Spring 2013

A system dynamics analysis of the growth in Virginia's residential electricity consumption trends, 1980-2010.

Raguram Sellakkannu
James Madison University

A System Dynamics Analysis of the growth in Virginia's Residential Electricity Consumption trends, 1980-2010.

By

Raguram Sellakkannu

A Dissertation submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY & UNIVERSITY OF MALTA

In

Partial Fulfillment of the Requirements

for the Degree of

Master of Science

Sustainable Environmental Resources Management
&
Integrated Science and Technology

May 2013

Dedicated with love and thanks to

My Mom and Dad for their support and unchanging faith in my abilities

My sister whose sweet and timely annoyance kept me focused throughout

My kin and friends who have been my greatest source of energy

And finally

My supervisor, Dr.D, who went out of his way to help me complete my work.

Acknowledgement

I would like to express my sincere gratitude to the following people who offered valuable help throughout the course of research that helped complete my dissertation:

Chief Supervisor, Professor Michael L. Deaton, Ph.D. Statistics, Virginia Tech; M.S Mathematics, Memphis State; who introduced me to the engaging field of *System Dynamics*. Without his guidance, motivation and persistent help, this dissertation would not have been possible.

Co-Supervisor, Professor Maria Papadakis, Ph.D., Indiana University, whose inputs on data collection techniques and analysis helped me get started.

Co-Supervisor, Liberato Camilleri, B.Ed.(Hons), M.Sc., Ph.D.(Lanc.), whose inputs on statistical data analysis have been of valuable use throughout this research.

Professor Jonathan Miles, Ph.D., Mechanical Engineering, University of Massachusetts at Amherst; B.A., Physics, Clark University; who constantly kept track of my progress and made sure all my research needs were met.

The '*Valley 25x25'* team for seeing potential in my work and providing financial support.

And a special thanks to **James Madison University** for welcoming me to the United States to conduct my research.

Raguram Sellakkannnu

April, 2013

Table of Contents

List of Figures

List of Tables

Abstract

Residential electricity consumption in the Commonwealth of Virginia has more than doubled in three decades, between 1980 and 2010. Per capita and per household consumption rates have grown faster than many other states including New York and California. The following dissertation applies systems dynamics methodology to explore the causes of growth in Virginia's per capita and per household residential electricity consumption rates in relative contrast to New York and California over the past several decades. Major databases used in the study were accessed from the United States Energy Information Administration and the Census Bureau.

Qualitative modelling applying system dynamics principles is used to understand the general dynamics that drive residential electricity consumption across U.S households. The extent to which these dynamics prevail in Virginia is then analyzed using the state's historical data. Further comparative analysis with benchmark states of New York and California helps identify if those dynamics uniquely prevail in Virginia or are common across the benchmark states too. The study finds that a combination of economic and lifestyle factors among Virginia's residents, compounded by a low-cost high-volume 'business as usual' strategy by the state's power utility sector with negligible investments in demand side management efforts, have worked relentlessly to cause per capita and per household residential electricity consumption rates to rise in the Commonwealth during the three decades.

The results of this study are intended to support in better management of residential electricity consumption rates in the Commonwealth of Virginia. Public educational programs, Government tax credits and rebates, and stronger utility demands side management are key recommendations in the interest of addressing the issue. A successful future reduction in consumption rates will help lessen pressures on the state's economy as well as the environment.

1 INTRODUCTION

1.1 OVERVIEW

The following dissertation applies system dynamics methodology to explain why per capita and per household electricity consumption rates among Virginia's residences have grown rapidly in the past several decades and have been distinctly higher compared to most other states in the U.S. The study's results and recommendations intend to aid better management of residential electricity consumption rates[1] in the Commonwealth through suitable policy instruments. Lowering residential consumption rates will be a small step forward in managing national energy demands with associated environmental and economic benefits. This research is specific to the state of Virginia and targets its residential population. The time frame is limited from 1980 to 2010 across which the study explores underlying dynamics that influence the state's per capita and per household residential electricity consumption rates. The study also contrasts these dynamics with those of two benchmark states, namely California and New York, which show notably different trends from Virginia. Contrasting the dynamics behind Virginia's high consumption rates with those of the benchmark states and elucidating the observed discrepancies may yield useful insight to policy makers in managing the issue. Future policies are expected to acknowledge conclusions made in this study to be more effective at curbing residential electricity consumption rates in the Commonwealth.

The dissertation applies a qualitative systems modeling approach to explain the dynamics underlying Virginia's residential electricity consumption trends and contrast them with those of the benchmark states. The methodology involves constructing a qualitative systems model which will provide a holistic view of the general dynamics behind electricity consumption among U.S

[1] Note: Unless specifically mentioned, the term *'residential electricity consumption (R.El.C) rates/trends'* or *'consumption rates/trends'* used throughout the paper will collectively refer to *'per capita'* as well as *'per household' residential electricity consumption rates/trends*; it will not include 'total' electricity consumption by the residential sector.

households. The key determinants of per household and eventually per capita consumption are identified based on the model and corresponding historical trends are then analyzed specific to Virginia. Based on the analysis findings, a dynamic hypothesis is formulated justifying the rising trend in the state's per capita and per household residential electricity consumption rates. In addition, a comparative analysis with the benchmark states will help identify aspects that the Virginia Commonwealth can improve using suitable policy instruments.

The following study is important as there are significant environmental and economic impacts associated with rising electricity consumption. Electric power generation in Virginia is predominantly coal based with 47% of it generated by coal-fired power plants (Maxted, 2008). Greenhouse gas emissions from fossil fuel combustion, especially coal, make the electric power industry the most environmentally sensitive sector of the U.S economy (Repetto & Henderson, 2003) in terms of global warming. From an economic perspective, rising state electricity consumption calls for increased supply and hence more investments in electricity generation in order to meet consumer demands. According to the 2010 Virginia Energy Plan, Virginia imports nearly 30% of its electricity from out-of-state sources and a 1% reduction in State electricity imports would increase state GDP by $20 million dollars (DMME, 2010). Hence, successful reduction of Virginia's residential electricity consumption rates alongside reductions in the commercial sector will help lessen pressures on the environment and the state's economy.

1.2 BACKGROUND ON VIRGINIA'S RESIDENTIAL ELECTRICITY CONSUMPTION PATTERNS

Virginia's total electricity consumption across all sectors has increased dramatically in several respects between 1980 and 2010. According to the U.S Energy Information Administration State Energy Data System (EIA, 2012b), total end use electricity consumption in the Commonwealth of Virginia has grown by 135% from 1980 to 2010, the state's residential sector alone consistently accounting for 40% of this consumption annually. Total residential electricity consumption in

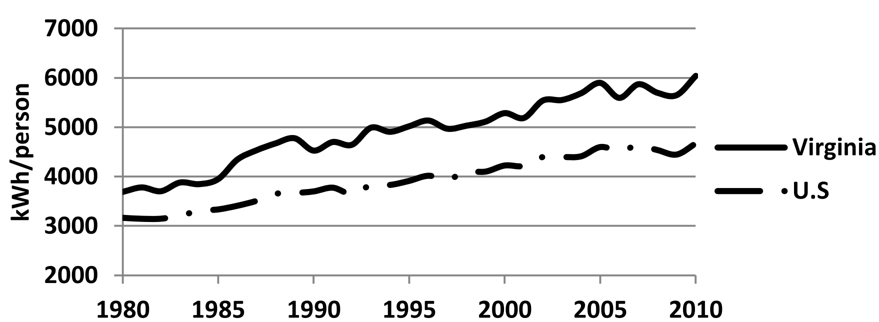
Virginia has shown a 145.5% increase during this time frame with simultaneous increases in per capita and per household residential electricity consumption (R.El.C) by 63.6% and 49.7% respectively. In addition, Virginia's per capita and per household R.El.C rates have been higher than corresponding national averages throughout the thirty years although the annual growth in R.El.C rates among the two have been fairly consistent (Figures 1.1&1.2).

1.2.1 COMPARISON OF R.EL.C TRENDS: VIRGINIA VS. UNITED STATES

1.2.1.1 Per Capita residential electricity consumption:

As per Figure 1.1, Virginia's annual per capita residential electricity consumption has been consistently above the national average and has increased from 3,690 KWh in 1980 to 6,036 KWh in 2010[2]. This trend persists although the 63.6% increase translates into an annual growth rate of 1.6% which is only marginally higher than the nationwide annual growth rate of 1.4%.

Figure 1.1: Annual R.El.C per capita, 1980-2010.



Source: (EIA, 2012b),(CensusBureau, 2012b).

,

1.2.1.2 Per Household residential electricity consumption:

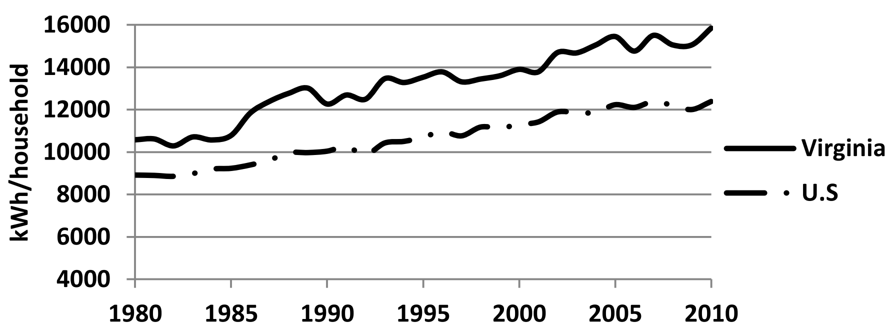
Virginia's per household residential electricity consumption also exhibits a similar comparison with the national trends. As per Figure 1.2, Virginia's annual figures grew from 10,591 KWh in 1980 to 15,850 KWh in 2010 equating to a 49.66% increase at 1.36% annual rate of growth. This

---

[2] Note that throughout this study, the term electricity and all relevant data used correspond to electricity from all fuel sources and not just fossil fuels.

is comparable to the nationwide annual growth rate of 1.22% which is representative of a 38.78% increase in per household R.El.C.

Figure 1.2: Annual R.El.C per household, 1980-2010.



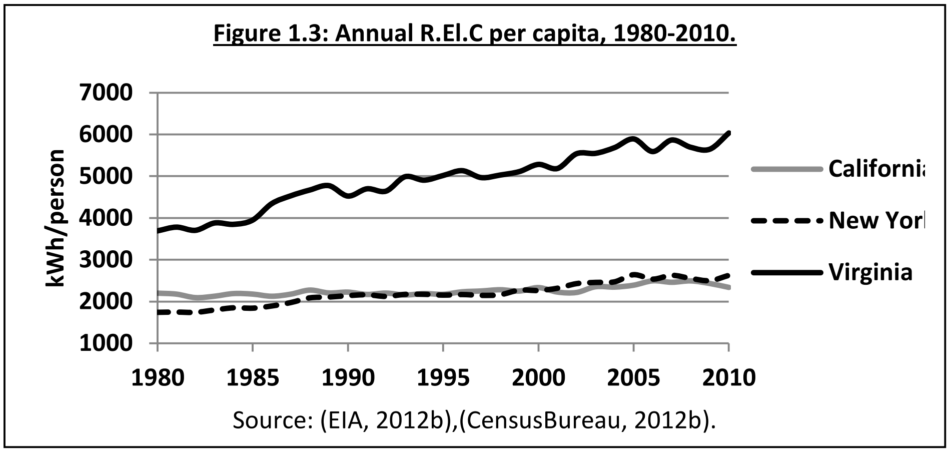
Source: (EIA, 2012b),(CensusBureau, 2012b).

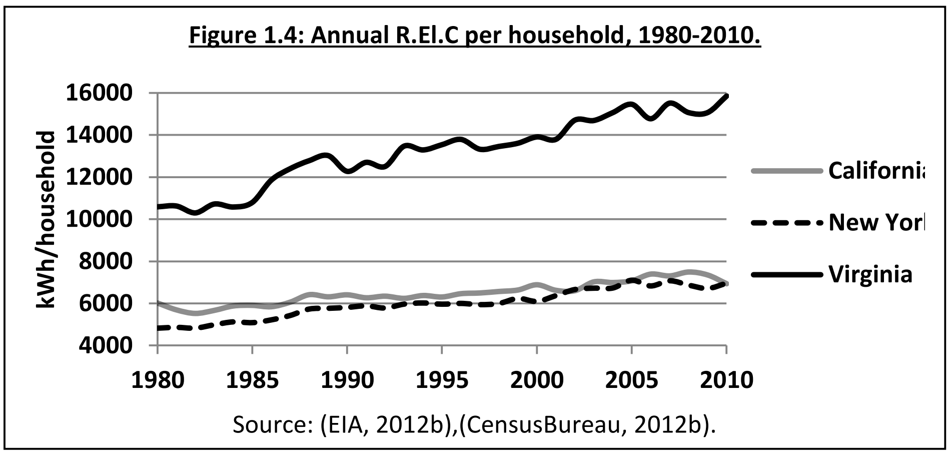
In summary, Figures 1.1&1.2 indicate that while the annual growth rates in Virginia's per capita and per household residential electricity consumption trends between 1980 and 2010 are representative of the nation as a whole, the actual consumption levels are in fact much higher than the U.S averages. Further comparison of Virginia's trends with those of benchmark states, namely California and New York, captures more intriguing discrepancies.

1.2.2 COMPARISON OF R.EL.C TRENDS: VIRGINIA VS. BENCHMARK STATES

During the thirty years, California and New York have exhibited higher annual total R.El.C rates compared to Virginia which are largely attributed to the much higher populations in these states (CensusBureau, 2012b). Despite this, the annual per capita and per household R.El.C rates of these two states have been much lower than Virginia's. Figures 1.3&1.4 illustrate these facts.

Average annual per capita and per household R.El.C levels for both California and New York have consistently been just about half of Virginia's corresponding levels between 1980 and 2010 (as seen in Figures 1.3&1.4). California's annual per capita and per household consumption levels are on average 53% and 50% lower respectively, and New York's figures are 55% and 54.6% lower respectively.





Figures 1.3&1.4 further indicate relatively fast rising trends in Virginia's per capita and per household R.El.C rates. Although the annual growth rates in New York's R.El.C trends are just about the same as Virginia's, California on the other hand shows relatively much lower growth rates in its R.El.C trends (Refer Table 1.1). These discrepancies are important since an understanding of why Virginia's per capita and per household residential electricity consumption rates are much higher than those of California and New York may provide useful insights on how the Commonwealth can reduce these levels.

Table 1.1: Annual growth rate in per capita and per household R.El.C

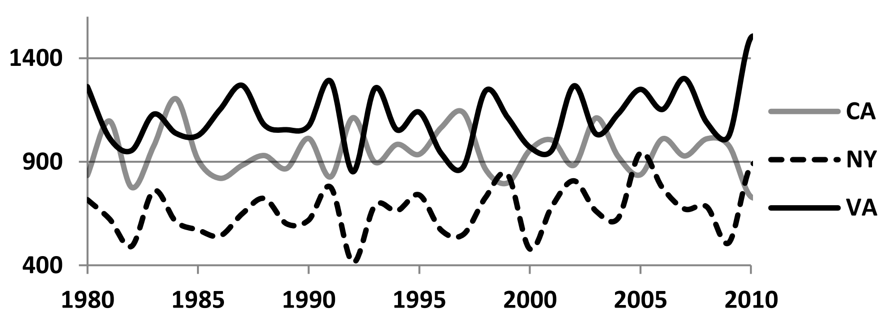
State	Annual growth rate	
	Per capita R.El.C	Per household R.El.C
Virginia	1.6%	1.4%
California	0.4%	0.9%
New York	1.4%	1.3%

Source: (EIA, 2012b),(CensusBureau, 2012b)

1.2.3 WEATHER PATTERNS, NOT A MAJOR FACTOR BEHIND VIRGINIA'S GROWING R.EL.C TRENDS

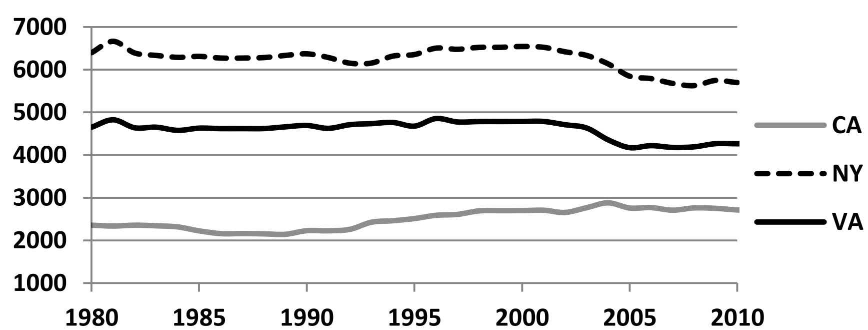
Weather patterns directly influence residential electricity consumption since extreme summers and winters impose greater electrical demands for cooling and heating respectively. Historical weather data shows that heating degree days (HDD) and cooling degree days (CDD) in Virginia have remained relatively flat between 1980 and 2010 (Figures 1.5&1.6). However during the same period, the state's per capita and per household R.El.C rates have shown dramatic increases (Figures 1.1&1.2). This indicates that changes in Virginia's weather pattern could not have been a major source of this growth even though they are a general contributor to residential electricity consumption[3].

Figure 1.5: Cooling degree days, 1980-2010.



Source: (National Climatic Data Center, 2012).

Figure 1.6: Heating degree days, 1980-2010.



Source: (National Climatic Data Center, 2012).

[3]This fact is further justified in appendix 1.

Furthermore, Virginia enjoys a humid subtropical climate which is neither very hot nor very cold (Terwilliger, Tate, & Woodward, 1995). Despite this fact, Virginia's residents have been consuming more electricity compared to both the benchmark states. It is arguable that California has a relatively milder climate which reduces the need for excessive electricity use in residential heating and cooling. However New York, though it experiences harsher weather conditions than both Virginia and California, has also maintained low per capita and per household R.El.C levels (EIA, 2012b). These observations indicate that there are factors other than climatic conditions that have caused higher residential electricity consumption rates in Virginia. On that note, the influence of weather conditions on Virginia's R.El.C rates will not be discussed in further chapters.

1.2.4 SUMMARY OF MAJOR FACTS

Based on the comparisons thus far, notable facts regarding Virginia's per capita and per household R.El.C rates between 1980 and 2010 are summarized as follows:

1. Virginia's per capita and per household residential electricity consumption rates have been consistently higher than the national averages between 1980 and 2010.
2. The state's per capita and per household R.El.C rates have been consistently much higher than those of California and New York during the same time frame.
3. The annual growth rates in Virginia's per capita and per household R.El.C rates are noticeably higher than California (which too has exhibited an overall increase, but not as rapid an increase as Virginia).
4. Weather patterns are not a major source of growth in Virginia's R.El.C trends and do not explain discrepancies with respect to the benchmark states.

Based on the above facts, it is seemingly possible that there are opportunities to improve management of residential electricity consumption in the Commonwealth. Contrasting Virginia's dynamics against those of the benchmark states and explicating the observed discrepancies will provide valuable insights that will aid in formulating new policies aimed at managing residential electricity consumption.

1.3 Role of Energy-Source Switching

The rising electricity consumption rates among Virginia's households are believed to be partly caused by energy-source switching; the term refers to a move made by residential consumers to switch from using non-electric appliances to those using electricity for major energy demands, usually space heating, water heating and cooking. There are several factors in the modern economy like affordability and fuel prices which can cause people to switch from traditional fuel use to electricity consumption. The study tracks the variation in 'percentage of energy use per household from electricity' over time to determine the possibility of energy-source switching[4] having occurred among households. Note, however, that the metric 'percentage of energy use per household from electricity[5]' is not an accurate indicator of energy-source switching since the metric is also influenced by the extent to which a household uses its electric and non-electric appliances; however its trend gives an idea if energy-source switching could have possibly occurred in a household. A study of Virginia's energy consumption trends indicates that the state's households may have switched energy sources considerably between 1980 and 2010; the following section supports the above fact.

