Impacts of climate change on residential demand for electricity in New Brunswick

by

Chi Danh Dao

Bsc. Finance and Banking, Tan Tao University, 2015

Report Submitted in Partial Fulfillment
of the Requirements for the Degree of

Master of Arts in Economics

in the Graduate Academic Unit of Department of Economics

Supervisor: Yuri Yevdokimov, PhD, Department of Economics

Examining Board: Luc Theriault, PhD, Department of Economics, Chair
Murshed Chowdhury, PhD, Department of Economics
Elif Dalkir, PhD, Department of Economics

This report is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

May, 2021

ABSTRACT

The relationship between climate change and energy is often misperceived as being unidirectional. That is, production and consumption of energy sources, including electricity, emit greenhouse gases (GHG) that contributes to global warming. While correct this view ignores the impacts of rising temperature on energy consumption. The feedback effects of climate changes are mainly due to changes in heating/cooling requirement and often vary geographically. So far, there has not been any studies investigating such relationship in the province of New Brunswick. This report seeks to fill this gap and looks at the impacts of climate changes on the future of households' demand for electricity in the province. In doing so, we come up with projections of future electricity demand in the province under different climate changes scenarios. Under our most aggressive projections, significant investment in power generating capacity will be needed to meet a demand of 11Mwh by 2095.

DEDICATION

For my amazing wife who has always been there for me. Thank you for always believing in me even when I did not

ACKNOWLEDGEMENTS

I would like to thank Dr. Yuri Yevdokimov for his comments and engagement throughout the entire process of this report. I also want to extend my gratitude to Dr. Murshed Chowdhury and Dr. Elif Dalkir as well as other professors and staffs at the Economic Department. This would have not been possible without your supports.

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

For the last century, climate change has been one of the most, if not the most, contentious challenges on the global state. In Canada, discussions around the Trans Mountain pipeline expansion serves as an excellent example to as why climate change mitigation remains tricky. On one hand, proponents of the project have argued that it has huge economic benefit through creation of new jobs and lower production costs. Among other issues, opposers of the project have suggested that the expansion would prevent Canada from meeting its 2030 emission target. This argument reflects the popular conception that relationship between energy consumption and climate change is unidirectional. That is, production and consumption of energy contribute directly to the global warming process. While correct, this view is incomplete and ignore the feedback effects of changes in weather pattern on the supply and demand for energy.

In the case of electricity, the generation process requires combustion of fossil fuels thus raising atmospheric concentrations of greenhouse gas. At the same time, changes in weather, especially those in temperatures, also lead to variations in demand for electricity. In some cases, rising temperature can, in fact, depress demand due to reduction in heating requirements. Given the bidirectional nature of their relationship, ignoring the impacts of climate changes on demand for electricity can lead to inefficient mitigation strategies. Speaking about electricity consumption and climate change, almost all studies emphasize the role of temperatures on electricity demand as the major factor. The nature of this relationship, however, varies across geographical locations due to differences in climates as well as sociological factors.

Electricity has been and will remain to be an integral part of Canada’s economy, New Brunswick included. As such, good understanding of the linkages between demand for electricity and temperatures is critical for the province. Given the lack of research conducted specifically for New Brunswick, this report hopes to provide some insights into the linkage between residential demand for electricity and climate changes in the province. Using monthly demand for electricity between Jan 2012- Sep 2019, we established that there exists a statistically and economically significant relationship between variations in temperatures and residential demand in New Brunswick. As part of the exercise, we also provide future projections for the province's residential demand for electricity under two different climate changes scenario. Under our most aggressive prediction, residential demand for electricity in New Brunswick will grow roughly to 11 million Mwh by 2095.

Chapter 2 Literature review

2.1 Theoretical framework

We follow Hausman (1979, 1985), Dubin et al. (1986) as well as Eskeland & Mideksa (2010) and assume that individuals derive utility from their perceived comfort level as well as consumptions of other goods. Formally, we define utility as a separate function of comfort and consumptions of other goods and services:

$$U_{it} = u(C_{it}, Z_{it}) \quad (1)$$

where U_{it} denote agent i's utility at time t. Let C_{it}, Z_{it} denote the agent's perceived comfort level and consumptions of other goods at time t. Adopting the approach in Eskeland & Mideksa (2010), we define the comfort level at time t- C_{it}- as a function of the climate- θ_{it}, adaptive devices (space heater, air conditioner, etc) - A_{it} and electricity use-E_{it}:

$$C_{it} = f(\theta_{it}, A_{it}, E_{it}) \quad (2)$$

Imposing standard assumptions on the utility function so that u_C, u_Z >0; u_{CC}, u_{ZZ} < 0 and the Inada conditions (i.e $\lim_{C\to 0} u_C = \lim_{Z\to 0} u_Z = +\infty$ and $\lim_{C\to\infty} u_C = \lim_{Z\to\infty} u_Z = 0$). Equations (1), (2) provide a theoretical justification for the relationship between climatic factors and residential demand for electricity. Starting from equilibrium level of energy consumption, as temperature varies this would lead to changes in θ_{it} and consequently in the comfort level perceived by the agent. Agent will try to maximize (1) subjected to his/her budget constraint and choose to "consume" a different level of C_i. In the short run, where capital stocks of adaptive devices− A_{it} − are fixed, this implies regulating the climate to θ_{it}^* such that $C_{it} = f(\theta_{it}^*) = C_{it}^*$ where C_{it}^* is the optimal comfort level. In the context of variations in temperature, this involves changes in utilization rate of existing heating and cooling devices to arrive at the desirable temperature.

Since demand for electricity is, in general, derived from demand for other activities it would be helpful to consider electricity consumption as an input to households' production process. Hausman (1979) separated input decision for this process into capital stock (of electrical devices) and utilization decision presenting the fixed and variable aspect of inputs. As discussed above, since capital stocks is fixed, short run variations in household's demand for electricity is determined solely by utilization decision of existing devices. In a sense, one can consider the purpose of this report as seeking to establish the short run relationship between households' utilization decision and variations in temperature.

As with most production processes, individuals can choose to invest in their "capital stocks" in the long run. In our context, agents can choose to install new air conditioning units in place of less effective devices (i.e fans). In fact, studies have cited air conditioners as one of households' main adaptation to rising temperature (David and Gertler, 2015; Santamouris (2016); Cian et al, 2020). As air conditioning units tend to consumer much more energy than other cooling devices, short run dynamics between demand for electricity and temperature will differ significantly from the relationship in the long run.

2.2 Empirical relationship between electricity and temperature

Early studies on determinants of electricity demand focused on the impacts of technological change, prices, income, and population growth (Fisher and Kaysen, 1962). Among early works that looked explicitly into the effects of climatic variable, Sailor and Munoz (1997) concluded that for the U.S electricity demand exhibited clear seasonal pattern with demand being higher during hot months. Later study by Mahmood et al (2013) also supported positive relationship between mean temperature and residential demand in Karachi District of Pakistan.

Beside temperature, other climatic variables that can potentially affect household's demand for electricity include humidity, windspeed and precipitation. When estimating the response function of demand with temperature, researches oftentimes include these factors as control variables (Robinson, 1997; Hor et al, 2005; Hernandes et al, 2012; Auffhammer, 2018). Holding temperature constant, perception of comfort depends on factors such as humidity and windspeed. For example, hot and humid days tend to incur more cooling requirement than drier days at the same temperature. Since variations in household's consumption patterns are mostly due to changes in heating/cooling requirements; these factors should also be controlled for to obtain unbiased estimations. Robinson (1997) explored the impacts of various climatic variables on demand for electricity. The author concluded that among climate-related factors temperature has the most impact on demand followed by humidity, wind, and precipitation. Later study by Hor et al (2005) for England and Wales included an equivalent set of climatic variables with heating degree days (HDD), cooling degree days (CDD), mean monthly relative humidity, mean monthly wind speed, mean monthly sunshine hours and monthly rainfall. Consistently with Robinson (1997)'s, their results suggested that temperature (CDD, HDD) is the most important factors among climatic determinants.

