When comparing actual generation to emissions, the relationship for both Canada and the US is strongly correlated at $R^2 > .99$, and carbon emitting technologies such as coal and natural gas are statistically significantly related to emissions ($P>0.001$).

Table 8

Regression 1 Generation Technology Employed Predicting Emissions

Model Name	R^2	R^2 Adjusted	Standard Error
Canada Actual (MWh)[a]	0.996	0.995	0.94147
USA Actual (MWh)	0.999	0.999	1.57769
Canada Percentage[b]	0.803	0.644	0.00463
USA Percentage	0.528	0.278	0.12592

Note: Abbreviation is Megawatt Hours (MWh)
[a]*Note*: generation technology measured from actual generation in MWh
[b]*Note*: generation technology measured as the percentage of total generation corrected for population

Table 8 shows the results of four models where each generation technology was modeled to predict emissions from electricity production. The models are separated as Canada and the US respectively. The first two models use the actual MWh of each generation technology to predict the emissions from electricity production. The actual generation capacity is uncorrected for region size. The R-square for each model is greater than 0.99 for both Canada and the US. The last two models are similarly separated, into Canada and the US; however, generation technology is quantified as the percentage of total generation in each region predicting emissions where the total generation in each region is divided by the region population. The last two models have an R-square of 0.803 and 0.528 for Canada and the US, respectively.

Figure 3

Correlation Matrix for Technology Variables in Canada Model

	Coal	Natural Gas	Petroleum	Nuclear	Hydro	Solar	Wind	Other
Coal	1							
Natural Gas	-0.825	1						
Petroleum	-0.001	0.061	1					
Nuclear	0.172	-0.332	0.049	1				
Hydro	0.128	0.224	0.045	-0.172	1			
Solar	0.209	0.087	-0.057	-0.485	0.505	1		
Wind	0.068	-0.391	0.046	0.173	-0.617	-0.722	1	
Other	0.089	-0.28	0.031	0.177	-0.322	-0.139	0.175	1

Note: Colour scale shows green as 1 and blue as -1

For the above shown Canada models in Table 8, the R values remain strong (from $R^2 > .99$ to $R^2 = .803$) when switching from MWh to percentage of total generation, but this is not the case for the US models ($R^2 > .99$ to $R^2 = .528$). This might be explained by the provinces that have large portions of natural gas and coal generation are the highest emitters of CO_2, confirmed by the statistical significance shown in Table 9. Why the model does not hold as strong in the US is undetermined but might be hypothesised as: states are more likely to have a diverse generation portfolio where changes in a single generation technology does not affect total emissions as strongly as a more homogeneous technology mix.

Figure 4

Correlation Matrix for Technology Variables in USA Model

	Coal	Natural Gas	Petroleum	Nuclear	Hydro	Solar	Wind	Other
Coal	1							
Natural Gas	-0.125	1						
Petroleum	-0.054	-0.323	1					
Nuclear	-0.348	-0.244	0.004	1				
Hydro	0.23	0.043	-0.035	-0.073	1			
Solar	0.042	-0.019	0.042	-0.013	0.036	1		
Wind	-0.205	-0.506	0.249	0.151	-0.13	-0.078	1	
Other	0.167	-0.294	0.05	-0.006	-0.208	-0.485	0.071	1

Note: Colour scale shows green as 1 and blue as -1

Table 9 and Table 10 summarize the coefficients that show the relative importance of each technology to their respective models. Canada is shown in Table 9, with the US shown in Table 10. Actual generation models are on the left of the tables, and percentage of total generation on the right of the tables, shown below. Technologies that represent a statistically significant ($P < 0.01$) component of the model are marked in bold.

Table 9

Regression 1 Generation Technology Predicting Emissions: Model Coefficients for Canada

Model: Canada Actual					Model: Canada Percentage				
Variable	Unstandardized	Standardized	t	P (sig.)	Variable	Unstandardized	Standardized	t	P (sig.)
Coal & Coke	9.89E-07	0.901	65.323	**0.000*** **	Coal & Coke	0.009	0.002	3.877	**0.000*** **
Hydro	1.12E-10	0.000	0.052	0.959	Hydro[a]	-	-	-	-
Natural Gas	1.74E-07	0.114	7.263	**0.000*** **	Natural Gas	0.007	0.005	1.462	0.146
Petroleum	8.30E-07	0.049	7.984	**0.000*** **	Petroleum	0.008	0.008	0957	0.340
Solar	-2.59E-07	-0.009	-0.746	0.457	Solar	-1.130	0.161	-7.010	**0.000*** **
Nuclear	4.48E-08	0.084	9.633	**0.000*** **	Nuclear	0.038	0.003	12.344	**0.000*** **
Wind	-1.85E-07	-0.029	-2.307	0.023*	Wind	-0.001	0.001	-0.863	0.390
Other	-4.28E-08	-0.004	-0.530	0.597	Other	-0.007	0.024	-0.280	0.780

[a]*Note*: Hydro technology is automatically omitted by SPSS from the percentage model due to no model component
*p < 0.05
**p < 0.01
***P<0.001

Table 10

Regression 1 Generation Technology Predicting Emissions: Model Coefficients for the United States

Model: USA Actual					Model: USA Percentage				
Variable	Unstandardized	Standardized	t	P (sig.)	Variable	Unstandardized	Standardized	t	P (sig.)
Coal & Coke	9.85E-07	0.818	440.383	**0.000*** **	Coal & Coke	0.256	0.024	10.885	**0.000*** **
Hydro	4.71E-09	0.002	0.909	0.364	Hydro	0.061	0.34	1.799	0.072
Natural Gas	4.05E-07	0.366	170.022	**0.000*** **	Natural Gas[a]	-	-	-	-
Petroleum	8.77E-07	0.051	31.004	**0.000*** **	Petroleum	0.216	0.258	0.759	0.448
Solar	-1.02E-07	-0.004	-2.022	0.044*	Solar	-0.512	0.539	-0.950	0.342
Nuclear	-9.26E-09	-0.005	-2.676	**0.008** **	Nuclear	-0.064	0.34	-1.864	0.063
Wind	1.03E-08	0.001	0.767	0.443	Wind	-0.372	0.85	-4.379	**0.000*** **
Other	-9.24E-08	-0.007	-3.361	**0.001** **	Other	0.315	0.340	0.928	0.354

[a]*Note*: Natural Gas technology is automatically omitted by SPSS from the percentage model due to collinearity tolerance
*p < 0.05
**p < 0.01
***P<0.001

Shown in Table 9 and 10, there is not an strong and consistent inverse relationship between renewables and emissions, which would show gains in wind and solar lead to emissions reductions. This implies that even regions that employ significant amounts of renewables still have substantial emissions from fossil fuel generation, or renewables are not being used to replace existing generation. This is confirmed with the descriptive statistics in Table 6 showing that most US regions that employ renewable generation still have some component of fossil fuel generation. The results of the US percentage in Table 10 also show a telling result. The insignificance of natural gas when corrected for population implies that the percentage usage of natural gas is extremely flat, with Table 5 showing usage at an average of 28%. Consequently, this implies natural gas is near colinear with population, which would support the idea that the technology is the backbone for generation in the US.

The results of the first regression model show a conclusive link between fossil fuel generation and emissions from electricity production. The results show a propensity for natural gas generation in the US as well as show that increases in renewable technologies do not have as direct a link to emissions. This indicates that using policies to increase renewable generation will not, per se, have a direct effect on lowering emissions.