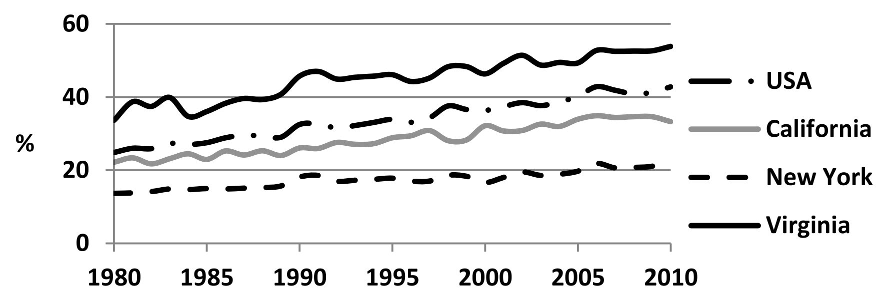
1.3.1 Energy-Source Switching Among Virginia's Households

Figure 1.7 illustrates the annual 'percentages of energy use per household from electricity' for Virginia, the two benchmark states and the U.S between 1980 and 2010. Virginia's energy use fraction from electricity is distinctly higher compared to California, New York and the U.S

[4] The term *energy-source switching* used throughout this paper will only refer to the transition from traditional fuel use towards electricity use and not vice versa.
[5] The percentage of energy use per household from electricity is calculated as the ratio of 'energy use per household' to 'electricity use per household' as a percentage.

average and is visibly rising during this period. This indicates the possibility of energy-source switching having occurred on a relatively greater scale amongst Virginia’s residences.

Figure 1.7: Percentage of residential energy use per household from electricity, 1980-2010.



Source: (EIA, 2012b)

Arguably, energy-source switching may be contributing to the high consumption rates amongst Virginia’s residences and eventually the discrepancies with respect to the benchmark states. It is therefore necessary to explore the dynamics behind energy-source switching in Virginia as we evaluate the sources of high per capita and per household R.El.C rates within the state.

1.4 RESEARCH AIM AND OBJECTIVES

The following dissertation aims to elucidate the dynamics behind Virginia’s high per capita and per household R.El.C rates and their rapid annual growth for the selected time frame using a system dynamics approach. The principal research question is as stated:

> ***What are the sources of high per capita and per household electricity consumption in Virginia’s residential sector and what has caused them to grow rapidly between 1980 and 2010, in contrast with benchmark states of California and New York?***

In order to answer this question, the remainder of this dissertation will focus on the following research objectives:

1. To develop a qualitative system dynamics model which explains the general dynamics that drive per capita and per household residential electricity consumption in U.S households.
2. To identify the major determinants of per capita and per household R.El.C and analyze their historical trends with respect to Virginia between 1980 and 2010.
3. To formulate a dynamic hypothesis that explains the trends in Virginia's per capita and per household R.El.C rates based on objectives 1&2.
4. To compare Virginia's dynamics with those of California and New York in order to identify differences that can be addressed to suppress the state's growing R.El.C rates.
5. To suggest meaningful recommendations based on the study results.

1.5 SYSTEM DYNAMICS, THE METHODOLOGY OF CHOICE

System dynamics methodology is a prominently used approach in studying problems with complex system behaviors that develop over extended periods of time. System complexity arises from feedback loops and delays which make it difficult to study such problems using conventional techniques. The methodology primarily involves defining the problem and determining the purpose of the study. This is followed by the construction of a qualitative system model using 'causal loop diagrams' in order to analyze and explain the individual dynamics that make up the problem. Based on qualitative findings, a dynamic hypothesis is formulated explaining the cause of the problem. System dynamics further uses the concept of 'stocks' and 'flows' to build a quantitative simulator model; this serves as a real-time decision making tool to policy makers and managers in developing solutions to complex problems (Sterman, 2000). However, the scope of the current dissertation is limited to quantitative system modeling and does not make use of simulation modeling concepts.

The current research problem has several characteristics that are typically found in a system dynamics case study. Most importantly, the problem is chronic as Virginia's per capita and per household R.El.C rates have grown over several decades. Multiple actors are involved including Virginia's residents and the state's power utilities. Multiple feedback dynamics exist with respect to household and utility actions; these interact with one another and give rise to complex system behaviors. The further existence of system delays and unintended consequences make the current problem worthy of a system dynamics investigation[6].

The following are some previous literature that have applied system dynamics methodology to study electricity related issues and have provided useful background knowledge applicable to the current research:

'Systems Dynamics and the Electric Power Industry', (Ford, 1997): Provides insight on the basic dynamics that are involved in functioning of power utilities and the management of utility resources, especially installed generation capacity. The study also sheds light on the famous *'utility death spiral'* which occurs as a consequence of high electricity prices and rapid expansion of generation capacity by utilities.

'*Modelling household responses to energy efficiency interventions via system dynamics and survey data'*, (Davis & Durbach, 2010): Provides insight on the intended and unintended consequences of efficiency interventions in household energy consumption. The study further explains the *'the rebound effect',* an unintended consequence where efficiency improvements can lead to increased energy consumption.

'*System dynamics modelling for residential energy efficiency analysis and management'* (Dyner, Smith, & Peña, 1995): Provides information on how subsidized electricity prices encourage higher demands further allowing utilities to increase the utilized generation capacity. By maximizing the utilized capacity, utilities are able to reduce their generation costs per unit of electricity further allowing prices to remain low.

'Investigation of pricing impact on the electrical energy consumption behavior of the household sector by a system dynamics approach' (Esmaeeli, Shakouri, & Sedighi, 2006): Explains how

[6] These dynamics are explained in subsequent chapters.

subsidized electricity prices in combination with greater family income encourage residential customers to consume more electricity.

'An Analysis of Residential Energy Intensity in Iran, A system Dynamics Approach', (Jamshidi, 2008): Explains how various factors like electricity pricing, consumption habits, pricing and efficiency of appliances, number of appliances per household, building efficiency, duration of appliance use, etc. impact residential energy demand.

Background knowledge obtained from the above literature form the basis for constructing the causal structures in chapter 2 and explaining the relevant dynamics in subsequent chapters.

1.6 DISSERTATION STRUCTURE

The subsequent chapters of the dissertation unfold according to the order of research objectives listed earlier. Chapter 2 uses the language and tools of system dynamics to formulate a ***systems-based explanation*** of the determinants of residential electricity consumption in U.S households. Chapter 3 lists out various possible scenarios under which high per capita and per household residential electricity consumption rates are bound to occur. In total, the chapter provides an understanding of how various unfavorable conditions work together to generate dynamics that lead to high per capita and per household R.El.C rates. Chapter 4 specifically explores how these dynamics have manifested in Virginia. Using the results, the chapter lays down a ***dynamic hypothesis*** which explains the cause of high per capita and per household residential electricity consumption rates and their rapid growth over time in Virginia. Chapter 5 involves a comparative analysis of Virginia's dynamics with those of the benchmark states to identify the differences that are uniquely contributing to the state's R.El.C trends. Chapter 6 concludes the dissertation with a summarized answer to the primary research question followed by meaningful recommendations aimed at improving the status quo in Virginia's residential electricity consumption trends. The dissertation does not provide a separate chapter on literature review since background knowledge gathered through the process has been used as groundwork for the various chapters.

2 SYSTEMS VIEW OF THE PROBLEM

The current chapter provides a systems view of the prevailing dynamics that drive residential electricity consumption in the U.S. The chapter walks the reader through a Causal Loop Diagram (CLD) which provides a general explanation of these dynamics; this is achieved by unfolding the relevant causal structures in a step-by-step fashion. The objective is to help the reader obtain a holistic view of the problem, gain knowledge about the various system variables, feedback loops, and interactions that impact residential electricity consumption. The analysis is organized into two sections: 1. household-level dynamics, and 2. utility-level dynamics. The former refers to those dynamics that impact residential electricity consumption from within the household. The structure includes appliance related factors like the number of appliances per household (appliance stock size), average appliance operating power (wattage), appliance run times; and other economic, social and lifestyle factors. The latter, utility level dynamics, describes the relationship between residential electricity demand and how utilities address pricing, generation capacity, and demand side management[7] strategies. The findings of the analysis will help explain Virginia's per capita and per household R.El.C trends in later chapters of the dissertation.

Note that the household and utility level dynamics, to be explained in sections 2.1 and 2.2 respectively, focus only on 'per household' residential electricity consumption. The explanation behind how these dynamics influence 'per capita' residential electricity consumption is accounted for towards the end of the chapter. This will lay the groundwork for subsequent chapters through which the principal research goal of explaining Virginia's per capita R.El.C trends is addressed.

[7] Demand side management refers to strategies employed by utility companies in order to manage electricity consumption on the consumer side of the power grid (Mohsenian-Rad et al., 2010).

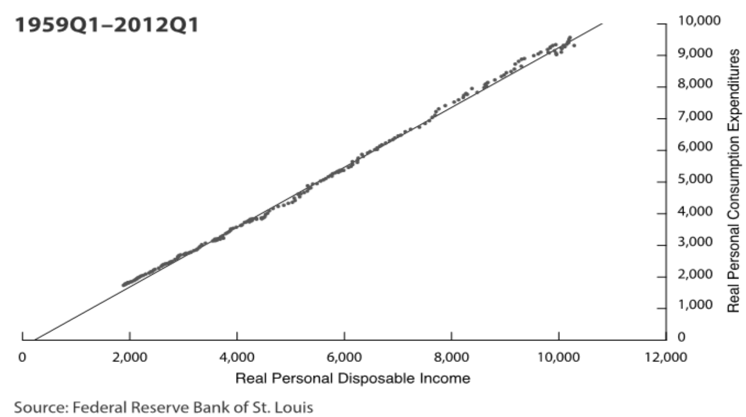
2.1 HOUSEHOLD LEVEL DYNAMICS

It is ultimately the type and extent of electrical appliance use for various residential services that determines the electricity consumption rate in a household. There are several forces that affect household-level decisions and actions which influence its electricity consumption patterns. These forces emerge out of interactions between economic factors like household income, social aspects like family lifestyle, household size, spending attitudes, and other factors such as technological advancements and climate. These interactions affect the net household electrical demand by influencing appliance related factors such as the number of appliances per household (appliance stock), their operating power (wattage), and their extent of use (run time). The discussions in this section will allow the reader to understand the interaction between these factors and the resulting impact on per household electricity consumption.

2.1.1 HOUSEHOLD INCOME: A CENTRAL FACTOR AFFECTING ELECTRICITY CONSUMPTION HABITS

A household's income level influences several factors including appliance stock, residential square footage, household power consumption attitude and also its ability to invest in home efficiency improvements or new energy efficient appliances. Consumer spending is strongly determined by the buying power concealed within paychecks, commonly referred by economists as the real personal disposable income. Figure 2.1 represents the close correlation between real personal disposable income and real personal consumption expenditures in the United States from 1959 to 2012 (Cunningham, 2012). Hence the absolute real disposable income of a household is positively associated with its spending capacity which therefore determines its ability to purchase electrical home appliances, or to make home renovations for efficiency gains, or to replace old inefficient appliances.

Figure 2.1: Correlation between real personal disposable income and real personal consumption expenditures.



Source: (Cunningham, 2012)

The study uses the term household discretionary income which is a more specific economic indicator compared to real personal disposable income. A household's discretionary income is defined as the income which is left after spending on essentials like food, clothing, shelter, taxes and utility bills. In other words it refers to the money available to the household to be spent on luxury goods, home expansion, non-essentials, etc. The term more specifically indicates a household's affluence and its influential role as an R.El.C aggressor within the household level dynamics is discussed in subsequent sections to follow.

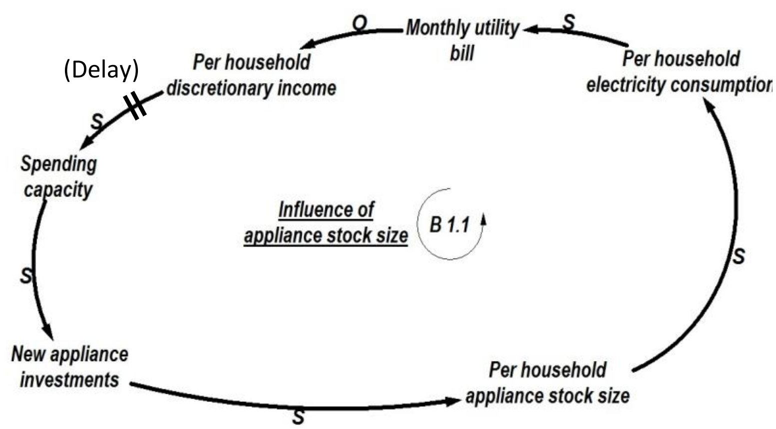
Before proceeding further, the study underlines an important delay dynamic with respect to discretionary income which is common among all the household level causal loops to follow. An increase in utility bills due to high household R.El.C[8] causes discretionary income to decline; however, it takes time for the discretionary income to drop below a certain threshold beyond which economic hardships manifest and the household's spending capacity decreases. Hence there exists a delay wherein it takes considerable time for households to realize the impact on spending capacity, identify the cause of economic hardship (high household R.El.C in this case) and take corrective action. This delay is longer in more affluent families due to their greater capacity to absorb high utility bills. On the other hand, when utility bills are low and households

[8] The term 'Household R.El.C' refers to 'per household R.El.C'.

are left with more discretionary income, it normally takes time for the savings and hence spending capacity to build up to an extent before further investments in home appliances, new larger homes or efficiency upgrades can be made. This delay is indicated in the causal loop diagrams that follow and will not be elaborated upon in further discussions. Sections 2.1.2 to 2.1.8 describe income-driven factors which influence residential electricity consumption among households.

2.1.2 INFLUENCE OF APPLIANCE STOCK SIZE

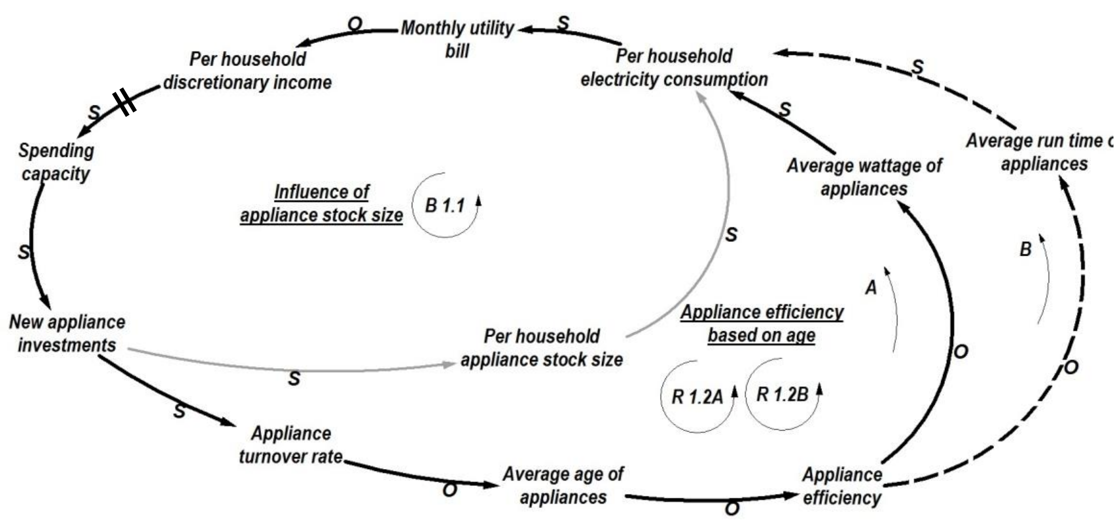
Figure 2.2 : Influence of appliance stock size



Since R.El.C is determined by the operating powers and run times of individual appliances, a large appliance stock will add to the electrical load of a household. Further, a larger stock would also imply more plugged-in appliances thereby increasing phantom loads. A larger electrical load combined with unwanted phantom loads will inevitably drive up the per household electricity consumption. Families with higher discretionary incomes are more likely to invest in new appliances for luxury and pile up their stock of appliances compared to low income families. According to loop B1.1 in Figure 2.2, a household with a large appliance stock will see higher consumption and utility bills which can choke the family’s discretionary income and further appliance purchase capacity. In a household with a relatively small appliance stock, the consumption and utility bills will likely be lower. The money saved will add to the discretionary income and improve the household's chances of purchasing more appliances. This explains the balancing nature of the loop.

2.1.3 INFLUENCE OF APPLIANCE EFFICIENCY (BASED ON AGE)

Figure 2.3 : Influence of appliance efficiency (based on age)



Loops R1.2A&B in Figure 2.3 are reinforcing feedback loops which describe how higher efficiency levels related to a younger stock of appliances in the household influence household R.El.C and cause the resulting savings to further reinforce the loop. Appliance efficiency levels are usually negatively associated with age since components begin to malfunction as appliances get older. Studies show that running an older model refrigerator can consume up to 66% more electricity than a new ENERGY STAR certified refrigerator (Ashley-Chicot Electric Cooperative). Newer appliances are advantageous not just for their minimized inefficiency but also because they possess more efficient latest technologies as explained below:

1. New efficient appliances are built to work with relatively lower operating power (wattage) making them cheaper to operate in the long run (R1.2A). Appliances with low operating

power consume fewer KW of electricity over a fixed run time compared to those with higher operating powers.

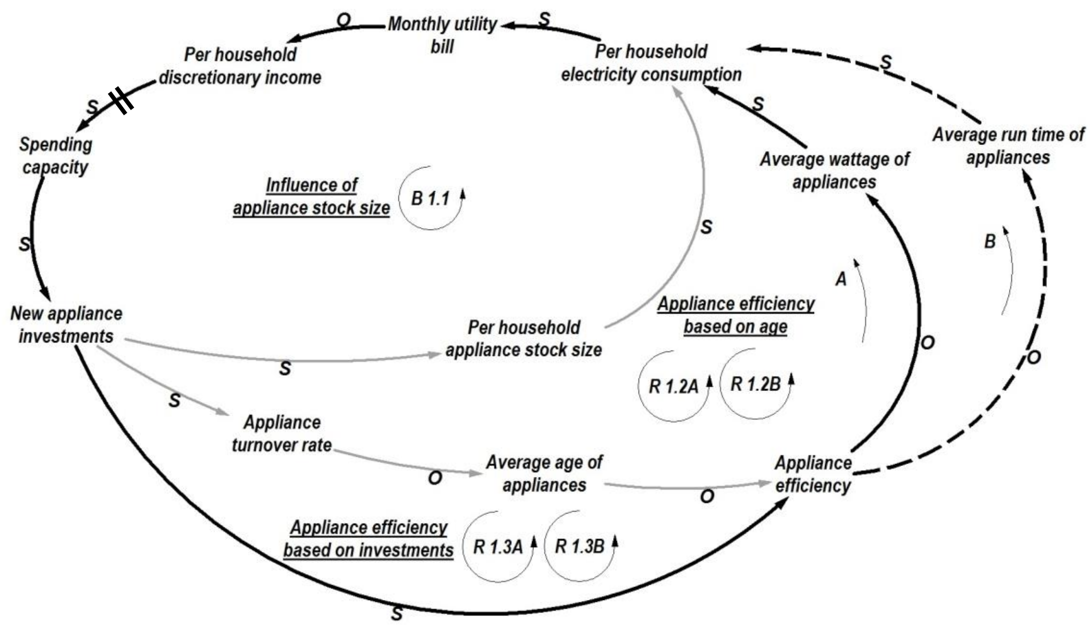
2. Newer appliances are typically built to reduce phantom loads which refer to the power consumed by plugged-in electronic devices or appliances even when they are switched off or in standby mode (Rusk, Mahfouz, & Jones, 2011). To avoid phantom loads, efficient devices enter a low power state during standby mode thereby reducing the actual appliance run time sharply (R1.2B).

