A System Impact Analysis of Government Policies and Regulations Concerning Demand Response

by

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SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ENGINEERING AND MANAGEMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

August 2012
[SEPTEMBER 2012]

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Abstract

A vision of distributed energy generation, storage, electric vehicles and a "smart-grid" has been the driving force of a number of regulations and policies to promote a steady evolution of the existing & future infrastructure relating to the generation, transmission, distribution and retailing of electrical energy. Demand Response (DR) is often cited for smoothing this evolution as it has the ability to shave peaks and provide flexibility in load to dynamically adapt to an increasingly variable supply from renewable energy resources.

In general, there are regulations and policies which are inadvertently increasing supply volatility (*e.g.,* wind & solar). There are regulations and policies increasing technology adoption to decrease supply volatility (*e.g.,* storage). There are regulations and policies which are inadvertently increasing demand volatility (*e.g.,* electric vehicles). Finally, there are regulations and policies to increase technology adoption to decrease demand volatility (*e.g.,* demand response). While the individual regulations are well-intentioned, from a holistic point-of-view, it is unclear how the combination of these government regulations will influence the electricity industry.

The approach to answer this question is the creation of a System Dynamics Model of the Electricity industry highlighting demand response, energy efficiency initiatives, electric vehicles, storage, and variable energy resources and associated regulatory levers. The model was used to analyze the impact of regulations on the medium to long term dynamics of the industry.

The result is a hypothesis that there will be a need for extra government incentives to increase the adoption of distributed generation, storage and demand response to align with the forecasted adoption rate of variable energy resources and electric vehicles in order to maintain grid reliability.

Thesis Supervisor: Henry Birdseye Weil
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Acknowledgements

I would like to thank my advisor, Professor Henry Birdseye Weil, for his guidance on this research, and his helpful insights on this work. In addition, I would like to thank him for his un-ending patience with me throughout this thesis.

I would also like to thank the following people for their helpful discussions, Professor Ignacio Pérez-Arriaga, Vivin Nath, Professor Carlos Batlle, Professor Harvey G Michaels, and Brendan Endicott.

I would like to also thank Patrick Hale for his encouragement and support while writing this thesis.

I would like to thank NSERC for their support for this degree.

Finally, I would like to thank my Mom, Dad, Sister and Brother-in law, along with many Friends for their tremendous support during my study. Without all of them, I would not have been able to complete this body of work.

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List of Acronyms and Abbreviations

C&I	Commercial and Industrial
DOE	Department of Energy
DR	Demand Response
DSM	Demand-Side Management
EE	Energy Efficiency
EEI	Edison Electric Institute
EIA	Energy Information Administration
FERC	Federal Energy Regulatory Commission
ISO	Independent System Operator
LM	Load Management
LMP	Locational Marginal Price
LSE	Load Serving Entity
MW	Mega-Watt
NARUC	National Association of Regulatory Utility Commissioners
NERC	North American Electric Reliability Corporation
NOPR	Notice of Proposed Rulemaking
RFC	Reliability First Corporation
RTO	Regional Transmission Operator
VER	Variable Energy Resources

Chapter 1 Introduction

1.1 Motivation

Renewed debate on global warming & the environment continued to dominate towards the end of twentieth century. General consensus was to reduce greenhouse gases produced by the burning of fossil fuels. Since the bulk of electrical energy is produced by the burning of fossil fuels, (*e.g.* coal), it became essential to develop & utilize clean energy technologies with the intent to reduce reliance on fossil fuels. Thus, alternate sources of energy such as solar, wind, and hydro became more attractive and are now making some contribution towards meeting this overall objective of reducing greenhouse gases. Latest EIA figures show that the renewable sources are about 14% (142GW) of the total installed capacity in the US.

More recently, a vision of distributed energy generation, storage, electric vehicles and a "smart-grid" has been the driving force of a number of regulations and policies to promote a steady evolution of the existing & future infrastructure relating to the generation, transmission, distribution and retailing of electrical energy [1].

Demand Response (DR) is often cited for smoothing this evolution as it has the ability to shave peaks and provide flexibility in load to dynamically adapt to an increasingly variable supply due to an increasing amount of renewable energy resources. Thus, DR is expected to help maintain an economically efficient, secure and environmentally friendly electricity infrastructure. The achievable participation of demand response is forecasted to grow to 14% of the peak-demand (138GW) by 2019 [2].

1.2 Problem Statement

Government policies and regulations have been, and will continue to be, a major force in shaping the electricity industry. As discussed by the leading electricity regulator, Professor Ignacio J. Perez-Arriaga "There is a growing consensus that the successful development of utility infrastructure – electricity, natural gas, telecommunications & and water – depends in no small part on the adoption of appropriate public policies and the effective implementation of these policies. Central to these policies is development of a regulatory apparatus that provides stability, protects consumers from the abuse of market power, guards' consumers and operators against political opportunism, and provides incentives for service providers to operate efficiently and make the needed investments."

Today, we see government incentives for the installation of smart meters & related investments for the management of load with the hope of driving up demand response adoption to meet forecasts. In parallel we see government policies for targets on renewables as part of a future generation mix. We also see incentives for the purchasing of electric vehicles, roof top solar panels and for creating/renovating buildings to make them more energy efficient [1].

In general, there is a set of climate change regulations and policies that is inadvertently increasing supply volatility (*e.g.,* wind & solar). There are regulations and policies increasing technology adoption to decrease supply volatility (*e.g.,* storage). There is a set of climate change regulations and policies which is inadvertently increasing demand volatility (*e.g.,* electric vehicles). Finally, there are regulations and policies to increase technology adoption to decrease demand volatility (*e.g.,* demand response).

While an individual regulation is well-intentioned, from a holistic point-of-view, it is unclear how the combination of these government regulations will influence the electricity industry. This thesis seeks to perform a System Impact Analysis of Government Policies and Regulations concerning the Electricity Industry and provide insights on the DR industry.

1.3 Thesis Research Questions

Thus, the following are the key questions to be addressed in this study:

- How could the combination of electricity regulations impact the DR industry and the future economic efficiency, security, and environmentally friendliness of the electric industry?
- Are there new regulations that maybe needed to ensure a smooth transition to the electric industry of the future?

In the end, the thesis hopes to provide insights on the DR and electricity industry.

1.4 Approach

A variety of electric power system models are used in the electricity industry. They range from having short-and medium term time horizons (*e.g.,* seconds for optimization of power flow, days for unit commitment, months for hydro-thermal scheduling) to having long term time horizons (*e.g.,* years for capacity expansion) (See ESD.S30 course notes). Depending on the time-horizon, different techniques maybe used to model the system. For the objectives of this thesis, we are looking at medium to long term dynamics in the industry (*e.g.,* months to years). Thus to help answer the thesis questions a System Dynamics Model of the Electricity industry highlighting demand response, energy efficiency initiatives, electric vehicles, storage, and renewables and associated regulatory levers was created. The model was used to analyze the impact of regulations on demand and supply volatility. Specifically, a business as usual base case was analyzed along with a number of scenarios including a range of renewable, electric vehicle and demand response adoption levels.

1.5 Contributions

The key contributions of the thesis are:

- New prospective on viewing the different types of DR in terms of Firmness and Flexibility
- A system dynamics model of the electricity industry with a focus on government regulations and DR
- A hypothesis that there will be a need for extra government incentives to increase the adoption of distributed generation, storage and demand response to align with the install base of variable energy resources and electric vehicles.

1.6 Organization of the Thesis

This thesis is organized into six chapters involving Demand Response, Government Regulations, a System Dynamics Model and scenario analysis. Chapter 2 provides background material on the electricity industry, and government regulations concerning said industry. Chapter 3 contains a review of system dynamics models of the electricity industry along with the model developed for this thesis. Chapter 4 presents the results of a series of scenario analyses of the impact of government regulations on the electricity industry. Finally Chapter 5 summarizes the analysis and presents conclusions and recommendations for future thesis research.

Chapter 2 Background

2.1 Demand and Demand Side Management

2.1.1 Demand Side Management

Demand Side Management (DSM) is a portfolio of measures (categorized as Demand Response or Energy Efficiency) for changing how electricity is consumed. The associated load shapes (Figure 1) range from load management (*i.e.,* temporary shifting of load) to improved energy efficiency (*i.e.,* permanent reduction in load) [3] [4].

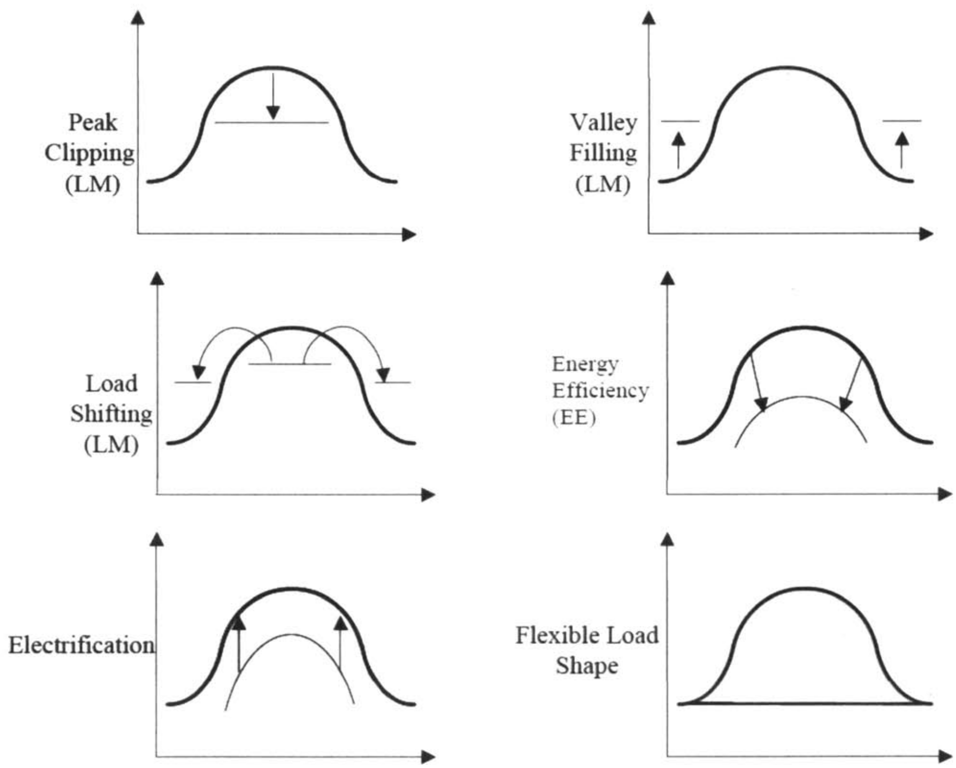


Figure 1: Load shapes associated with Demand-Side Management. (Source: Figure 2-1 of [5])

2.1.1.1 Demand Response

Figure 2 shows a supply *vs.* price curve and two demand levels. As drawn, a relatively small reduction in demand from Q to Q_{DR} results in relatively large price reduction from P to P_{DR}. The shift from Q to Q_{DR} is initiated either voluntarily (*i.e.,* price transparency allows the customer to benefit from the avoided cost when the value of the energy is larger than the value of its use), or involuntary (*i.e.,* the ISO dispatches a customer to change load based on an incentive payment). Thus, Demand Response is defined by FERC as "Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [5].

Figure 3 shows from a system wide view of DR and the general stakeholder value flow of an electricity wholesale market. The figure attempts to depict the common types of DR Business models in use today (Table 1). See [6] for a detailed description of the DR Business Models.