Despite the well-established link between demand and variations in temperature, the magnitudes vary across places. Using a simple linear model, Parkpoom and Harrison (2008) concluded that electricity consumption patterns in Thailand are highly seasonal. The marginal effects of 1^0C increase in mean temperature ranges from 2.2% in November to 10.6% in March. Projections of future demand for electricity in the U.S appear to follow similar pattern. By the end of the century, Fonseca et all (2018) predicted that the U.S's electricity consumption may increase by 20% during summer months whereas consumption during winter may decrease by 6%.

Strong seasonality is a persistent feature of demand for electricity and emerges from the nonlinear relationship between demand and variations in temperature. As mentioned above, fluctuations in residential demand for electricity are mostly due to changes in heating/cooling requirements in response to variations in temperature. Starting from a very cold weather, rising temperature will initially reduce demand for electricity due to lower heating requirements. As temperature continues to rise, so will consumption of electricity for cooling purposes. Theoretically speaking, this will give rise to a U-shaped relationship between quantity demanded and temperature. Later works by Ruth and Lin (2006), Deschênes and Greenstone (2007), Franco and Sanstad (2007), Aroonruengsawat and Auffhammer (2011), Li et all (2018) have mostly confirmed the nonlinear nature of the relationship between fluctuations in demand and temperature for various countries.

Franco and Sanstad (2007) analyzed the linkages between average daily temperature and daily electricity demand in California. Using a cubic polynomial of daily average temperature, they observed a U-shaped response function between variables in question. Eskeland and Mideksa (2010) conducted a similar study for 31 European countries using Cooling and Heating degree day (CDD/HDD) instead of average temperature as independent variable. Their results suggested that the impacts of global warming on demand for electricity in Europe is rather minor at only 0.04% and 0.01% increases per one-unit increase in CDD and HDD respectively. Using a similar framework, an earlier article by Sihvola et all (2009) arrived at similar conclusion where one-unit increase in HDD would increase demand by 0.00%-0.05% while coefficients on CDD were insignificant in most cases.

In a somewhat related paper, Deschênes and Greenstone (2007) estimated the relationship between residential energy consumption, including electricity and other energy sources. To account for nonlinearity, the authors divided the range of mean daily temperature into bins and used the number of days belong to each bin as independent variable. Their findings also suggested a U-shaped response function between temperature and residential demand for energy. Using similar method, Aroonruengsawat and Auffhammer (2011) analyzed residential demand for electricity in California at household levels. They observed that the temperature response function's shape varies across climate zones- ranging from flat to U-shape to reserved L-shape. Their results indicated that linkage between residential demand for electricity and temperature is idiosyncratic to the region.

2.3 Residential demand for electricity and macroeconomic variables

Apart from climate-related factors, several scholarly works have established a strong link between households' consumption of electricity and macroeconomic variables (Ghosh, 2002; Krueger, 2006; Doytch and Narayan, 2016; Omri and Kahouli, 2013; Abdouli and Hammami ,2017; Ridzuan et al ,2020). Ridzuan et al (2020) explored the long-run relationship between major macroeconomic indicators including economic growth, urbanization population growth, financial development, and inflation. Using the Autoregressive Distributed Lags bound-testing approach, the authors concluded that these variables significantly influenced electricity demand in Malaysia in the long-run.

Sharma and Kautish (2019) employed nonlinear autoregressive distributed lag (NARDL) model to examine the influence of GDP per capita, foreign direct investment and crude oil demand on per capita electricity consumption in the short and long run in India. The short run results show that positive shocks in GDP and FDI have direct impact on per capita electricity consumption, though GDP has more significant effect than FDI. Similarly, the long run results confirmed that growth in national output and FDI will increase electricity demand. Most papers on the relationship between demand for electricity and macroeconomic variables do not distinguish between commercial and residential sector. However, as electricity can be considered as a normal goods, economics theories suggested that the observed relationship is true for both sectors.

As highlighted by the results from Aroonruengsawat and Auffhammer (2011), linkage between variations in temperature and those in residential demand for electricity are specific to a region. Thus, imposing the observed relationship from one region to another can lead to misleading conclusions. Due to the distinctive demography of New Brunswick (older population with relatively low income), one can expect the linkage here to be different than that of other provinces in Canada. To the best of our knowledge, this report is the first attempt to investigate the impact of climate change, specifically those of global warming, on residential demand for electricity for the province of New Brunswick. Yevdokimov et all (2018) estimated the willingness-to-pay (WTP) for electricity in New Brunswick for the period between 1991-2013. Even though the authors included environmental variables as one of the determinants for WTP; they did not explore its effects explicitly.

Climate change has been, and remains to be, one of the most consequential challenges of the last century. Amidst this, a good understanding on the dynamics between global warming and demand for electricity demand is of great importance for the province of New Brunswick. The main contribution of this report, then, is to inform policy makers with insights into this dynamic in New Brunswick.

Chapter 3 Methodology

Historically, studies have used both the "primitive" meteorological variables and derived heating/cooling degree day to estimate the sensitivity of households' demand for electricity to fluctuations in temperature. The main implication of the linkage involving residential demand for electricity, comfort level and temperature as described in 2.1 is that the relationship between fluctuations in temperature and demand is non-linear. Starting from high temperature, comfort level will first increase as temperature decreases. As temperature continues to drop, comfort level will then decrease leading to higher level of consumption.

Since inclusion of higher order terms introduces collinearity into the model and reduces estimations' precision. Degree day variables address nonlinearity without using higher order terms of average temperature, thus improving the model's accuracy. Sailor and Munoz (1997) concluded that for electricity demand derived variables performs better than "primitive" climatic variables. Usages of degree day variables can be traced back to Dubin et al. (1986) which looked residential demand for heating and cooling. Specifically, the authors specified a utility function of the form:

$$U = u(\tau - \tau^{*}, Z)$$

where τ, τ^{*}, Z denote the temperature, blissful comfort level and consumption of other goods respectively. The term $\tau - \tau^{*}$ measures the differences between the actual and ideal temperature than can induce discomfort in agents. Since agents seeks to maximize their comfort level, ceteris paribus, this would lead to changes in their demand for electricity. Cooling and heating degree day are often defined in similar fashion relatively to some base temperature(s):

$$CDD = T - Temp_{Cooling}$$

$$HDD = Temp_{Heating} - T$$

where $T, Temp_{Cooling}, Temp_{Heating}$ are the actual temperature, the threshold above (below) which individuals will become uncomfortable.

It should come as no surprise that the value of $Temp_{Cooling}$ and $Temp_{Heating}$ often vary across geographical locations. For example, Li(2018) chose $Temp_{Cooling} = 26^0C$ and $Temp_{Heating} = 18^0C$ when looking the relationship between residential demand for electricity and temperature in using Nanjing, China. For European country, Eskeland and Mideksa (2010) defined $Temp_{Cooling} = 22^0C$ and $Temp_{Heating} = 18^0C$. A commonly use threshold in North America is to set the base temperature equal to 18^0C for both cooling and heating (Nall and Arens, 1979; de Dear and Brager, 2001). Ruth and Lin (2006) argued that these thresholds depend on highly specific factors such as building stocks and cultural preferences. The authors empathized the need to identify the place-specific base temperature when conducting analysis at subnational level.

For New Brunswick, there is a lack of CDD and HDD projections with heating and cooling threshold specific to the province. Since one of this report's objectives is to provide "business-as-usual" projections for residential demand, we opt for the conventional approach in the literature for North American and define $Temp_{Cooling} = Temp_{Heating} = 18^0C$. More details regarding CDD and HDD variables will be provided in section 4.2.

Chapter 4 Empirical work

4.1 Data description

4.1.1 Residential demand for electricity

We use data from NB Power's System Information Archive from January 2012 to September 2019 to estimate the relationships between changes in climatic variables and residential demand for electricity in New Brunswick. Since NB Power's System Information Archive does not differentiate between residential and industrial demands, the raw data obtained are total demands (residential and industrial) for electricity in New Brunswick. To arrive at the relevant data, we use the annual dataset from Statistic Canada which disaggregates total electricity consumption into four categories (residential, agriculture, mining and manufacturing and other industries). From there we assume that annual percentage of residential consumption over total consumption is constant throughout the year. Furthermore, as data for 2019 is not available we assume that the percentage stays constant between 2018 and 2019.