4.2.2 GDP Control

This regression shows the results of the test between economic activity and generation technology employed. Table 11 and Table 12 show the results of the regression model testing the relationship between GDP and the use of different generation technologies. Table 11 shows the result from the percentage of total generation. Table 12 shows the results of absolute generation in MWh. The results of comparing GDP to the technology used by regions shows no strong relationship ($R^2 > 0.6$) between GDP and the use of certain technologies. When removing regions without a particular technology (the zero cases), then Solar and Other both have less than 20 cases, violating reliability minimums and hinting at a sampling bias. This is likely due to some of the largest GDP outliers, Texas, California, Ontario and Quebec, having a strong influence on the relationship for marginally used renewable technologies. Removing the largest GDP regions leads to no significant relationship between GDP and technology used. This is explored in Chapter 5: Discussion and Conclusions and is a candidate for further research. The results in Table 12 indicate that large economies invest in more generation, likely related to the increased requirement for electricity. However, the low strength of the relationship indicates that GDP is not a significant and primary driver of investment in specific technology.

Table 11

Regression 2 Summary of GDP Predicting Percentage of Generation Technology Employed

Model name	R^2	R^2 adjusted	Prob(F-stat)
Coal & Coke %	0.042	0.024	0.125
Hydro %	0.004	0.014	0.649
Natural Gas %	0.033	0.016	0.170
Petroleum %	0.026	0.009	0.223
Solar %	0.163	0.148	0.001**
Nuclear %	0.043	0.026	0.116
Wind %	0.019	0.002	0.298
Other %	0.076	0.060	0.036*

*$p < 0.05$
**$p < 0.01$

Table 12

Regression 2 Summary of GDP Predicting Generation Technology Employed in MWh

Model name	R^2	R^2 adjusted	Prob(F-stat)
Coal & Coke	0.045	0.028	0.110
Hydro	0.036	0.019	0.153
Natural Gas	0.393	0.382	0.000***
Petroleum	0.003	-0.015	0.686
Solar	0.580	0.572	0.000***
Nuclear	0.183	0.169	0.000***
Wind	0.184	0.169	0.000***
Other	0.506	0.498	0.000***

***$p < 0.001$

4.3 Repeated Measures ANOVA

The next two models use a Repeated Measures ANOVA to analyse the longitudinal data and determine the significance of each factor across a broad time-period. This is to determine if each factor retains significance in each year and is intended to be combined with the analysis from Section 4.4 MANOVA Analysis.

Repeated Measure ANOVA's have the ability to test observations taken at separate times, thus making it an option to analyse time series data while reducing errors that might occur from a regular ANOVA (Tabachnick & Fidell, 2013). Repeated Measures have two underlying assumptions; first is normality and the second is sphericity. The data is assumed to be normally distributed due to the central limit theorem. If this assumption does not hold then violations of normality can be assumed to be insignificant due to the robustness of the tests increasing as sample size increases past n = 20 (Tabachnick & Fidell, 2013, p. 253). Violations of sphericity can be corrected for using the Greenhouse-Geisser correction, which is automatically computed via SPSS (Greenhouse & Geisser, 1959).

4.3.1 Emissions from 1990 to 2017

The results of the first repeated measures analysis summarized in Table 13 shows the test for sphericity to determine if the Greenhouse-Geisser correction must be made. In the point in the analysis, with $P < 0.05$, we can assume that sphericity has been violated and the correction must be made. Table 14 shows the significant results from the analysis with the measure being CO_2 emissions from electricity production by region by year.

Table 13

Mauchly's Test of Sphericity on Repeated Measures 1

Within Subject Effect	Mauchly's W	Approx. Chi-Square	df	P (sig.)
Emissions	0.000	2507.575	337	0.000

Table 14 shows that year, as well as country, are strong and significant factors for predicting emissions from electricity production. This result is expected since CO_2 emissions overall have increased since 1990 and the emissions magnitude differs between the US and Canada. The significant factors that showed a deviation from the norm was the use of an

Emissions Trading Scheme, and the use of an Alternative energy Portfolio Standard. These factors in combination with the year were significant with $P < 0.05$.

The use of any RPS shows an approach significance with a P-value less than 0.1 but greater than 0.05. Also interesting is that combining an RPS with a FIT was found to be statistically significant and a strong contribution to the model ($P < .05$), but not necessarily the combinations of other policies such as an RPS with an ETS. There appears to be no difference between market types when it comes to emissions and no interaction between market type and renewable energy policies. Controls for geographic region were also not significant aside from the 'plains' region, defined as any region not touching mountains or ocean. This is likely showing some difference in generation that shifted over time, but this should be confirmed by reviewing the results of Section 4.3.2 Technology Choice from 2005 to 2019 to determine if the emissions are related to use of coal or natural gas.

Table 14

Repeated Measures 1 Tests of Univariate Tests: Measured by Emissions Predicted by Policy Factors by Year from 1990 to 2017 using Greenhouse-Geisser correction

Factor	Type III ∑ of Squares	df	Mean Square	F	P (sig.)
Year	6117.020	2.701	2265.122	8.179	0.000***
Year x Any RPS	1917.715	2.701	710.126	2.564	0.064
Year x ETS	2535.977	2.701	939.068	3.391	0.024*
Year x FIT	604.121	2.701	223.705	0.808	0.481
Year x Regulated	0	0	-	-	1.000
Year x Restructured	0	0	-	-	1.000
Year x ETS x FIT	1866.313	2.701	691.093	2.495	0.690
Year x Any RPS x FIT	2535.556	2.701	938.912	3.390	0.024*
Year x APS	4320.781	2.813	1536.139	6.100	0.001***
Year x Country	2454.395	2.813	872.595	3.465	0.020*
Year x Plains	2134.987	2.813	759.038	3.014	0.035*

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), Renewable Portfolio Standard (RPS), and Clean Energy Standard (CES)
*p < 0.05
**p < 0.01
***P<0.001

4.3.2 Technology Choice from 2005 to 2019

This section uses the same methods as above (repeated measures ANOVA) to analyse the technology used from 2005 to 2019 to determine policy differences and interactions. Table 15 shows the output of Mauchly's test of sphericity. Again, sphericity is not met and the Greenhouse-Geisser lower bound correction is used in Table 16.

Table 15

Mauchly's Test of Sphericity on Repeated Measures 2

Measure	Mauchly's W	Approx. Chi-Square	df	P (sig.)
Coal	0.000	2782.170	104	0.000
Natural Gas	0.000	2097.566	104	0.000
Hydro	0.000	2998.948	104	0.000
Petrol	0.000	-	104	0.000
Nuclear	0.000	2250.575	104	0.000
Wind	0.000	2262.148	104	0.000
Solar	0.000	-	104	0.000
Other	0.000	-	104	0.000

Table 16 shows the results of the Within-Subject Effects after taking the Greenhouse-Geisser correction into account. Sections are summarized showing just the statistically significant results with $P < 0.05$ and other results of interest approaching significance. Also shown are the regulated and restructured model components showing no statistical significance to the model.