Table 1: Types of DR Business Models (from [6])

Item	Description
1	Traditional utility: No DR program
2	Utility as retail load manager: Utility buys DR from its retail consumers, to manage the utility's own load, without any resale into the wholesale market
3	Retail consumer (*e.g.,* Large Aluminum manufacture) sells DR directly to the wholesale market
4	Utility as aggregator: Utility buys DR from its retail consumers, then resells the aggregated amounts into the wholesale market
5	Nonutility as aggregator, operating as the utility's agent: Non-utility entity buys DR from retail consumers, then provides this information to the utility, who either uses it to reduce load or resells it into the wholesale market (*e.g.,* The company EnerNOC)
6	Nonutility as aggregator: Nonutility entity buys DR from retail consumers, then resells the aggregated amounts into the wholesale market (*e.g.,* The company EnerNOC)

Although Figure 3 has Generators, Transmission, Distribution and Retailing as separate entities, there are various types of entities (*e.g.,* Cooperatively Owned Utility, Independent Power Producer) that will be a combination of them. Therefore, depending on the other stakeholders combined with, the resulting net benefits to that organization will change.

The main benefits of DR in organized wholesale markets are primarily economic and reliability (*e.g.* security of supply) in nature. As discussed, one of the most important benefit of DR is improved resource-efficiency of electricity production due to an increased alignment between customers' electricity prices and the value they place on electricity. Additional benefits include lowered required network capacity, improved capacity utilization of existing generation, increased system reliability, reduced spot prices, reduced price volatility and hedging costs, reduced market power, reduced emissions and finally a reduction in the total cost of delivering energy. However, the realization of these benefits varies between seconds (*e.g.,* reduction in load to maintain security of supply) to years (*e.g.,* avoided cost of generation, transmission and distribution investment). In addition, the attribution, durability and magnitude of these benefits vary depending on the stakeholder in question and the number of DR adopters. See [7] and [8] for a detailed discussion of the benefits of DR.

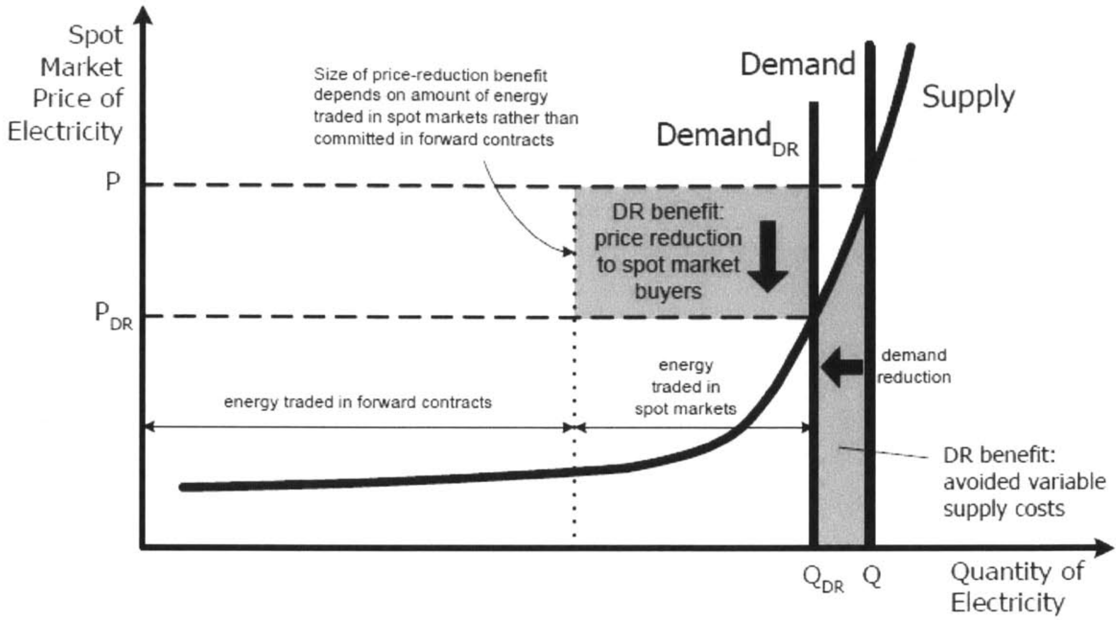


Figure 2: Impact of DR in Regions with Organized Wholesale Markets. (Source: Figure B-3 of [7])

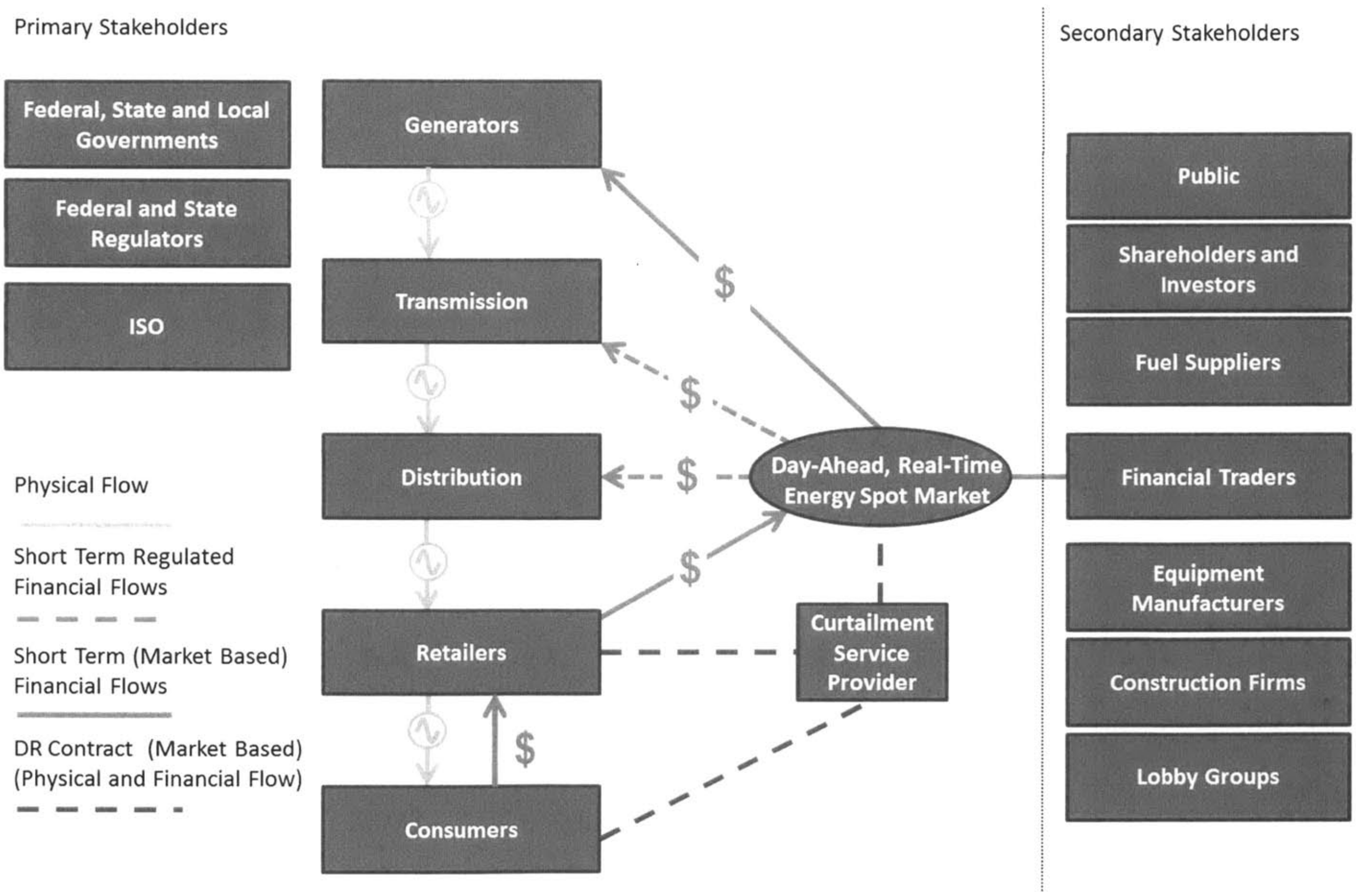


Figure 3: Primary and Secondary Stakeholders and Key Value Flows in DR Energy Spot Market

The costs of DR are correlated to firmness and flexibility of the demand response. We define firmness as the precision in the amount of the load reduction, and flexibility as the advanced notice for the load reduction and the amount of load change. Reducing load by exactly 10 MW vs 10MW +/- 100 KW has higher costs. Similarly, changing load with sub-millisecond control with 5 seconds notice costs much more (*e.g.,* requires Advanced Metering Infrastructure and Direct Load Control) than 30 min range with 24 hours' notice (*e.g.,* requires a phone call). Again, the attribution, durability and magnitude of these costs vary depending on the stakeholder in question and the number of DR adopters. See [7] and [8] for a detailed discussion of the costs of DR.

In general, the relative benefits and costs of various types of demand response (attributed to different stakeholders) is an active area of research ([9] pg. 21.)

2.1.1.2 Types of DR

There are a variety of ways DR maybe segmented based on dimensions of dispatchability (incentive-based or price-based), reason for use (reliability or economic), or time with respect to standard electric system planning and operations theory (See Figure 4 and Figure 5).

Incentive-based demand response (i.e., dispatchable) compensate participating customers who reduce consumption at times defined by the program sponsor (e.g., Utility or ISO). The period is typically triggered either by economic (e.g. high electricity prices) or a reliability reasons (e.g. grid stability). The amount of compensation (or penalty) is determined by the program sponsor or by market mechanisms.

Price-based demand response provide customers time-varying rates that reflect the value and cost of electricity which tend to result in customers voluntarily using less electricity at times when electricity prices are high. See [7] and [14] and for definitions of the remaining terms shown in the figures. Note, demand response may be manually or automatically controlled.

An additional dimension to segment DR is based on the load shape adjustment method (i.e., Foregoing, Shifting or Behind the fence/On-site Generation). Foregoing (i.e., peak shaving) is reducing usage at times of high prices or DR events. This is different than energy efficiency as the reduction is temporary. Shifting (i.e., Load shifting) is rescheduling usage away from times of high prices or DR event to another time. Finally, on-site generation has customers responding by using onsite or backup emergency generation instead of the grid without making it up later [10]. Although not explicit in [10], Valley Filling and Flexible Load shape should be considered as two additional items to be added to this dimension.

Finally, the last segmentation dimension used in this thesis is related to consumption as defined by William Hogan [15] – Real-time Pricing DR, Explicit Contract DR, and Imputed DR. Real-time pricing DR is defined as "Consumers paying the applicable LMP for their marginal consumption". Explicit Contract DR is defined as "Consumers purchase a fixed quantity of electricity but consume less than the purchased amount and sell back the difference". Imputed DR is defined as "consumers have an estimated consumption baseline and the difference between actual consumption and the baseline is the imputed demand response".