Households must invest liberally in order to maintain a decent appliance turnover rate. Relatively more affluent families are likely to replace old, outdated electrical appliances more frequently with newer efficient technology compared to less affluent ones. The resulting savings seen by such families will add to their discretionary income and reinforce further spending capacity on newer appliances. Turnover rates are likely to be low among lower-income families due to reduced spending capacity; the inefficiencies from ageing appliances will reflect in the utility bills which in turn will further cramp the family's discretionary income and spending capacity. This explains the reinforcing behavior of the loop.

2.1.4 INFLUENCE OF APPLIANCE EFFICIENCY (BASED ON INVESTMENTS)

The efficiency of appliances purchased by consumers depends on the amount of money they decide to invest. Although the entire appliance market has grown in electrical efficiency over the past three decades, not all appliances are equally priced and equally efficient. In today's market, more efficient appliances cost more. For example, the more efficient 'ENERGY STAR' labeled consumer appliances and electronics carry a higher price quote compared to less efficient models. However, the operating cost of such efficient appliances is much lower compared to their counterparts as these utilize lesser electricity in the long run; this can be attributed to their lower wattage (R1.3A) and lower absolute run time (R1.3B). This makes the life cycle cost, which is the purchase price and operating cost combined, of an 'ENERGY STAR' labeled appliance typically lower than a less efficient model (I.F.E, 2010). Investing up front in highly efficient appliances can also help reduce the need for frequent turnover as discussed in the previous section.

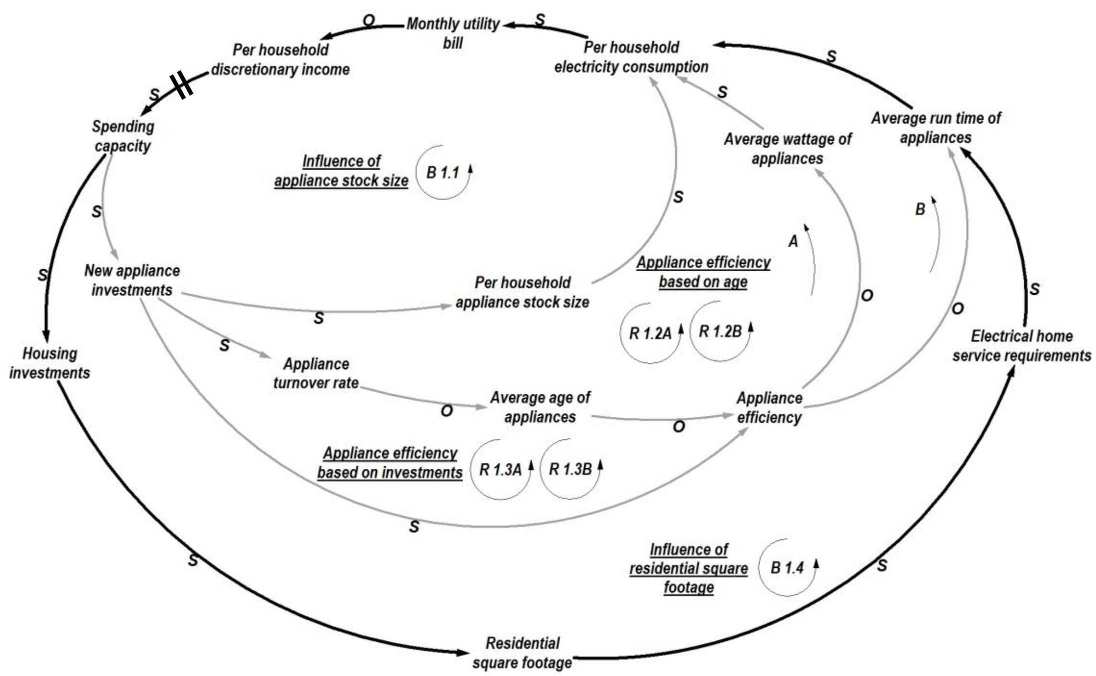
Figure 2.4 : Influence of appliance efficiency (based on investments)



Consumers must choose wisely to invest in efficiency while purchasing appliances in spite of the high initial costs involved as it will pay off in the long run. Affluent households are more likely to make such wise investments that will result in future electricity savings, reduced utility bills and a subsequent increase in the household discretionary income. On the other hand, less affluent households may find it difficult to put up with high initial costs and may opt for cheaper less efficient appliances that are more electrically intensive. This will result in an increase in consumption and higher utility bills further suppressing the spending capacity of the household due to a lowering in discretionary income. This explains the reinforcing nature of loops R1.3A&B.

2.1.5 INFLUENCE OF RESIDENTIAL SQUARE FOOTAGE

Figure 2.5 : Influence of residential square footage

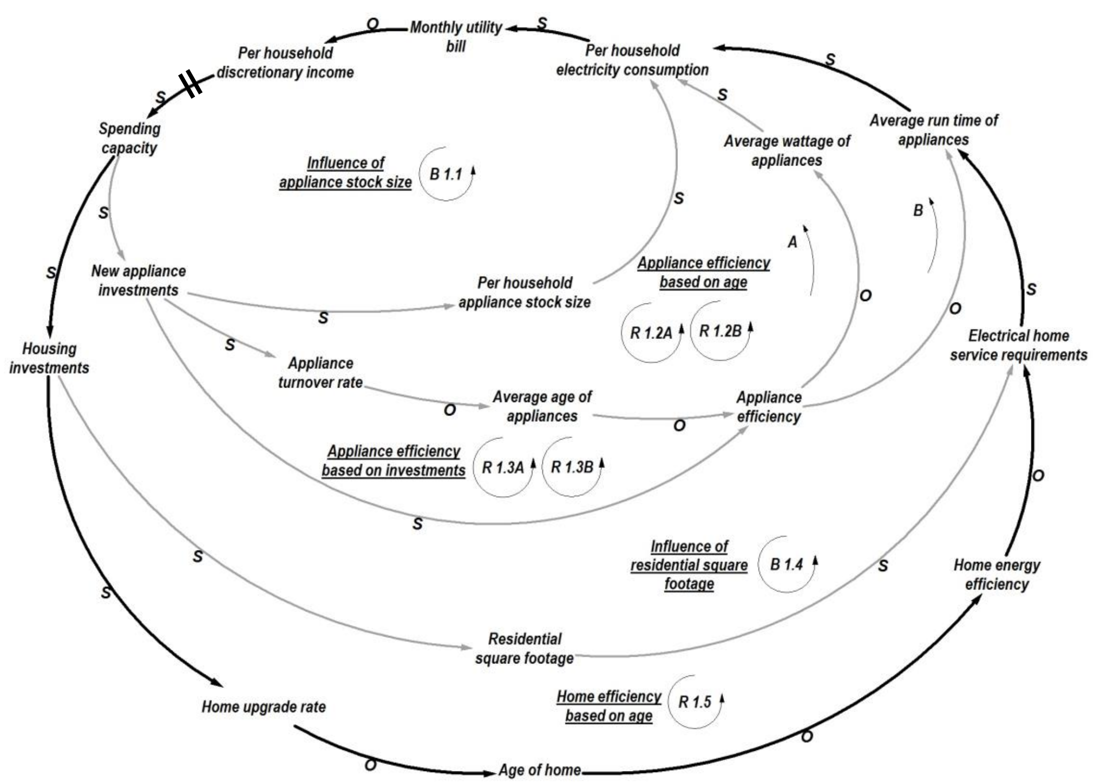


Loop B1.4 is a balancing feedback loop in which residential square footage is the fundamental variable. The square footage of a household's residence is prominently determined by the family's discretionary income. More affluent families tend to live in larger homes which require more space heating, cooling and lighting as they are more spacious. These are collectively referred as electrical home services requirements in Figure 2.5. The respective appliances such as heat pumps, air conditioners, electric lamps, etc. are likely to be run for longer durations in larger homes. Eventually, the electricity consumption per household is positively associated to the residential square footage.

The loop is balancing since variations in the monthly utility bills are accompanied by a balancing effect on the household's discretionary income and eventually it's spending capacity. In the case of larger residences, the resulting higher utility bills will lower the discretionary income and choke the spending capacity of the household making it difficult for further home expansion or even forcing the family to move to a smaller home. Likewise, families living in smaller residences are likely to see lower utility bills thus leaving them with more discretionary income and a better chance to expand their homes.

2.1.6 INFLUENCE OF HOME EFFICIENCY (BASED ON AGE)

Figure 2.6 : Influence of home efficiency (based on age)



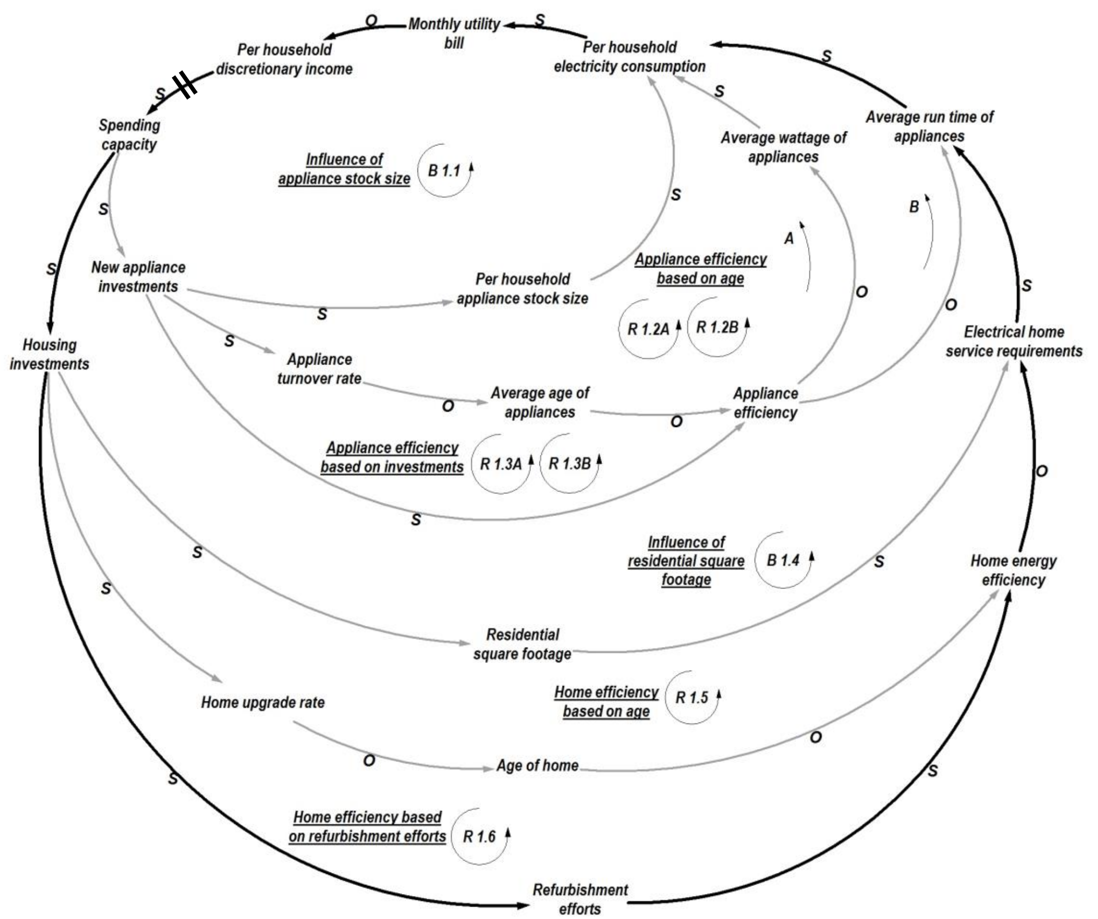
Age is an important indicator of electrical inefficiency in housing units. As housing-units age, they tend to leak conditioned air from within due to ruptured sealing and inadequate thermal insulations. During winter for instance, hot inside air leaks out through holes or cracks and is replaced by colder ambient air. This unwanted leakage is known as infiltration. Apart from infiltration, heat can also be lost in the form of conduction, convection and radiation losses through walls, windows, ceilings, floors and doors (Randolph & Masters, 2008). Such inefficiencies will automatically raise the need for residential electrical services, especially home heating, cooling and water heating, as the appliances will have to work harder to overcome the heat losses due to home inefficiencies. This will eventually drive up per household R.El.C. The above mentioned losses are relatively lower in newly built homes as they usually comply with efficiency standards implemented in the U.S Department of Energy's Building Energy Codes Program. Upgrading to newly built and efficient homes at reasonable intervals can therefore help reduce per household R.El.C.

Affluent families are more likely to upgrade to newer homes as they are financially capable. Monthly electricity savings will add to their discretionary income and further reinforce their capacity for future home upgrades. Low-income families on the other hand may rarely or almost never upgrade their homes due to financial constraints; the inefficiencies associated with ageing homes will further constrain their spending capacity through greater utility bills. This explains the reinforcing behavior of loop R1.5 in Figure 2.6.

2.1.7 INFLUENCE OF HOME EFFICIENCY (BASED ON REFURBISHMENT EFFORTS)

Households that like to live in vintage homes for their historic value, or are unable to upgrade to newer homes due to financial constraints can consider home refurbishments to improve energy efficiency. Energy inefficiencies due to infiltration and heat losses can be significantly reduced through suitable building refurbishments; these include investing in efficiency upgrades like thermal insulations, double pane windows, etc. Such technologies allow home appliances to run more efficiently as unwanted run times for heating or cooling applications are reduced. Furthermore, improving home efficiency through refurbishment efforts also lessens the need to upgrade to a more efficient home.

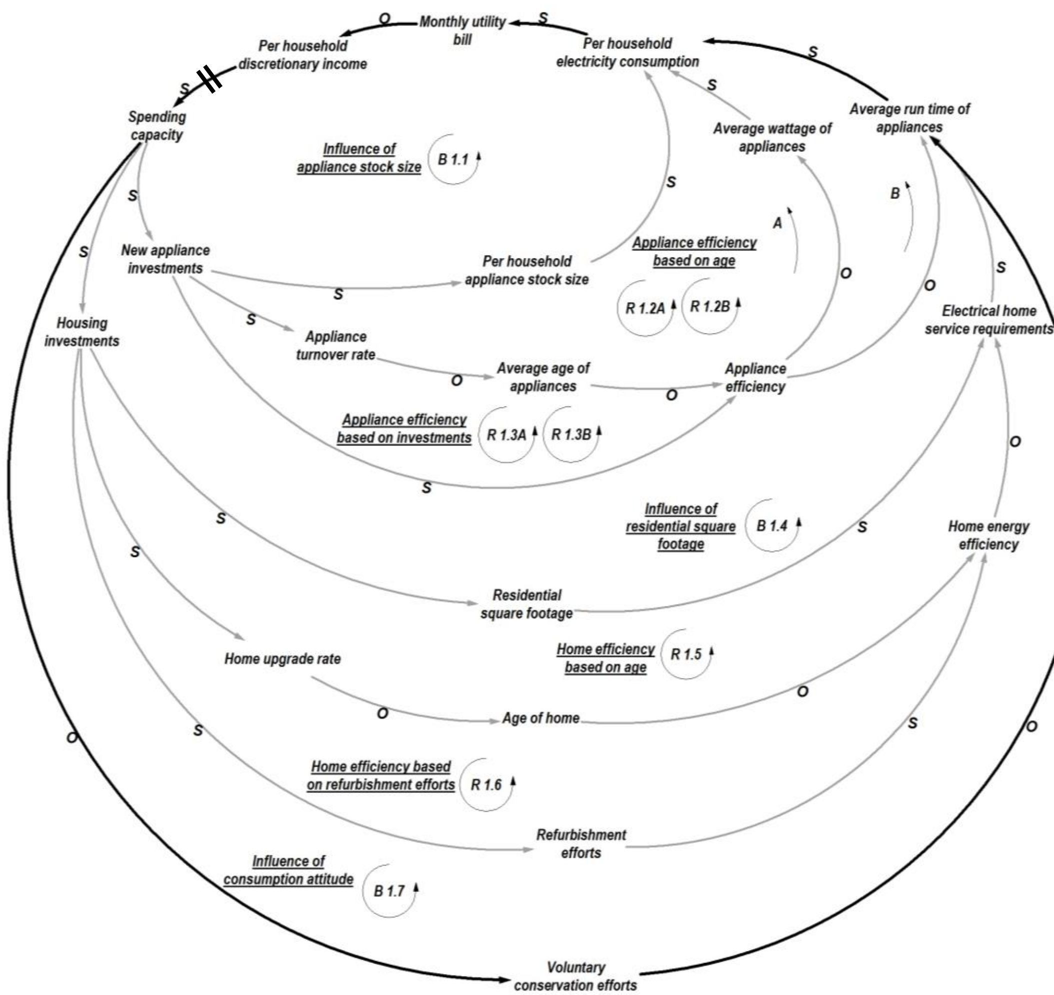
Figure 2.7 : Influence of home efficiency (based on refurbishment efforts)



According to reinforcing loop R1.6, investing in home refurbishments helps realize electricity savings and eventually increase household discretionary income due to lower utility bills. This reinforces household spending capacity and allows for further refurbishment investments (Figure 2.7). Neglecting residential energy inefficiencies and failure to invest in home refurbishment will only increase per household R.El.C and monthly utility bills. This in turn will choke the household's discretionary income and future capacity to invest in refurbishment efforts.

2.1.8 CONSUMPTION ATTITUDE, A FUNCTION OF DISCRETIONARY INCOME

Figure 2.8 : Influence of consumption attitude



Balancing loop B1.7 in Figure 2.8 illustrates the influence of a family's discretionary income on its diligence toward electricity conservation. In a family whose members are careless about electricity consumption, the run times of various appliances are automatically high due to unnecessary use. The resulting increased utility bills will tend to choke the family's discretionary income making it necessary for its members to reconsider their consumption attitudes and be more cautious; this promotes voluntary electricity conservation measures. However, there is always a chance that savings which result from conservation measures will ease the strain on the family's spending capacity by reinforcing its discretionary income and reduce its attention towards voluntary conservation measures. This explains the balancing or goal seeking dynamics of the loop.

2.1.9 EXOGENOUS FACTORS AFFECTING RESIDENTIAL ELECTRICITY CONSUMPTION

Apart from the variables in Figure 2.8, there are several others that influence household R.El.C and are treated exogenous to the problem. These include the number of heating/cooling degree days, household size (# members per household), market pricing of appliances, house price index, market pricing of building refurbishment materials and technological advancements. The impacts of these variables on per household residential electricity consumption are explained in the following sections.

2.1.9.1 Heating/cooling degree days:

Heating degree days (HDD) and cooling degree days (CDD)[9] provide a measure of the climatic intensity of a given location with respect to temperature. For a given electricity-based heating and cooling system, the electricity required for home heating is proportional to the annual HDD while that required for home cooling is proportional to the annual CDD (Thevenard, 2011). This is because high figures in annual HDD or CDD for a particular location raises the need for residential heating or cooling services respectively as HVAC units would have to run for longer durations to heat or cool the home. This results in increased per household R.El.C. Conversely, lower annual HDD or CDD will reduce home heating or cooling needs and allow for reduced per household R.El.C.

[9] The HDD and CDD for a particular year are calculated as the summation of the differences between the daily average temperature and the base temperature for an entire year; the base temperature refers to the temperature level that is adequate for human comfort. Daily average temperatures in case of HDD calculations are usually lower than the base temperature and higher in case of CDD calculations.