Table 16

Repeated Measures 2 Univariate Tests: Measured by Technology Percentage Predicted by Policy Factors by Year from 2005 to 2019 using Greenhouse-Geisser correction

Source	Measure	Type III ∑ of Squares	df	Mean Square	F	P (sig.)
Year	NG	4.606E-5	1.110	4.150E-5	11.582	0.001**
	Hydro	4.079E-5	1.020	3.999E-5	4.634	0.036*
	Nuclear	4.514E-5	1.004	4.495E-5	3.590	.065
Year * AnyRPS	Hydro	4.996E-5	1.020	4.899E-5	5.676	0.021*
Year * ETS	NG	3.394E-5	1.110	3.058E-5	8.535	0.004**
	Nuclear	4.390E-5	1.004	4.371E-5	3.491	0.068
Year * FIT	NG	3.555E-5	1.110	3.203E-5	8.939	0.003**
Year * regulated	Coal	0	0	.	.	1.000
	NG	0	0	.	.	1.000
	Hydro	0	0	.	.	1.000
	Petrol	0	0	.	.	1.000
	Nuclear	0	0	.	.	1.000
	Wind	0	0	.	.	1.000
	Solar	0	0	.	.	1.000
	Other	0	0	.	.	1.000
Year * restructured	Coal	0	0	.	.	1.000
	NG	0	0	.	.	1.000
	Hydro	0	0	.	.	1.000

	Petrol	0	0	.	.	1.000
	Nuclear	0	0	.	.	1.000
	Wind	0	0	.	.	1.000
	Solar	0	0	.	.	1.000
	Other	0	0	.	.	1.000
Year * AnyRPS * ETS	Hydro	3.780E-5	1.020	3.707E-5	4.295	0.044*
Year * ETS * FIT	NG	6.136E-5	1.110	5.528E-5	15.429	**0.000*** **
Year * Country	Hydro	3.644E-5	1.020	3.573E-5	4.140	0.047*
	Wind	3.665E-6	1.053	3.481E-6	2.658	0.109
Year * Country* Any RPS	Wind	1.178E-5	1.053	1.119E-5	8.548	0.005**
Year * Country * RPS	Hydro	3.056E-5	1.241	2.462E-5	3.478	0.059
	Wind	8.566E-6	1.052	8.145E-6	6.360	0.014*
Year * RPS	Wind	8.995E-6	1.052	8.552E-6	6.678	0.012*
Year * RPSGoal	Hydro	3.789E-5	1.241	3.053E-5	4.312	0.035*
	Nuclear	0.000	1.004	0.000	10.202	0.003**
	Solar	1.929E-9	1.190	1.620E-9	5.386	0.019*

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), Renewable Portfolio Standard (RPS), and Natural Gas (NG)
*p < 0.05
**p < 0.01
***P<0.001

The first result from Table 16 shows that Year is a significant factor in the model, and this is expected since technology changed away from coal technologies and toward natural gas technologies in the sample years. This was due more with the cost of fuels and not the consequence of direct influence of renewable energy policies (Woo et al., 2014). Next, Table 16 shows that Renewable Portfolio Standards are related to differences in hydroelectric technology while Feed-in Tariffs alone and combined with an ETS are related to natural gas technology. Again, we see that the combinations of policy factors do have some model significance as both the use of FITs with an ETS or an RPS with an ETS are shown in Table 16 just as they appeared in Table 14.

For the control categories, country is shown as a statistically significant factor showing differences in the use of hydro and wind technologies. While some provinces in Canada do resemble the United States for technology used in generation, in aggregate, Canada is showing that provinces have a generation portfolio which differs from the US specifically on the use of hydro technology. This is illustrated with the example of Quebec and BC both having above 90% hydro generation, whereas no state comes close (see 4.1.2 Descriptive Statistics). Table 16 shows wind energy to be related to most policy combinations. I believe these to be sampling bias, as wind technologies are employed within regions in miniscule percentages. Therefore, any small change is compared against regions with zero implementation and zero change, thus these technologies are amplified by the statistical methods used.

To illustrate this point on sample bias further, only seven regions employ an RPS goal. Four regions used nuclear in 2005 but only three used nuclear in 2019. So, this could indicate a sample bias, describing the one region (Vermont) which reduced nuclear use, whereas other regions in other policy categories may not have used nuclear in the first place. The results of Table 16 require further context from Section 4.4.3 Technology Change from 2005 to 2019 to understand what the data this repeated measures ANOVA is picking up on. This analysis is testing technology used from 2005 to 2019 whereas Section 4.4.3 tests the magnitude of technology change. Therefore, the results of Section 4.4.3 are important to combine with these results for further context in understanding how the policies influenced not just technology choice, but technology change. The results of the later section will show that the regions employing an RPS goal likely did not have large changes in generation to, and thus the relation found in Table 16 is likely a sample bias. This observation is elucidated further along with a discussion of other related limitations and the implication of the control variable findings in Chapter 5: Discussion and Conclusions.

4.4 MANOVA Analysis

These following sections make use of a multivariate analysis of variance (MANOVA) to test three different outcomes; emissions, generation technology, and change in technology. The SPSS output for a MANOVA model contains four statistics. In this case, Pillai's trace will be used to determine each variable's contribution to the model. Following guidance from Olson (1974), Pillai's trace is generally regarded as more robust than the other statistics when the degrees of freedom for error is greater than ten. Pillai's trace is a positive value from zero to one, with higher numbers showing greater model contribution.

4.4.1 Emissions in 1990 and 2005

This analysis is the first of three MANOVA tests. This analysis created a model where CO_2 emissions from electricity generation in three years (1990, 2005 and 2017) was analysed against the independent and control factors. Table 17 below shows the summary of significant effects with a P-value of less than 0.05.

Table 17

MANOVA 1 Summary of Emissions Predicted by Policy Factors in 2018

Factor	Pillai's Trace	Wilks' Lambda	Hotelling's Trace	Roy's Largest Root	Error Df	P (sig.)
Country	0.150	0.850	0.177	0.177	47.000	0.052
Any RPS	0.321	0.679	0.472	0.472	47.000	0.001**
ETS	0.453	0.547	0.829	0.829	47.000	0.000***
FIT	0.283	0.717	0.394	0.394	47.000	0.002**
Any RPS x FIT	0.257	0.743	0.345	0.345	47.000	0.004**
ETS x FIT	0.463	0.537	0.864	0.864	47.000	0.000***
Regulated	0.000	1.000	0.000	0.000	47.000	1.000
Restructured	0.000	1.000	0.000	0.000	47.000	1.000

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)
**$p < 0.01$
***$P<0.001$

Table 17 shows first that Country is weakly significant (P = 0.052) but not large factor (Pillai's Trace = 0.150) in determining emissions. This is likely explained by the size difference between Canada and the US. Emissions Trading Schemes are shown to be an equally significant predictor for emissions. When FITs are combined with an ETS, it would seem to be a slightly larger component of the model. However, this is likely selection bias as only four regions employ both an ETS and a FIT. Again, there is no observed significance between regulated and restructured regions.

To confirm no difference, a T-test was conducted testing the difference in means of emissions for regulated and restructured regions. The results of this test can be found below in Table 18. Table 18 shows conclusively that in the first year (1990) the midpoint (2005) and in the last year (2017), there is no statistically significant difference in emissions levels between regulated regions and restructured regions.

Table 18

T-test 1 Regulated Market Tested Against Restructured Markets for Emissions

Year	Equal Variance	Levene's F (prob)	P (sig.)
1990	Assumed	0.330	0.850
	Not Assumed		0.887
2005	Assumed	0.644	0.575
	Not Assumed		0.667
2017	Assumed	0.188	0.581
	Not Assumed		0.713

4.4.2 Generation Technology in 2005 and 2019

This section analyses generation technology in 2018 among all the regions and constructs a MANOVA model to determine the influence of each factor. Summarized results are found below in Table 19. This analysis is testing the relationship of each technology as a percentage of total generation against each of the independent and control factors corrected for population.