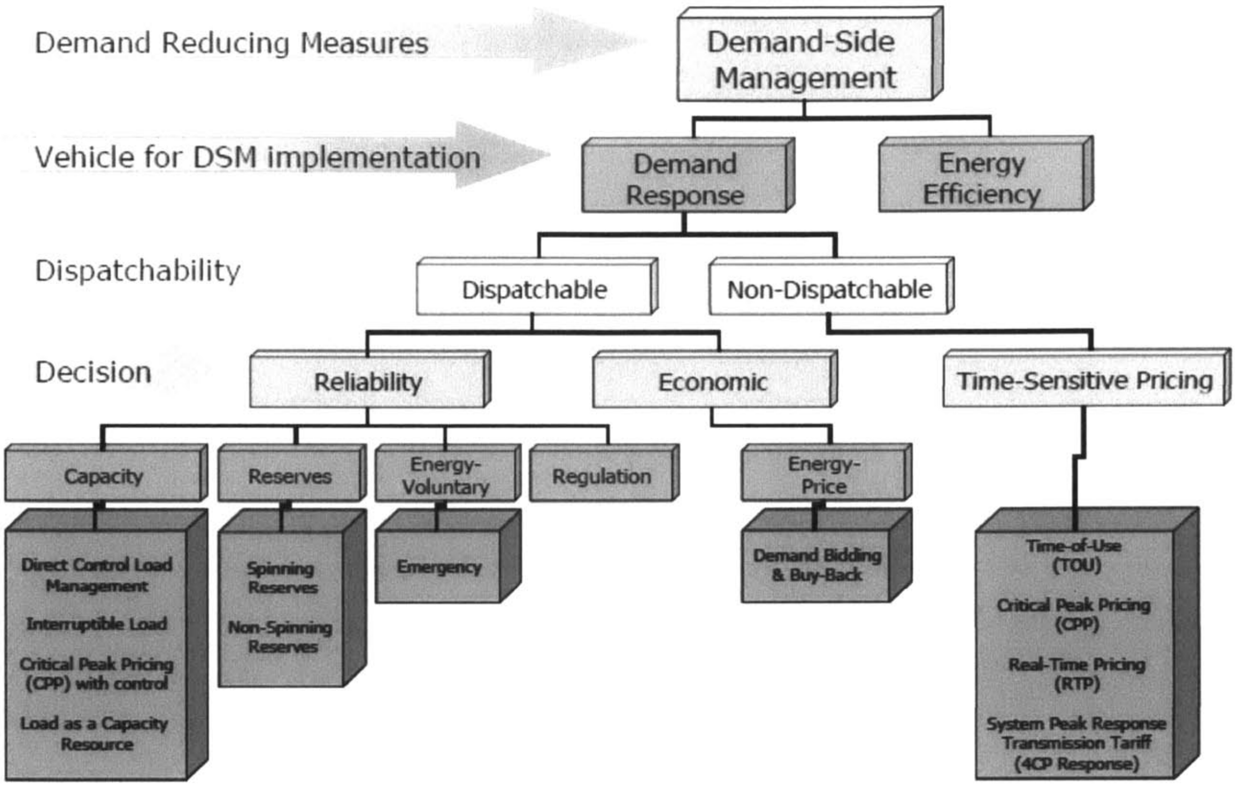


Figure 4: Demand Side Management Categories (Source: Figure 2 of [11])

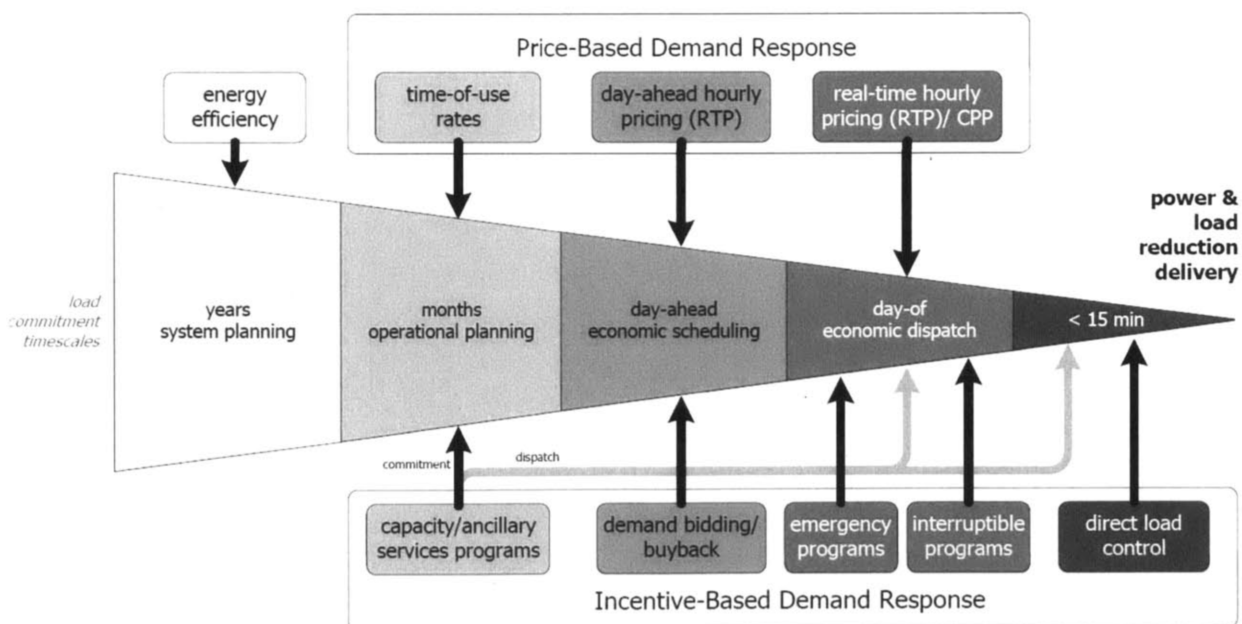


Figure 5: Demand Response in Electric System Planning (Source: Figure 2-3 of [7])

Figure 6 shows the amount of MegaWatts that were reported to be available for Demand Response per program in 2010.

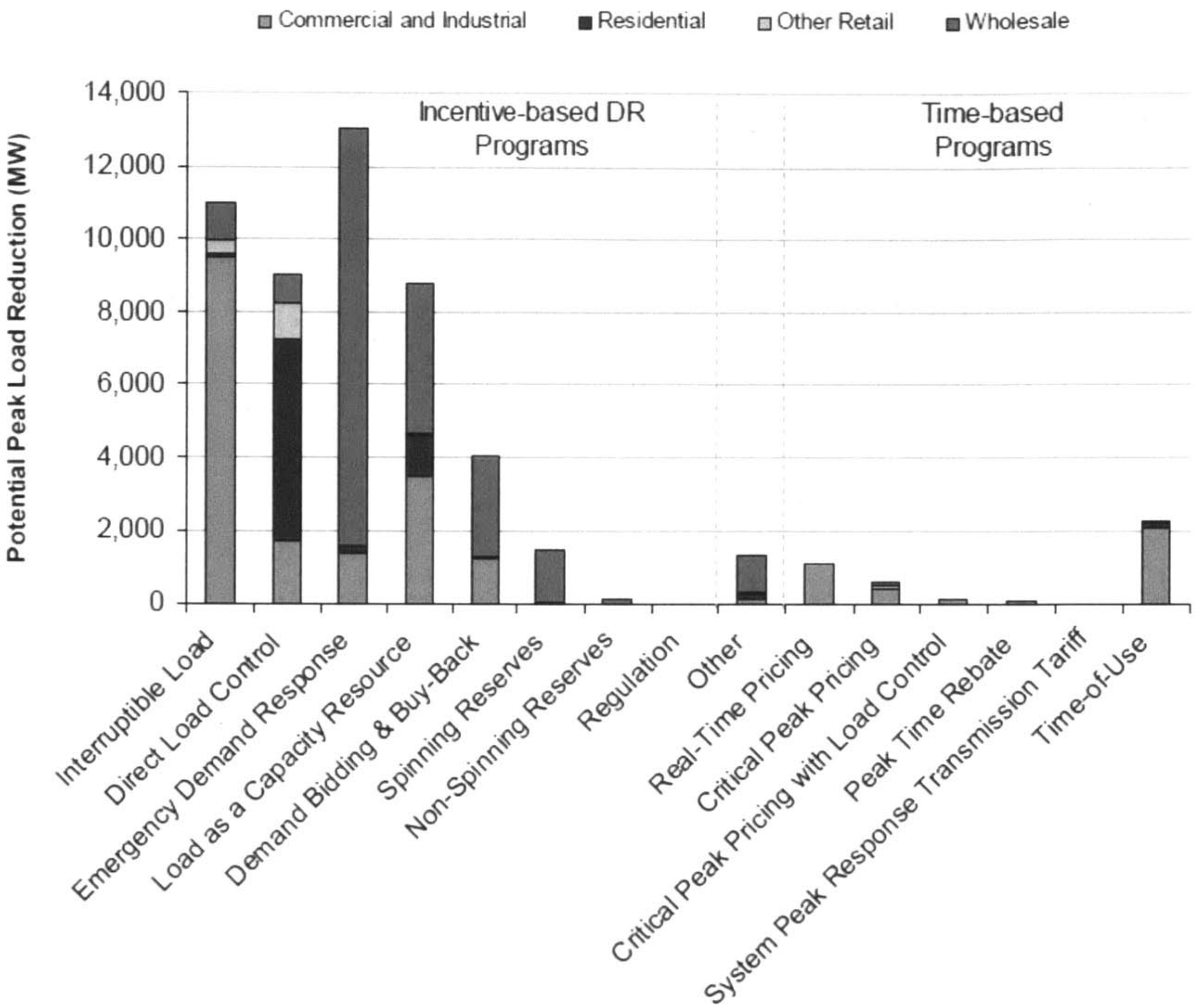


Figure 6: Reported amount of DR under management in the US per customer type in 2010 (Source: Figure 4.9 of [12])

Table 2 contains a summary of the segmentation dimensions for DR (Note, not all combinations are possible.). See [7] and [8] for a detailed discussion of the types of DR.

Table 2: Demand Response Categories and Attributes

Attribute	Values				
Dispatchability	Dispatchable (Incentive Based)	Non-Dispatchable (aka, Price-Based, Time-Based *i.e.*, not controlled by System Operator)			
Reason (Decision)	Reliability -Capacity -Reserves -Energy-Voluntary -Regulation	Economic Energy-Price	Time-Sensitive Pricing -TOU -CPP -RTP -Sys Peak Tariff		
Incentive Determinant	Market-based	Regulated			
Load Commitment Timescales	System Planning (years)	Operational Planning (months)	Economic Scheduling (day-ahead)	Economic Dispatch (day-of)	Balancing (< 15min)
Load Shape Adjustment	Peak Shaving	Load Shifting	Behind the Fence Gen	Valley Filling	Flexible Shape
Dispatch Method	Manual	Automated			
Consumption Contract	Real-Time Pricing	Explicit Contract	Imputed Demand		

However, the remainder of this thesis will attempt to describe the type of DR in terms of its ability to reduce volatility in the electric industry. In the end, the increased adoption of demand response is able to lower peak loads, shift loads and thus, lower demand volatility.

2.1.1.3 Energy Efficiency

Energy Efficiency (EE) is defined as using less energy to provide the same or improved level of service to the energy consumer in an economically efficient way (from [13]).

The benefits of energy efficiency include (i) Lower energy bills, greater customer control and greater customer satisfaction, (ii) Lower cost than supplying new generation only from new power plants, (iii) it's typically Modular and quick to deploy, (iv) avoided cost of purchasing energy, (v) lower emissions, (vi) Job creation and (vii) improved energy security ([13]).

The types of EE typically manifest themselves in consumer products via appliance standards (*e.g.,* Energy Star), buildings through building standards (*e.g.,* LEED) and renovation incentives, or through more efficient processes/systems.