4.1.2 Climatic variables

Cooling degree days (CDD) and heating degree days (HDD) are defined as the difference between the average temperature and a predetermined base temperature. To compute daily CDD and HDD, we first collect data on daily average temperature from Environment and Climate Change Canada's Climate dataset. Specifically, we use daily data from Woodstock station, New Brunswick. From there, we calculate monthly CDD and HDD using the following formulas:

$$CDD_{month} = \sum_{i} (Temp_i - 18)$$

$$HDD_{month} = \sum_{i} (18 - Temp_i)$$

where $Temp_i$ is daily average temperature. As this report was conducted using monthly data, CDD_{month} and HDD_{month} capture the total differences between average daily temperature and the blissful comfort level within a month. For example, suppose that during January daily average temperatures are always at -10^{0}C, HDD_{Jan} will be calculated as:

$$HDD_{Jan} = \sum_{1}^{31} 18 - (-10) = 31 * 28 = 868$$

Similarly, suppose that daily average temperatures in July are always at 22^{0}C, CDD_{Jul} will be:

$$CDD_{Jul} = \sum_{1}^{31} 22 - 18 = 31 * 4 = 124$$

Notice here that, HDD is defined only for days where daily average temperature is below 18^{0}C, and conversely for CDD. By design, both variables will only take on positive values which allow them to capture the positive impact of increased heating as well as cooling requirements on households' consumption level.

4.1.3 Electricity price and macroeconomic variables

Data on nominal electricity in New Brunswick is obtained through our communication with NB Power. This report uses average price for residential customer from NB's power as electricity price. In practice, electricity in New Brunswick is priced progressively by blocks. Hence, our use of average price is obviously simplification of the reality. For macroeconomic variables such real GDP and CPI, we again utilize datasets from Statistics Canada. Since GDP is available only in annual form, we again assumed monthly GDP to be constant within the same year. Table 1 summarizes the data used in this report.

Table 1: Descriptive statistics of variables

Variable	Number of observations	Mean	Standard deviation	Min value	Max value
Residential demand (Mwh)	93	524443.7	116946.7	374062	783279
Real GDP (2012 constant price-CAD)	93	1958065	98159.79	1800000	2100000
Total CPI (base 2002)	93	127.9	4.83	121	137.4
Electricity CPI (base 2002)	93	141.15	6.699	132.9	153.5
Nominal electricity price (CAD/kW)	93	10.39	.41	9.85	11.18
Monthly mean temperature (^{0}C)	93	5.43	10.64	-15.42143	21.10968
Cooling degree days	93	13.71	24.89	0	107.6
Heating degree days	93	392.06	302.32	5.3	935.8

4.2 Model specification

4.2.1 Residential demand

Since the main goal of this study was estimation of the relationship between extreme temperatures and residential demand for electricity, we assumed that this relationship can be captured using the following functional form

$$Y_t = Y(CDD, HDD, Price, H, Y_{t-1})$$

where H is a vector of macroeconomic variables. Particularly, monthly residential demand was regressed on the relevant factors using the following 8 specifications:

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 HDD_t + \alpha_1 Price_t + \alpha_2 Real\ GDP + \alpha_3 Overall\ CPI + \alpha_4 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (1)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 HDD_t + \alpha_1 ln(Price_t) + \alpha_2 ln(Real\ GDP) + \alpha_3 ln(Overall\ CPI) + \alpha_4 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (2)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + \alpha_1 Price_t + \alpha_2 Real\ GDP + \alpha_3 Overall\ CPI + \alpha_4 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (3)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + \alpha_1 ln(Price_t) + \alpha_2 ln(Real\ GDP) + \alpha_3 ln(Overall\ CPI) + \alpha_4 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (4)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 HDD_t + \alpha_1\ Electricity\ CPI + \alpha_2 Real\ GDP + \alpha_3 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (5)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 HDD_t + \alpha_1 ln(\ Electricity\ CPI) + \alpha_2 ln(Real\ GDP) + \alpha_3 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (6)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + \alpha_1 Electricity\ CPI + \alpha_2 Real\ GDP + \alpha_3 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (7)

$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + \alpha_1 ln(ElectricityCPI) + \alpha_2 ln(RealGDP) + \alpha_3 Y_{t-1} + \alpha_4 year + \alpha_5 summer + \varepsilon_t$ (8)

where:

Y_t : residential demand in period t

CDD_t: Total cooling degree days for period t

HDD_t: Total heating degree days for period t

$Price_t$: Nominal price of electricity for residential customers

$Real\ GDP_t$: Real GDP (2012 constant price)

$Overall\ CPI_t$: CPI measured for all goods and products (2002 =100)

$year_t$: annual trend variable from 2012 to 2019 (2012=1, 2019=8)

$summer$: dummy variable (1: May-September, 0: otherwise)

Specification (3), (4), (7), (8) contain a squared term of CDD to allow for nonlinearity in the relationship between temperature and residential demand for electricity.

As the relationship between climate changes as well as macroeconomic factors and energy demand is bidirectional, OLS estimations from specifications (1)-(8) will most likely face with endogeneity problem. One method to deal with the problem of endogeneity is to adopt the instrumental variable (IV) or 2-stage least square (2SLS) approach instead of OLS. Both methods require a variable the satisfies both the inclusion (strong predictor of endogenous variable) and exclusion (uncorrelated with dependent variable) criteria which was not present in the current literature.

Another approach to address the bidirectional nature of the relationship between electricity demand and climate changes is the use time series framework (Emodi et all, 2017). Common time series frameworks such as Auto Regressive Distributed Framework (ARDL) and Vector Error Correction Model (VECM) require data to be of either I(0) or I(1). Specifically, VECM requires all series to be of I(1) whereas ARDL allows for a mixture of I(0) and I(1) processes. Since results from both augmented Dickey–Fuller test (ADF) test for unit root (Appendix-Table A.3) suggested residential demand for electricity is of neither I(0) nor I(1), these approaches are not applicable in our case.

Confronted with the lack of good IV from the literature and the nature of our data, we elected to estimate our models using the OLS method. This is indeed one of the limitations of this report as well as this stream of literature in general.

ADF test also reveal that some of the macroeconomic variables (i.e price, electricity CPI) are integrated of order 1. Regressing non-stationary variables introduces the risk of spurious relationship between variables in questions. To this end, we followed Woodbridge (2012) and included trending variable-$year$- as a remedy.

4.2.2 Parameters estimation for projections

To arrive at projections for residential demand for electricity in New Brunswick, we re-estimate the relationship between variations temperature and demand using the following specification:

$$Y_t = \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + \alpha_1 year + \varepsilon_t \quad (9)$$

This specification is specification (7),(8) without vectors of macroeconomic factors and prices as control variables. Since access to high-quality projections of real GDP, electricity prices and CPI is not available, specification (9) allows us to obtain forecast for demand in province using only CDD and HDD predictions from Climate atlas of Canada.

4.3 Statistical estimation

Table 2 represents our estimation of the residential demand for electricity in New Brunswick.