Table 19

MANOVA 2 Summary of Generation Technology Predicted by Policy Factors in 2018

Factor	Pillai's Trace	Wilks' Lambda	Hotelling's Trace	Roy's Largest Root	Error Df	P (sig.)
Country	0.795	0.205	3.886	3.886	25	0.000***
Any RPS	0.688	0.312	2.203	2.203	25	0.003**
ETS	0.795	0.205	3.872	3.872	25	0.000***
FIT	0.706	0.294	2.402	2.402	25	0.002**
Any RPS x ETS	0.395	0.605	0.652	0.652	25	0.470
Any RPS x FIT	0.000	1.000	0.000	0.000	-	1.000
ETS x FIT	0.577	0.423	1.365	1.365	39.000	0.043*
Regulated	0.000	1.000	0.000	0.000	-	1.000
Restructured	0.000	1.000	0.000	0.000	-	1.000

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)
*p < 0.05
**p < 0.01
***P<0.001

Table 19 shows that country is a significant factor in the choice of generation technology. This mirrors the finding from Section 4.3.2 Technology Choice from 2005 to 2019 also showing that Canada and the US have different generation portfolios. Table 18 shows that each of the three policies individually are statistically significant. The analysis found that a FIT combined with an ETS was statistically significant in the model, but no longer when combined with an RPS. This differs from the findings in Table 17. Also inconsistent with the analysis from previous Section 4.4.1, was that an RPS combined with an ETS was a significant factor in the model. No statistical difference was observed between regulated and restructured market.

Controls for geography showed no deviations towards significance. No significant statistical difference was found between the use of any RPS and the three RPS subtypes.

Table 20 below shows the significance of each technology relating to the most significant factors from the model as shown in Table 19. Table 20 indicates that the two countries differ on the use of some generation technologies. This is the expected result, as no difference is observed for renewable technologies such as wind and solar. Table 19 also shows that each policy combination of significance does not relate strongly to specific technology choices. Where some policies appear to approach significance for some generation technologies, very few have a $P < 0.05$.

Table 20

MANOVA 2 Detailed Between-Subject Effects of Generation Technology

Factor		Technology							
	Statistic	Coal	Natural Gas	Hydro	Petrol	Nuclear	Wind	Solar	Other
Country	Type III ∑ of Squares	1.46E-7	1.605E-8	1.00E-7	5.259E-10	5.032E-9	2.995E-7	.000	6.96E-10
	F-stat	2.554	.588	1.612	13.206	.605	.506	.000	28.057
	P (sig.)	.118	.448	.212	0.001**	.441	.481	1.000	0.000***
Any RPS	Type III ∑ of Squares	1.50E-8	2.79E-9	1.0E-8	1.55E-10	1.07E-8	3.00E-7	.000	3.40E-10
	F-stat	0.261	0.102	0.167	3.902	1.281	0.507	.000	13.683
	P (sig.)	0.612	0.751	0.685	0.055	0.264	0.481	1.000	0.001**
ETS	Type III ∑ of Squares	3.06E-8	1.23E-9	1.3E-7	.000	5.94E-9	6.80E-7	2.92E-10	.000
	F-stat	0.532	0.045	2.098	.000	0.714	1.149	1.759	.000
	P (sig.)	0.47	0.833	0.155	1.000	0.403	0.290	0.192	1.000
FIT	Type III ∑ of Squares	6.9E-10	1.36E-9	4.3E-8	.000	.000	1.37E-7	4.51E-10	.000
	F-stat	0.012	0.05	0.699	.000	.000	0.231	2.722	.000
	P (sig.)	0.913	0.825	0.408	1.000	1.000	0.633	0.107	1.000
ETS x FIT	Type III ∑ of Squares	1.23E-8	7.15E-9	1.9E-8	.000	8.09E-9	2.13E-8	.000	.000
	F-stat	0.215	0.262	0.191	.000	0.973	0.036	.000	.000
	P (sig.)	0.645	0.612	0.664	1.000	0.330	0.851	1.000	1.000

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)
$^{**}p < 0.01$
$^{***}P<0.001$

Table 21 shows the results of a T-test to determine if there is a significant difference between regulated and restructured markets for technology choice. The results of which show there was significance found between the use of coal and natural gas technology employed between the two market types. The negative mean difference for coal shown in the table indicates that regulated markets use 21.9% more coal than restructured markets. Also shown is that positive difference in mean indicates that restructured markets use 21.5% more natural gas than regulated markets. This replicates the findings from Csereklyei and Stern (2018) and Kim (2013), which showed that restructured regions favoured natural gas generation and regulated markets favoured coal generation respectively. The reasons for this are discussed in Chapter 5: Discussion and Conclusions.

Table 21

T-test 2 Regulated Market Tested Against Restructured Market for Generation Technology Choice

Technology	Equal Variance	Levene's F (prob)	P (sig.)	Mean Difference
Coal	Assumed	0.004	0.004	-21.9%
	Not Assumed		0.000***	
NG	Assumed	0.461	0.004**	21.5%
	Not Assumed		0.018	
Hydro	Assumed	0.121	0.476	-6.1%
	Not Assumed		0.332	
Petrol	Assumed	0.068	0.422	-0.2%
	Not Assumed		0.158	
Nuclear	Assumed	0.004	0.108	9.2%
	Not Assumed		0.208	
Wind	Assumed	0.156	0.361	-4.6%
	Not Assumed		0.172	
Solar	Assumed	0.098	0.679	-0.4%
	Not Assumed		0.546	
Other	Assumed	0.049	0.312	-0.5%
	Not Assumed		0.068	

Note: negative percentage mean difference indicates regulated markets employed more of the listed technology
**p < 0.01
***P<0.001

4.4.3 Technology Change from 2005 to 2019

The last statistical analysis was a MANOVA analysing the change in each technology as a percentage of total generation. That is, each region was assigned a percentage increase or decrease in each technology that occurred from 2005 to 2019. This analysis indicates which effects lead to the greatest amount of change in technologies during the sample period. The summary of the relevant effects is reported in Table 22 below.

Table 22

MANOVA 3 Summary of Change in Generation Technology Predicted by Policy Factors from 2005 to 2018

Factor	Pillai's Trace	Wilks' Lambda	Hotelling's Trace	Roy's Largest Root	Error df	P (sig.)
Any RPS	0.157	0.843	0.186	0.186	36	0.476
ETS	0.332	0.668	0.497	0.497	36	0.03*
FIT	0.343	0.657	0.522	0.522	36	0.024*
Any RPS * FIT	0.353	0.647	0.546	0.546	36	0.019*
ETS * FIT	0.394	0.606	0.65	0.65	36	0.008**
Any RPS * ETS	0.098	0.902	0.109	0.109	36	0.783
Regulated	0.000	1.000	0.000	0.000	38.000	1.000
Restructured	0.000	1.000	0.000	0.000	38.000	1.000

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)
**p < 0.01

The results of this last analysis revealed no strong effect from the control variables, with this test not agreeing with the previous analyses. The control factor 'country' is no longer a statistically significant factor (P = 0.072). Table 21 shows that RPS policies are no longer statistically significant. FITs retain statistical significance along with ETSs maintaining statistical significance. The combination of an ETS and a FIT also retains significance in this model. This indicates that both individually and combined, an ETS and a FIT are both related to technology change with indications that these policies are responsible for said change in generation technology choice.

Table 23 shows the output of the Between-Subject effects from the third MANOVA. Shown in the table is the statistical significance of each technology of the four factors from Table 22, ETS, FIT, ETS combined with FIT, and RPS combined with FIT. Table 22 shows that an ETS is related to a change in hydro generation, wind generation and other type generation. FITs are shown to be related to a change in Natural Gas generation.