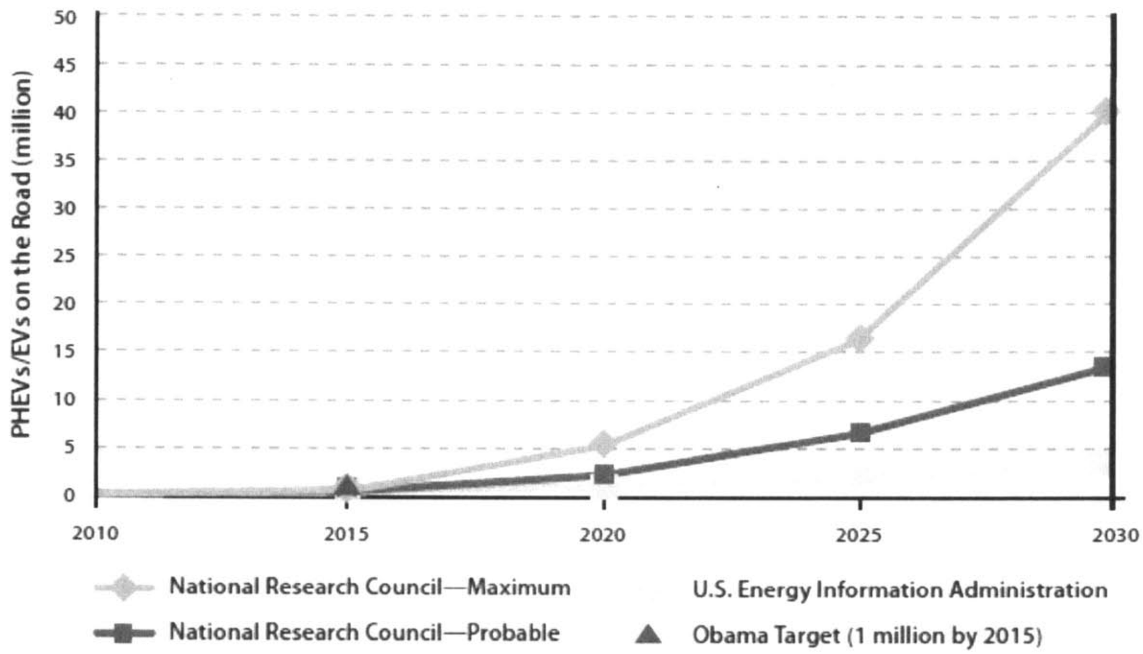
The EIA Electric Power Annual Report estimates that in 2010, 86,926 Thousand MegaWatt-Hours were avoided using Energy Efficiency initiatives at a cost of ~$97,671/MW (comparable to peakers)[1]. In summary, energy efficiency initiatives lower demand, but have a cost.

2.1.2 Electric Vehicles

The shift towards electric vehicles will have a large impact on the electricity industry. Consider the peak charging load (1.92. kW to 19.2 kW) of an EV is similar to that of a house. Figure 7 shows a range of potential adoption rates of EV in the US. The National Research Council Estimates that in 2030, 13 Million, or 4.5% of the total cars in the US will be electric [1].

NERC reports that the impact of the vehicles on the electric grid will be a need for increased generation. NERC estimates that 5.5% increase in generation would be required to support a US fleet with 25% Plug-in Hybrid Electric Vehicles (PHEV). In addition to generation needs, there is a belief that there will be overloading residential transformers from peaking loads originating from PHEV charging. Thus, it is likely there will be a need for demand response technology to manage the charging of electric vehicles [1]. In summary, the adoption of electric vehicles is increasing demand, peak demand and thus adding new volatility to electricity demand. This will require the addition of new generation and higher adoption rates of demand response to maintain a reliable grid.

[1] Electric Power Annual 2011, Released: January 2012, Revised: March 2012 Table ES1, Summary Statistics for United States 1999 through 2010. The number was calculated by converting 86,926 Thousand Megawatt-hours to average MW by dividing by 8760 hours. Adding the value of Peak Load reduction of 33,283 MW and dividing by the given DSM cost of $4,220 Million Dollars.



Source: Projection data from Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies and National Research Council, *Transitions to Alternative Transportation Technologies—Plug-in Hybrid Electric Vehicles* (Washington, DC: National Academies Press, 2010); Daily Compilation of Presidential Documents 2011 DCPD No. 00047, p. 3 (January 25, 2011); and U.S. Energy Information Administration, *Annual Energy Outlook 2011* (Washington, DC: U.S. Department of Energy, 2011).

Figure 7: Projected Electric Vehicles on the Road by 2030 (from [1])

2.2 Supply and Supply Side Management

2.2.1 Renewables and Variable Energy Resources

Wind, solar, biomass, geothermal, hydro are common types of renewable generation found in the US. In the next 20 years it is expected the adoption of these generation resources are to increase mainly based on legislated state targets [14]. The EIA 2012 annual energy outlook base case forecasts the penetration of renewables is to increase from 142 GW of installed capacity in 2011 to 156.1 GW by 2030. It is generally understood that the integration of wind and solar will pose challenges due to the variable nature of these resources (*i.e.,* the amount of generation is dependent on uncertain weather conditions).

The variability of the wind and solar resource depends on the time scale in question. In less than one minute, wind typically varies less than 0.2% of nameplate capacity, while thermal solar is less due to inertia, but solar photovoltaic upto 90%[1]. The variation from the average daily profile can be as much as 60% of nameplate capacity for wind, and up to 40% of nameplate capacity for solar. To smooth out the variability, demand response is commonly offered as a solution. However, it is uncertain if there will be enough demand response resources to adequately meet this need, and thermal generation and storage solutions maybe required to fill the gap [1] [14]. In the end, the adoption of wind and solar generation is increasing supply volatility and thus causing a need for more flexible supply and demand and higher reserves.

2.2.2 Non-Renewables

Coal, Oil and Natural Gas, Diesel based generators are a core source of electricity in the US today, and will be for the foreseeable future. While renewables will hover around 14% today, that implies non-renewables and nuclear will supply 86% of the electricity in the US. The EIA forecasts that by 2035 that non-renewables and nuclear will still be the source of 84% of all electricity.

However, the Energy Information Administration 2012 Outlook[2] has predicted the generation mix will shift away from coal (312 GW to 270 GW) and oil and natural gas steam power plants (105 GW to 87 GW) in 2012 towards more use of combined cycle plants (184 GW to 246 GW) and renewable generation (142 GW to 169 GW) by 2035. However, the total electricity capacity is predicted to change relativity little (1041 GW to 1112 GW) mainly due to demand side management initiatives, and due to low stable economic growth resulting in total electricity consumption increasing at an average annual rate of 0.4%.

2.2.3 Distributed Generation

Distributed generation (DG) are generators which are connected to the grid and the distribution level and product several kilowatts (kW) to tens of megawatts (MW) [1]. These generators include solar photovoltaics (*e.g.,* roof top panels) roof top panels, wind turbines, fuel cells and even gas turbines. In 2009, DG contributed about 16 GW out of 1025 GW total capacity in the US [1].

The benefits of DG include (i) Reliability and Security Benefits, (ii) Economic Benefits (*e.g,* peak shaving), (iii) Emissions Benefits, and (iv) Power Quality Benefits (*e.g.,* Reduced Flicker) (Source [1] Section 5.2).

One of the costs of DG are upgrades to the distribution networks to protect utility workers when fixing power lines. Consider now when fixing a power line both ends of a line would need to be disconnected to ensure it was de-energized [1].

In summary, distributed generation can increase supply, lower demand volatility and supply volatility.

2.2.4 Storage

Pumped-Hydro, Compressed Air, Flywheels, Utility Scale Batteries are a just a few of the technologies being researched for adding electric storage to the grid. Storage adds flexibility to the grid to improve reliability and resilience to outages and peak demands. However, at this time it is economically infeasible to store electricity in bulk. Aside from a major breakthrough, it is unlikely storage will be a significant part of the electric grid prior to 2030 [1]. In general, storage increases supply, but in general lowers supply volatility.

[2] Electricity Generating Capacity Reference case from EIA 2012 Annual Electricity Outlook

2.3 Transmission and Distribution

To support new electricity flows caused by distributed generation, electric vehicles, storage and variable energy resources, upgrades to the transmission and distribution networks will be required. For example, distribution networks may need to be configured to support the injection of electricity back into transmission lines. Upgrades to these networks will be a cost which should be spread amongst all beneficiaries of the benefits [1]. Essentially this falls under the major upgrade to the grid to create a "smart-grid". In the broadest sense, the "smart-grid" is defined as "efforts to improve the resiliency, security, efficiency and reliability of the electric grid through the increased use of new communications, sensing, and control systems." [1].

2.4 Regulations and Policies Concerning Energy Industry in the US

2.4.1 Regulations Overview

It is generally agreed that the successful development of a utility infrastructure is dependent on the adoption of appropriate public policy and the effective implementation of these policies through regulations (from [15]).

The three major objectives of electricity regulation are (a) economic, (b) security of supply, and (c) environmental (The combination of which comprise the maximization of social benefit) (from [16]). Security of Supply can be further broken into four dimensions (time related) – (a) Security (very short term – after gate closure), (b) Firmness, (c) Adequacy, and (d) Strategic expansion.

Security is typically addressed by "Ancillary Services" – (a) Frequency control (primary, secondary and tertiary operating reserves), (b) reactive power for voltage regulation (which can be broken into primary, secondary and tertiary), and (c) black-start-capabilities (restoration of power). Firmness (short to mid-term issue) is defined as the ability of installed units to respond to demand efficiently. This thesis extends the definition to include responding to supply efficiently as well. Adequacy (long term issue) is defined as the existence of enough installed or planned generation and network capacity to efficiently meet demand in the long term. Finally, Strategic expansion is the very long term availability of energy resources to meet needs (from [16]).

These objectives are typical met through various regulatory levers. These levers range include Cost-of-service subject to regulatory oversight, Price cap or revenue caps, Unbundling of activities, Subjecting agents to competitive pressures, Competition "in the market", Competition "for the market", Benchmarking of regulated monopolies, Application of economic (or other) incentives, Use of command & control (*e.g.,* standards, targets, penalties) Conditions in licenses to operate, Conditions in authorization of mergers & acquisitions, Obtaining & analyzing information and finally Monitoring market behavior. These levers maybe applied *ex-ante* (e.g., before-hand) or *ex post* (*e.g.,* penalties) (from [15]).

These regulations should meet a number of principles in-order to be effective. These principles include being sustainability (economically viable), Economically Efficiency, Equitable (or Non-Discrimination), Transparent, Stable, Simple, Additive, and Consistent (from [15]).

The remainder of this section discusses various regulations concerning different parts of the electricity industry and their targeted goals. Again, one of the objectives of this thesis is to determine if these regulations are consistent with each other through our system dynamics model and simulations.

2.4.2 Demand and Demand Side Management

2.4.2.1 Demand Response

FERC Order 719 and 890 were key regulations have enabled Demand Response to be an approved resource in the US electricity industry [6] , and FERC 1000 enabled DR (and energy efficiency) to be an approved resource in long term transmission planning [10]. However, the key regulation for DR is FERC 745.

FERC order No. 745 (2011) standardized the compensation amount paid to DR resources that participate in the organized wholesale energy markets by requiring Independent System Operators (ISO) and Regional Transmission Organizations (RTO) to pay demand response resources the market price for energy [17]. The regulation also stipulated that the "costs associated with demand response compensation be spread proportionally to all entities that purchase from the relevant energy market in the areas(s) where the demand response reduces the market price for energy at the time when the demand response resource is committed or dispatched." Note, this regulation also implied that measurement and verification infrastructure needs to be in place for the system to ensure fairness. Note, the rule also does not apply to capacity (e.g., forward capacity of ancillary) markets.

The primary purpose of this regulation is to "ensure the competiveness of organized wholesale energy markets and remove barriers to the participation of demand response resources", and to "move prices closer to the levels that would result if all demand could respond to the marginal price of energy" [17].

Leading economist Dr. Alfred E. Kahn and a coalition of DR supporters agreed that the regulation would achieve these goals [17],[18]. However his peers, Dr. William Hogan, Dr. Hung-po Chao, and a number of dissenters from various utilities disagreed [17],[10],[11]. Dr. Hogan believes the regulation creates a perverse double payment incentive which will result in inefficient price formation and a lowering of the social welfare. However, Dr. Kahn and FERC dismissed this argument for a number of reasons, including that as long as the transaction results in a net benefit, there is no reason to lower the payment (from the LMP) as both generators and DR providers should have been providing their resource at their economically efficient marginal costs [6].

Transmission and Distribution companies were against the rule (and demand response in general) as it results in a lowering of electricity on their networks. As they are currently paid based on a regulated price cap ($/MW) it is easy to understand why they would be against it.