2.1.9.2 Household size (# household members):

Household size influences household R.El.C in the following ways:

1. The total demand for electrical home services like water heating, electric cooking, laundry and lighting increases significantly with household size since each household member must satisfy his/her personal needs. This in turn would increase total electricity consumption of the household.
2. More people in a household typically require a larger stock of appliances especially due to personal electronic gadgets like cell phones, tablets, laptops, etc. Hence the size of a household affects R.El.C per household by influencing its appliance stock.
3. Household size also indirectly affects per household R.El.C. The number of members in a household has a direct impact on its total expenditure for basic needs such as food, shelter, clothing, utilities, etc. In a larger household, although the per capita expenditure for basic needs including electricity consumption may reduce due to sharing of certain services (e.g. home heating, lighting, etc.), the net expenditure of the entire household is usually higher (Cutright, 1971). Discretionary income will eventually reduce thereby affecting the way future household decisions are made; for instance, investments in efficiency upgrades may not be seen as an immediate priority and this will impact electricity consumption rates. The opposite is the case for smaller households.

2.1.9.3 Market pricing of appliances:

Market diffusion rates of home appliances and electronics are affected by how they are priced. Cheaper and affordable prices can boost diffusion rates and hence result in appliances accumulating across consumer residences. Larger appliance stocks among households will eventually drive up per household R.El.C as explained in Section 2.1.2. Note that market pricing also affects the diffusion rates of appliances that are certified for higher efficiency. High pricing of efficient appliances could slow down their penetration especially into less affluent households. On the other hand, affordable pricing of such appliances can encourage consumers to invest and improve efficiency levels among their households. Hence, appliance prices indirectly affect household R.El.C by influencing efficiency levels and appliance stock size among households.

2.1.9.4 **Average prices of homes:**

Affordable sale or rental prices of homes will provide a better chance for households living in older homes to upgrade to newer and more efficient households. High prices on the other hand would make it difficult for less affluent households to make such an upgrade. Furthermore, affordable prices can also result in more affluent households willing to adopt larger sized homes. As explained in Section 2.1.5, residential square footage in turn is proportional to household residential electricity consumption. Therefore, sale or rental prices of homes indirectly influence per household R.El.C.

2.1.9.5 **Market pricing of building refurbishment materials:**

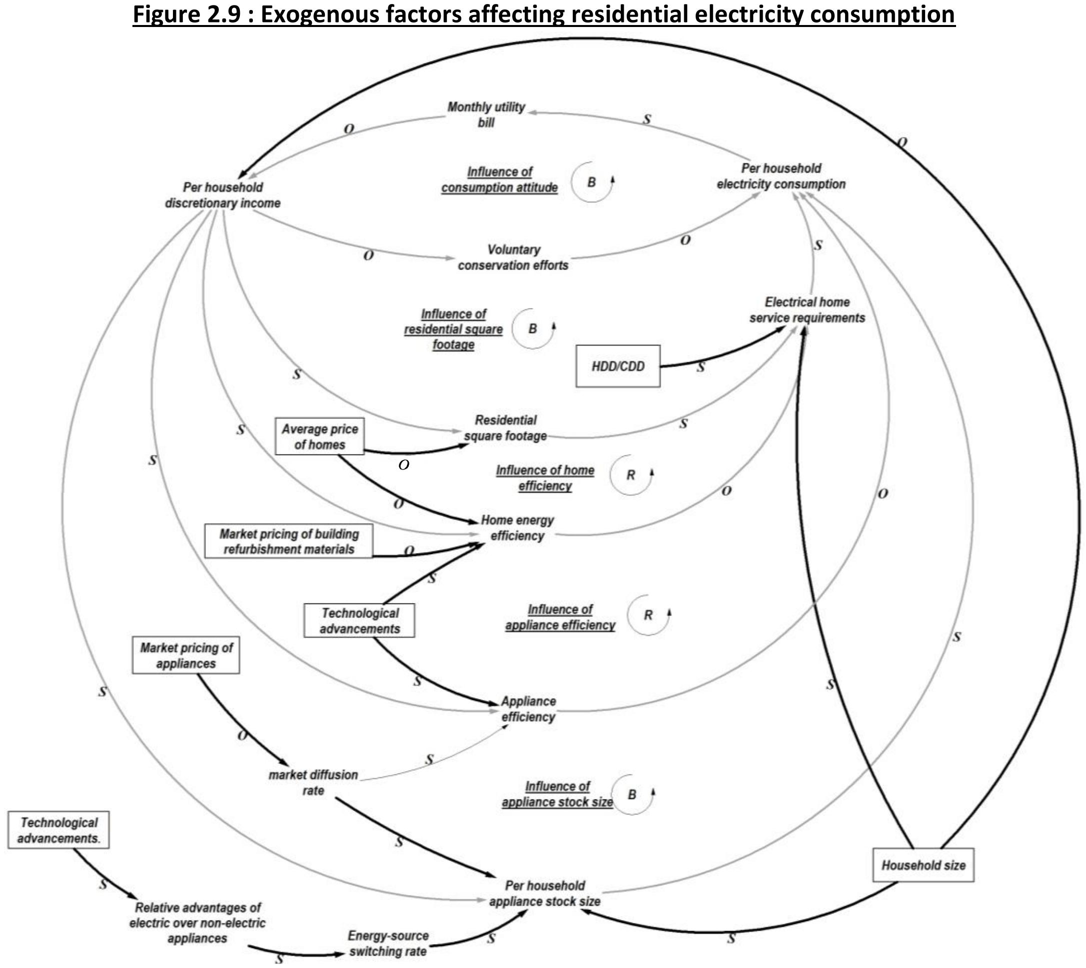
Affordable refurbishment materials like thermal insulations, double pane windows, etc. will encourage households to make necessary investments to improve home efficiency levels. High prices on the other hand could slow down their market diffusion rates and indirectly affect residential electricity consumption rates among households.

2.1.9.6 **Technological advancements:**

Ever since 1980, electrical appliances have gained significant improvements in efficiency standards while their prices to consumers have in general decreased (Yost, 2010). New building materials have been developed that are more energy efficient; these include thermal insulations, double pane windows, etc. These improvements can be attributed to continual investments in research and technological development by the appliances and building industries. As discussed earlier, efficiency improvements are necessary to dampen household R.El.C and continual technological advancements are necessary for future improvements in efficiency standards.

Besides efficiency improvements, technological advancements have also improved the relative advantages of electrical appliances in several respects and made them preferable over their non-electrical counterparts. Advantages include - (i) relative cost effectiveness of electrical equipment with respect to purchase, operating and maintenance costs, (ii) and operating convenience i.e. the ease of use to consumers. Although they do have their cons, these relative advantages are possible reasons that could cause people to switch from using conventional or even renewable-based appliances like gas stoves, solar heaters, etc. towards using electrical appliances; this is otherwise referred to as energy-source switching as discussed in chapter 1.

Figure 2.9 : Exogenous factors affecting residential electricity consumption



2.2 UTILITY LEVEL DYNAMICS & THEIR INTERACTIONS WITH RESIDENTIAL ELECTRICITY CONSUMPTION

The dynamics discussed thus far form the basis for electricity consumption patterns within individual households. The current section will focus on utility level dynamics which refer to the dynamics in which power utilities have a role to play and which go on to affect residential electricity consumption. The causal-loop diagrams in this section will explain the utility's actions in response to total residential electricity demand. Such actions may include (i) adjusting utility prices in response to variations in consumer electricity demand, (ii) adjusting prices to pay for capacity expansion, and (iii) promoting demand side management strategies to reduce consumer demand. The influence of these actions on residential electricity consumption and subsequent feedbacks are illustrated in the following discussions.

Figure 2.10 : Simplified household level CLD

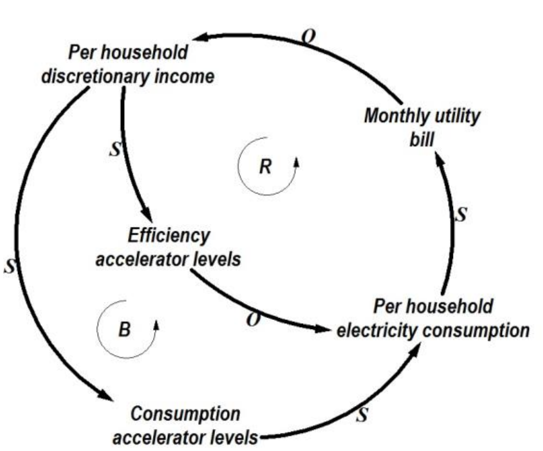


Fig.2.10 represents a simplified version of the household-level causal loop diagram. It is a condensed representation of the household-level dynamics that drive residential electricity consumption and is used as the basis to show how they are influenced by utility-level dynamics. Exogenous variables are not shown since their states are not affected by utility level dynamics. Also, all endogenous variables that lie between 'per household discretionary income' and 'per household electricity consumption' in Figure 2.9 are aggregated under two variables; these are

consumption accelerator levels and ***efficiency accelerator levels*** according to the role they play within the household level dynamics. Greater levels of consumption accelerators will drive up R.El.C rates while greater levels of efficiency accelerators will suppress R.El.C rates. Table 2.1 lists the various endogenous household level variables categorized under residential consumption accelerators and efficiency accelerators. The balancing loop (B) in Figure 2.10 represents how higher discretionary income drives up R.El.C rates by intensifying consumption accelerator variables like appliance stock size, appliance run time, etc. and how the resulting utility bills reduce household discretionary income. The reinforcing loop (R) represents how higher discretionary income will help dampen R.El.C rates when invested in efficiency upgrades and how the resulting savings will reinforce the household's discretionary income.

Table 2.1 : Categorized list of endogenous household level determinants

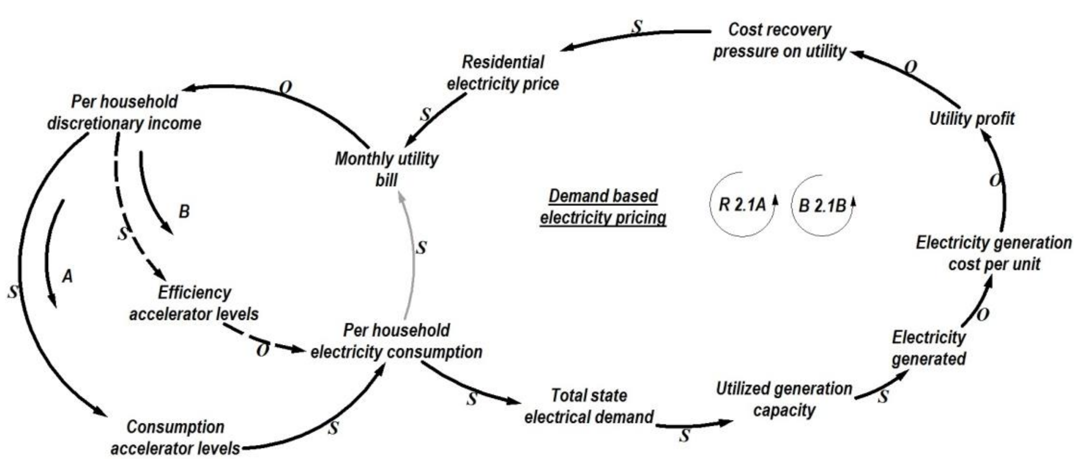
Consumption accelerators	**Efficiency accelerators**
Positively associated factors w.r.t consumption	Negatively associated factors w.r.t consumption
1. Appliance stock size per household 2. Average wattage of appliances 3. Average run time of appliances 4. Average age of appliances 5. Residential square footage 6. Age of home 7. Electrical home service requirements	1. Appliance efficiency 2. Appliance turnover rate 3. Home upgrade rate 4. Home energy efficiency 5. Refurbishment efforts 6. Voluntary conservation efforts

The various utility level causal-loop diagrams (CLDs) to follow are constructed using the simplified CLD shown in Figure 2.10 as the foundation.

2.2.1 DEMAND BASED ELECTRICITY PRICING

Figure 2.11 illustrates the possible variation in residential electricity prices in response to changes in consumer demand and how this impacts household residential electricity consumption. Loop R2.1A represents feedback with respect to consumption accelerators while loop B2.1B represents feedback with respect to efficiency accelerators. Based on commodity system dynamics, high consumer demand is vital for increased producer profits. Higher demands encourage producers to increase their production volume which in turn will lower the unit production cost since total production costs are distributed across a larger production volume; production volume is increased either by maximizing utilization of existing production facilities or by building new facilities or by a combination of both. Lower production cost per unit in turn results in a greater profit margin for the producer (Sawin et al., 2003). The same applies to power utilities. A high total residential electricity demand in the state will prompt utilities to increase utilization of their existing plants to generate more electricity; the result is a greater profit margin per unit of electricity sold due to lower generation costs per unit (Figure 2.11). Greater profits will reduce utility pressures to recover its operating costs and investments; this will hence allow utilities to sell electricity at modest or even lower prices to its consumers.

Figure 2.11 : Demand based electricity pricing



Under a low electricity pricing scenario, households will enjoy lower utility bills and increased discretionary incomes which are likely to be followed by increases in the levels of residential consumption accelerators (loop R2.1A). The resulting increase in R.El.C rates across households will increase the state's residential electricity demand and will allow for further lower electricity prices; this explains the reinforcing behavior of the loop. In case of high electricity prices, households are more likely to take measures to curb electricity consumption hence reducing the total demand. This will increase unit cost of electricity production due to reduced capacity utilization, hence causing utilities to face lower profit margins. Utilities will therefore be pressured to recover lost revenue by requesting the State Commission to raise electricity prices to its customers. Without other checks and balances, utilities will eventually enter a vicious loop commonly known as ‘the utility death spiral’ in which increasing the utility prices will only lower further demand and create the need for another price hike (Ford, 1997). This makes the reinforcing loop R2.1A crucial to the study. Also note that among highly affluent households, high electricity prices may not pose an economic pressure. This is referred to as low price elasticity of demand and in such case, household electricity consumption may continue to rise up to a threshold beyond which the economic pressures are felt.

As per balancing loop B2.1B, low electricity prices will leave households with higher discretionary incomes that may be invested in efficiency upgrades. Although this may help lessen unnecessary consumption, such efficiency improvements among households may not be significant enough to actually lower the net demand to utilities and cause an increase in electricity prices. This is because low prices boost consumption accelerator levels simultaneously (as per loop R1.2A) and generally leading to greater consumer demand (Ford, 1997). In summary, the feedback due to efficiency accelerators (loop B2.1B) is considered relatively weaker than that due to consumption accelerators (loop R1.2A), i.e. total state electricity demand has a net negative association with electricity prices and the reinforcing behavior due to consumption accelerators is relatively more dominant. Similar theory applies to further discussions as necessary.

2.2.2 ASSET BASED (INSTALLED UTILITY CAPACITY) ELECTRICITY PRICING

Figure 2.12 : Asset based electricity pricing

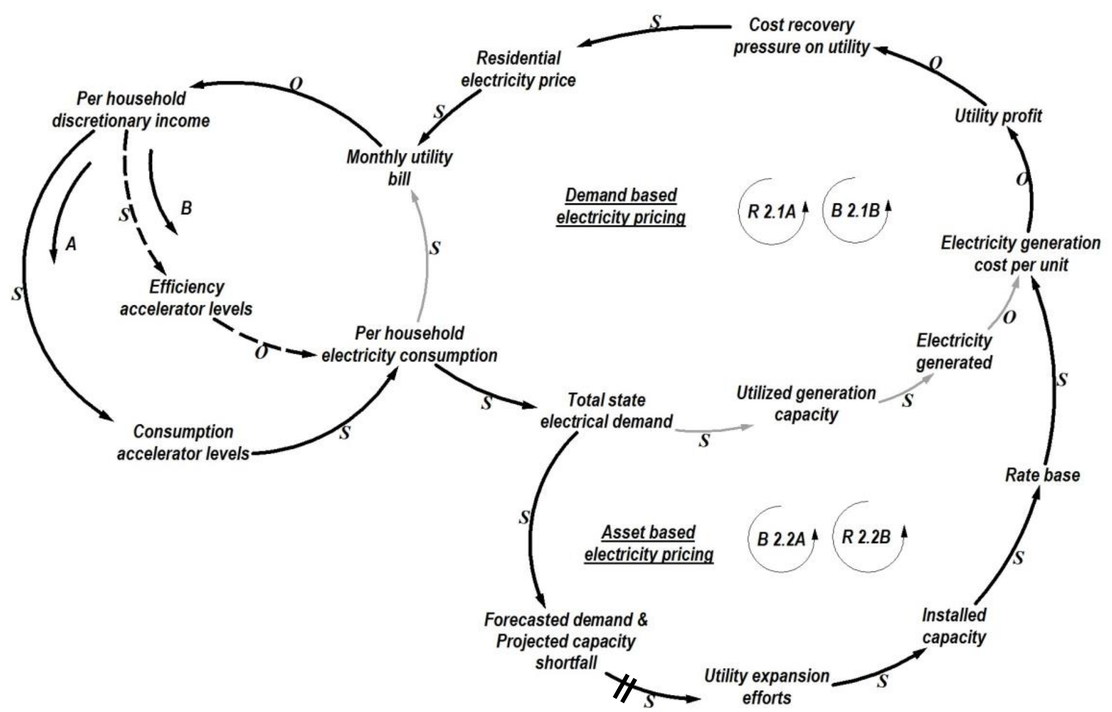


Fig.2.12 illustrates pricing variations in response to utility expansion efforts and the resulting impact on household R.El.C rates. Loops B2.2A & R2.2B represent feedback dynamics with respect to consumption and efficiency accelerator levels respectively with the former being more dominant of the two. Power utilities in the U.S periodically forecast electricity demands five years out in order to determine if they have the necessary generation capacity to meet those demands. In the case of a high projected capacity shortfall which is likely to occur with steep growths in total state electricity demand, utilities may have to expand by installing new generation capacity. This will increase the power utility's rate base which refers to the total value of a utility's assets and is considered a key factor in determining the electricity price to consumers (Scott, 2003). A larger rate base would imply larger electricity generation costs per unit and higher pricing to customers since investments in new capacity installations will have to be

recovered. When demand remains such that utilities do not have to expand capacity, electricity prices to customers can remain modest or low depending upon generation costs. Note that installing new capacity is a long term process and hence a delay exists before prices actually rise up in response to capacity expansions.

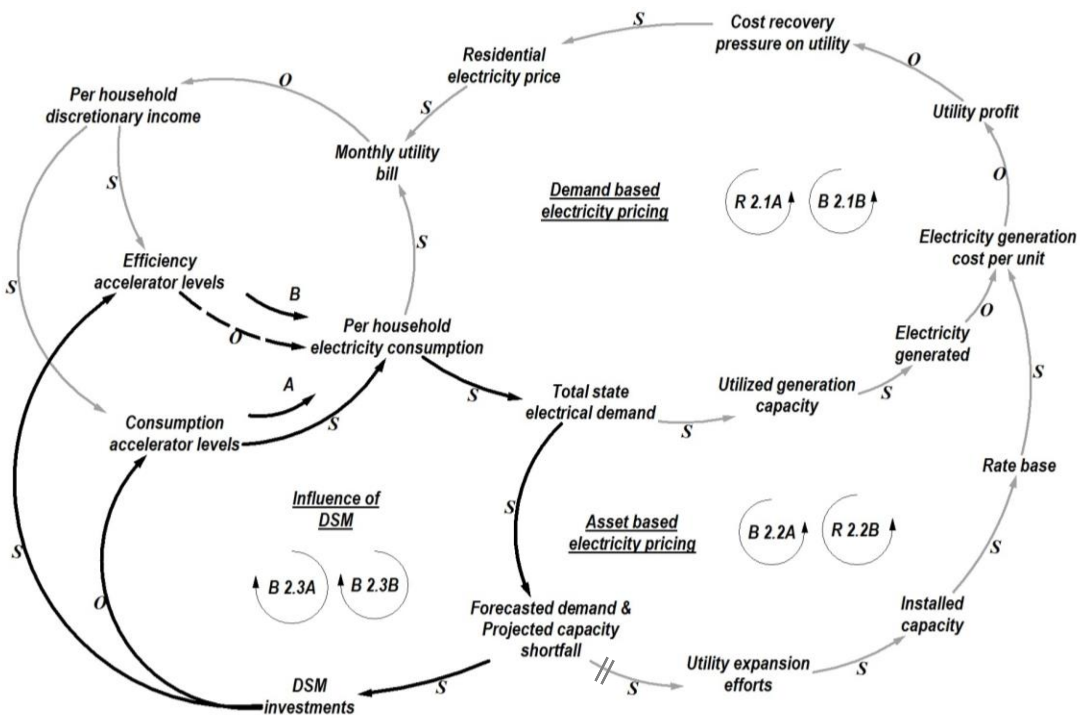
As discussed previously, the feedback due to consumption accelerators (loop B2.2A) is relatively more dominant and eventually the total state electricity demand is negatively associated with electricity pricing. In the case of a price hike due to capacity expansion, households are likely to take efforts to reduce power consumption by suppressing consumption accelerator levels; this will eventually balance the loop by lowering the state's total electricity demand hence reducing further needs to install new utility capacity. On the other hand, when there is no need to expand utility capacity, electricity prices may remain low but will boost R.El.C rates among households. This in turn can drive up total state demand and possibly cause the need to install new generation capacity, thereby explaining the balancing feedback of loop B2.2A.