Table 23

MANOVA 3 Detailed Between-Subject Effects of Technology Change

Factor	Technology								
	Statistic	Coal	Natural Gas	Hydro	Petrol	Nuclear	Wind	Solar	Other
ETS	Type III ∑ of Squares	13.411	1.125	496.753	14.626	457.225	33.385	23.94	0.844
	F-stat	0.079	0.005	11.385	0.792	4.237	0.421	5.409	0.612
	P (sig.)	0.780	0.945	0.002**	0.379	0.046	0.52	0.025*	0.438
FIT	Type III ∑ of Squares	414.227	1295.012	69.944	50.889	283.33	132.387	24.631	0.25
	F-stat	2.44	5.444	1.603	2.755	2.625	1.668	5.565	0.182
	P (sig.)	0.126	0.024*	0.212	0.104	0.113	0.204	0.023*	0.672
Any RPS x FIT	Type III ∑ of Squares	603.382	0.203	122.864	0.459	60.948	1.64	36.907	0.423
	F-stat	3.555	0.001	2.816	0.025	0.565	0.021	8.338	0.307
	P (sig.)	0.066	0.977	0.101	0.875	0.457	0.886	0.006**	0.583
ETS x FIT	Type III ∑ of Squares	6.188	599.716	304.021	4.27	50.493	23.085	31.237	0.622
	F-stat	0.036	2.521	6.968	0.231	0.468	0.291	7.057	0.452
	P (sig.)	0.849	0.12	0.012*	0.633	0.498	0.592	0.011*	0.505

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)
*p < 0.05
**p < 0.01
***P<0.001

Below is Table 24, which summarizes the output of the T-test to determine the difference between regulated markets and restructured markets in changes of technology. Shown are the eight generation categories, with the output of Levene's test for equal variance and significance indicated in bold. Only two technologies were found to be statistically different between regulated and restructured regions. Coal is the first technology that had differing rates of change between the two market types, with regulated markets having a mean decrease of 35% and restructured markets having a mean decrease in coal of 3.5%, as shown in column 5 of the table. Natural gas is the second technology that had statistically differing rates of change between the two market types. Restructured markets decreased natural gas usage by a mean of 13%, but regulated markets increased usage by 6%.

Table 24

T-test 3 Regulated Market Tested Against Restructured Market for Generation Technology Change

Technology	Equal Variance	Levene's F (prob)	P (sig.)	Mean Difference	Mean[a]	
Coal	Assumed	0.031	0.001	31.8%	-35.3%	-3.5%
	Not Assumed		**0.000*** **			
NG	**Assumed**	0.397	**0.023***	-19.9%	+6.1%	-13.7%
	Not Assumed		0.053			
Hydro	Assumed	0.373	0.699	-2.6%	+2.2%	-0.4%
	Not Assumed		0.754			
Petrol	Assumed	0.687	0.283	-6.2%	+12.0%	+5.8%
	Not Assumed		0.315			
Nuclear	Assumed	0.986	0.770	1.7%	-9.0%	-7.3%
	Not Assumed		0.768			
Wind	Assumed	0.235	0.567	-2.1%	+6.6%	+4.5%
	Not Assumed		0.526			
Solar	Assumed	0.587	0.805	-0.1%	+0.3%	+0.2%
	Not Assumed		0.728			
Other	Assumed	0.372	0.545	-0.9%	+0.8%	-0.1%
	Not Assumed		0.268			

[a]*Note: left cell indicates regulated market change, right cell indicates restructured market change*
*p < 0.05
***P<0.001

4.5 Results Summary

The main results of all the analysis are summarized as follows, with a visual summary available in Table 25 and Table 26. Table 25 contains outcomes related to emissions of CO_2, while Table 26 contains outcomes related to generation technology use. The regression models (Section 4.2 Regression Models) found a clear link between carbon-based generation (coal, natural gas, petroleum) and CO_2 emissions from electricity production. The regression models also showed that there is no strong link between GDP and the choice of technology, aside from a small link to solar technology. This indicates that while the availability of wealth in a region may be a small factor in the choice of generation technology, it is not a large or significant component when compared to the policy factors. The repeated measures ANOVA models (Section 4.3 Repeated Measures ANOVA) showed that regions that employed Emissions Trading Schemes or Renewable Portfolio Standards combined with Feed-in Tariffs had lower emissions year over year compared to other factor combinations. In addition, the repeated measures models also indicated that the separate policies are related to different sets of technology use (see Table 25). Lastly, the MANOVA models showed that all the policy factors were related to some positive outcome (see Table 25), but ETSs, FITs, and the combination of the two, showed the most consistent relationship to renewable technology use and the two outcomes of lower emissions and increases in renewable technology generation. The control factors showed no consistent deviations, except for the country. There appears to be a significant difference between Canada and the US for the generation used, even though both are North American western democracies. For the market type, there was no difference between regulated and restructured regions except for the rates of decommissioning coal generation and subsequent replacement with natural gas technologies. Regulated markets showed no difference from restructured markets for the adoption or use of renewable energy technologies.

Table 25

Summary of Results for Outcomes on Emissions

Factor	**Section 4.3.1** **Repeated Measures ANOVA**	**Section 4.4.1** **3-year MANOVA**
ETS	Significance found	Significance found
Any RPS	–	Significance found
FIT	–	Significance found
RPS x FIT	Significance found	Significance found
ETS x FIT	–	Significance found
RPS x ETS	–	–
Regulated	–	–
Restructured	–	–
Technology Factors	**Section 4.2.1**	**Result**
Coal	Significance found	Increases emissions
Natural Gas	Significance found	Increases emissions
Petroleum	Significance found	Increases emissions

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)

Table 26

Summary of Results for Outcomes on Technology Choice

Factor \ Resulted in	**Section 4.3.2 Repeated Measures ANOVA**		**Section 4.4.2 3-Year MANOVA**	**Section 4.4.3 MANOVA** (Tech change from ’05 – ’19)	
	Higher Use	**Lower Use**	**Policy Significance (P value)**	**New Installations**	**Decommissioning**
ETS	-	Natural Gas	0.000***	Hydro, Solar	–
Any RPS	Hydro	–	0.003**	–	–
FIT	–	Natural Gas	0.002**	Solar	Natural Gas
RPS x FIT	–	-	P > 0.05	Solar	–
ETS x FIT	-	Natural Gas	0.043*	-	Hydro, Solar
RPS x ETS	Hydro	–	P > 0.05	–	–
Regulated	–	–	-	–	–
Restructured	–	–	-	–	–

Note: Abbreviations are Emissions Trading Scheme (ETS), Feed-in Tariff (FIT), & Renewable Portfolio Standard (RPS)
*p < 0.05
**p < 0.01
***P<0.001

Chapter 5: Discussion and Conclusions

5.1 Discussion

5.1.1 The Influence of Generation Technology and Policy on CO_2 Emissions

In answering the first research question, the results indicate a link between the generation technology employed and resulting CO_2 emissions. The results in Section 4.3.1 Emissions from 1990 to 2017 show that CO_2 emitting technologies such as coal and natural gas are responsible for the largest component of emissions from electricity generation. A contribution of this study is the finding that the link between emissions and technology does not hold for renewable energy technologies. This indicates that increasing the adoption of technologies like solar or wind will not necessarily result in CO_2 emissions reductions, an important contextual consideration to assumptions in existing research (Shafiei & Salim, 2014). This finding underscores the importance of decommissioning coal and natural gas generation and suggests that such policies and efforts should be prioritized.

Next, the findings related to policy factors and lowering emissions show that most policies and policy combinations influenced the rate at which emissions decreased. Particularly, Emissions Trading Schemes were shown to be a significant factor in both the repeated measures ANOVA and the MANOVA tests, indicating that regions with an ETS had lower emissions throughout the entire test period and lowered emissions more than other regions. Some policies (FIT, RPS) only showed significance in the MANOVA test, suggesting that these regions did not reduce their rates of emissions or that these policies do not directly affect emissions. These findings support existing research into the effectiveness of policies (ETS and

FIT) to reduce carbon emissions (Chaton & Guillerminet, 2013; Haas et al., 2011; Palmer & Burtraw, 2005). But the existing research is extended by the inclusion of policy combinations, specifically showing that regions with both an RPS and a FIT had emissions reductions.