Leadership in Energy and Environmental Design (LEED) rating system has established a credit to incentivize demand response in buildings. LEED demand response credits are broken into types and levels of automated response: manual, semi-automated, and fully automated options. [12] "Credit by demonstrating their ability to shift energy consumption during peak events by 10 percent of peak load demand will earn a point towards LEED certification when they participate in existing utility-sponsored demand response programs that meet guidelines established in the pilot credit. Additional points are available for projects that implement semi or fully automated demand response programs in their buildings."

In general, DR regulations increase the adoption of demand response which should result in lower peak demand, and in general lowers the demand volatility.

2.4.2.2 Energy Efficiency

The Energy Policy Act of 1992[3], The Energy Policy Act of 2005[4] and the Energy Independence and Security Act of 2007[5] contain a number of targets and funds to promote energy efficiency use for homes, buildings, vehicles and manufacturing. The EIA 2012 Annual Energy Outlook estimated that in 2010 - 86,926 thousand Megawatt-hours of energy savings occurred from energy efficiency initiatives. In summary, Energy Efficiency regulations help increase the adoption of EE and thus lower demand.

2.4.2.3 Electric Vehicles

There are a number of state incentives, utility incentives, laws and regulations policies to help increase the adoption rate of electric vehicles.[6] For example, California has mandated to have 1.4 Million electric and hybrid vehicles on the roads by 2025. The objective of these policies is to reduce greenhouse gas emissions. However, as discussed earlier, utilities in areas with potentially high penetrations of EVs will need incentives to help regulate charging so as not to jeopardize the reliability of the grid. Thus, an increase in incentives will increase the adoption of electric vehicles, but also increase demand volatility and the need for demand response.

2.4.3 Supply and Supply Side Management

2.4.3.1 Variable Energy Resources (and Renewables)

There is a set of Renewable Portfolio Standards (RPS) and Goals for most states in the US today. Twenty-nine states have RPS policies while 9 others have non-binding goals. For example, California seeks to have 33% of the state's electricity from renewables by 2020. While North Dakota has a goal of 10% of the electricity from renewables[7]. The EIA in their 2012 Annual Energy Outlook estimates 16% of the entire US capacity will be from renewables by 2035. As discussed before, as the targets for wind and solar increase, the variability in the supply increases and this will increase the need for demand response and other supply response in-order to maintain the reliability of the grid.

[3] http://www1.eere.energy.gov/femp/regulations/epact1992.html
[4] http://www1.eere.energy.gov/femp/regulations/epact2005.html
[5] http://www1.eere.energy.gov/femp/regulations/eisa.html
[6] http://www.afdc.energy.gov/fuels/laws/3270
[7] http://www.ferc.gov/market-oversight/othr-mkts/renew/othr-rnw-rps.pdf

2.4.4 Carbon Tariffs

Currently there is no Carbon tax in the US, but a few states have implemented such measures. Maryland for instance charges $5 per ton of CO_2 emitted[8]. These revenues are typically fed back into energy efficiency initiatives. The stakeholders that would be most impacted by a carbon tax are non-renewable based generators (e.g., Coal). Thus, should a large carbon tax be levied it would most likely result in a lower adoption of non-renewable capacity resources, and increase the adoption of renewable generation. As discussed earlier, an increase in renewable variable energy resources would increase supply variability and increase the need for flexibility in the grid, which could be partially met by demand response. In addition, tax revenues would increase the amount spent on energy efficiency initiatives which should result in lower demand and demand growth.

[8] http://itsgettinghotinhere.org/2010/05/19/breaking-news-montgomery-county-passes-nation%E2%80%99s-first-carbon-tax/

Chapter 3 System Dynamics Model Approach

3.1 Approach

As discussed in Chapter 1, a variety of electric power system models are used in the electricity industry. They range from having short-and medium term time horizons (*e.g.,* seconds for optimization of power flow, days for unit commitment, months for hydro-thermal scheduling) to having long term time horizons (*e.g.,* years for capacity expansion). Depending on the time-horizon, different techniques maybe used to model the system. For the purpose of this thesis, we are looking at medium to long term dynamics in the industry (*e.g.,* months to years). Thus to help answer the thesis questions a System Dynamics Model of the Electricity industry was created.

The model presented in this thesis was influenced by the background research and by a number of previously created models. The first model reviewed was the "The Strategy Modeling System Utility", by James Lyneis. It is a model designed to develop strategies for US electricity utility as it entered the new liberalized market structure [21]. The second model reviewed was created by Andrew Ford [22] [23]. It modeled large-scale power systems over a long-term horizon focusing on the interplay between the economic, technical and environmental factors in the system. Next, Zertsim (adopted from Vogstad 2004 Ph.D. thesis) was a System Dynamics model of the German electricity market that was studied [24]. Finally, ENERGY2020, a System Dynamics model of Energy Industry created George Backus (Sandia) and Jeff Amlin (Systematic Solutions) was reviewed [25].

The remainder of this chapter will discuss the model in detail, the scenarios to be studied, and finally a description of the source data to be used in simulations. Chapter 4 contains a discussion of the results.

3.2 Model Breakdown

The following figure is the casual loop diagram created to obtain a better understanding of how government regulations may impact the electricity industry and demand response. The remainder of this section goes into detail of describing different portions of the model. It highlights sections related to demand response, energy efficiency, electric vehicles, variable energy resources, non-renewables, distributed generation and storage. Appendix A contains a complete source code listing of the causal loop diagram.

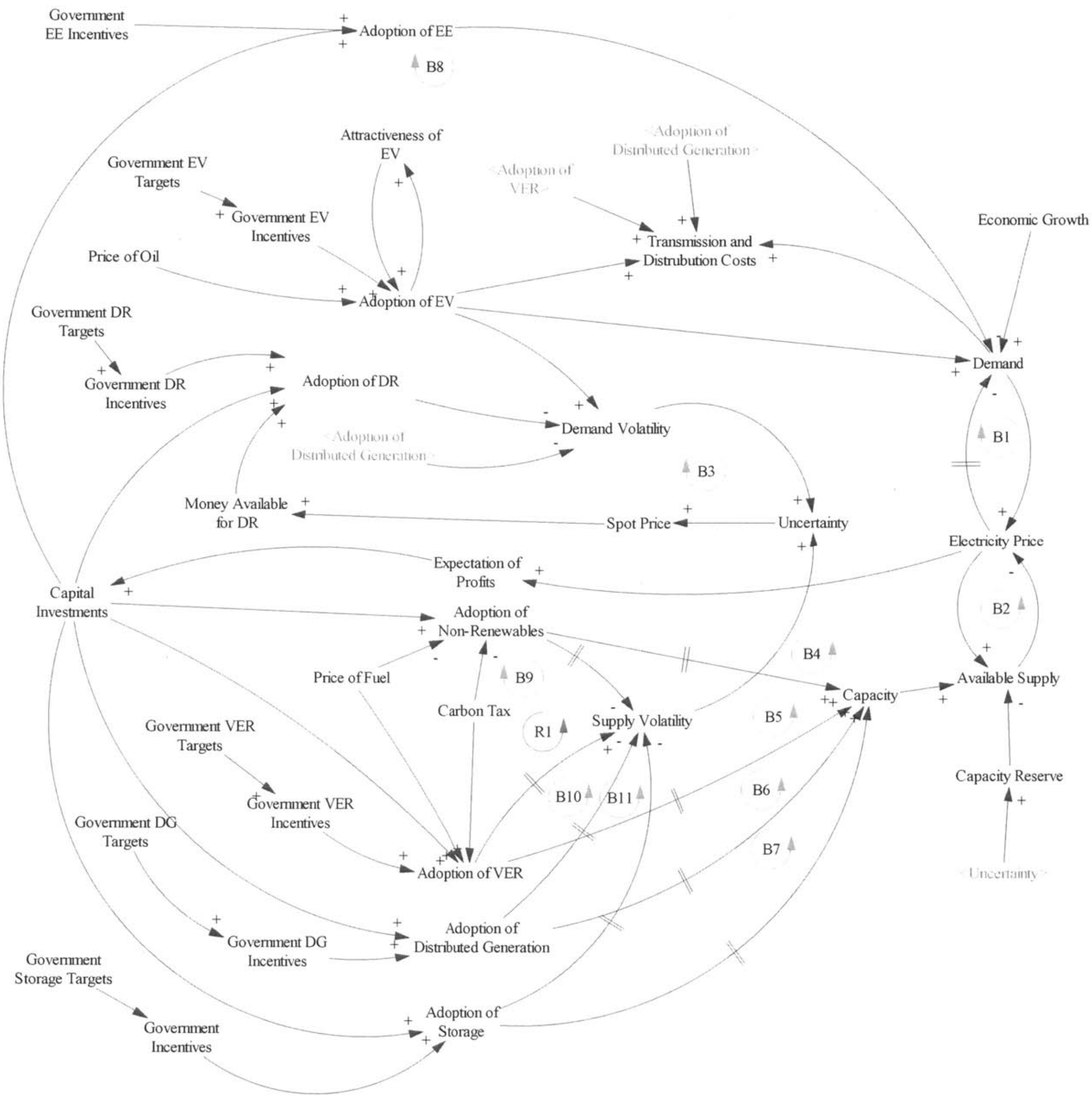


Figure 8: Causal loop diagram of Electricity Industry

3.2.1 Demand, Demand Response and Supply

The relationship between Supply, Demand and Price is a major dynamic at play in the electricity industry. As shown in loop B1, as demand increases, price increases, and as price increases, demand decreases after a delay. The delay is because demand in the electricity industry is quite in-elastic. It is not typical for consumers to immediately curb demand after the average price rises since most consumers are on fixed priced contracts which obscure pricing. Tied to loop B1, is balancing loop B2.Here as price increases, supply increases, and then price decreases.

Loop B3 describes the dynamics of demand response. As uncertainty in the availability of electricity increases, the spot price for electricity increases, this increases the money available to offer to people to curb demand, this increases the number of DR adopters, which lowers demand volatility and lowers uncertainty. However, there is a point at which the adoption of DR will slow down or stop. As discussed in Chapter 2, there is a maximum expected adoption level of DR. There comes a point where the cost to keep consumers in the program will outweigh the money available for DR. One may imagine the value of DR vs. number of adopters to be a parabolic curve where there is a peak in benefits.

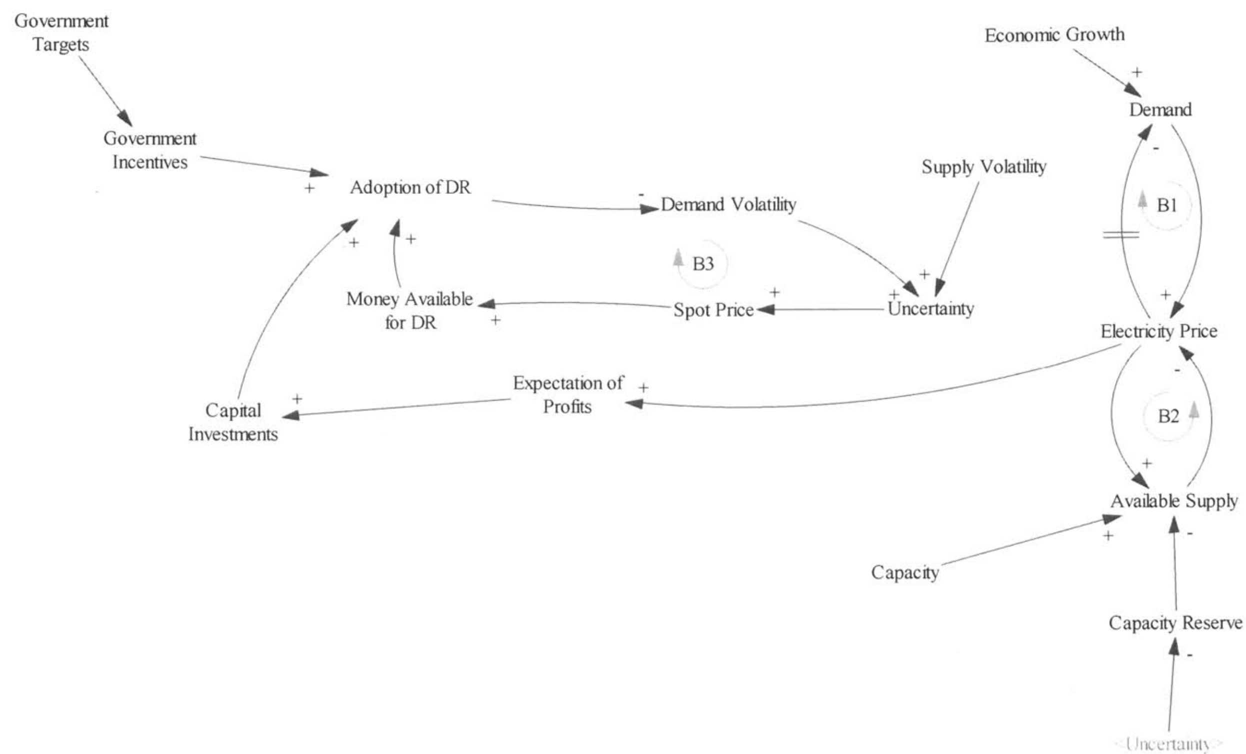


Figure 9: Impact of DR on the Electricity Industry

3.2.2 Energy Efficiency

The following figure shows the key relationships between the adoption of energy efficiency initiatives and the electricity industry. In loop B8 as electricity price increases, expectation of profits increase, capital investments increase, which leads to increased adoption of energy efficiency initiatives. Together this causes a lowering in demand and a lowering in the electricity price.