According to reinforcing loop R2.2B, high electricity prices due to capacity expansions can suppress investments in efficiency upgrades due to lower discretionary income among households. Unnecessary electricity consumption due to household inefficiencies will cause total state electricity demand to rise and may bring the need for further utility capacity expansion in case of a projected shortfall. However, since high prices generally reduce overall demand by suppressing consumption accelerator levels, the reinforcing feedback corresponding to loop R2.2B is considered less significant.

2.2.3 INFLUENCE OF DEMAND SIDE MANAGEMENT

Investing in demand side management (DSM) strategies is the central aspect illustrated by balancing loops B2.3A & B2.3B (Figure 2.13). Demand side management refers to strategies employed by utility companies in order to manage electricity consumption on the consumer side of the power grid (Mohsenian-Rad, Wong, Jatskevich, Schober, & Leon-Garcia, 2010). A wide range of DSM strategies are employed by utilities and these can be categorized under two broad approaches - (i) strategic measures including conservation to manage the load curve[10], and (ii) consumer-side improvements in electricity use efficiency to minimize consumption.

Figure 2.13 : Influence of demand side management (DSM)



Utilities strengthen their DSM efforts by investing more when they forecast a high future demand and foresee a potential capacity shortfall. When they do suffer a shortfall, utilities might pursue DSM strategies in combination with capacity expansion. In loop B2.3A, DSM efforts are aimed at reducing impacts due to consumption accelerators, for e.g. through awareness programs or incentive programs to initiate voluntary conservation efforts to reduce careless consumption and appliance run times. In loop B2.3B, DSM efforts are aimed at improving efficiency levels among households in order to curb unnecessary electricity consumption. These efforts are expected to bring down both, per household R.El.C and the total state residential electricity

[10] Load curve in the utility sector refers to the electricity consumption by power consumers plotted with reference to time.

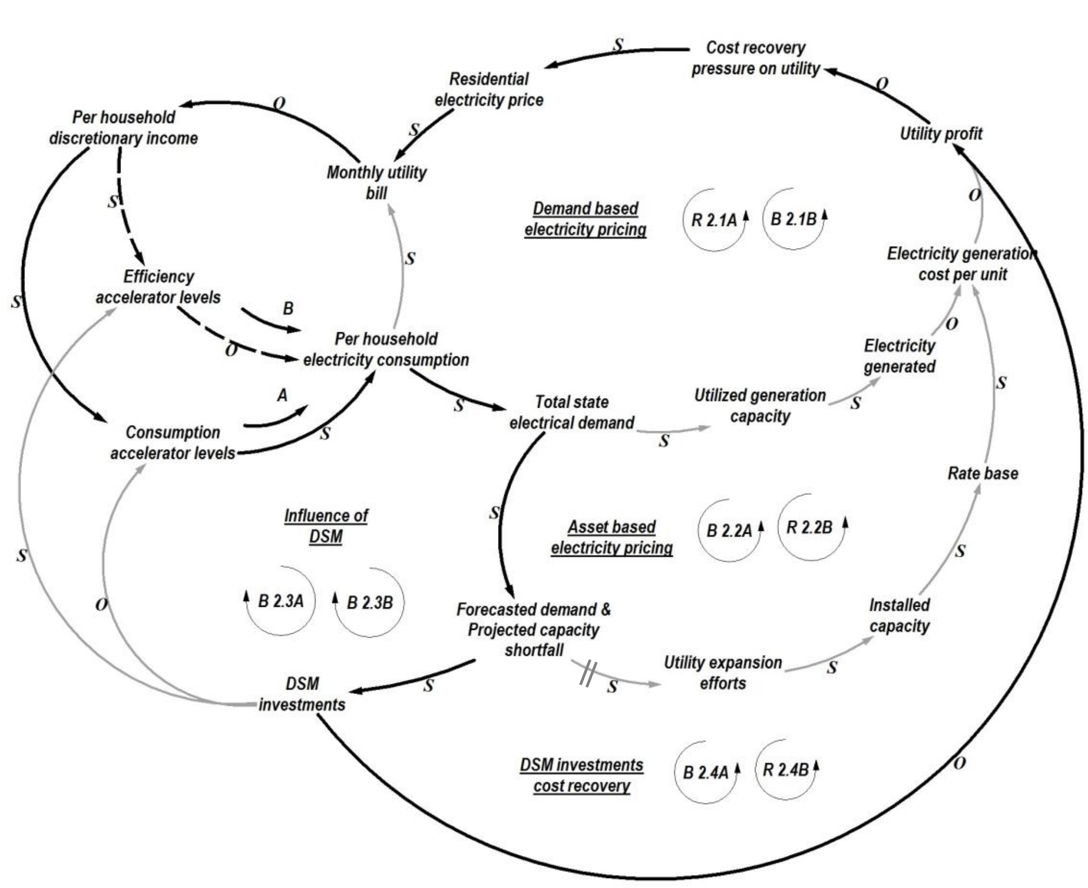
demand. The resulting feedback will help in balancing out the initially high forecasted demands or any projections in capacity shortfall. This explains the goal seeking behavior of balancing loops B2.3A&B.

On the other hand, when residential electricity demand in the state is low with less likeliness of a capacity shortfall, utilities may be reluctant to invest in DSM measures to avoid further undercutting the demand. Under such a scenario, utilities would be motivated to encourage more consumption by customers in order to better utilize their capacity and reduce per unit generation costs (loop R2.1A). Reduced DSM efforts will cause consumption accelerator levels to rise and leave household inefficiencies unchecked thereby resulting in higher household R.El.C and higher total state electricity demand. High demands can increase the likeliness of a future shortfall in capacity and would therefore have to be checked by strengthening DSM efforts.

2.2.4 DSM INVESTMENTS COST RECOVERY

DSM efforts can require significant financial investments by utilities and this may use up a fraction of their profits depending upon how big their investments are. Balancing loop B2.4A (Figure 2.14) illustrates the possibility of an electricity price hike in case utilities feel a pressure to recover large DSM investments; this will consequently impact total state residential demand as households will lower their consumption accelerator levels. Future forecasted demands could eventually drop hence necessitating investments cuts in DSM strategies. The dynamics of this loop are not usually felt as DSM investments are voluntary and made in the interest of reducing consumer demand and to lower the rate of utility expansion.

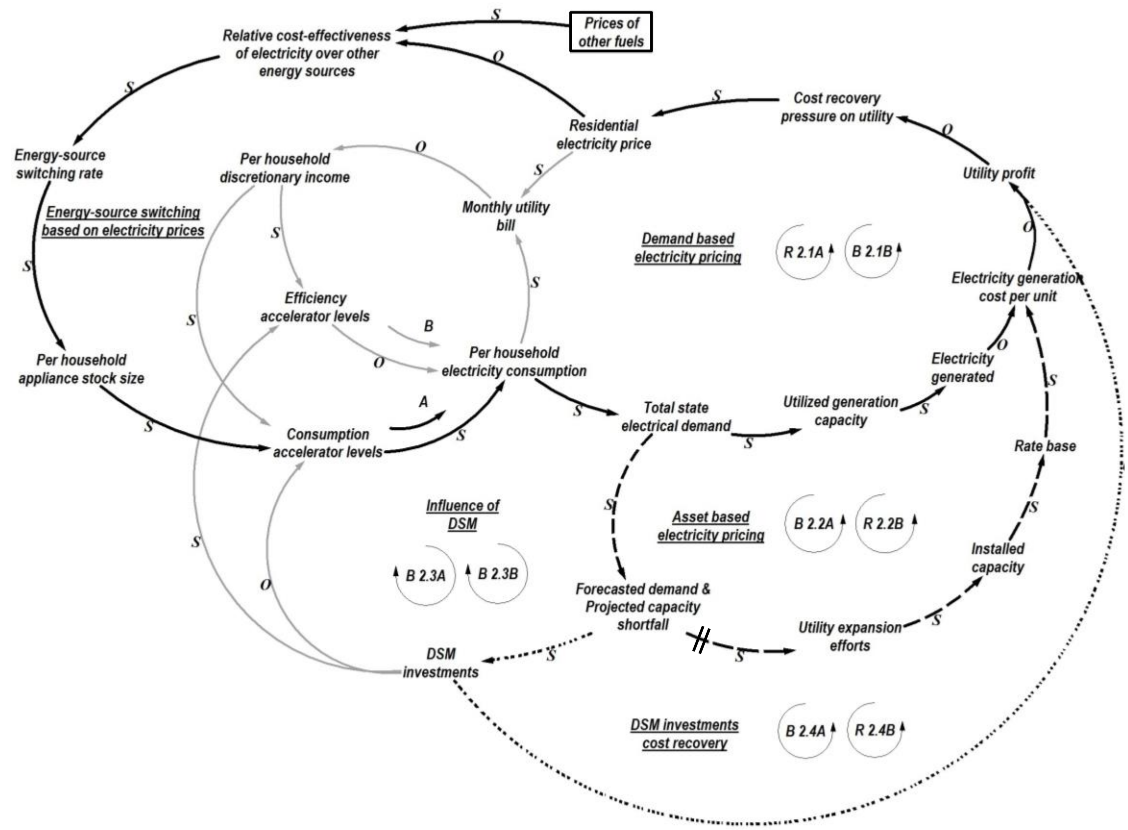
Figure 2.14 : DSM investments cost recovery



According to reinforcing feedback loop R2.4B, high electricity prices due to greater DSM efforts can make it difficult for households to invest in efficiency upgrades due to the impact on discretionary income. This can cause an increase in R.El.C rates across households and in the state total electricity demand. Higher demands may then call for stronger DSM efforts further increasing the electricity prices to customers. However as already discussed previously, the feedback due to efficiency accelerator levels (loop R2.4B) is relatively less significant compared to the feedback due to consumption accelerator levels (loop B2.4A).

2.2.5 ENERGY-SOURCE SWITCHING BASED ON ELECTRICITY PRICES

Figure 2.15 : Energy-source switching based on electricity prices



Residential electricity prices also influence household decisions regarding the type of appliances purchased, whether electrical or non-electrical. This is because electricity prices determine the operating costs of respective appliances. When prices are such that the operating costs of electrical appliances are cheaper than gas based counterparts, households may prefer using the former class of appliances to save money. Such decisions can increase the energy-source switching[11] rate across households by purchasing more electrical appliances. On the contrary, when cost-effectiveness of using electrical appliances is relatively lower, then households might prefer using gas or other fuel based appliances. Hence electricity prices can influence energy-source switching in turn affecting household's electrical appliance stock size which is a

[11] The term *energy-source switching* in this paper refers to the transition from traditional fuel use towards electricity use and not vice versa.

consumption accelerator. Feedback dynamics with respect to energy-source switching are similar to those represented by loops R2.1A, B2.2A & B2.4A; the only difference being that the variations in consumption accelerator levels is due to energy-source switching among households and not due to their discretionary income levels. Besides electricity prices, the prices of other fuels also determine the relative cost-effectiveness of electricity and is considered an exogenous variable that influences energy-source switching among households.

Note that the household and utility level dynamics explained so far focus only on 'per household' residential electricity consumption. Except for household size, all other variables among the household and utility level dynamics influence 'per capita' residential electricity consumption in similar fashion. Unlike per household R.El.C which is positively associated with household size, per capita R.El.C is negatively associated with the number of members in a household. A larger household size implies that the total electricity consumption is shared among more household members resulting in lower per capita consumption. Table 2.2 shows how per capita expenditure on basic requirements decreases as household size increases.

Table 2.2 : Per capita expenditures for different family (household) sizes and income ranges, Urban United States, 1960-61.

	Family Disposable Income							
	$1,000-1,999	$2,000-2,999	$3,000-3,999	$4,000-4,999	$5,000-5,999	$6,000-7,499	$7,500-9,999	$10,000-14,999
Mean Money Income After Taxes	$1,692	$2,572	$3,583	$4,668	$5,593	$6,783	$8,623	$11,811
Family Size	Food Expenditure Per Family Member							
Two	309	378	459	511	535	629	726	840
Three	208	263	340	383	422	470	569	659
Four	—*	251	283	315	351	407	465	549
Five	—*	203	256	279	294	353	410	462
Six or more**	—*	169	183	221	250	282	330	376
	Housing, Shelter, Utilities and Operation Per Member							
Two	351	454	578	673	707	880	1,049	1,219
Three	239	312	391	459	508	608	686	875
Four	—*	289	297	347	406	458	523	652
Five	—*	206	270	271	317	376	404	535
Six or more**	—*	134	155	196	223	269	319	349

Source: (Cutright, 1971)

In summary, the various factors and dynamics that have a role to play in influencing 'per household' and 'per capita' electricity consumption rates have been laid out in this chapter. The discussions thus far will form the basis for subsequent chapters to develop a dynamic hypothesis that would answer the primary research question i.e. what is causing per capita and per household residential electricity consumption rates in Virginia to grow rapidly?

3 ANALYSES OF 'HIGH RESIDENTIAL ELECTRICITY CONSUMPTION' SCENARIOS

The following chapter makes use of dynamics described in chapter 2 to identify possible scenarios that can potentially lead to high per capita and per household residential electricity consumption rates. Outlining such high residential electricity consumption scenarios[12] will provide the basis to formulate a dynamic hypothesis that explains why Virginia's growing per capita and per household residential electricity consumption rates are climbing annually. Consistent with the analyses in chapter 2, the discussion in this chapter utilizes two different lenses for understanding this problem: household-level analysis, and utility-level analysis.

3.1 HOUSEHOLD LEVEL ANALYSIS

According to the simplified household level CLD shown in Figure 2.10, high residential electricity consumption rates[13] occur as a direct result of either a **surge in electricity consumption accelerator levels** or a **decline in efficiency accelerator levels**. The possible reasons behind the occurrence of these two conditions among high R.El.C scenarios are explained as follows.

3.1.1 CAUSES OF SURGE IN CONSUMPTION ACCELERATORS

1. **Excessive discretionary income** has a reinforcing effect on the levels of consumption accelerators which in turn yields high per capita and per household electricity consumption rates. The following are system conditions that prevail amidst high R.El.C scenarios due to the influence of discretionary income:

[12] The term 'High residential electricity consumption (R.El.C) scenario' used throughout this chapter refers to a scenario where 'per capita R.El.C' and 'per household R.El.C' rates are both high.
[13] The term 'residential electricity consumption (R.El.C) rates' used throughout this chapter refers to both 'per capita R.El.C' and 'per household R.El.C'.

- Households living in larger homes which in turn increase the need for electrical home services.
- Larger appliance stock per household.
- Careless electricity consumption attitude and reduced voluntary conservation efforts that are associated with an affluent lifestyle.

2. Besides discretionary income, various exogenous factors also have reinforcing effects on consumption accelerators. These include:
    - **Higher heating or cooling degree day figures,** which increase space cooling or heating demands of households respectively.
    - **High sale or rental prices of homes,** since this can make it difficult for households living in ageing, inefficient homes to upgrade to newer and more efficient homes.
    - **High market prices of building refurbishment materials,** as this would slow down their diffusion since households may not often be willing to make such costly investments towards efficiency upgrades.
    - **Cheaper market prices of electrical appliances,** as they boost market diffusion rates and increase appliance stock sizes across households.
    - **Increased energy-source switching rates,** which may be triggered by greater relative advantages of electrical over non-electrical appliances resulting from technological advancements. This can also add to the appliance stock of households.
    - Household size (i.e. number of people per household), since **larger households** exert pressure on consumption accelerators such as electrical home services and appliance stock due to the presence of more individuals in the household; this consequently induces a high R.El.C scenario. While **smaller households** may be economically beneficial, they are also likely to increase the per capita R.El.C since major consumption demands like heating and cooling will now be shared among lesser number of people. In addition, the discretionary spending capacity of smaller households tends to be higher since their basic

expenditures are relatively lower due to less number of household members. This in turn can reinforce consumption accelerators thereby resulting in high R.El.C rates.

3. Loop polarities play a significant role in determining how long a scenario's outcome will prevail. As per Figure 2.10, consumption accelerators are associated with balancing loop in which there is a **delay involved before the loop's corrective action can take effect and R.El.C rates can actually start declining**. This is due to the possibility that a household's spending capacity may remain unaffected until its discretionary income drops below a certain threshold beyond which significant economic pressures are felt; this is usually the case in high income families. During such a delay, R.El.C rates will either remain steady or continue to rise but will rarely decline. There is even further delay involved as households will need time to change their consumption habits in order to noticeably reduce their electricity consumption.
4. Effect of efficiency accelerator loop (R) on the consumption accelerator loop (B): Due to the reinforcing behavior of the efficiency loop, savings that result from a significant improvement in efficiency conditions will reinforce a household's discretionary income; this will allow for even further efficiency investments and cost savings (Figure 2.10). However, efficiency improvement as a household-level policy measure to decrease electricity consumption can have an unintended consequence. Higher efficiency levels from appliance or home upgrades will result in cost savings that add to the household's discretionary income; this in turn is likely to cause a surge in consumption accelerators as discussed earlier in section 'a'. The surge is mostly due to careless consumption attitudes since the operating costs of appliances are relatively lower after efficiency improvements. This chain of events is called **the rebound effect** (Berkhout, Muskens, & W. Velthuijsen, 2000) and contributes towards a high R.El.C scenario.

3.1.2 CAUSES OF DECLINE IN EFFICIENCY ACCELERATORS

1. **Low discretionary income** contributes towards high R.El.C scenarios too; this is because efficiency accelerator levels are undermined due to reduced capacity to invest in energy efficient appliances and home improvements. The following conditions are likely to prevail in such scenarios:
    - **Slower appliance turnover rate,** which results in ageing appliances which grow in inefficiency levels with time.
    - **Purchase of low-end appliances**, especially those which are not efficiency certified. Such appliances are electrically more intensive compared to their efficiency certified but more expensive counterparts.
    - **Inability to invest in new homes or home refurbishments** in order to minimize the inefficiencies associated with ageing homes.
2. Exogenous factors that have an undermining effect on efficiency accelerators:
    - **Old homes,** as they are generally less energy efficient, depending on how well they are refurbished.
    - **Larger households,** since they are likely to be left with less discretionary income to invest in efficiency improvements, either home refurbishments or more efficient appliances. The reason is because their basic expenditures are relatively higher due to more number of household members.
    - **High market prices of more efficient appliances,** since consumers will settle for lower priced appliances which tend to be relatively less efficient.
    - **High market prices of building refurbishment materials,** since this would slow down their diffusion rates and households may feel reluctant to invest in such expensive upgrades.

3. As per Figure 2.10, efficiency accelerators are associated with reinforcing loop (R). High household electricity consumption resulting from low initial efficiency levels will choke the household's discretionary income therefore restricting further efficiency investments. This endless reinforcing dynamic will ultimately give rise to a scenario with high per capita and per household R.El.C rates.
4. Effect of consumption accelerator loop (B) on the efficiency loop (R):

   High R.El.C rates in the case of a surge in consumption accelerators will cause a decline in the household's discretionary income due to increased utility bills. For example, larger housing units imply higher utility bills in addition to higher mortgage payments and maintenance costs. This will consequently choke the household's spending capacity making it almost impossible to invest in efficiency upgrades until the consumption accelerator loop (B) balances itself (Figure 2.10). This sequence of events will eventually induce a high R.El.C scenario.