5.1.2 The Influence of Renewable Energy Policy on Technology Choice and Technology Changes

Research question 1b asks "Which set of renewable energy policies are more effective for increasing adoption of renewable energy technologies?" The answer to the influence of policy on technology choice is less clear from the present findings than the effects of technology on emissions. The descriptive results presented in Table 6 in Section 4.1.2 Descriptive Statistics, show that in aggregate, coal usage decreased while natural gas usage has increased. Wind generation increased by a significant but minor amount, with all other technologies showing a marginal change. Feed-in Tariffs are the only factor that related to a reduction in coal. This supports research by Rivard and Yatchew (2016), which linked the use of FITs to a reduction in coal usage in Ontario. When considering the results summarized in Table 26 (see Section 4.5 Results Summary), Feed-in Tariffs and Emissions Trading Schemes, and the combination of both, where the only factors to show consistent effects across the three analyses. ETSs and FITs also related to increases in renewable technology, however, as stated above, only ETSs were related to lower emissions while alone FITs were not. These findings are not unique and fit the existing research (Alagappan et al., 2011; Carley, 2009; Haas et al., 2011; Ritzenhofen et al., 2016). Specifically, the claims in both Alagappan et al. (2011) and Ritzenhofen et al. (2016) about the effectiveness of FITs are well supported in this thesis as well. In contrast however, the claims of effectiveness and robustness of RPSs found in

Ritzenhofen et al. (2016) were not replicated in from the above analyses. And as such, this thesis comes to the same as Carley (2009), in that RPSs are not achieving desired outcomes within the North American context.

Lastly, the results of technology change showed some exploratory findings for how regions switch technologies and the rates at which this happens. All regions made and are continuing to make changes to generation technologies as a logical consequence of a broader understanding about climate change (Safarzynska & van den Bergh, 2011). This manifests in ways such as decommissioning coal, but eventually most regions find all the proverbial low hanging fruit, i.e., all easiest changes to generation technology (See Tables 6 and 7 in Section 4.1.2 Descriptive Statistics). Certain policies can influence the rate at which this happens (FIT and ETS), but logically regions will eventually run out of coal plants to decommission, irrespective of policies. A key pattern found in this research is that regulated regions switched from coal to natural gas, and restructured regions from natural gas to other technologies. Csereklyei and Stern (2018) mention that the choice of natural gas is likely related to the low costs of fuels and the return on investment when switching from coal to natural gas. This is also supported by other authors who mention fuel cost as a driving factor for investment, and historically low natural gas prices incentivising investment in natural gas generation (Arango & Larsen, 2011; Haratyk, 2017; Rivard & Yatchew, 2016; Safarzynska & van den Bergh, 2011; Woo et al., 2014).

Considering the results from Section 4.4.3 Technology Change from 2005 to 2019, this research finds that while all other policies were not significant or were related to marginal technologies (e.g., Wind, Solar, Biomass and Geothermal), it does show that FITs are a significant factor. However, they are related to natural gas reduction rather than coal reduction as shown from the other sections. This might indicate that FITs, and potentially other policies, could accelerate the switch from natural gas to renewables as the policies did in the switch from coal to natural gas, but the lifecycle of this change is too early to tell conclusively. An important caveat to improving the rates of renewable adoption are shown in the findings from Section 4.2.1 Emissions by Technology Use, whereby renewable technology was not found to be related directly to reductions in emissions. And while FITs and ETSs were both shown to increase renewables, only ETSs were related to lower emissions. Thus, an effective strategy to combat climate change should keep in mind that increases in renewables may not be the same thing as reduction in carbon emissions, and literature that equates policies for reductions in emissions may only be accomplishing the former (Chaton & Guillerminet, 2013; Shafiei & Salim, 2014).

5.1.3 Restructured Markets vs. Regulated Markets

In line with explicitly answering research question 2 (Do energy markets facilitate renewable energy policies for increasing adoption renewable energy technologies?), this study tested the performance of renewable energy policies within restructured markets against regulated markets for emissions reductions and generation technology change. The analyses did not find any practical difference between the two market types, with the exception of the analysis from Section 4.4.3 Technology Change from 2005 to 2019. The change in technology showed that regulated markets had greater reductions in coal generation but greater amounts of natural gas adoption, independent of renewable energy policy. Due to limitations from the dataset, it is possible that restructured regions had higher rates of coal reduction prior to 2005, where regulated regions later caught up. The assumption that restructured regions changed technology early or prior to the sample timeframe is supported by research conducted by Csereklyei and Stern (2018), which showed the switch from coal to natural gas by restructured regions. Extending this assumption using the findings from the above analyses, this thesis likely indicates that restructured regions are faster at implementing technological change, but regulated regions will eventually catch up to the gains made. Therefore, it is not outlandish to claim that restructured markets allow for greater responsiveness by allowing private equity to fund generation switching (Frame et al., 2018; Rivard & Yatchew, 2016; Shao et al., 2020; Woo et al., 2014). However, restructured markets appear to eventually slow technology switching as the easy gains are completed, or as these markets get locked into the cheapest fuel or most profitable technology (see Section 4.1.2 Descriptive Statistics). In brief, restructuring seems to promote new investments in electricity, provided the new investments have some profitable improvement on existing technologies, through economic incentives and/or market-based environmental policy, but is not a be-all and end-all and is still subject to the negative effects mentioned in Section 2.3 Restructured Markets (Brown, 2018b; Csereklyei & Stern, 2018; Delmas et al., 2007).

A notable finding throughout the analysis is that not only did the market type have no visible effects on the outcomes, the market type also did not visibly interact with the policy choices, as suggested in the research questions and literature review. Articles claim that government intervention in the market, such as market regulation, has wide reaching effects on firm behaviour (Simshauser, 2014b, 2018). However, the results of this study failed to show any major difference between the climate-based outcomes for the two radically different market models. Section 4.4.3 Technology Change from 2005 to 2019 showed the only observable difference as the rates of change in coal and natural gas, and this is in line with the previous mentioned articles (Csereklyei & Stern, 2018; Rivard & Yatchew, 2016). This is where the resolution to the tension between Carley (2009) and Alagappan et al. (2011) can be addressed. The findings in this thesis provide support for past research by Alagappan et al. (2011) showing that market type is not solely related to the adoption of renewable technology, and furthers this research with the finding that market type does not interact noticeably with renewable energy policies. However, the apparent contradiction observed in Carley (2009), where the article claims restructured markets have lower investment in renewables, can be explained as the restructured market preference for natural gas during a prior timeframe. From this understanding of the difference between regulated and restructured markets observed in this thesis, the existing research by Csereklyei and Stern (2018) into the prior change from coal to natural gas by restructured regions, and the research by Delmas et al. (2007) and Shao et al. (2020) into the lack of responsiveness of regulated markets, we can synthesize an additional finding. That is, the switch from coal to natural gas observed in Carley (2009) and Csereklyei and Stern (2018) by restructured regions is a similar change observed in Section 4.4.3 Technology Change from 2005 to 2019. This might indicate that the switch from natural gas to renewables by restructured regions might be replicated by regulated regions in the near future.