Table 2: Estimations of residential demand for electricity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CDD	853.3***	849.8***	1363***	1360***	908***	909.7***	1958***	1974***
CDD^2			-5.49	-5.493			-11.4***	-11.56298***
HDD	413.9***	412.6***	418.2***	416.9***	436.8***	435.8***	442.6***	441.8***
Price	19466.36		10138.92					
ln(Price)		248978.5		152263				

Real GDP	.146*		.147*		-.01		.02	
ln(real GDP)		310858**		311716**		46710		95972.8
Overall CPI	-11701***		-10878.7***					
ln(overall CPI)		-1542201***		-1437889***				
Electricity CPI					-3779**		-4191.4***	
ln(electricity CPI)						-470535.9*		-539150.1***
Y_{t-1}	.049	.051	.045	.049	.034	.04	.031	.04
year	19691.8***	18943.7**	19678.5***	18983.9**	16247.96**	13533.2**	16298.5**	14043.5**
summer	19281.95**	19211.22**	14659.45	14578.25	19384.92**	19718.63**	9920.34	10023.35
constant	1238803***	2626707	1227150***	2333511	794003***	1904180	789658***	1526403

4.3.1 Temperature and residential demand for electricity

Across all specifications, both CDD and HDD are observed to have economically and statistically significant effects on residential demand for electricity in the province of New Brunswick. Additionally, these effects are also robust to changes in specifications. For HDD, increases in demand due to an additional heating degree day ranges from 413.9 Mwh to 435.83 Mwh (significant at 1%). For specification (1), (2), (5), (6) the effect of a unit increases in CDD were observed to be between 849.8 Mwh and 909.68 Mwh (significant at 1%).

Earlier in this report, we mentioned that regressing demand on derived variables such as CDD and HDD accounts for nonlinearity in the relationship between temperature and demand for residential electricity without inclusion of higher order terms. In New Brunswick's case, however, since Environmental Canada adopts the same base threshold (18^0C) for both cooling and heating degree day, there may still exist nonlinearity in the linkages between households' demand for electricity and derived variables. For example, one can expect demand to decline initially at low level of CDD as temperature starts to rise due to decreased demand for heat. Once temperature passes a certain threshold, i.e at higher CDD level, demand will pick up to meet the increases in cooling needs.

To capture this, we included a squared term of CDD in specification (3), (4), (7) and (8). In this study, we decided not to include a squared term of HDD (HDD^2) as our previous analysis had suggested the effect is economically insignificant (close to 0)[1].

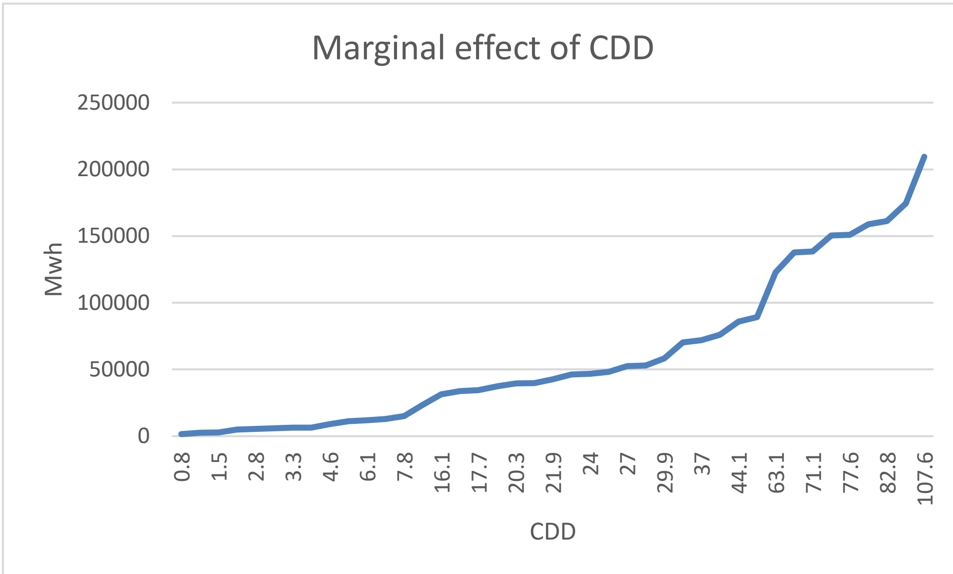
For specification (7) and (8) coefficients associated with CDD^2 are negative and significant at 1%. Specification (7) and (8) suggest that the relationship between CDD and residential electricity demand follows an inverted U-shaped pattern. In this sense, our results are inconsistent with the observed pattern in the literature (Franco and Sanstad (2008), Fonseca et. all (2019)). However, Li et. all (2018), which looked at residential demand for electricity in China, observed a similar relationship between CDD and residential demand as with ours.

Moreover, holding everything else constant the relationship between CDD and residential demand for electricity within the ranges of our data appears to on the increasing segment of the U-shaped curve. Figure 1 illustrates the marginal effect of CDD on residential demand within the ranges of CDD observed.

---

[1] The effect of HDD^2, or lack thereof, reflects the fact that households use other sources of energy instead of electricity as heating demand increase, especially during the coldest months.

Figure 1 Marginal effect of CDD on residential demand



For specifications (7) and (8), we cannot offer a general statement involving the marginal effects of CDD. As explained above, this relationship varies between ranges of CDD, and can be characterized by the following relation: $\beta_1 + \beta_2 CDD_t$ where β_1, β_2 are coefficients attached to CDD and CDD^2 respectively.

To control for seasonal patterns in residential demand for electricity, we included a dummy variable for summer months (May to September) in all specifications. Interestingly enough, coefficients associated with this dummy variable are insignificant when CDD^2 is included (specifications (3), (4), (7),(8)) but are highly significant otherwise. Average temperature in New Brunswick rarely rises above 18^0C outside of summertime. Consequently, instances with CDD above 0 are observable almost exclusively during the summer season. Statistically this implies that the CDD and the dummy variable are highly correlated. As a result, the inclusion of CDD^2 in specifications (3), (4), (7) and (8) may have caused coefficients associated with the dummy variable to be insignificant.

Without the squared term, we observed a significant and noticeable difference between consumption pattern during summer and other seasons. Particularly, holding everything else constant, the difference between total demand in summer months and the rest of the year ranges from 19,281 to 19,718.63 Mwh. Compounded with the effect of CDD, this implies residential demand for electricity is highly seasonal with demand being higher during summertime. Seasonality in households' use of electricity can be explained by the lack of alternative energy sources for space cooling purposes. Since there exists cheaper and more efficient alternatives for heating purposes (natural gas and firewood for example), households will switch to these alternatives as temperatures get colder. Nevertheless, such alternatives are not commonly available for most cooling devices such as fans and air conditioners.

We opted to keep the dummy variable to demonstrate explicitly the seasonal nature of residential demand in New Brunswick despite the reduction in accuracy of estimated coefficients on CDD and CDD^2. As will be shown later, estimations from specification (9) which does not include the dummy variables are reasonably close to results from Table 2.

4.3.2 Price and income effects:

Economic theory suggests that electricity should be a normal good. This is the case since higher income should encourage more utilization of electronic devices powered by electricity. Consequently, one can expect residential demand for electricity to increase as income rises. Indeed, apart from specification (5), the relationship between demand and income as proxied by real GDP takes on the expected positive sign. Results from specifications (1) and (3) suggest that an increase in GDP by CAD$1 would drive up households' demand for electricity by 0.147 Mwh (significant at 10%).

Since economic progress is often measured in term of GDP growth rate, specifications (2) and (4) provide a more natural interpretation of the relationship between income and demand for residential electricity. Specifically, specifications (2) and (4) suggest that a 1% growth of real GDP would increase demand by approximately 310,000 Mwh. The above coefficients measure the marginal effects of GDP on monthly demand for residential electricity. To arrive at the effect of GPD on annual demand, one will have to multiply these coefficients by 12. This implies that an additional dollar in real GDP will increase annual demand by 1.764 Mwh; whereas a growth rate of 1% in GDP will bring demand up by 3.72 million Mwh. Though imprecise, these simple estimations allow us to illustrate the importance of GDP in determining residential demand. While our results involving the relationship between GDP and residential electricity demand are rather conclusive, we did not find a statistically significant relationship between electricity price and residential demand.

Price was included as an independent variable in specification (1), (2), (3) and (4). Since price data from NB Power were presented in nominal terms, we also included monthly CPI, calculated for all goods and services. As overall CPI is a proxy variable for inflation, including this as an independent variable allows us to control for inflation and to capture the effect of increase in real price on demand for electricity. However, the observed relationships in our data are statistically insignificant. This appears to be a data problem as electricity price is highly correlated with real GDP and CPI (p_{GDP}= 0.9204, p_{CPI}= 0.9454).