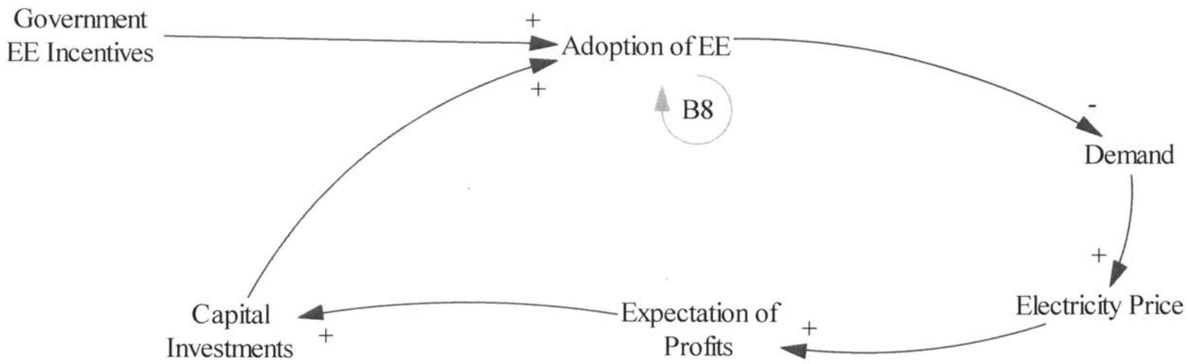


Figure 10: Impact of EE on the Electricity Industry

3.2.3 Electric Vehicles

The following figure shows the key relationships between the adoption of electric vehicles and the electricity industry.

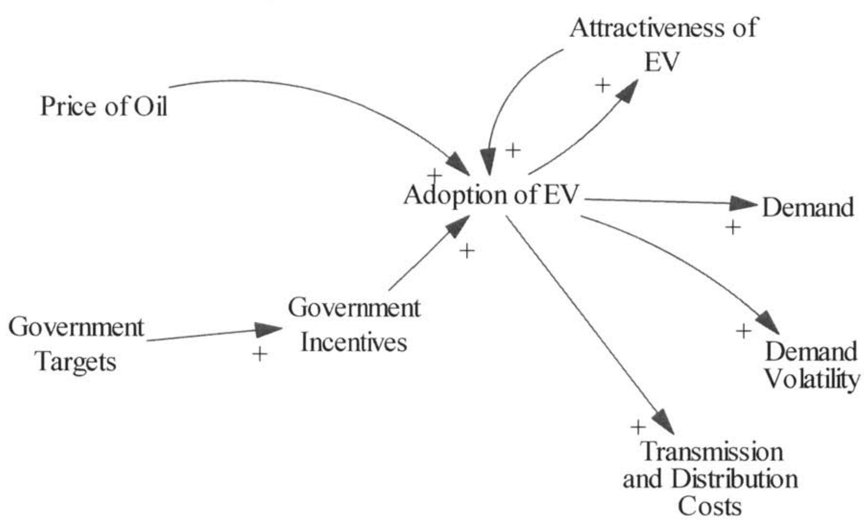


Figure 11: Impact of EV on the Electricity Industry

3.2.4 Renewables and Variable Energy Resources

The following figure shows the key relationships between the adoption of variable energy resources and the electricity industry.

Loop R1 is the reinforcing dynamics for VER increasing uncertainty in the electricity industry. As electricity price increases, expectation of profits increases, capital investments increase, the adoption of VER increases, supply volatility increases, uncertainty increases, capacity reserve increases, available supply decreases and electricity price increases.

Loop B5 is the dynamics for capacity addition to the electricity industry. As the electricity price increases, the expectation of profits increases, capital investments increase, this leads to increased investments in variable energy resources. Together this increases capacity, the available supply, which results in a lowering of the electricity price. In the capacity addition loop, government incentives may increase the adoption of the resource.

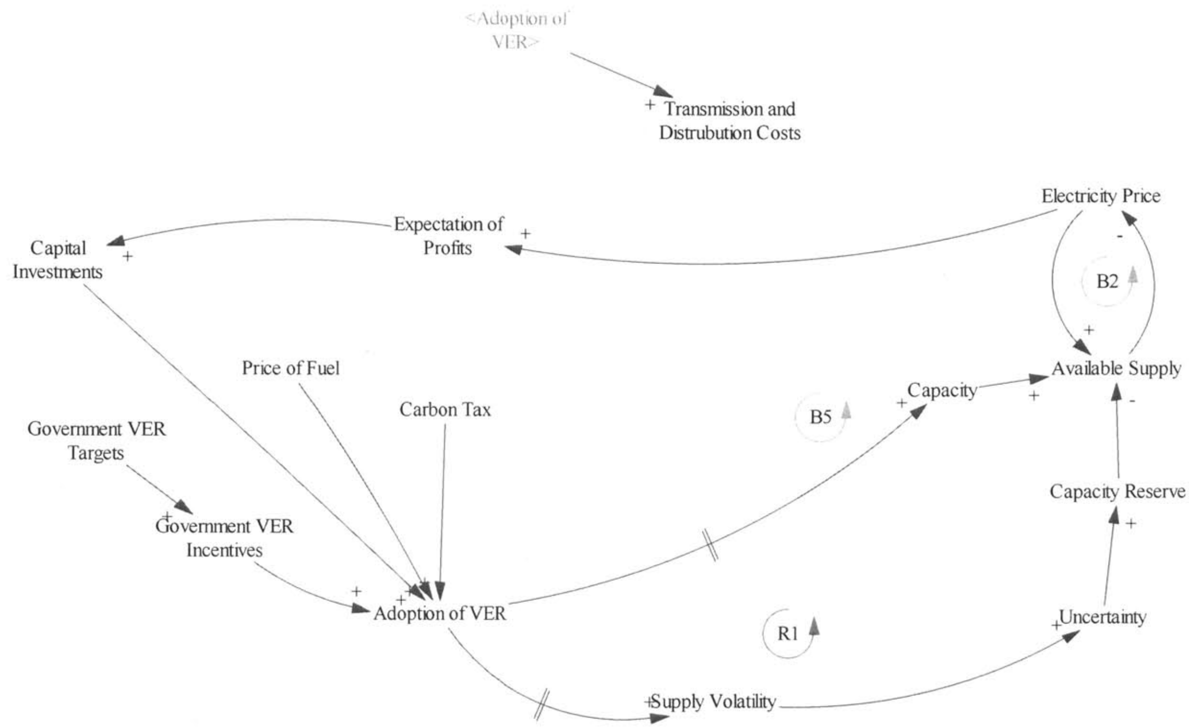


Figure 12: Impact of VER on Energy Industry

3.2.5 Non-Renewables

The following figure shows the key relationships between the adoption of non-renewable energy resources and the electricity industry.

Loop B4 is the dynamics for non-renewable capacity addition to the electricity industry. As the electricity price increases, the expectation of profits increases, capital investments increase, this leads to increased investments in non-renewables. Together this increases capacity, the available supply, which results in a lowering of the electricity price.

Loop B9 is a balancing loop decreasing uncertainty of the availability of electricity. As electricity price increases, the expectation of profits increases, capital investments increase, the adoption of non-renewables increases, supply volatility decreases, uncertainty decreases, capacity reserve decreases, available supply increases and the electricity price decreases.

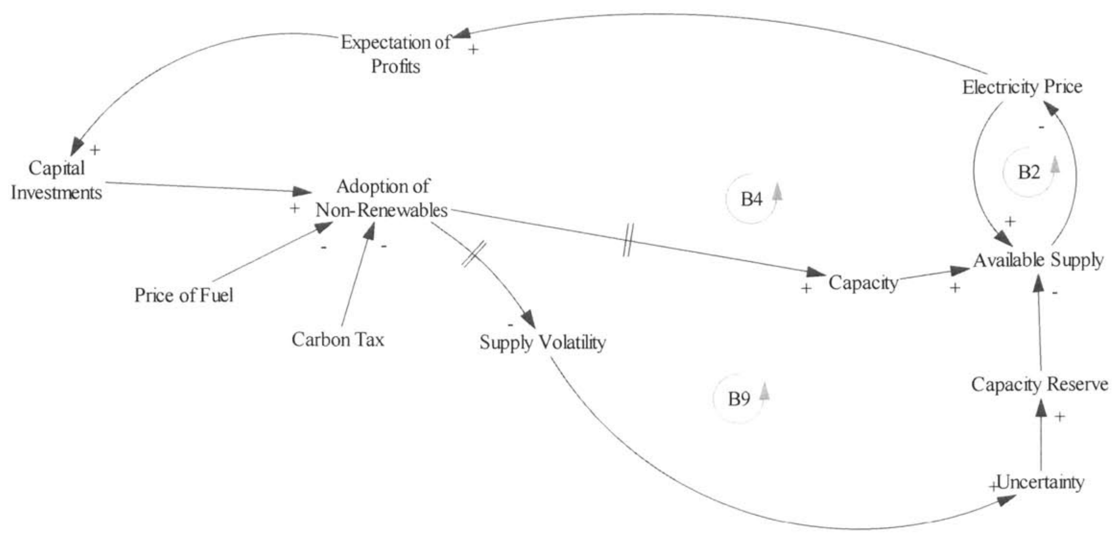


Figure 13: Impact of Non-Renewables on Energy Industry

3.2.6 Distributed Generation

The following figure shows the key relationships between the adoption of distributed generation and the electricity industry.

Loop B6 is the dynamics for DG capacity addition to the electricity industry. As the electricity price increases, the expectation of profits increases, capital investments increase, this leads to increased investments in distributed generation. Together this increases capacity, the available supply, which results in a lowering of the electricity price. In the capacity addition loop, government incentives may increase the adoption of the resource.

Loop B10 is a balancing loop decreasing uncertainty of the availability of electricity. As electricity price increases, the expectation of profits increases, capital investments increase, the adoption of DG increases, supply volatility decreases, uncertainty decreases, capacity reserve decreases, available supply increases and the electricity price decreases.