With the justification for the difference between the two market types as market responsiveness, return on investment and fuel cost, logically policies that adjust those factors should interact with restructured markets in some way to amplify the observed effect

(Alagappan et al., 2011; Csereklyei & Stern, 2018; Delmas et al., 2007; Haratyk, 2017; Kim, 2013; Woo et al., 2014). FITs in particular, as a market-based policy that effects the operational costs of certain generation technologies, should plausibly interact with the market type, and while suggested in other research (Rivard & Yatchew, 2016), FITs was not observed interacting with restructured markets in this research. Whether the interaction between a FIT and a restructured market is too subtle to observe by the methods used, or the effects of a FIT supersede that of a restructured market, remains undetermined.

5.2 Study Limitations and Directions for Future Research

5.2.1 Limitations

The limitations of this research are separated into two subcategories. The limitations of the methods and the limitations of the dataset. The primary limitation of this study had to do with the sample size. This study sampled 58 regions across 29 years of data, however there were sample size limitations when analysing between policies. For example, about 40% of regions employed no policies during the sample timeframe. While this established a solid control group of which to compare policy usage against in the analysis, less popular policies were underrepresented in the North American context. Feed-in Tariffs are only employed by seven regions, out of a total fifty-eight, and only four regions employed both a Feed-in Tariff and an Emissions Trading Scheme. Carbon taxes had to be omitted from the analysis entirely since only two regions instituted carbon taxes prior to the 2018 Canadian federal carbon tax.

The sample size limitation exists primarily for the FIT policy, as well as most of the controls such as the policy subtypes of RPS, but also exists at the intersection of policy groups. While the findings of the study are still robust, a causal relationship cannot logically be determined, nor was this the intention of this research. Whether the policies are responsible for the group deviations observed throughout the analysis, or some underlying unmeasured variables are at the helm, is of concern for future works. For example, constructs such as political alignment could be responsible for the changes in technology, or also related to the implementation of policies. So, while this study did explore the various policies and the relationship between them, it is not able to draw causal conclusions or conclusions about policies effectiveness outside of the measured contexts. The study is only able to illustrate the relationship between the policies such as Feed-in Tariffs and outcomes such as a reduction in natural gas generation, and this is limited to the North American context.

This study is also limited by its method of analysis; however, this limitation is also related to data availability. While the three-step analysis is intended to be as robust as possible within the constrains of the data available, other methods such as hierarchical linear modelling may have resulted in stronger conclusions about the effects of interest. However, the scope of this project's timeline and the availability of data limited the choice of available methods for analysis. This project was limited in time and cost, so readily available public data was chosen. This data however comes with limitations for analysis. Had the data been collected in such a manner as to allow for the grouping into levels such as generating firms, municipal regulators, state/provincial regulators, inter-regional regulators, and federal regulators, the use of HLM would have been practical and may have provided insight that the chosen methods may not show (Woltman, Feldstain, MacKay, & Rocchi, 2012). The absence of more granular data about firm investment decisions and ownership structures, or specific date for the implementation of policies in each region limited both the choice of methods for model construction as well as generalizability to other context.

Lastly, as mentioned in Chapter 2: Literature Review, Independent Power Producers (IPP) are legally distinct from generators in markets. This thesis assumed that difference between IPPs and electrical utilities is negligible due to the limited size and number of IPPs. However, some research indicates that IPPs are a method to increase investment in renewables without impacting incumbent firms in electrical markets (Bonardi, Holburn, & Bergh, 2006; Szulecki, Pattberg, & Biermann, 2011). If IPPs have confounding effects for the adoption of renewables in electrical markets, then those effects limit the generalisability of this research.

5.2.2 Future Research

The potential future research directions stem first from the limitations of this study. Future research could consider constructing a stronger dataset in which to analyse. Future studies could invest monetarily in high-quality privately-owned data from organizations such as the International Energy Agency. In addition, investments of time could be made on a larger scale project to construct a dataset with firm level and region level data to implement hierarchical modeling and/or more granular data with specific policy groups based on regional implementation differences. Future research might also consider including regions outside of the North American context. Some existing work exists analysing climate change policies in both Asia and Europe (Haas et al., 2011; J. H. Williams & Kahrl, 2008), so future analyses could integrate findings across all major world regions.

Future research directions may also experimentally analyse the effects found in this research. While the interactions between market and policy appear insignificant, the inter-policy interaction, such as the effectiveness of FITs combined with ETSs, could be tested specifically. Future research may also consider testing for confounding variables not considered in this study. Effects of political alignment or natural resource abundance can be further explored to find a causal relationship. This research did control for regional differences, and found, generally insignificant effects. However, future research could separate geographical regions using resource dependency theory to determine if the availability of specific natural resources aligns to specific technologies in a more focused experiment. Additionally, regions could be divided by political alignment to determine the effects of politics on the implementation and effectiveness of climate change policies.

Future research can examine to what extent the policy facilitates specific changes, and how much external intervention is needed. A policy that stipulates some mandatory percentage of renewable energy but leaves a region up to its own devices without direction likely will not see those minimums being met. This is because of the regions sampled, 40% made no effort to implement any policy, and some regions chose unaffordable goals (RPS goals) rather than actual enforceable policies. I suspect that this 40% of regions have some other barriers with inhibit actions to fight climate change, and future research should also consider discovering what these barriers might be.

As time continues and life cycles of generation technologies mature, future research concerned with market responsiveness and government induced organizational inertia could specifically examine the claim that the changes made by restructured markets are mirrored by regulated markets at a later time. While this research shows some support for this, separate and hypothesis directed research would be well positioned to confirm or refute this claim in the coming years as energy markets continue to change from fossil fuels to renewables.

Lastly, to explore further into energy market regulatory models and the interaction of climate change policy, future research may seek to include constructs of firm ownership and the effects of public vs private utility ownership on the effectiveness of market regulation and renewable energy policies. Existing research indicates the possibility of performance and outcome differences between publicly-owned and privately-owned utilities under the assumptions of public choice and property-rights theories (Renzetti & Dupont, 2004). This thesis also did not consider the inclusion of independent power producers and the effects of policy on small scale generation. Future research should consider an integration of these concepts to understand how private ownership might affect the market-based solutions of Feed-in Tariffs and Emissions Trading Schemes, and private equity focused restructuring of energy markets.

5.3 Conclusion

The primary conclusions of this thesis are that there are some differences in the effectiveness of renewable energy policies, with Feed-in Tariffs found as the most consistent for positive outcomes measured. The idea that FITs as a form of price-driven regulation are effective for incentivising technology switching is not just logically supported through the findings in this thesis research, but is well supported directly and indirectly in many other articles (Arango & Larsen, 2011; Csereklyei & Stern, 2018; Haas et al., 2011; Haratyk, 2017; Safarzynska & van den Bergh, 2011; Woo et al., 2014). With the understanding that many other authors suggest that fuel price and return on investment are direct factors for choosing a generation technology for firms investing in new generation, then FITs as a governing factor logically follow as a market-based method for incentivising change when implemented to support renewable energy technologies. However, this is dependent on an implementation focused on fighting climate change through energy policy.

The two largest contributors to carbon emissions in the United States are transportation and electricity generation (EPA, 2020). Therefore, the key path to achieving the emission reduction targets of SDG #13 and the Paris Agreement is to reduce emissions from these two categories. This thesis explored the market and policy factors and interactions looking for reductions in greenhouse gas emissions and ways to improve adoption of renewable energy technologies. A core assumption of all these policies explored is that governments enact them with the goal of making some positive change within energy markets, whether that be the increases in renewables or a decrease in emissions. Thus, a key understanding is revealed: these policies are not the panacea for enacting change but must be a force multiplier of political will. Regions that want to combat climate change likely will also take other steps in parallel to address climate change. Political will does not seem uniform as many states and provinces actively fight climate-based policies such as carbon taxes. What’s more, the reduction of carbon-based energy generation is just one facet of the fight for a cleaner future. However, the interaction of markets is fundamentally tied to a worldview based in capitalism, with the profit motive of corporations at odds with the public interest in reversing a climate catastrophe, as evidenced by 40% of the states analysed not having any related renewable energy policies in line with fighting climate change.