Nevertheless, the observed relationship between inflation, as proxied by CPI, is negative and statistically significant. Specifications (3) and (4) indicate that the effect of the inflation rate of 1% varies from -1.4 million Mwh to -1.5 million Mwh (significant at 1%) suggesting that demand is much more sensitive to changes in CPI.

Compared to the marginal effect of 1% growth of GDP at approximately 310,000 Mwh, the magnitude of these coefficients is remarkable. One possible explanation for this finding is: inflation makes households more unsure about the future. Consequently, they will reduce their overall consumptions including consumption of electricity.

As already mentioned, electricity price was found to be highly correlated with other macroeconomic variables. This situation is referred to as the issue of multicollinearity and often results in imprecise estimation of the coefficients. To overcome this issue, in specifications (5)-(8) we attempted to estimate the relationship between price and demand using CPI for electricity. Similar to how overall CPI measures changes in the overall price level, CPI for electricity measures fluctuations in electricity price. For these specifications, we observed a negative and significant relationship between electricity price and demand.

According to specifications (5) and (6), the estimated decrease in monthly demand due to one unit increase in electricity CPI level varies between -3,779.91 Mwh (significant at 5%) and -4,191.35 Mwh (significant at 1%). The effects of 1% hike in electricity price, as estimated in specifications (7) and (8), will result in monthly demand shrinking by 470,535.9 Mwh (significant at 10%) and 539,150.1 Mwh (significant at 1%) respectively. Since fluctuations in both real price and overall inflation will be reflected in CPI for electricity, specification (5)-(8) do not allow for differentiation between the effect of inflation and real price. In a sense, these coefficients reflect changes in demand in response to surge in nominal price of electricity[2].

4.3.3 Lag value:

Results from the ADF test suggests that data for residential demand in New Brunswick is integrated of order higher than 1. This is inconsistent with results from (1)-(8) which found the lagged term to be statistical insignificant. While we cannot offer an explanation to as why this is the case; main conclusions of this report with respect to our main variables of interest, CDD and HDD, are still applicable when (1)-(8) were estimated without the lagged term (Table 8- Appendix)

---

[2] Since relevant coefficients for equivalent specifications with price instead of electricity CPI are insignificant; we did not include their results in this report.

4.3.4 Parameters estimation for projections:

As mentioned above, the first step to obtain projections for residential demand in New Brunswick is to estimate the effects of CDD and HDD on demand in the absence of macroeconomic variables. Table 3 summarizes results of specification (9)

$$Y_t = \beta_0 + \beta_1 CDD_{it} + \beta_2 CDD_{it}^2 + \beta_3 HDD_{it} + \alpha_1 year + \varepsilon_{it}$$

Table 3: Parameters for projection of future demand

Variable	Estimated Coefficient
β_0	306676.4***
β_1	2112.96***
β_2	-12.6269***
β_3	443.6857***
α_1	5690.976***

While estimated coefficients from (9) will suffer from omission biases, estimations of $\beta_1, \beta_2, \beta_3$ from Table 3 are comparable to coefficients associated with those of specification (7) and (8) from Table 2. This is rather reassuring as this implies the bias found in (9) are not too severe, and we can utilize these parameters to arrive at future demand.

Recall that our analysis so far has been conducted on monthly basis. Projections of CDD and HDD, however, are in annual form. To reconcile this fact, we assume that annual demand for electricity can be calculated as sum of monthly demand and perform the following algebraic manipulation of equation (9):

$$Y_t = \sum_1^{12} Y_{it} = 12 * \beta_0 + \beta_1 \sum_1^{12} CDD_{it} + \beta_2 \sum_1^{12} CDD_{it}^2 + \beta_3 \sum_1^{12} HDD_{it} + 12 * \alpha_1 year + \varepsilon_{it}$$

$$= 12 * \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + 12 * \alpha_1 year + \varepsilon_t \quad (10)$$

where $Y_{it}, CDD_{it}, HDD_{it}$ are monthly value of residential demand, Cooling and Heating degree day of month i during year t respectively. Y_t, CDD_t, HDD_t then denote the yearly value of these variables.

Readers may have notice that we also multiply the yearly fixed effect by 12 in (10). While this is correct algebraically, we acknowledge that there is no econometric justification for raising the yearly fixed effect by 12 times. To address this, we also introduce another treatment of (10) where the magnitude of α_1 is left untouched:

$$Y_t = 12 * \beta_0 + \beta_1 CDD_t + \beta_2 CDD_t^2 + \beta_3 HDD_t + \alpha_1 year + \varepsilon_t \quad (11)$$

Henceforth, we will refer to specification (10) and (11) as projections with normal and constant trend. Before moving on with our predictions, we wish to discuss some of the assumptions made in the forecasting process.

First, by using the estimated value of slope coefficients associated with climate factors, we essentially assume that demand's response function will stay constant for the entire projection period from 2021- 2095. As pointed out by Aroonruengsawat and Auffhammer (2011), this is a very strong assumption. For this assumption to hold, not only do we require utilization rate of electrical heating as well as cooling devices to stay constant, we also ignore any possible technological innovation that can improve electrical efficiency of these devices. Additionally, our forecast presumes that factors such as economic, population growth follow a linear trend within the period of projection. If 2020 has taught us anything, it is that these assumptions are highly unlikely to hold. Regardless, our forecasts provide a business-as-usual scenario for the trajectory of household's demand for electricity. As inaccurate as they may be, our forecasts can still provide useful insights into the future demand for electricity in New Brunswick.

4.3.5 Projections of future demand in New Brunswick

In this section, we will simulate the effect of climate change on households' demand for electricity in New Brunswick. Projections of future demand for electricity also require simulations of future CDD and HDD specifically for the province of New

Brunswick. To this end, we relied on Climate atlas of Canada- a website maintained by University of Winnipeg. Climate atlas of Canada published predictions of future climatic variables, including CDD and HDD under two different climate change scenarios: RCP 4.5 and RCP 8.5.

Originally developed for the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (IPCC, 2014), RCP 4.5 and RCP 8.5 are trajectories of GHG concentration by 2100. RCP 4.5 is considered by the IPCC as the "intermediate" whereas RCP 8.5 is described as the worst-case scenario. By 2100, under RCP 4.5 Earth's mean temperature is projected to rise by 2.2^{0}C whereas increases in mean temperature under the latter is 3.7^{0}C. We utilized projections of these two scenarios from 24 different climate change models. Since climate change models differ in their predictions, combining their projections allow for more robust forecast of future demand. For sake of clarity, we will present in only the average values of these projections. Figure 2 and 3 summarize trajectories of CDD and HDD under these two scenarios. As temperature continues to rise CDD, and hence cooling requirement, will decline whereas the opposite the true for HDD and heating requirement. As can be observed from Figure 2 and 3, changes in CDD and HDD are more notable under RPC 8.5 than under RCP 4.5 reflecting a more significant increase in mean temperature under the former.