Highlighted so far are the household level system conditions which give rise to high residential electricity consumption rates. The following section will explore further causes of high R.El.C rates due to dynamics at the utility level.

3.2 Utility Level Analysis

According to the utility level CLD shown in Figure 2.15, high residential electricity consumption rates occur as a result of ***affordable retail electricity prices*** or ***insufficient demand side management (DSM) efforts***. Low retail prices can lead to a surge in consumption accelerators since lower utility bills would leave households with more discretionary income. Reduced economic pressures will eventually allow for excessive consumption of electricity amongst residences. Low electricity prices furthermore incentivize home owners to use more electricity-based appliances due to the energy source being cost effective, therefore increasing energy-source switching rates among households. However, in a 'low price elasticity of demand' scenario, household R.El.C rates may continue to rise despite high electricity prices. This is because when a household is more affluent, higher utility bills may not have a significant impact on its discretionary income and R.El.C rates are likely to rise as long as economic pressures are not felt by the household. Besides electricity prices, insufficient DSM measures on the part of utilities also induce high household R.El.C rates as inefficiencies among residences are left unattended.

3.2.1 REASONS BEHIND LOW RETAIL ELECTRICITY PRICING

The following conditions among utility level endogenous variables account for low retail prices:

1. A **high total demand for residential electricity in the state** allows for more efficient utilization of utility generation capacity, and hence lower electricity generation costs and retail prices.

2. **Slower capacity expansion rates** by utilities helps them avoid immediate pressures to recover capital investment costs, hence allowing them to maintain low retail electricity prices (Ford, 1997).
3. **Lesser investments in demand side management** also helps utilities maintain low electricity prices by avoiding additional cost recovery pressures.

Note that a high R.El.C scenario due to low electricity prices will persist until total electricity demand increases to a threshold beyond which a capacity expansion or a rapid push for DSM to curb demand is necessary. These corrective actions can cause a potential electricity price hike as they increase utility operating costs. There also exists a period of delay before electricity prices can actually climb since it takes considerable period of time for a capacity shortfall to occur and also for new capacity installations to come online.

3.2.2 REASONS BEHIND INSUFFICIENT DSM EFFORTS

Minimal efforts to promote demand-side management (DSM) can be the status quo with a utility whose electricity generation capacity is underutilized. In such a case, the utility is likely to place lower priority on DSM measures since such efforts will only further reduce electricity consumption rates, undercut the total demand and lead to even lower utilization of generation capacity. This would only go on to accelerate the utility death spiral (as described by Loop R2.1A in Figure 2.11) and hence utilities have a strong incentive to compromise on demand side management efforts. Low monetary investments by utilities and less Government and third party provisions are other reasons behind insufficiencies in demand side management efforts.

Insufficiency in DSM efforts will drive up consumption accelerators and suppress efficiency accelerators. The resulting increase in household electricity consumption will accelerate the reinforcing behavior of the demand based pricing loop (effect of loops B2.3A&B on R2.1A). Hence household consumption will continue to increase endlessly therefore giving rise to a high R.El.C scenario.

3.2.3 GENERAL DYNAMIC HYPOTHESIS

Up to this point, it has been established that residential electricity consumption trends in the U.S are driven by a combination of factors which, under the right circumstances, can together create a "perfect storm" on account of which growth in per capita and per household residential electricity consumption rates are virtually inevitable. This perfect storm emerges out of cohesive interaction between a collection of reinforcing and balancing feedback dynamics described thus far. In short, this perfect storm can be described as a situation in which

1. discretionary incomes of households incomes are on the rise
2. household consumption accelerator levels are rising and household inefficiencies are left unchecked

3. utilities, in order to maintain a profitable ‘business as usual’ strategy and to minimize under-utilization of their generation capacity, remain motivated to increase consumer demand by maintaining affordable prices and neglecting investments in demand-side management strategies
4. electricity costs are low enough to encourage more consumption among households and promote energy-source switching
5. the price elasticity of electricity demand is low which means that increases in retail prices of electricity have little effect on demand

The feedback dynamics under the existence of such conditions work relentlessly to drive up consumption with time. A sufficiently large capacity shortfall occurs eventually that justifies expensive capacity expansion by utilities. Although utilities may have to recover huge costs in order to pay for the expansion, such costs are shared by increasingly more consumers and the electricity prices are seldom enough to significantly dampen the growth in demand. Moreover, after expansion, utilities have strong disincentives to promote DSM efforts, but rather have strong incentives to promote demand growth until the newly expanded generation capacity is fully utilized. The net result of the above dynamics is hence a perfect storm in which a growth in rapid R.El.C rates is imminent. Chapters 4 and 5 are focused on evaluating the validity of the above described dynamic hypothesis with respect to Virginia.

4 VIRGINIA'S TRENDS AND RELEVANT INFERENCES

We now turn our attention to the original problem that this dissertation addresses: ***Why does Virginia exhibit trends in per capita and per household electricity consumption from 1980 and 2010 that are so different than in the benchmark states of California and New York?*** In order to answer this question, the following chapter first analyzes and evaluates the validity of the dynamics described in chapters 2 and 3 with respect to Virginia. Historical trends of major relevant determinants are analyzed for Virginia to determine how evident the corresponding dynamics induced by them are in the State. Chapter 5 then compares these trends with those of the benchmark states to identify which of those dynamics are uniquely causing per capita and per household R.El.C rates to climb rapidly in Virginia. Note that weather conditions have already been considered not to be a major driving force behind Virginia's R.El.C trends and are hence not discussed in the following chapters.

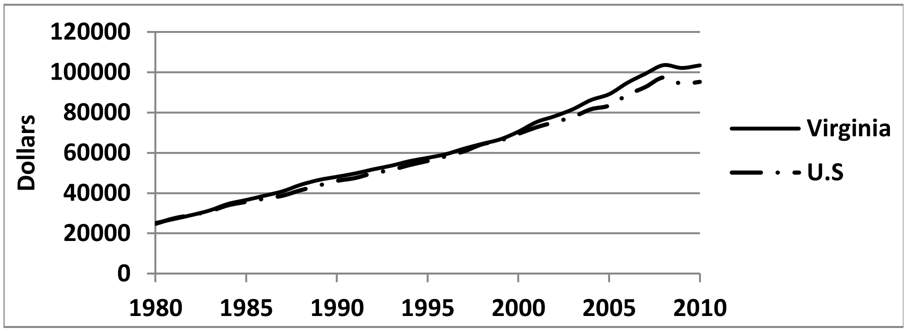
4.1 HOUSEHOLD LEVEL DETERMINANTS

4.1.1 DISCRETIONARY INCOME

The study uses annual data on *average disposable income per household* to infer a trend for the *average discretionary income per household*[14] since specific historical data could not be obtained. Figure 4.1 illustrates the historical trend in *average disposable income per household* for Virginia alongside that of the United States. Between 1980 and 2010, the average disposable income per household amongst Virginia's residences has seen over a four-fold increase from $25162 to $103401 at 4.7% avg. annual growth rate. This trend is very close to the U.S. average.

[14] Discretionary income per household represents the average income left to a household after taxes and other mandatory expenses are deducted.

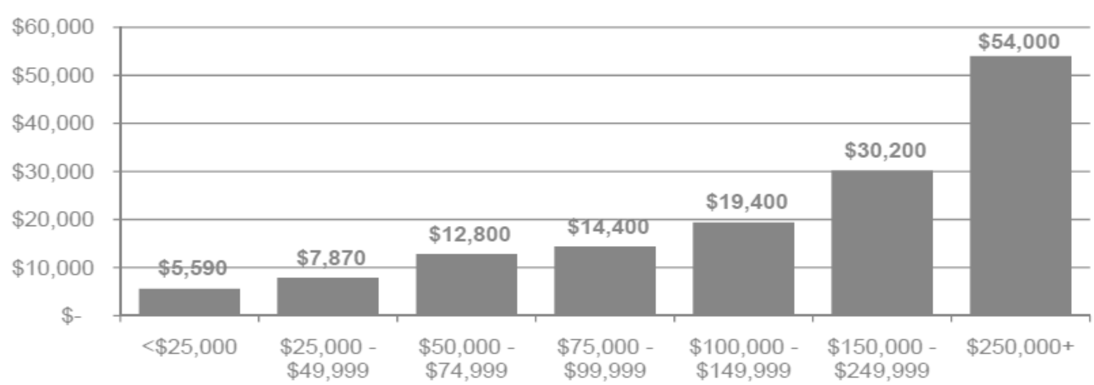
Figure 4.1: Average disposable income per household, 1980-2010.



Source: (CensusBureau, 2011)

Figure 4.3, according to a 2011 report (Simmons, 2011), illustrates the correlation between a household's discretionary spending and its real disposable income. Based on Virginia's disposable income figures, the chart implies that discretionary spending among the state's households has approximately increased from roughly $7,870 to $19,400 during the thirty year window, suggesting a corresponding increase in *household discretionary income* figures.

Figure 4.2: 'Average annual household discretionary spending' vs 'household disposable income'.



Source: (Simmons, 2011)

The rise in Virginia's discretionary income levels across between 1980 and 2010 signifies the following implication:

1. Greater discretionary income levels imply the possible reinforcement of the various consumption accelerators. These are square footage of residences, appliance stock per household and careless consumption attitudes.

2. Higher discretionary income enables households to absorb increased utility bills before feeling a strain on their budget. The increases in utility bills maybe either due to greater R.EL.C rates or increases in electricity prices.
3. Although Virginia's households have seen increases in discretionary income, it is likely that they are not making the choice to invest in efficiency upgrades since R.El.C rates are continuing to climb. Virginians might not be as willing to replace ageing inefficient appliances with new products on the market, or make the extra investment required to purchase relatively expensive but more efficient appliances or even invest in new homes or refurbishment efforts to improve efficiency. The negligence to make such valuable choices is chiefly attributed to high initial investment costs and long payback times.

4.1.2 APPLIANCE RELATED TRENDS

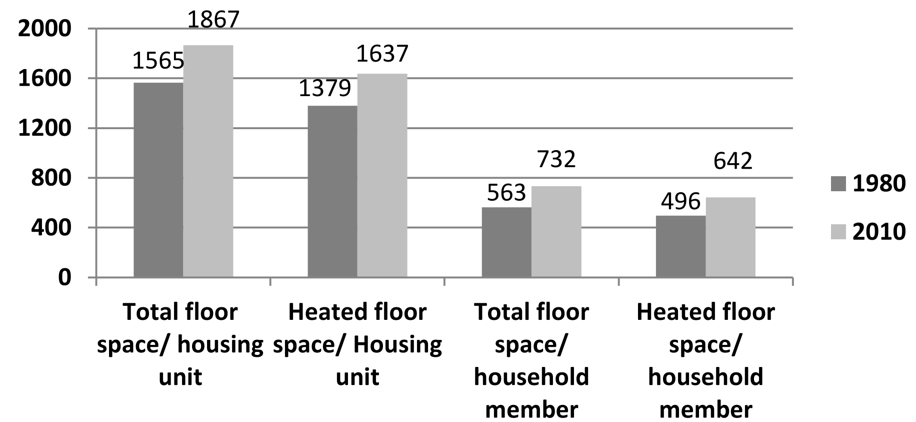
A dramatic increase in the penetration of consumer electrical appliances and electronics has been observed across the United States since the 1980s (Fernandez, 1999); this can generally be attributed to them becoming more cheaper and affordable with time (Yost, 2010). Appliances such as refrigerators, television sets and washing machines have reached high levels of saturation. This trend in market diffusion of appliances can be assumed to be the same with Virginia and hence the stock of appliances across the state's households is expected to have increased over the years.

Evidence from market data and interviews confirm that the purchase prices of more efficient electrical appliances are relatively higher than their less efficient counterparts. This forms a general barrier that slows down the penetration of more efficient appliances into consumer households (Attali, Bush, & Michel). Since this is a general fact across the country, it is speculated that the accelerating R.El.C trends in Virginia could be partly due to households purchasing low end home appliances and electronics that are not efficiency certified.

4.1.3 RESIDENTIAL SQUARE FOOTAGE

RECS data suggests that households among the Southern states are now living in larger homes with respect to floor space compared to 1980 (Figure 4.3). The trend is assumed to be the same for Virginia which is one among the Southern States. Increased residential square footage of housing units implies greater electricity demands for home services like electrical heating, cooling, lighting, etc.

Figure 4.3: Residential square footage in Virginia.



Source: (EIA, 2010)

4.1.4 AGE OF HOUSING UNITS

According to U.S Census data, the number of housing units in Virginia aged 30 years or less has dropped 8% between 2000 and 2010, while the number of housing units aged 30+ has increased by 50%. This implies that the number of existing structures ageing out into the 30+ category is more than the number of new structures built during the ten year period. In other words, Virginia has a large stock of ageing housing units.

Table 4.1: Number of housing units by age in Virginia.

Year	Total	30 years and less		30 years +	
		Count	% of total	Count	% of total
2000	2904192	1719964	59.2%	1184228	40.8%
2010	3315739	1566881	47.3%	1748858	52.7%

Source: (CensusBureau, 2012a)

Table 4.1 highlights the fact that the percentage of homes in Virginia older than 30 years formed the majority in 2010. This growth in the number of older homes is an indicator that efficiency accelerators have possibly declined in Virginia.

4.1.5 HOUSEHOLD SIZE (# HOUSEHOLD MEMBERS)

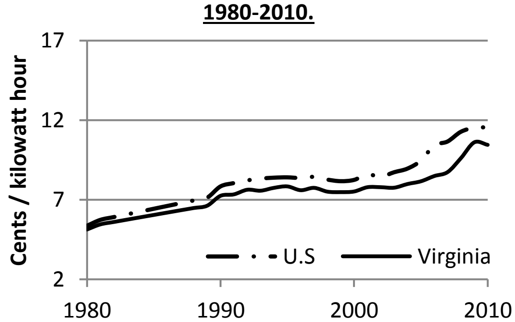
The average household size in Virginia has dropped from 2.63 people in 1980 to 2.57 people in 2010 (CensusBureau, 2012b). This may appear to be a very small change but a decreasing trend in household size implies that household electricity consumption for various services will be shared among lesser household members. Per capita residential electricity consumption is therefore bound to increase.

4.2 UTILITY LEVEL DETERMINANTS

4.2.1 RETAIL ELECTRICITY PRICES

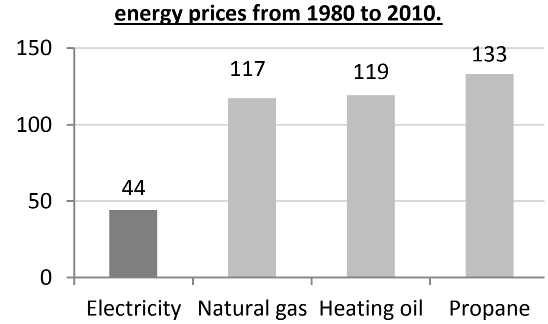
Historical data in Figure 4.4 shows that retail electricity prices in Virginia have consistently remained below the National average price between 1980 and 2010 (EIA, 2012a). This indicates that Virginians have enjoyed relatively lower retail prices compared to several other states. Furthermore, electricity prices have grown only by 44% unlike the prices of natural gas, heating oil and propane which have exhibited growths of over 100% across the thirty years. This has allowed Virginians to rely on electricity as a cost-effective energy source.

Figure 4.4: Retail electricity prices by state, 1980-2010.



Source: (EIA, 2012a)

Figure 4.5: Virginia percentage change in residential energy prices from 1980 to 2010.



Source: (EIA, 2012b)

The above electricity pricing trends suggest the following:

1. The growth in Virginia's retail electricity prices between 1980 and 2010 has not had a significant impact on the discretionary incomes of households and hence has allowed them to consume more electricity with hardly any economic pressures. This low price elasticity of demand can be attributed to the significant growth in the discretionary income of households during the same time frame.
2. Electricity has remained reliably cost-effective in the state compared to other energy sources. This partly explains why a large percentage of Virginia's residential energy use comes from electricity.

4.2.2 UTILITY INVESTMENTS IN DEMAND SIDE MANAGEMENT (DSM)

History of DSM efforts in Virginia show insignificant investments by utilities that are almost negligible. The above fact is supported by the following data from the *American Council for Energy-Efficient Economy* (ACEEE) State Energy Efficiency Scorecards, corresponding to the time frame between 2006 and 2011 (Eldridge et al., 2008; Eldridge, Prindle, York, & Nadel, 2007; Molina et al., 2010; Sciotino, 2011):

1. The ACEEE State Energy Efficiency Scorecards show that Virginia has consistently scored 0 out of 15 points in three categories: Utility spending on electricity efficiency programs, net electric savings and utility incentive programs for efficiency improvements.

2. Table 4.2: Net utility spending in electric efficiency programs

year	VA	U.S
2006	$84,000	$1.6 Billion
2007	$1,000	$2.2 Billion
2009	$400,000	$3.4 Billion
2010	$200,000	$4.6 Billion

During these years, the annual DSM investments by VA utilities as a percentage of their annual revenues have been negligible (less than 0.05%).

3. Table 4.3: Net annual electric savings by utilities

year	VA	U.S
2006	63 MWh	7.8 million MWh
2007	83 MWh	9.8 million MWh
2008	14 MWh	10.6 million MWh
2009	1029 MWh	13.1 million MWh

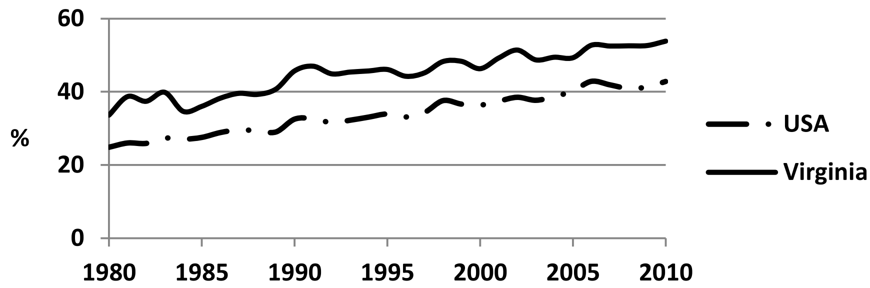
The effectiveness of DSM efforts is positively associated with the resulting electricity savings. Virginia's annual electric savings as a percentage of its annual net electrical sales have also been negligible (less than 0.05%).

It is evident from the above facts that Virginia's demand-side management efforts have been insufficient in managing the state's rising electricity demands through efficiency and conservation. This in turn has allowed consumption accelerators to gain momentum and inefficiencies to persist among Virginia's residences hence inducing a high R.El.C scenario in the state.

4.2.3 PERCENTAGE OF RESIDENTIAL ENERGY USE FROM ELECTRICITY:

As already mentioned in chapter 1, the percentage of Virginia's residential energy use from electricity has been much higher than the National average over the past three decades. The energy use from electricity fraction amongst Virginia's residences has increased from 34% in 1980 to 54% in 2010 (Figure 4.6). This is a definite factor behind the growth rates in Virginia's per capita and per household R.El.C rates.

Figure 4.6: Percentage of residential energy use per household from electricity, 1980-2010.



Source: (EIA, 2012b)

Following are some reasons behind the above trend:

1. As discussed earlier, electricity in Virginia has consistently remained a cost-effective energy source. Affordable prices have always encouraged households to consume more electricity in relation to other fuels and possibly even causing households to switch from non-electrical energy sources.
2. According to RECS Survey data, majority of Virginia's households in 2009 used electricity as the energy source for major applications like space heating, water heating and cooking. Only a minority of households used alternate fuels like natural gas, propane and LPG for these applications.