We have known about anthropogenic climate change for the better part of a century, and yet, our world stands on the precipice of global climate catastrophe. World powers seem unfocused in commitments to climate action, as demonstrated by the United States leaving and rejoining the Paris agreement within the span of a year (Stracqualursi & Kann, 2021). This project sought to contribute to the body of literature in support of potential solutions and answer questions about the steps towards a sustainable future. It is imperative that regardless of the potential answers to questions explored, decisive and tangible actions are taken to save our world from irreversible climate collapse.

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Appendix

Appendix 1: Python Scripts

Data Normalizer Python Code

```
import os #used to navigate to where the file is stored
import pandas as pd #the dataframe package
import plotly.express as px
import plotly.graph_objects as go
#import scipy.stats as stats
import statsmodels.api as sm
import numpy

#set view options
pd.set_option("display.max_columns", 16)
pd.set_option("display.max_rows", 100)
pd.set_option("display.expand_frame_repr", False)

#read data sheets from excel
dfcan = pd.read_excel('can_electricity-generation 2005-2019.xlsx')

dfusa = pd.read_excel('US_Electrical_annual_generation_state-1990 to 2019.xlsx')

dfcode = pd.read_excel('coding table.xlsx')

dfusa.drop(dfusa.loc[dfusa['Energy source']=='Total'].index,inplace=True)

print(dfusa,dfcan)

#concatenate the US and Canada Data into one dataframe
dfcat = pd.concat([dfcan,dfusa])

print(dfcat)

#left outer join using relational algebra on the region abbreviation column as key
dfjoin = pd.merge(dfcat,dfcode, how="left", on=["Abb"])

print(dfjoin)
#print resulting dataframe to an excel sheet for later processing
with pd.ExcelWriter('normalized_data_joined.xlsx') as writer:
    dfjoin.to_excel(writer)
```

Analysis 2 Python Code

```
import os #used to navigate to where the file is stored
import pandas as pd #the dataframe package
import plotly.express as px
import plotly.graph_objects as go
#import scipy.stats as stats
import statsmodels.api as sm
import numpy

#set view options
pd.set_option("display.max_columns", 16)
pd.set_option("display.max_rows", 100)
pd.set_option("display.expand_frame_repr", False)

#load data
df1 = pd.read_csv('analysis two gdp x tech.csv')

#run regression on %
m1 = sm.OLS.from_formula(formula='df1["Biomass-Other-P"] ~ GDP', data=df1).fit()
m2 = sm.OLS.from_formula(formula='df1["Coal-Coke-p"] ~ GDP', data=df1).fit()
m3 = sm.OLS.from_formula(formula='df1["Hydro-p"] ~ GDP', data=df1).fit()
m4 = sm.OLS.from_formula(formula='df1["Natural-Gas-p"] ~ GDP', data=df1).fit()
m5 = sm.OLS.from_formula(formula='df1["Nuclear-p"] ~ GDP', data=df1).fit()
m6 = sm.OLS.from_formula(formula='df1["Petroleum-p"] ~ GDP', data=df1).fit()
m7 = sm.OLS.from_formula(formula='df1["Solar-p"] ~ GDP', data=df1).fit()
m8 = sm.OLS.from_formula(formula='df1["Wind-p"] ~ GDP', data=df1).fit()

#print results
print(m1.summary(), m2.summary(), m3.summary(), m4.summary(), m5.summary(),
m6.summary, m7.summary(), m8.summary())

#print graph of solar %
fig1 = px.scatter(df1, x='GDP', y='Solar-p', color='Region', title="Solar % x GDP")
trendline = m7.fittedvalues
fig1.add_traces(go.Scatter(x=df1['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))
#fig1.show()

#run regression on absolute tech
m1 = sm.OLS.from_formula(formula='df1["Biomass-Other"] ~ GDP', data=df1).fit()
m2 = sm.OLS.from_formula(formula='df1["Coal-Coke"] ~ GDP', data=df1).fit()
m3 = sm.OLS.from_formula(formula='Hydro ~ GDP', data=df1).fit()
m4 = sm.OLS.from_formula(formula='df1["Natural-Gas"] ~ GDP', data=df1).fit()
m5 = sm.OLS.from_formula(formula='Nuclear ~ GDP', data=df1).fit()
m6 = sm.OLS.from_formula(formula='Petroleum ~ GDP', data=df1).fit()
```

```
m7 = sm.OLS.from_formula(formula='Solar ~ GDP', data=df1).fit()
m8 = sm.OLS.from_formula(formula='Wind ~ GDP', data=df1).fit()

print(m1.summary(), m2.summary(), m3.summary(), m4.summary(), m5.summary(),
m6.summary, m7.summary(), m8.summary())

fig1 = px.scatter(df1, x='GDP', y='Biomass-Other', color='Region',title="Biomass \ Geothermal \
Other x GDP")
trendline = m1.fittedvalues
fig1.add_traces(go.Scatter(x=df1['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))
fig2 = px.scatter(df1, x='GDP', y='Natural-Gas', color='Region',title="Natural Gas x GDP")
trendline = m4.fittedvalues
fig2.add_traces(go.Scatter(x=df1['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))
fig3 = px.scatter(df1, x='GDP', y='Solar', color='Region',title="Solar x GDP")
trendline = m7.fittedvalues
fig3.add_traces(go.Scatter(x=df1['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))

#fig1.show()
#fig2.show()
#fig3.show()

df1 = df1.sort_values(by=['GDP'], ascending=False)
fig = px.bar(df1, x='Region', y='GDP', title="GDP")
#fig.show()

#redo the stats without zeros
df2 = df1[df1['Solar-p'] != 0]
df3 = df1[df1['Biomass-Other'] != 0 ]
df4 = df1[df1['Natural-Gas'] != 0 ]
df5 = df1[df1['Solar'] != 0 ]

m1 = sm.OLS.from_formula(formula='df2["Solar-p"] ~ GDP', data=df2).fit()
m2 = sm.OLS.from_formula(formula='df3["Biomass-Other"] ~ GDP', data=df3).fit()
m3 = sm.OLS.from_formula(formula='df4["Natural-Gas"] ~ GDP', data=df4).fit()
m4 = sm.OLS.from_formula(formula='Solar ~ GDP', data=df5).fit()

print(m1.summary(), m2.summary(), m3.summary(), m4.summary())

fig1 = px.scatter(df2, x='GDP', y='Solar-p', color='Region', title="Solar % x GDP")
trendline = m1.fittedvalues
fig1.add_traces(go.Scatter(x=df2['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))
```

```
fig2 = px.scatter(df3, x='GDP', y='Biomass-Other', color='Region',title="Biomass \ Geothermal \
Other x GDP")
trendline = m2.fittedvalues
fig2.add_traces(go.Scatter(x=df3['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))
fig3 = px.scatter(df4, x='GDP', y='Natural-Gas', color='Region',title="Natural Gas x GDP")
trendline = m3.fittedvalues
fig3.add_traces(go.Scatter(x=df4['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))
fig4 = px.scatter(df5, x='GDP', y='Solar', color='Region',title="Solar x GDP")
trendline = m4.fittedvalues
fig4.add_traces(go.Scatter(x=df5['GDP'], y=trendline, mode = 'lines', marker_color='black',
name='Trendline'))

fig1.show()
fig2.show()
fig3.show()
fig4.show()
```