Figure 2 Trajectories of Cooling and Heating Degree Day under RPC 4.5

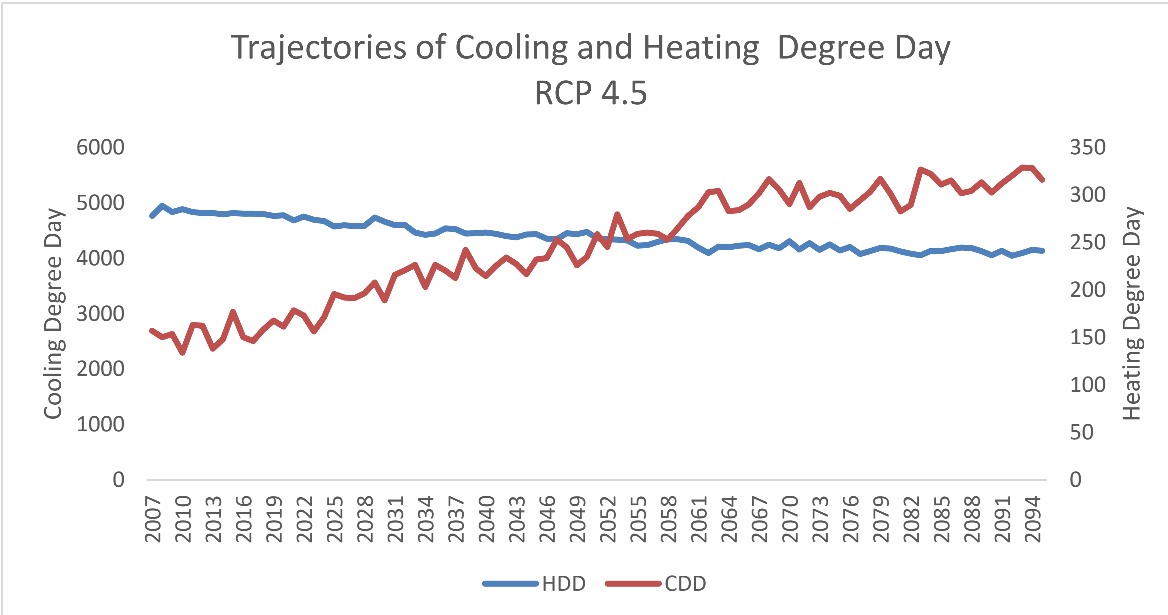
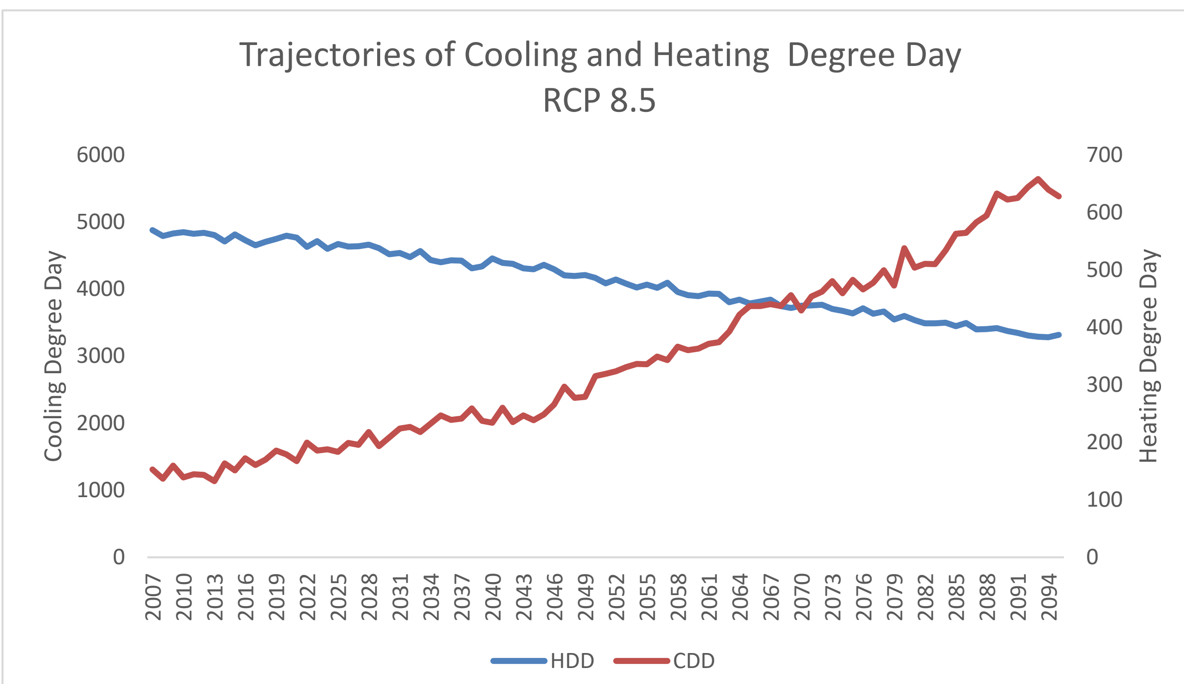


Figure 3 Trajectories of Cooling and Heating Degree Day under RPC 8.5



For sake of clarity, we have presented here only the average (orange) as well as 90th percentile (blue) of all projections for the two treatments of the yearly trend. Forecasts under RCP 4.5 are graphed using a dotted line whereas a solid line is used for predictions under RCP 8.5. Figure 4,5 summarize our predictions.

Figure 4 Projection of residential demand for electricity in New Brunswick assuming constant trend

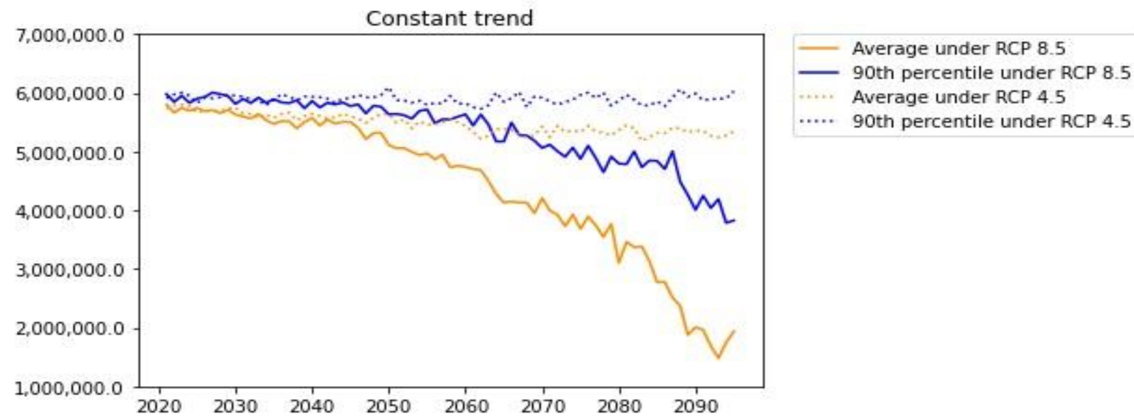
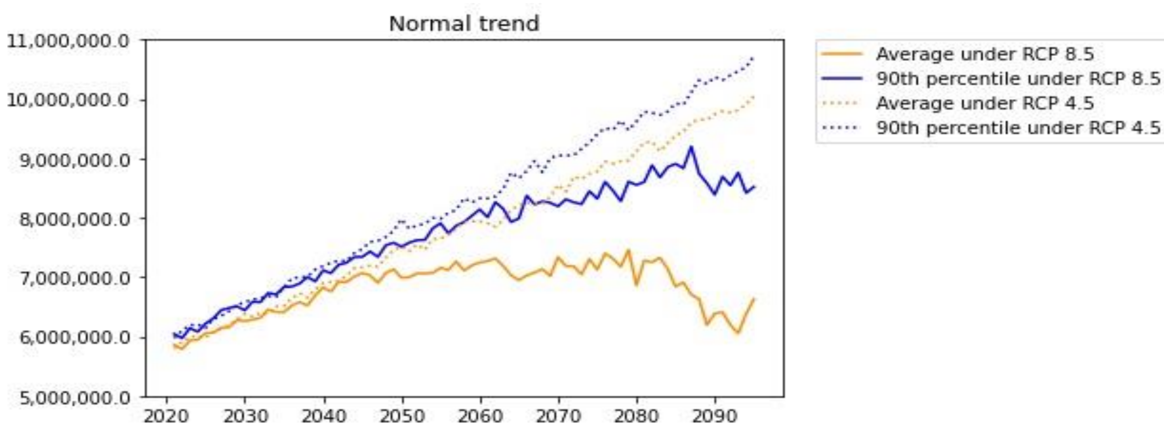


Figure 5 Projection of residential demand for electricity in New Brunswick assuming normal trend



With normal treatment of the yearly trend (Figure 5), under RCP 8.5 residential demand for electricity will increase up to a certain threshold before slowing down before experiencing a downward trend. Demand under RCP 4.5, on the other hand, continues to grow almost linear throughout the period of projection. Recall from Figure

2 and 3 that CDD increases at a much higher rate for the latter half of the analysis under RCP 8.5 scenario. Since the slope coefficient associated with CDD_t^2 takes on the negative sign; the effect of the squared term will dominate the positive effect of CDD_t as CDD_t continues to raise. HDD also exhibits steeper downward trend under RCP 8.5 as in RCP 4.5 which would result in less heating requirements in the former.