Table 4.4 Fuels used for various end uses among VA homes, 2009.

Service type	Number of VA homes (in millions) using		
	Electricity	Natural Gas	Propane
Space heating	2.2	1.1	0.3
Primary	1.6	1.0	-
Secondary	0.8	0.3	0.3
Water heating	1.8	1.1	-
Cooking	2.2	0.8	0.1
Other	3.0	0.2	1.3

Source: (EIA, 2010)

This has been the case despite wide spread agreement that gas-based appliances are relatively more fuel efficient and environmentally friendly (AGA, 2012). It may therefore be implied that Virginians have preferred electrical appliances for their cost effectiveness and their operating convenience.

3. Besides heating and cooking appliances, many other new consumer products today use electricity (mobile devices, computers, personal gadgets, etc.). The fact these products have gotten cheaper with time combined with more affluent households and affordable electricity prices in Virginia is another possible reason for the state's high percentage of energy use from electricity.

Note that although there is the possibility of energy-source switching having occurred in the state, it is however difficult to determine how much it has contributed to the growth in R.El.C rates with the limited data available.

4.3 SUMMARY OF FACTS: SOURCES OF GROWTH BEHIND VIRGINIA'S R.EL.C RATES

Data suggest that 'per household' and 'per capita' residential electricity consumption in Virginia's residential sector have grown due to a combination of several trends that together feed dynamics to induce a continuous growth in the state's R.El.C rates. The various trends discussed so far in the chapter are briefly summarized below.

Virginia's households have become more affluent in recent years and are able to absorb greater utility bills due to their increased spending capacities. Greater affluence has allowed them to invest more in electrically intensive lifestyle improvements. Electrical appliance stock sizes have increased across households due to their preference over electrical space heating, water heating, cooking, etc. and also due to increasing use of personal electronics. Households are also now living in larger residences which further increase the need for electrical home services like heating, cooling, lighting, etc. The size of households (# members) in Virginia has gradually reduced over the years meaning that electrical services especially space heating and cooling are now shared among fewer members thus increasing per capita residential electricity consumption.

The above trends combined with affordable electricity prices have further accelerated per capita and per household R.El.C rates in Virginia. Electricity has also remained more cost-effective compared to other energy sources in the state and is hence expected to have caused households to switch energy sources towards using electricity. Greater relative cost-effectiveness of electricity, preference over electrical appliances by majority of Virginia's households and the increase in use of personal electronic gadgets have all resulted in electricity accounting for the greater percentage of energy use in the state and eventually causing the growth in R.El.C rates. Besides the trends in electricity prices, the increase in discretionary incomes among Virginia's households have also lowered the price elasticity of electricity demand.

The data further suggests low overall efficiency levels among Virginia's households. Primarily, demand side management efforts in the state have been negligible implying that inefficiencies among households have been left unchecked and conservation measures have been insufficient. Secondly, Virginia has a large stock of ageing housing units meaning that inefficiencies prevailing in such units could be causing its occupants to consume electricity unnecessarily. Furthermore, the growth in residential electricity consumption rates with simultaneous growth in the affluence of Virginia's population suggest the possibility that households are reluctant to invest in efficiency upgrades to suppress those consumption rates. The penetration of efficiency upgrades into consumer residences is further slowed down due to their higher prices in the market. Since the analysis typifies low overall efficiency levels among the state's households, it is mostly skeptical if the rebound effect may have contributed significantly to the growth in Virginia's R.El.C rates.

The above summary may be interpreted as the dynamic hypothesis that answers why Virginia's per capita and per household residential electricity consumption rates have been growing rapidly between 1980 and 2010. However, at this point in the analysis, it is not clear if the various conditions summarized uniquely prevail in Virginia or are common across the benchmark states too. In order to determine this, chapter 5 involves a comparative analysis in which Virginia's trends among the relevant R.El.C determinants are compared with those of the benchmark states, namely California and New York.

5 COMPARATIVE ANALYSIS WITH BENCHMARK STATES

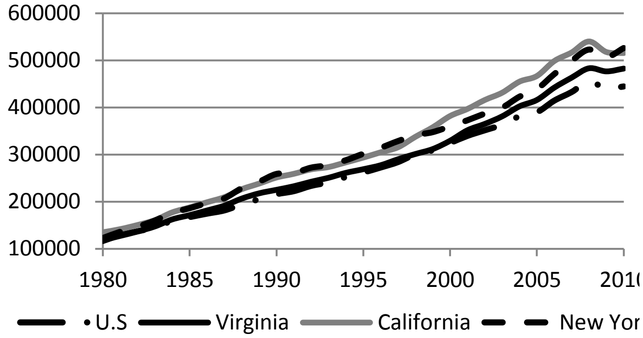
The comparative analysis in this chapter aims to identify the discrepancies that exist between Virginia and benchmark states and hence identify which of the hypothetical conditions summarized in chapter 4 uniquely drive ‘per capita’ and ‘per household’ residential electricity consumption growth in Virginia. In other words, the analysis helps to further enhance the dynamic hypothesis specifically for Virginia. The study also provides Virginia’s policymakers with insight on opportunities for policy action and forms the basis to develop meaningful recommendations towards addressing the issue. Findings from the analysis suggest that residential square footage, household size, age of housing units, retail electricity prices, DSM investments and the percentage of residential energy use from electricity are the major factors that have uniquely influenced Virginia’s residential electricity consumption rates in comparison with the benchmark states.

5.1 COMPARISONS WITH RESPECT TO HOUSEHOLD LEVEL DETERMINANTS

5.1.1 DISCRETIONARY INCOME

Near similar trends in annual household discretionary spending according to Figure 5.1 and Table 5.1 imply that corresponding discretionary incomes, respective annual growth rates and percentage changes for Virginia and the benchmark states are fairly comparable during the thirty year period. This indicates that although the rising trend in annual discretionary income may have contributed to Virginia’s rising R.El.C trends, the trend is not unique to Virginia and is common across the benchmark states.

Figure 5.1: Annual discretionary spending per household, 1980-2010.



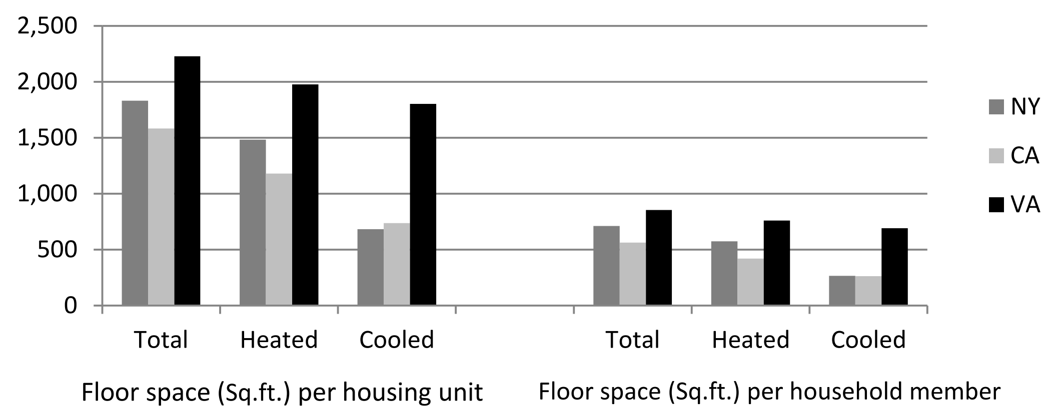
Source: (CensusBureau, 2011)

Table 5.1: Growth in annual discretionary income between 1980 and 2010.

Annual discretionary spending per household		
State	% change	Annual growth rate
US	233.5	4.5
VA	256.5	4.7
CA	239.9	4.7
NY	276.4	4.7

5.1.2 RESIDENTIAL SQUARE FOOTAGE

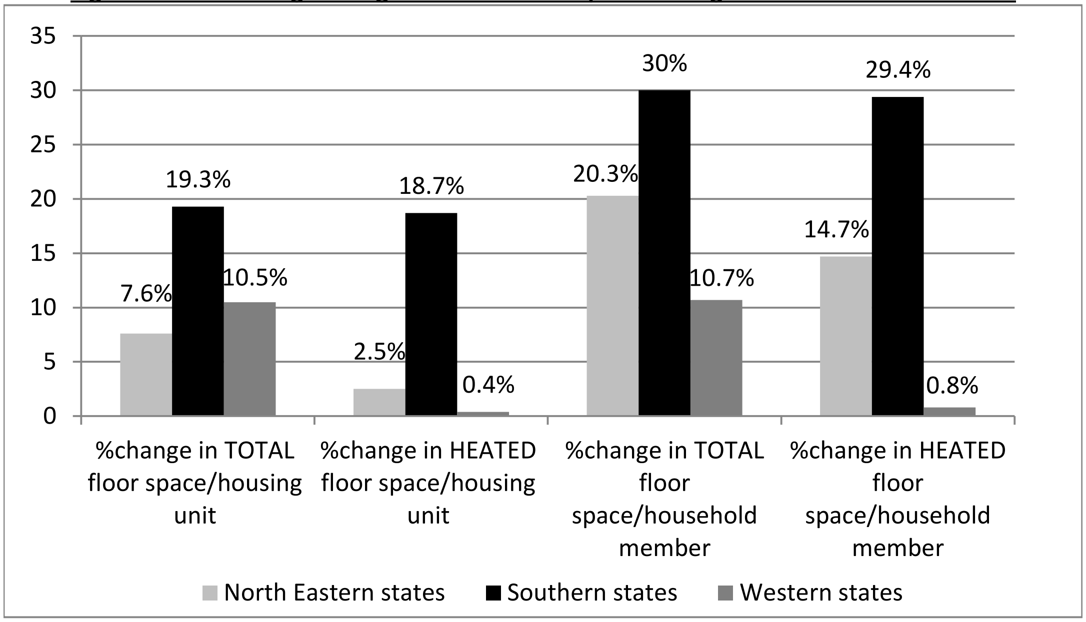
Figure 5.2: Average residential square footage, 2009.



Source: (EIA, 2010)

In 2009, according to Figure 5.2, the square footage per housing unit as well as per household member was noticeably higher in Virginia than in the benchmark states. This indicates that Virginia's households are now living in larger residences than those in California and New York; also each Virginian household member is now occupying more floor space to himself compared to those in the benchmark states.

Figure 5.3: Percentage changes in residential square footage between 1980 and 2009.



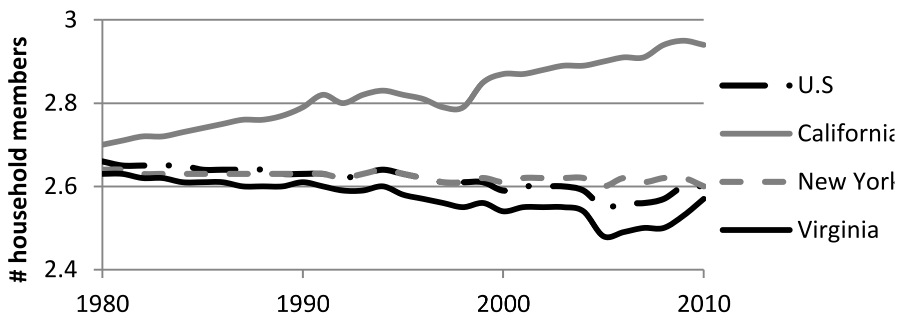
Source: (EIA, 2010)

A comparison of region specific data[15] corresponding to 1980 and 2009 finds that housing units among southern states have shown the highest percentage growth in residential square footage during the period, both total as well as heated floor space (Figure 5.3). Notice that the change in per capita floor space is more appreciable than the change in per housing unit floor space. Being a southern state, it is inferred that Virginia's annual growth rates in residential square footage, both total and heated, have been far higher than those of California or New York. The above differences between Virginia and the benchmark states have occurred despite the fact that discretionary income has grown quite evenly among all states. It is hence concluded that the growing trend in size of Virginia's housing units is unique to the state and is expected to be a major contributor to the state's rising R.El.C trends.

[15] New York, Virginia and California belong to the North Eastern, Southern and Western states respectively. The trend in residential square footage growth for each state is assumed to be the same as the respective regions they belong to.

5.1.3 HOUSEHOLD SIZE (# RESIDENTS PER HOUSEHOLD)

Figure 5.4: Household size, 1980-2010.



Census: (CensusBureau, 2012b)

The comparison in Figure 5.4 shows that Virginia has had the lowest average household size compared to the benchmark states between 1980 and 2010. The state's figures have also declined gradually and remained consistently below the national average during this time frame. The fact that the Virginia's household size has decreased over the years while the square footage of homes has increased translates into higher per capita electrical needs for services like heating, cooling and lighting among the state's households.

5.1.4 AGE OF HOUSING UNITS

Table 5.2: Number of housing units based on age category, 2000-2010.

Year	State	Total	30 years and less		Above 30 years	
			Count	Percentage of total	Count	Percentage of total
2000	CA	12214549	6179911	50.6	6034638	49.4
	NY	7679307	1985706	25.9	5693601	74.1
	VA	2904192	1719964	59.2	1184228	40.8
2010	CA	13552624	4971595	36.7	8581029	63.3
	NY	8050835	1506171	18.7	6544664	81.3
	VA	3315739	1566881	47.3	1748858	52.7

Source: (CensusBureau, 2012a)

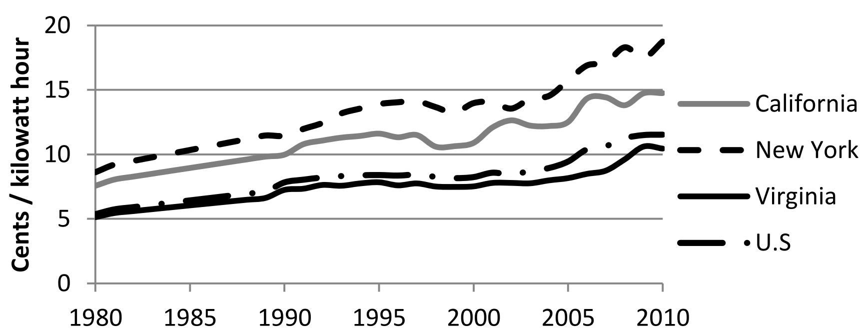
According to figures shown in Table 5.2, housing units aged above thirty years have increased and the relatively younger housing units have declined among all three states between 2000 and

2010. In fact, the older group of households formed the majority in 2010 among the three states. A closer look at the data shows that the percentage of homes older than thirty years has been the highest for New York between 1980 and 2010, followed by California. This could intuitively imply larger inefficiency levels associated with ageing homes and therefore higher per capita and per household R.El.C rates among those states. However, this has not been the case and R.El.C rates among California and New York have been significantly lower compared to Virginia despite the latter having a relatively smaller population of homes older than thirty years. This is a precursor towards the possibility of high efficiency levels prevailing amongst New York and Nevada's households which is also supported by the trends in demand side management among those states. However, the bottom line is that the increasing trend in the number of housing units aged above thirty years is common across all three states and not unique to just Virginia.

5.2 Comparisons with respect to utility-level determinants

5.2.1 Retail electricity prices

Figure 5.5: Retail electricity prices by state, 1980-2010.



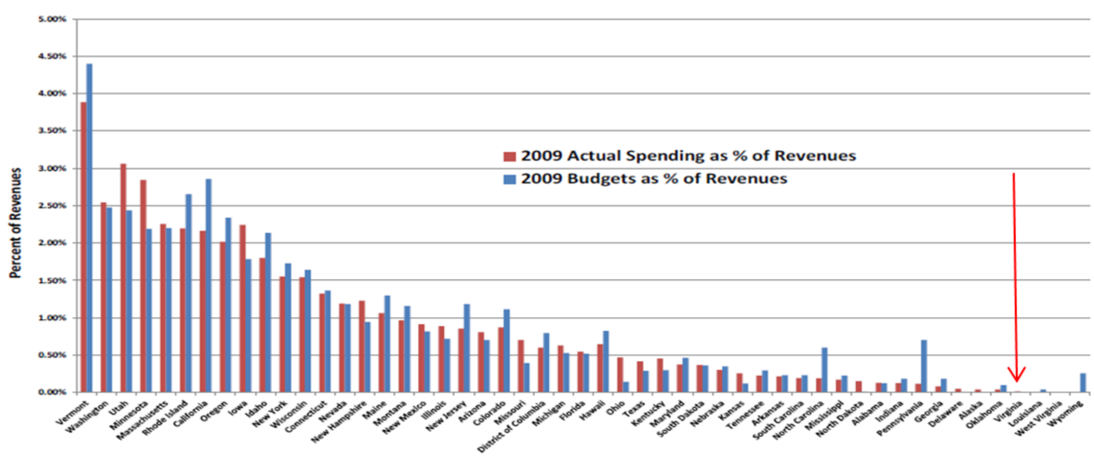
Source: (EIA, 2012a)

Figure 5.5 shows that Virginia's retail electricity prices have been much lower than California, New York and even the National average between 1980 and 2010. Virginia has had the cheapest prices compared to the benchmark states since 1980. It is apparent that the high consumption rates amongst Virginia's households can be largely attributed to the fact that the state has been enjoying relatively more affordable prices compared to other states over a long period of time.

5.2.2 UTILITY INVESTMENTS IN DEMAND SIDE MANAGEMENT (DSM)

One of the major findings of this study is that Virginia's investments in DSM are negligible and not worth mentioning compared to almost all other states in the United States. Figure 5.6 shows the percentage of utility revenue spent on electric efficiency programs in different states in 2009 and Virginia's utilities are found to have invested nearly zero percent of their revenues during that year.

Figure 5.6: 2009 Electricity efficiency program state wise spending and budgets.



Source: (Molina et al., 2010)

Table 5.3: Net utility spending in electric efficiency programs:

year	U.S	VA	CA	NY
2004	$1.4 billion	0	380 million	147.2 million
2006	$1.6 billion	$84,000	357 million	224.9 million
2007	$2.2 billion	$1,000	755 million	241.5 million
2009	$3.4 billion	$400,000	998 million	378 million
2010	$4.6 billion	$200,000	1158 million	584 million

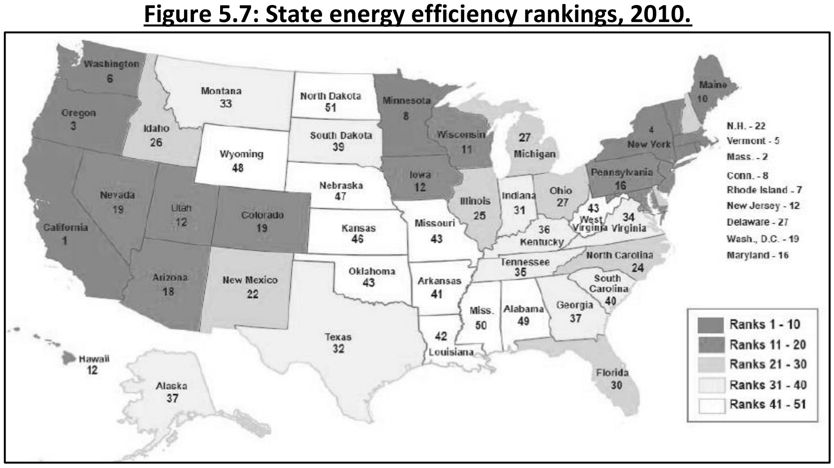
Table 5.4: Net electric savings by utilities through electric efficiency programs:

year	U.S	VA	CA	NY
2006	7.8 million MWh	63 MWh	1.9 million MWh	0.8 milloin MWh
2007	9.8 million MWh	83 MWh	3.4 million MWh	.5 million MWh
2008	10.6 million MWh	14 MWh	3 million MWh	0.47 million MWh
2009	13.1 million MWh	1029 MWh	2.3 million MWh	0.9 million MWh
2010	18.4 million MWh	677 MWh	4.6 million Mwh	1.2 million Mwh

The data shown in Tables 5.3 & 5.4 are based on the *American Council for Energy-Efficient Economy* (ACEEE) State Energy Efficiency Scorecards, corresponding to the time frame between 2006 and 2011 (Eldridge et al., 2008; Eldridge et al., 2007; Molina et al., 2010; Sciotino, 2011). As seen in Table 5.3, Virginia's net utility spending in DSM programs have been significantly low compared to the benchmark states with New York having made the highest investments among the three states. Table 5.4 shows the proportional amounts of electricity saved every year through efficiency programs and Virginia has quite apparently saved the least.