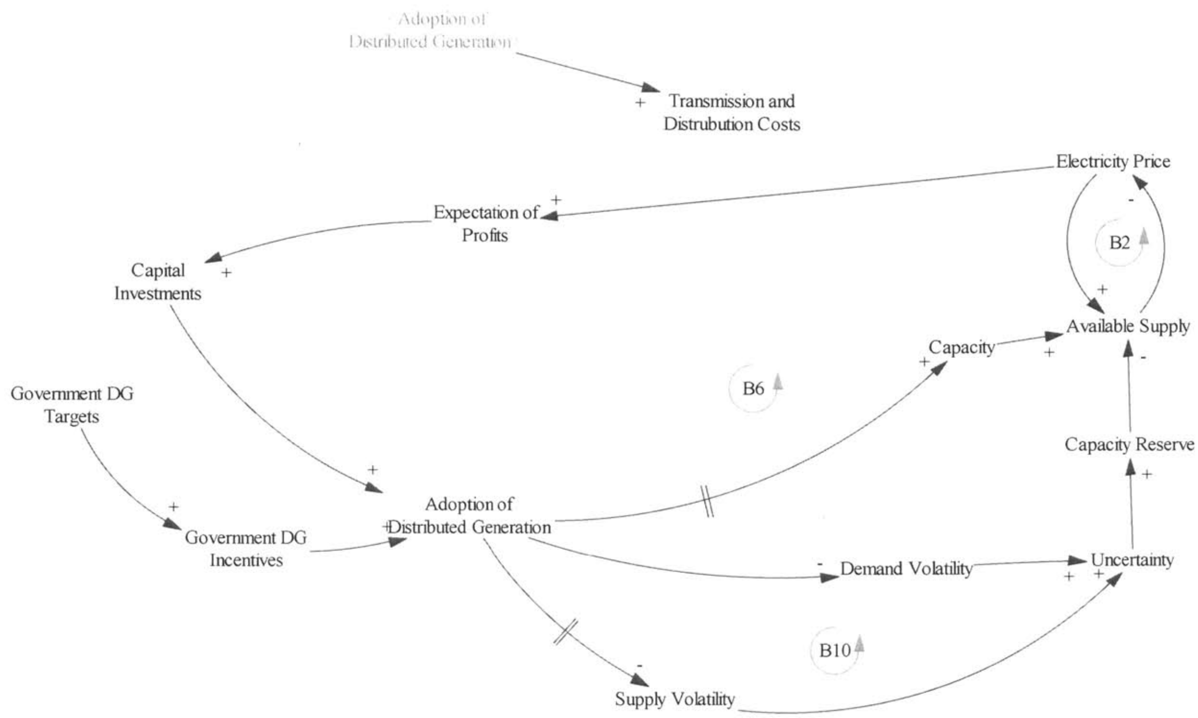


Figure 14: Impact Distributed Generation on Energy Industry

3.2.7 Storage

The following figure shows the key relationships between the adoption of grid storage resources and the electricity industry.

Loop B7 is the dynamics for storage capacity addition to the electricity industry. As the electricity price increases, the expectation of profits increases, capital investments increase, this leads to increased investments in storage. Together this increases capacity, the available supply, which results in a lowering of the electricity price. In the capacity addition loop, government incentives may increase the adoption of the resource.

Loop B11 is a balancing loop decreasing uncertainty of the availability of electricity. As electricity price increases, the expectation of profits increases, capital investments increase, the adoption of storage increases, supply volatility decreases, uncertainty decreases, capacity reserve decreases, available supply increases and the electricity price decreases.

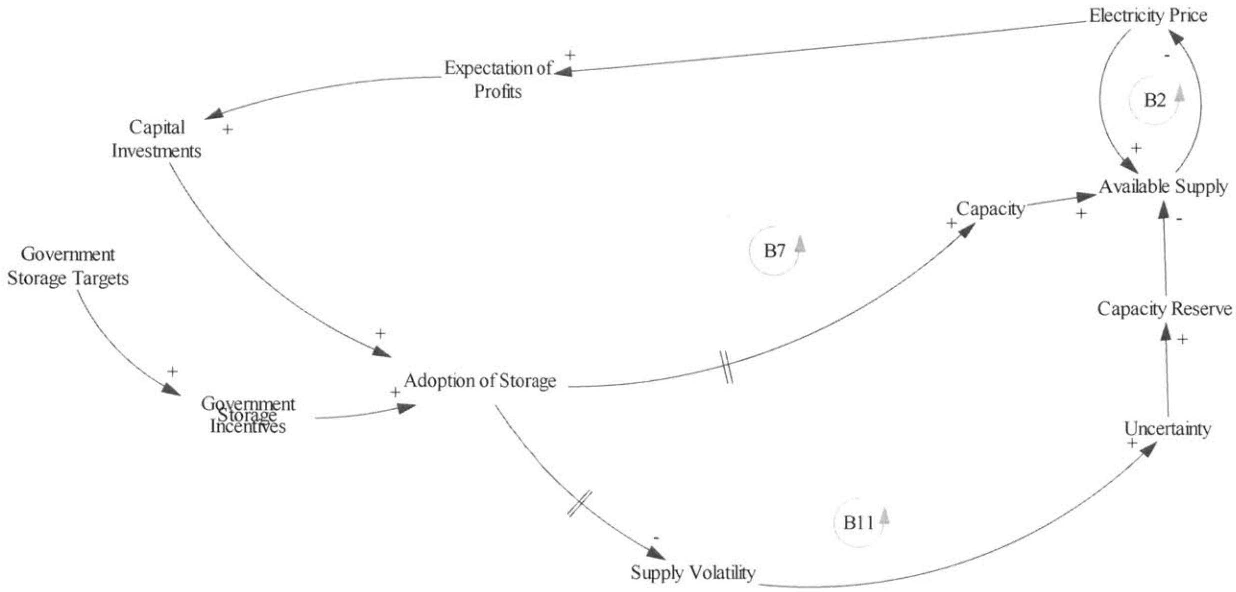


Figure 15: Impact of Storage on Energy Industry

3.2.8 Exogenous Variables

The key exogenous variables are economic demand growth, government incentives and targets, fuel prices and carbon tax price. These will be used to create different scenarios to analyze in the thesis.

3.3 Base Case and Scenario Analysis

To develop a set of insights on the impact of government regulations on the electricity industry, a number of simulations under different scenarios may be performed. The remainder of this section describes the scenarios.

3.3.1 Base Case Description and Source Data

The base case should simulate the US electricity industry from 1999 to 2020 (also known as our business as usual). The output of the model should be compared with historical data from 1999 to 2010 to ensure it is producing realistic outputs.

The primary sources of data for the base case are from the U.S. Energy Information Administration (EIA) Electric Power Annual 2011[9] and 2012 Annual Energy Outlook[10], the NADR (National Demand Response Potential) Model[11] and the DRIVE (Demand Response Impact and Value Estimation) Model[12].

[9] http://www.eia.gov/electricity/annual/html/tablees1.cfm (Table ES1)
[10] http://www.eia.gov/forecasts/aeo/
[11] http://www.ferc.gov/industries/electric/indus-act/demand-response/dr-potential/assessment.asp
[12] http://www.ferc.gov/industries/electric/indus-act/demand-response/dr-potential/action-plan.asp

The Electric Power Annual 2011 contains historical summary statistics on demand and capacity levels (broken into non-renewables and renewables), and demand side management metrics from 1999 to 2010. The Annual Energy Outlook 2012 (AEO2012) contains outputs from a model used to predict the future of the US Energy Industry from 2011 to 2035. In addition, it projects alternative future based different scenarios (*e.g.,* high and low economic growth, high and low greenhouse gas emission taxes). This data will give guidance on base case growth rates for different stocks in our model.

The NADR model provides a set of projections on the potential adoption levels of DR under different conditions (see Figure 16). The DRIVE model is designed to estimate the impact of demand response and smart grid programs of the US Electricity Industry, using various characteristics of a power system as inputs. Finally, information presented in Section. 2.1.2 may be used for electric vehicle adoption estimates.

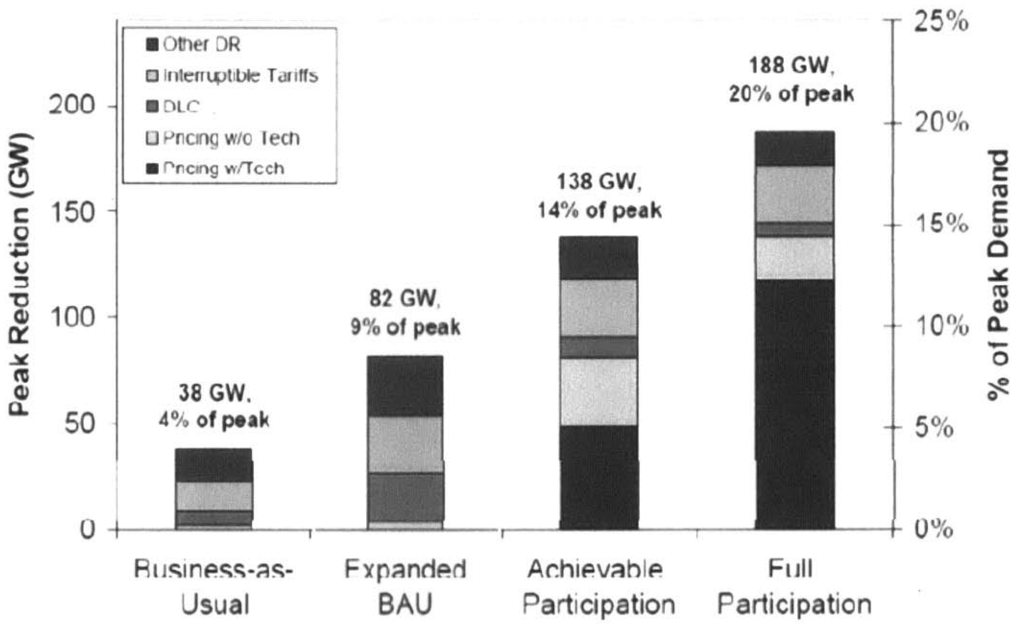


Figure 16: Potential Adoption Levels of DR in the US (from [2])

3.3.2 Scenario 1

After analyzing the base case, the first scenario to investigate is the relationship between different levels of DR adoption (controlled by government incentive polices) and different levels of renewable adoption. The matrix below describes different levers used to create the scenario. DR Fatigue is a drop off in DR adoption due to lack of interest by the consumers.

Adoption Level	**Low penetration of renewables**	**Expected penetration of renewables**	**High penetration of renewables**
DR fatigue (Behavioral Dynamic)	-Low fuel prices -Lower than expected CO2 tax	-Forced fall off of DR adoption	-High fuel prices -Higher than expected CO2 tax

Adoption Level	Low penetration of renewables	Expected penetration of renewables	High penetration of renewables
	-Lower than expected Government Incentives for renewables -Forced fall off of DR adoption		-Higher than expected Government Incentives for renewables -Forced fall off of DR adoption
Lower amount of DR	-Low fuel prices -Lower than expected CO2 tax -Lower than expected Government Incentives	-Lower than expected Government Incentives for DR	-High fuel prices -Higher than expected CO2 tax -Higher than expected Government Incentives for renewables - Lower than expected Government Incentives for DR
Expected amount of DR	-Low fuel prices -Lower than expected CO2 tax -Lower than expected Government Incentives for renewables	**BAU (Business as Usual)**	-High fuel prices -Higher than expected CO2 tax -Higher than expected Government Incentives for renewables
Higher amount of DR	-Low fuel prices -Lower than expected CO2 tax -Lower than expected Government Incentives for renewables. - Higher than expected Government Incentives for DR	-Expected fuel prices -Higher than expected Government Incentives for DR	-High fuel prices -Higher than expected CO2 tax -Higher than expected Government Incentives for renewables - Higher than expected Government Incentives for DR

3.3.3 Scenario 2

The next scenario to investigate is the relationship between different levels of DR adoption and different levels of electric vehicle adoption. The matrix below describes different levers used to create the scenario.