Similar patterns can also be observed for the constant treatment of the yearly trend (Figure 4). In this treatment, mean residential demand remains relatively flat under RCP 4.5 while declines significantly from around 6 mil Mwh in 2021 to around 2 mil Mwh by 2095 under RCP 8.5. As explained above, the declining trend under RCP 8.5 is a combination of a high growth rate in CDD and steep reduction in HDD. Under this storyline, our predictions are consistent with Pilli-Sihvola et al. (2010)'s forecast for Finland, Germany and France where demands are forecasted to decline due to reduction in heating requirement.

In the normal trend treatment and RCP 8.5 trajectory, mean projections for residential demand in New Brunswick will grow to approximately 7 mil Mwh by 2060. After that, demand is forecast to stay relatively flat up until 2080 before showing declining trend toward the end of the projection period. Similar trend can also be observed from the 90th percentile projections. Here demands will continue to increase past 2085 reaching roughly 8.9 mil Mwh before dropping slightly back to 8.5 Mwh by 2095.

Average and 90th percentile projections under RCP 4.5 tell a radically different story where demand grows continuously within from 2021 to 2095 reaching 9.5 Mwh (11 mil Mwh- 90th percentile) by the end of the projection period. Under this climate change scenario, drastic investments will be required to meet household's growing demand for electricity.

Chapter 5 Conclusion

We have studied the relationship between climate change and residential demand for electricity by regressing monthly residential electricity demand in New Brunswick on average monthly temperature as well as on extreme temperatures captured by cooling and heating degree days (CDD/HDD). To control for standard demand factors, such as income and price, we also included New Brunswick's real GDP as well as CPIs in our regressions.

Our results are consistent with the existing studies and indicate that both CDD and HDD are important factors in determining residential electricity demand. Particularly, coefficients associated with CDD and HDD are positive and significant across all specifications. Moreover, depending on the specification, the size of the estimated coefficients associated with CDD are roughly twice as bigger as those associated with HDD. This observation appears to be a common occurrence across the existing literature as there is no easily available alternative energy source for cooling devices.

In addition to the above results, our estimations suggest that residential electricity demand is very sensitive to changes in inflation. The effect of a 1% increase in the inflation rate was found to be approximately five times as great as the growth rate of 1% in real GDP. This is a rather unexpected result. A comprehensive understanding of the underlying mechanism involving this relationship would require a separate study. Relationship between price, income and residential electricity demand in the province are as expected. Positive changes in income, as proxied by GDP, cause residential demand to increase. Since price is highly correlated with other variables in our regressions, we were not able to provide a precise estimation regarding the relationship between price and demand. We were, however, able to estimate the relationship between nominal price, as proxied by CPI for electricity, and residential electricity demand. Consistent with economic theory, the observed relationship is negative and statistically significant.

It should be clear that as the main goal of this study was to explore the potential impact of extreme temperatures on households' demand for electricity in the province of New Brunswick, we did not conduct a comprehensive study on standard demand factors such as income and price. Inclusion of these variables was mainly to control for factors other than temperature. A detailed study on the residential electricity demand will require a much bigger dataset. At this stage, we refrain from making any conclusions about the nature of such relationship, especially the relationship between inflation and demand. Regardless, it is obvious from our data that these factors play an important role in households' demand for electricity in the province of New Brunswick.

Finally, this report provides some baseline projections for future demand for electricity in New Brunswick. To arrive at these predictions, we first re-estimated the relationship between temperatures and variations in households' demand for electricity without controlling for macroeconomic factors- specification (9). We opt to go this route since access to long-term projections for electricity price, GDP and CPI are not available. Despite the existence of omission bias, estimated coefficients in (9) take on similar values as in specification (7) and (8) when other factors are controlled for. We then forecast future demand using estimated parameters and projections of future CDD as well as HDD from Climate Atlas of Canada under two different emission scenario- RCP 4.5 and RCP 8.5.

Our most aggressive forecast suggests that residential demand for electricity will grow significant to roughly 11 million Mwh by 2095. Our predictions suggest that as temperature continues to rise, positive changes in demand due to increased usage of cooling devices would override reduction in heating requirement. To avoid overstressing the supply, improvements in buildings design and insulation should be made to reduce the need for air conditioning.

In coming up with these projections, we have imposed some rather restrictive assumptions regarding the future. Particularly, we assume away the possibility of notable changes in utilization rate as well as electrical efficiency of heating/cooling devices within the period of projections from 2021 to 2095. We also require that changes in socioeconomic factors such as prices, income, population growth during the same period to follow a linearly increasing trend. Obviously, these are very strong assumptions which are unlikely to hold. Our forecasts, however, are useful as a baseline scenario for the future of residential demand in New Brunswick.

Bibliography

Abdouli, M. and Hammami, S. (2017), Exploring links between FDI inflows, energy consumption, and economic growth: further evidence from MENA countries, Journal of Economic Development, Vol. 42 No. 1, pp. 95-117.

2. Abokyi, E.A., Appiah-Konadu, P., Sikayena, I. and Oteng-Abayie, E.F. (2018), Consumption of electricity and industrial growth in the case of Ghana, Journal of Energy, Vol. 2018, pp. 1-11, available at: https://doi.org/10.1155/2018/8924835.

3. Agurto, R., Fuentes, F., García, C.J. et al. (2020), The macroeconomic impact of the electricity price: lessons from Chile, Empirical Economics. https://doi.org/10.1007/s00181-020-01883-7

4. Bekhet, Hussain Ali, and Othman, Nor Salwati (2017), Impact of urbanization growth on Malaysia CO2 emissions: Evidence from the dynamic relationship. United Kingdom: N. Web. doi: 10.1016/j.jclepro.2017.03.174.

5. Breslow P.B., Sailor D.J. (2002), Vulnerability of wind power resources to climate change in the continental United States, Renewable Energy, 27:585–98.

6. Chakraborty, C. and Nunnenkamp, P. (2008), Economic reforms, FDI, and economic growth in India: a sector level analysis, World Development, Vol. 36 No. 7, pp. 1192 1212.

7. Ciarreta, A., and A. Zarraga. (2008) “Economic Growth and Electricity Consumption in 12 European Countries: A Causality Analysis Using Panel Data”, Working Paper, Dept. of Applied Economics III (Econometrics and Statistics), University of the Basque Country.

8. Doytch, N. and Narayan, S. (2016), Does FDI influence renewable energy consumption? An analysis of sectoral FDI impact on renewable and non-renewable industrial energy consumption, Energy Economics, Vol. 54, February, pp. 291-301.

9. Emodi N.V., Chaiechi T. and Beg R.A. (2018), The impact of climate change on electricity demand in Australia, Energy and Environment, Vol. 29(7), 1263-1297

10. Enu, P. and Havi, E. (2014), Influence of electricity consumption on economic growth in Ghana: an econometric approach introduction, International Journal of Economics, Commerce and Management, Vol. 2 No. 9, pp. 1-20.

11. Essien, Anietie (2011), The Nigeria Energy Sector: Electricity Consumption and The Macroeconomic Performance (1980-2009). Available at SSRN: https://ssrn.com/abstract=2150459 or http://dx.doi.org/10.2139/ssrn.2150459

12. Faisal, F., Tursoy, T., Resatoglu, N.G. and Berk, N. (2018), Electricity consumption, economic growth, urbanization and trade nexus: empirical evidence from Iceland, Economic Research-Ekonomska Istraživanja, Vol. 31 No. 1, pp. 664-680.