The above facts concerning Virginia easily suggest that insufficient DSM investments over long periods must have contributed vastly to the state's high consumption figures due to unaddressed inefficiencies across households. Figure 5.7 shows the ranks of different states based on their efficiency levels and efforts made to improve them. Virginia ranks 34th in the country while California and New York rank 1st and 4th respectively.

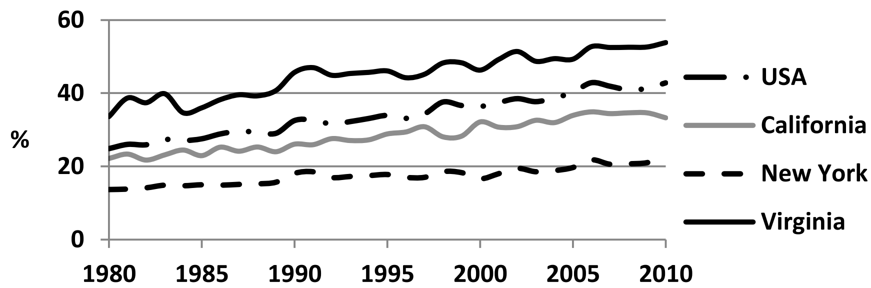
Figure 5.7: State energy efficiency rankings, 2010.



Source: (Molina et al., 2010)

5.2.3 PERCENTAGE OF RESIDENTIAL ENERGY USE FROM ELECTRICITY

Figure 5.8: Percentage of residential energy use per household from electricity, 1980-2010.



Source: (EIA, 2012b)

As described in chapter 1, the percentage of Virginia's residential energy that comes from electricity is visibly higher compared to those of the benchmark states and is also gradually rising with time (Figure 5.8). The above discrepancy among the three states may be attributed to differences that exist among them with respect to electricity pricing and energy source preferences among the states' households. As previously discussed (Figure 5.5), electricity prices are more expensive in California and New York than in Virginia. Unlike Virginia where electricity is the preferred choice of energy source among majority of households, majority of California and New York's households use natural gas for major home services which include space heating, water heating and cooking (Table 5.9). The above reasons provide a possible explanation for why the percentage of energy use from electricity among households of California and New York are lower than in Virginia. It is ultimately clear that the energy use trend amongst Virginia's households is uniquely contributing to the growth in the state's residential electricity consumption rates.

Table 5.5: Fuels used for various end uses among CA and NY homes, 2009.

Service type	Number of CA households (millions) using			Number of NY households (millions) using		
	Electricity	Natural Gas	Propane	Electricity	Natural Gas	Propane
Space heating	4.6	7.5	0.4	1.5	4.2	0.1
Primary	2.6	7.2	0.3	0.5	4.1	-
Secondary	2.5	0.9	0.1	1.0	0.3	-
Water heating	1.4	10.3	0.5	1.2	4.4	0.2
Cooking	4.8	7.8	0.3	2.3	4.3	0.4
Other	12.2	5.0	4.0	7.2	1.4	2.3

Source: (EIA, 2010)

The comparative analysis therefore makes it clear that ***square footage in housing units, household size, retail electricity prices*, *demand side management efforts and the percentage of residential energy use from electricity*** have hypothetically been the most influential factors behind Virginia's R.El.C trends. Policy actions will need to focus on the above aspects in order to effect positive change in managing per capita and per household residential electricity consumption rates in the state. Chapter 6 provides a conclusive hypothesis based on the results of the comparative analysis and, in doing so, answers the dissertation's primary research question:

> ***What are the sources of high per capita and per household electricity consumption in Virginia's residential sector and what has caused them to grow rapidly between 1980 and 2010, in contrast with benchmark states of California and New York?***

The chapter then concludes the dissertation with general recommendations and a brief outlook on further areas for research.

6 CONCLUSION: SOURCES OF GROWTH IN VIRGINIA'S R.EL.C TRENDS

This dissertation has applied system dynamics principles and explored the roots of increasing per capita and per household consumption in Virginia over a 30 year time period from 1980 through 2010. This trend stands in stark contrast to the benchmark states to which Virginia was compared: California and New York. In both these states, per capita and per household residential electricity consumption rates (hereafter referred to as "normalized R.El.C") are dramatically lower than those of Virginia. Moreover, the gap between Virginia's normalized consumption and the benchmark states is continuously increasing.

The dissertation initially outlined the general dynamics that drive total state residential electricity consumption and then contrasted how these dynamics, though present in Virginia and the two benchmark states, can vary across states in terms of which elements behind those dynamics dominate the scene. Although some commonalities were observed across the three states, several important differences were also identified.

6.1 COMMONALITIES AMONG VIRGINIA AND THE BENCHMARK STATES

Residents of all three states have exhibited more or less similar trends in discretionary income with increases ranging from 256% (in Virginia's case) to 276% (in New York's case) between 1980 and 2010, and with similar annual growth rates (4.7%) during this period. These trends reflect a probable growth in household discretionary income across Virginia, California and New York. The above fact, coupled with factors like a growing array of electrical appliances that have generally become more affordable over the decades, have led to increasingly greater electrical household demands; this has been a general trend among all three states.

Although technological improvements in electrical heating, air conditioning, cooking appliances, etc. have provided efficiency level gains that help reduce electrical demand, the high cost of conversion to efficiency certified appliances significantly dampens their favorable impact on total electricity demand. Since heating and cooling are the primary components of residential energy demand, a slow migration to either more efficient electric units or to other energy sources (such as natural gas) will only continue keep electricity demands high owing to inefficient consumption. Without adequate incentives to make such useful efficiency upgrades, homeowners will be slow to make substantive reductions in their electricity demand. This is partly the reason that all of the states in the study show, at best, level normalized R.El.C rates over the thirty year study period.

Another common trend observed was that the stock of ageing housing units is growing across all three states and units aged over thirty years formed the majority among these states in 2010. Although the above trend may imply that growing inefficiency levels due to ageing homes would be a subsequent commonality, greater demand side management efforts in California and New York however suggest that residential inefficiencies have been better managed in these two states in contrast to Virginia.

6.2 DIFFERENCES BETWEEN VIRGINIA AND THE BENCHMARK STATES

In 2009, Virginia homes had the highest average square footage among the three states. In addition, the average square footage of homes has increased faster in the Southern States region, where Virginia belongs to, than in the Western or North Eastern states regions which represent California and New York respectively. Perhaps most significantly, and possibly because of the impacts of many other factors, the average number of people living in a household in Virginia has decreased by about 2.2% over the 30 year study period, while the same has either remained relatively flat (New York) or increased (California) in the other states. In other words, the average personal floor space of a Virginian resident that needs to be heated, cooled and lit has increased over time thereby driving up per capita consumption needs for the respective electrical services.

For most of the 21st century, Virginians have enjoyed lower electricity rates than any of the benchmark states. Electricity has remained the cost effective energy source and also the preferred choice by majority of Virginia's households for major electrical services including space heating, cooking and water heating. The above combination of trends has resulted in electricity accounting for a major percentage of Virginia's residential energy-use unlike California and New York where natural gas is the major energy source. Moreover, the fact that households have become more affluent in Virginia has resulted in a low price elasticity of demand scenario and hence the gradual increase in the state's electricity prices between 1980 and 2010 has not had much of an impact on the ability of households to absorb greater utility bills.

Finally, investments in demand side management by Virginia's power companies have been negligible compared to the benchmark states. In 2009, the electric utilities in California and New York have spent at least 1% of their revenues to promote demand side management to decrease consumer electricity demand. Virginia's utilities, on the other hand, have spent almost nothing to promote consumer conservation and appear to be competing with West Virginia for the lowest ranking state in demand-side management efforts in the nation. The above facts give the impression that Virginia's power utilities, with a motive to attract high consumer demands, may have avoided large investments in DSM efforts in fear that it would undercut demand and lead to revenue losses. In summary, insufficient utility measures to promote efficiency and conservation amongst Virginia's households have left inefficiency levels unchecked eventually allowing wasteful increases in normalized residential electricity consumption.

Hence in Virginia, a combination of several elements has given rise to that "perfect storm" which has led to ever growing normalized R.El.C rates in the state. While some elements of this perfect storm may be present to varying degrees in the benchmark states, the particular combination in Virginia is unique when compared to California and New York. The key elements are identified as follows:

1. Increasing discretionary income, a common trend found among the three states
2. Larger homes with average floor space increasing at a faster rate than in the benchmark states
3. Fewer people per household and a declining trend in contrast to the benchmark states
4. Lowest electricity costs among the three states
5. Lowest utility efforts toward demand side management among the three states; one of the lowest ranked states in the country in terms of DSM efforts.
6. Low overall efficiency levels among households
7. Greater preference over electrical appliances for major household services which in turn contributes towards a larger percentage of residential energy use from electricity

6.3 POLICY RECOMMENDATIONS

Listed below are recommendations for policy actions focused on how per capita and per household electricity consumption rates in Virginia may be suppressed. Policy actions may be classified under three categories. These include public educational programs, governmental policy actions and power utility measures.

Public educational programs are a powerful tool that can be used to spread information and awareness among Virginia’s residents. People need to be primarily educated about the various dynamics that contribute to increased household electricity consumption and greater monthly utility bills. Residents should be made aware of the different methods that can be employed to cut down unnecessary electricity consumption. These include making costly but worthwhile investments in efficiency upgrades i.e. efficiency certified appliances and building refurbishment materials. Residents must be educated about the pay back times of such upgrades and should be encouraged to make the necessary investments when possible despite the high initial costs involved. People should be made aware of the inefficiencies associated with ageing household appliances and housing units and how timely upgrades can help improve efficiency levels and save electricity. Further awareness should be raised regarding the benefits that small housing units bring in terms of electrical cost savings. Educational programs may be organized by non-profit organizations, power utility companies, etc.

Governmental policy actions may consist of incentives or tax credit programs, rebate programs and enforced regulations. Providing residents with tax credits and rebates to adopt efficiency upgrades may help increase the penetration rates of more efficient appliances and building refurbishment materials that are available in the market into consumer households. Tax credits may also be useful to encourage households to purchase newly built housing units and move from older homes. Enforcement of stricter efficiency standards for appliances and new building constructions would push the respective industries to further improve corresponding energy efficiency technologies. **Power utility measures** must focus on improvement of demand side management in the state without compromising on such efforts due to concerns over demand under-cutting. Government and third party funding may also be useful in promoting utility DSM efforts. Stricter governmental policies like establishing a required annual minimum of electricity savings can cause utilities to emphasize more on conservation through demand side management.

6.4 POTENTIAL FOR FURTHER RESEARCH

The boundaries of the current dissertation were limited by the quality and resolution of data that were available. On that note, there is still potential for future research that can further enhance current knowledge on the various aspects responsible for Virginia's residential electricity consumption patterns. Following are areas that can be explored via future research by collecting the relevant data:

1. Study of usage patterns of home electrical appliances and personal electronics by analyzing the specific usage times of various appliances. This would provide information on how much electricity is being spent monthly for various electrical home service e.g. space heating, air conditioning, etc. and possible opportunities for reduction.
2. Household decision making with regards to investments in efficiency upgrades. This would shed light on whether households are making the right choices when it comes to purchasing the right appliances or the necessary home refurbishment materials that can help in reducing household inefficiency levels.
3. To better understand the electricity pricing structure in Virginia and to determine if an increasing block pricing structure would be beneficial in reducing residential electricity consumption rates.
4. To determine the extent to which energy-source switching and the rebound effect may be contributing to the growth in Virginia's residential electricity consumption rates.
5. To analyze how pricing of other fuels influence household decisions on the type of fuel preferred for major household services like cooking, space heating, water heating, etc.
6. To develop a quantitative stock and flow model of the system using system dynamics principles.

The use of system dynamic methodology has therefore proved effective in exploring the sources of high per capita and per household electricity consumption in Virginia's residential sector between 1980 and 2010 and has helped identify the reasons behind their growth in relative contrast with benchmark states, namely California and New York. Qualitative analysis using system dynamics principles provided insight on the general dynamics that drive residential electrical consumption rates across U.S households. Further validating these dynamics with respect to Virginia and contrasting them with the benchmark states helped identify those unique set of conditions which, upon interaction, created that 'perfect storm' which inevitably caused a continuous growth in Virginia’s residential electricity consumption rates. Ultimately, it has been found that a combination of economic and lifestyle factors among Virginia’s residents compounded by a low-cost high-volume ‘business as usual’ strategy by the state’s power utility sector with negligible investments in demand side management efforts have worked relentlessly to cause per capita and per household residential electricity consumption rates to rise in the Commonwealth during the three decades. The results of this study are intended to support in better management of residential electricity consumption rates in the Commonwealth of Virginia. A successful future reduction in consumption rates will help lessen pressures on the state’s economy as well as the environment.

REFERENCES

AGA. (2012). *Homes With Natural Gas Appliances Save An Average of $518 Annually* A. G. Association (Ed.) Retrieved from http://www.aga.org/Newsroom/news-releases/2012/Pages/Homes_With_Natural_Gas_Appliances_Save_An_Average_of_$518_Annually.aspx

Ashley-Chicot Electric Cooperative, I. Energy Star Appliances - Old Appliances. Retrieved 3-2-2013, from http://www.ashley-chicot.com/energy-efficiency/energy-star-appliances

Attali, S., Bush, E., & Michel, A. Factors influencing the market penetration of energy efficient electrical appliances into national markets in Europe: Report for Defra/the Market Transformation Programme by SoWATT and Bush Energie GmbH. Can be downloaded at: http://www. topten. eu/english/all_news. html and data from the Swiss Association of the Domestic Electrical Appliances Industry FEA.

Berkhout, P. H. G., Muskens, J. C., & W. Velthuijsen, J. (2000). Defining the rebound effect. *Energy Policy, 28*(6–7), 425-432. doi: http://dx.doi.org/10.1016/S0301-4215(00)00022-7

CensusBureau, U. S. (2011). *People and households, Historical Income data*. Retrieved from: http://www.census.gov/hhes/www/income/data/historical/index.html, 9th August, 2012

CensusBureau, U. S. (2012a). *American Community Survey, Housing*. Retrieved from: http://www.census.gov/housing/, 9th August, 2012

CensusBureau, U. S. (2012b). *People and Households* Retrieved from: http://www.census.gov/people/ , 7th August, 2012

Cunningham, S., Director of Research and Education. (2012). *Stimulate what?* American Institute for Economic Research. Retrieved from https://www.aier.org/article/7696-stimulate-what

Cutright, P. (1971). Income and family events: family income, family size, and consumption. *Journal of Marriage and the Family*, 161-173.

Davis, S., & Durbach, I. (2010). Modelling household responses to energy efficiency interventions via system dynamics and survey data. *ORiON, 26*(2), 79-96.

DMME. (2010). *The Virginia Energy Plan*. Commonwealth of Virginia: Department of Mines, Minerals and Energy Retrieved from http://www.dmme.virginia.gov/DE/VEP_TitlePage.html.

Dyner, I., Smith, R. A., & Peña, G. E. (1995). System dynamics modelling for residential energy efficiency analysis and management. *Journal of the Operational Research Society*, 1163-1173.

EIA. (2010). *Residential energy consumption survey* [Residential square footage]. Retrieved from: http://www.eia.gov/consumption/residential/data/2009/index.cfm

EIA. (2012a). *Electricity, Detailed State Data*. Retrieved from: http://www.eia.gov/electricity/data/state/

EIA. (2012b). *State Energy Data System : 1960-2010* [consumption data]. Retrieved from: http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=VA

Eldridge, M., Neubauer, M., York, D., Vaidyanathan, S., Chittum, A., & Nadel, S. (2008). *The 2008 State Energy Efficiency Scorecard*.

Eldridge, M., Prindle, B., York, D., & Nadel, S. (2007). *The state energy efficiency scorecard for 2006*.

Esmaeeli, Z., Shakouri, H., & Sedighi, A. (2006). *Investigation of pricing impact on the electrical energy consumption behavior of the household sector by a system dynamics approach.* Paper presented at the International System Dynamics Conference, Nijmegen, The Netherlands.

Fernandez, V. (1999). Forecasting home appliances sales: Incorporating adoption and replacement. *Journal of International Consumer Marketing, 12*(2), 39-62.

Ford, A. (1997). System dynamics and the electric power industry. *System Dynamics Review, 13*(1), 57-85.

I.F.E. (2010). Energy efficiency is great, but we have to ask at what cost? Retrieved 3-3-2013, from http://www.instituteforenergyresearch.org/2010/03/11/energy-efficiency-is-great-but-we-have-to-ask-at-what-cost/

Jamshidi, M. (2008). *An analysis of residential energy intensity in Iran, a system dynamics approach.* Paper presented at the Proceedings of the 26th International Conference of the System Dynamics Society, Athens, Greece.

Maxted, B. E. (2008). Developing Wind Power in the Commonwealth: No Longer a Quixotic Quest to Build Wind Farms in Virginia. *Wm. & Mary Envtl. L. & Pol'y Rev., 33*, 319.

Mohsenian-Rad, A., Wong, V. W., Jatskevich, J., Schober, R., & Leon-Garcia, A. (2010). Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid. *Smart Grid, IEEE Transactions on, 1*(3), 320-331.

Molina, M., Neubauer, M., Sciortino, M., Nowak, S., Vaidyanathan, S., Kaufman, N., & Chittum, A. (2010). The 2010 State Energy Efficiency Scorecard. *ACEEE-E107, October*.

National Climatic Data Center, N. (2012). *Heating and Cooling Degree Day Data*. Retrieved from: http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp, 7th August, 2012

Randolph, J., & Masters, G. M. (2008). *Energy for sustainability: technology, planning, policy*: Island Pr.

Repetto, R., & Henderson, J. (2003). Environmental exposures in the US electric utility industry. *Utilities Policy, 11*(2), 103-111.

Rusk, B., Mahfouz, T., & Jones, J. (2011). Electricity's "Disappearing Act": Understanding Energy Consumption and Phantom Loads. *Tech Directions, 71*(1), 22-25.

Sawin, B., Hamilton, H., Jones, A., Rice, P., Seville, D., Sweitzer, S., & Wright, D. (2003). Commodity system challenges. Moving sustainability into the mainstream of natural resource economies. *The Sustainability Institute, Hartland, Vermont, USA*.

Sciotino, M. (2011). *The 2011 State Energy Efficiency Scorecard*.

Scott. (2003). Wall Street Words: An A to Z guide to Investment Terms for Today's Investors by David L. Scott, 2003: WordNet.

Simmons. (2011). The 2011 Discretionary Spend Report. Pg-6. http://www.experian.com/simmons-research/register-2011-discretionary-spend-report.html

Sterman, J. D. (2000). *Business dynamics: systems thinking and modeling for a complex world* (Vol. 19): Irwin/McGraw-Hill Boston.

Terwilliger, K., Tate, J. R., & Woodward, S. L. (1995). *A guide to endangered and threatened species in Virginia, pp.15-20*: McDonald & Woodward Pub.

Thevenard, D. (2011). Methods for Estimating Heating and Cooling Degree-Days to Any Base Temperature. *ASHRAE Transactions, 117*(1), 884-891.

Yost, P. (2010). Are Energy-Inefficient Appliances Worth It? Retrieved 03-06, -2013, from http://www.greenbuildingadvisor.com/blogs/dept/green-communities/are-energy-efficient-appliances-worth-it