13. Franco, G., Sanstad, A.H. Climate change and electricity demand in California, Climatic Change 87, 139–151 (2008). https://doi.org/10.1007/s10584-007-9364-y

14. Ghosh, S. (2002), Electricity consumption and economic growth in India, Energy Policy, Vol. 30 No. 2, pp. 125-129.

15. Gómez, M. and Rodríguez, J. (2016), Analysis of causality between economic growth and carbon emissions: the case of Mexico 1971-2011, International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering, Vol. 10 No. 12, pp. 1086-1091.

16. Hernández, L.; Baladrón, C.; Aguiar, J.M.; Calavia, L.; Carro, B.; Sánchez-Esguevillas, A.; Cook, D.J.; Chinarro, D.; Gómez, J. (2012), A Study of the Relationship between Weather Variables and Electric Power Demand inside a Smart Grid/Smart World Framework, Sensors, 12, 11571-11591. https://doi.org/10.3390/s120911571

17. Howden, S. M. and Crimp, S. (2001) Effect of Climate and Climate Change on Electricity Demand in Australia. CSIRO Sustainable Ecosystem.

18. Hör, C. L., S. J. Watson, and S. Majithia (2005), Analyzing the Impact of Weather Variables on Monthly Electricity Demand, IEEE Transactions on Power Systems 20:4, 2078-2085.

19. Krueger, A. (2006), “Financial markets and economic growth”, available at: www.imf.org/en/News/ Articles/2015/09/28/04/53/sp092806 (accessed 28 April 2018).

IEA (2015), The World Energy Outlook, International Energy Agency, Paris.

20. Lehner B., Czisch G., Vassolo S. (2005), The impact of global change on the hydropower potential of Europe: a model based analysis, Energy Policy, 33(7):839–55.

21. Mirasgedis S., Sarafidis Y., Georgopoulou E., Kotroni V., Lagouvardos K., and D. P. Lala, (2007), Modeling framework for estimating impacts of climate change on electricity demand at regional level: Case of Greece, Energy Conversion Management, vol. 48, pp. 1737–1750.

22. Munoz J.R., and Sailor D.J. (1998), A modeling methodology for assessing the impact of climate variability and climatic change on hydroelectric generation, Energy Conversion Management, 39:1459–69.

23. Narayan, P.K. and R. Smyth (2005), The Residential Demand for Electricity in Australia: An Application of the Bounds Testing Approach to Cointegration, Energy Policy, 33: 467-474.

24. Neeliah, H. and Deenapanray, S. (2012), The economic growth and electricity consumption nexus: evidence from Mauritius, Economics Bulletin, Vol. 32 No. 4, pp. 2930-2940.

25. Omri, A. and Kahouli, B. (2013), “Causal relationships between energy consumption, foreign direct investment and economic growth: fresh evidence from dynamic simultaneous-equations models”, MPRA Paper No. 82502, Munich Personal RePEc Archive, Munich University Library.

26. Qian, H., Yuan, S., Sun, J. et al (2004), Relationships between energy consumption and climate change in China, Journal of Geographical Sciences, 14, 87–93. https://doi.org/10.1007/BF02873095

27. Pryor S.C., Barthelmie R.J., Kjellstrom E.P. (2005), Potential climate change impact on wind energy resources in northern Europe: analyses using a regional climate model, Climate Dynamics, 25:815–35.

28. Ralston Fonseca, F., Jaramillo, P., Bergés, M. et al. (2019), Seasonal effects of climate change on intra-day electricity demand patterns, Climatic Change 154, 435–451 (2019). https://doi.org/10.1007/s10584-019-02413-w

29. Ridzuan, A.R., Kamaludin, M., Ismail, N.A., Razak, M.I.M., Haron, N.F. (2020), Macroeconomic indicators for electrical consumption demand model in Malaysia, International Journal of Energy Economics and Policy, 10(1), 16-22.

30. Robinson P. (1997), Modeling utility load and temperature relationships for use with long-lead forecasts, Journal of Applied Meteorology, 36:591–8.

31. M. Ruth and A.-C. Lin (2006), Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA, Energy Policy, vol. 34, pp. 2820–2833.

32. Sharma, R. and Kautish, P. (2019), Dynamism between selected macroeconomic determinants and electricity consumption in India: An NARDL approach, International Journal of Social Economics, Vol. 46 No. 6, pp. 805-821. https://doi.org/10.1108/IJSE-11-2018-0586

33. Shiu, A. and Lam, P. (2004), Electricity consumption and economic growth in China, Energy Policy, Vol. 32 No. 1, pp. 47-54.

34. Sailor, David J., and J.R. Munoz. (1997), Sensitivity of Electricity and Natural Gas Consumption to Climate in the U.S.A.—methodology and results for eight states, Energy 22:987–998.

35. The Pakistan Development Review, Winter 2013, Vol. 52, No. 4, Papers and Proceedings: PART I The 29th Annual General Meeting and Conference of the Pakistan Society of Development Economists Islamabad, December 19 - 21, 2013 (Winter 2013), pp. 467-477.

36. Zachariadis, T. (2010), Forecast of Electricity Consumption in Cyprus up to the year 2030: The Potential Impact of Climate Change, Energy Policy 38:2, 744-750.

37. Zheng, S.; Huang, G.; Zhou, X.; Zhu, X. (2020), Climate-change impacts on electricity demands at a metropolitan scale: A case study of Guangzhou, China, Applied Energy, 261, 114295.

Appendix

Table 4: Correlation matrix for independent variables

	CDD	HDD	Price	Real GDP	Overall CPI	Electricity CPI	summer
CDD	1						
HDD	-0.6482	1					
Price	-0.0018	-0.0396	1				
Real GDP	-0.0124	-0.0018	0.9204	1			
Overall CPI	0.0286	-0.1015	0.9658	0.9454	1		
Electricity CPI	-0.0084	-0.0335	0.9945	0.9198	0.9683	1	
Summer	0.6335	-0.8603	0.0403	0.0395	0.1072	0.0353	1

Table 5: VIF for specification (1)-(4)

Variable	**VIF**
CDD	24.88
CDD^2	18.16
HDD	7.34
Price	40.92
Real GDP	15.43
Overall CPI	28.34

Year	65.93
summer	5.22
Y_{t-1}	4.42
Mean VIF	23.41

Table 6: VIF for specification (5)-(8)

Variable	**VIF**
CDD	22.44
CDD^2	16.55
HDD	6.94
Real GDP	13.02
Electricity CPI	24.49
Year	42.76
summer	5.02
Y_{t-1}	4.07
Mean VIF	16.91

Table 7: ADF test

Variable	Level form	Differenced
CDD	-7.537***	-7.960***
HDD	-5.697***	-3.228*
Price	-2.530	-6.862***
Real GDP	N/A	N/A
Overall CPI	-3.765**	-6.315***
Electricity CPI	-2.205	-6.579 ***
Electricity demand	-0.244	4.118

Table 8: Estimations of residential demand for electricity without lagged term.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CDD	840.73***	835.62***	1371***	1368.4***	896.83***	897.1***	1960.1***	1981.5***
CDD^2			-5.71	-5.73			-11.5***	-11.8***
HDD	423.9***	422.8***	427.6***	426.5***	443.3***	444.1***	448.3***	449.1***
Price	-5021.9		-13591.2					
ln(Price)		-16204.1		-105137				
Real GDP	.13*		.13*		-.01		.019	
ln(real GDP)		279179.3*		282338.1*		34945.77		87066.37
Overall CPI	-12017***		-11158 ***					
ln(overall CPI)		-1601323***		-1491052***				
Electricity					-4779***		-5122***	

CPI								
ln(electricity CPI)						-636933***		-692458***
year	25922***	25701***	25632***	25447***	19763***	17678***	19548***	17828***
summer	18307**	18046**	13481	13204	18582**	18884**	8989	9006
constant	1559283***	3986672*	1532825***	3613211	943976***	2898134	927809***	2414058

Curriculum Vitae

Candidate's full name: Chi Danh Dao

Universities attended (with dates and degrees obtained): Tan Tao University, Bsc, 2011-2015

Publications: None

Conference Presentations: None