Tech Adoption	Low penetration of EV	Expected penetration of EV	High penetration of EV
DR fatigue (Behavioral Dynamic)	-Low fuel prices -Lower than expected CO2 tax -Forced fall off of DR	-Forced fall off of DR adoption	-High Fuel Prices -Higher than expected Government Incentives for EV

Tech Adoption	Low penetration of EV	Expected penetration of EV	High penetration of EV
	adoption -Lower than expected Government Incentives for EV		-Higher than expected CO2 tax -Forced fall off of DR adoption
Lower amount of DR	-Low Oil Prices -Low Biofuel Prices -Lower than expected CO2 tax -Network virus - Low Distribution Grid Reliability -Economy grows slower than expected - Lower than expected Government Incentives for DR -Lower than expected Government Incentives for EV	- Lower than expected Government Incentives for DR	-High Fuel Prices -Higher than expected Government Incentives for EV -Higher than expected CO2 tax - Lower than expected Government Incentives for DR
Expected amount of DR	-Low fuel prices -Lower than expected CO2 tax -Lower than expected Government Incentives for EV	**BAU (Business as Usual)**	-High fuel prices -Higher than expected Government Incentives for EV -Higher than expected CO2 tax
Higher amount of DR	-Low Oil Prices -Low Biofuel Prices -Lower than expected CO2 tax -Network virus - Low Distribution Grid Reliability -Economy grows slower than expected - Higher than expected Government Incentives for DR -Lower than expected Government Incentives for EV	- Higher than expected Government Incentives for DR	-High Fuel Prices -Higher than expected Government Incentives for EV -Higher than expected CO2 tax - Higher than expected Government Incentives for DR

3.3.4 Scenario 3

The scenario investigates impact of different levels of DR adoption. The matrix below describes different levers used to create the scenario.

Tech Adoption			
DR fatigue (Behavioral Dynamic)	-Forced fall off of DR adoption		
Lower amount of DR	- Lower than expected Government Incentives for DR		
Expected amount of DR	**-Business as usual**		
Higher amount of DR	- Higher than expected Government Incentives for DR		
DR Compensation	Half the DR compensation (i.e., FERC 745 repealed).		

Chapter 4 Results and Analysis

This section contains the results of the scenario analysis. The chapter begins with a discussion of the base case analysis followed by discussions of the scenarios tested. The following is a diagram of the Vensim stock and flow model that maybe expanded to perform a complete simulation. Appendix A contains a complete source code listing.

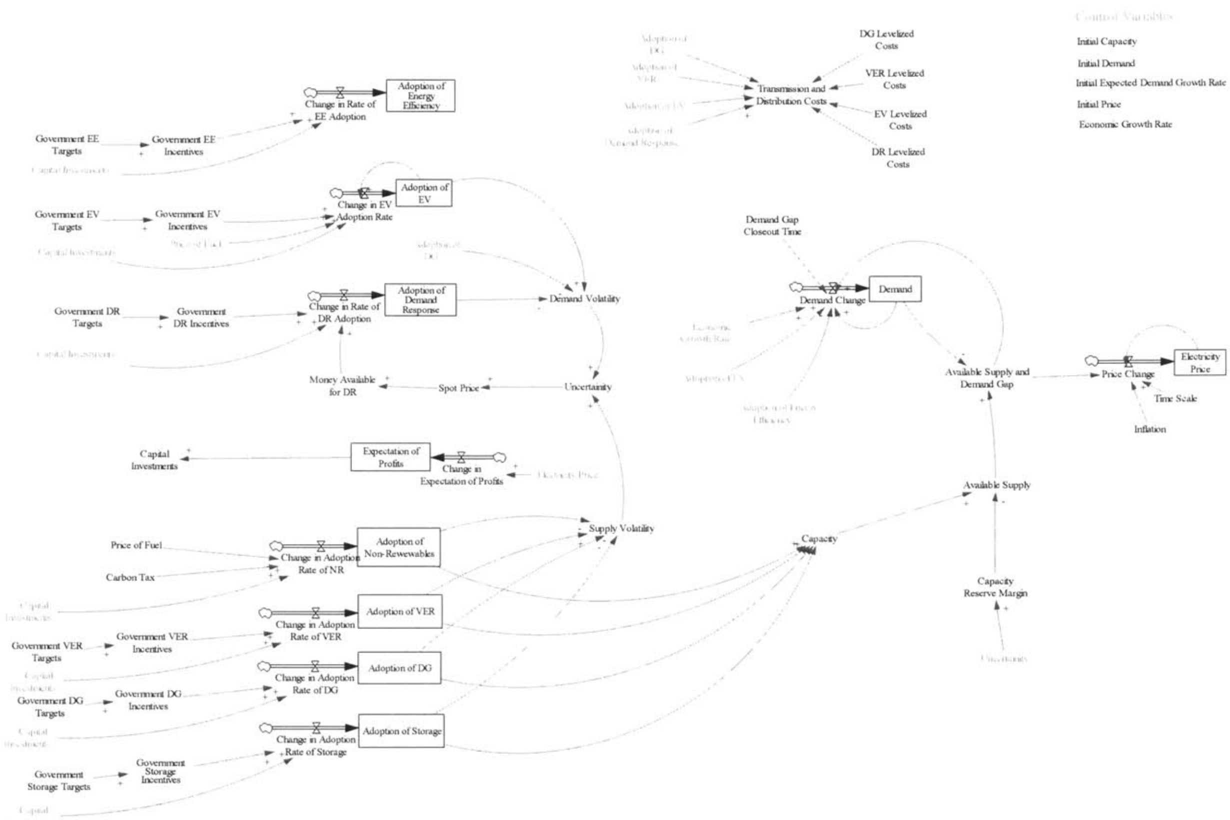


Figure 17: Stock and Flow Model

4.1 Base Case Analysis

The demand response (B3), capacity addition (B4 and B5) and supply volatility (R1 and B9) are the key groups of dynamics controlling the base case. These three groups are biased by two key trends; causal loop B8 constantly lowering demand, and the dynamics of EV addition constantly increasing demand and demand volatility. Casual loops involving DG (B6 and B10), and storage (B7 and B11) have weak influences on the system as they have relatively low adoption levels when compared to non-renewables and VER causal loops.

It is expected loops B1 and B2 would cycle as demand and supply try to balance each other. Constant demand growth from economic growth and EV addition minus EE addition would cycle with capacity additions and a changing capacity reserve. This would cause a cyclical increase in electricity price which would lead to more investments in DR leading to cyclical demand volatility in loop B3. The cyclical increasing electricity price would also cause cycling in the addition of capacity and increase in supply volatility. Thus, it is expected that the demand volatility and capacity reserve would have sinusoidal patterns, but be out of phase with each other due to a delay in capacity addition.

Thus, there would be an inefficient amount of capacity reserves at times. In addition, eventually there would be a point where DR adoption would peak (due to maximum expected penetration), and lead to increased uncertainty beyond this point. Therefore, to counteract this trend, a large investment from the government to increase non-renewables, DG, storage would be needed to maintain the reliability of the electricity system.

DR business wise, it would seem the peak in DR value would require a different business model to maintain growth. Storage or distributed generation aggregation are two potential options.

In the base case, the costs to upgrade the transmission and distribution network are constant and inevitable. One should consider modifying regulations concerning the compensation scheme of distribution companies to a non-volume based method to align them with the objective of the future flexible grid.

4.2 Scenario 1 Results and Analysis

The dynamics of the adoption of DR and VER are complex. As discussed, casual loop B3 indicates the adoption of DR results in a decrease of uncertainty. Casual loop R1 indicates the adoption of VER increases uncertainty. However, there is a point when DR resources will reach its maximum potential. Beyond this point, the uncertainty caused by additional VER will not be able to balance out the addition of DR. Thus, it is likely a lower amount of DR will materialize, and there will be an increased need for more reserves or DG, non-renewables or storage to lower uncertainty. In the short term, the government should consider policies which jointly encourage the adoption of VER and DR resources. In the long term, an increased adoption of VER will likely require maintenance of higher reserves.

4.3 Scenario 2 Results and Analysis

The dynamics of the adoption of DR and EV are linked through uncertainty. The addition of EV simultaneously increases demand, demand volatility and uncertainty. However, there are no significant dynamics that would reduce the adoption of EVs based on factors from the electrical industry. A combination of expected or high penetration of EV with DR fatigue or low penetration of DR would decrease grid reliability. Thus, the government should consider policies which jointly encourage the adoption of EV and DR resources. Regulations to allow utilities or 3rd parties to control EV charging would be beneficial. In the end, an increased adoption of EV will likely require higher DR adoption levels.

4.4 Scenario 3 Results and Analysis

The interesting results here deal with a falloff in DR adoption and halving of DR compensation.

The dynamics of DR fatigue involve loops B3, R1, B9, B10 and B11. Looking at loop B3, if there is DR fatigue, it would cause a drop in adoption of DR, an increase in demand volatility, an increase in uncertainty, an increase in the spot price, and more money available for DR. However, due to fatigue there would not be the same adoption rate as in the past due to more money. Since uncertainty has increased, the R1, B9, B10 and B11 loops will attempt to compensate. The increase in uncertainty causes an increase in reserve, a lowering of supply, and an increase in electricity price. This results in an increase expectation of profits, an increase in capital investments, and an increase in adoption of non-renewables, VER, DG and Storage. This should cause (should VER additions not dominate), a lowering of supply volatility, a lowering of reserves, more supply and a lowering of the electricity price. As it takes time to increase capacity, it is likely that there will be a need for more cycling of dispatchable resources such as mid-range and base load generators to fill in the gap. This need in combination with low gas prices (for the foreseeable future), should result in investments in CCGT plants to add flexible mid-range plants to the generation mix. If too much VER were added to compensate, it may lead to an increase in uncertainty in the grid. In any event, careful monitoring for DR fatigue is important so as to be prepared to increase reserves (or not lower them too quickly).

The dynamics of halving DR compensation (*i.e.,* FERC 745 is repealed) primarily involve causal loop B3. Looking at causal loop B3, if there is a discontinuity there will be an immediate lowering of DR adoption, an increase in demand volatility and an increase in uncertainty. Given it takes time to lower uncertainty, through the dynamics of B9, B10 and B11 , there would be a period where the reliability of the grid would be lowered. If slowly clawed back over time, it would give stakeholders time to build up alternate resources to lower demand volatility (*e.g.,* distributed generation). Slowly reducing compensation would likely change the dynamics to look like DR fatigue. However, the government would now have more control over the time period additional reserve or other mitigating technology is introduced. Thus, it is recommended that if compensation is reduced, than this reduction should take place slowly over time.

Chapter 5

5.1 Conclusions & Recommendations

Government policies mitigating climate change are resulting in the increase of adoption of renewable energy (supply) and electric vehicles (demand). However, these policies are unintentionally fostering an increase in supply-side and demand-side volatility which would degrade electric grid reliability and quality of service. Adoption of supply-side and demand-side management technologies (*e.g.,* storage and demand response) could mitigate this, but not without government incentives to accelerate the adoption of these technologies. Having a holistic view suggests the need for government to consider climate change policies that invest in supply & demand and supply-side & demand-side management technologies to ensure a smooth evolution of the existing & future infrastructure relating to the electricity industry. For example, a policy to promote the construction of wind farms in concert with demand response resources, or a policy to promote the addition of electrical vehicles in step with a home participating in demand response. In the interim, government regulators should be wary of how to calculate the capacity reserve and the assumptions made to arrive at any particular requirement. Finally, modifying regulations concerning the compensation scheme of distribution companies to a non-volume based method is needed for these stakeholders to help develop the infrastructure needed to support a future vision of the electricity industry.

5.2 Future Research Questions

It is recommended to convert the system dynamics model into a complete stock and flow diagram, and perform the described simulations. Performing this task may lead to new insights on government policies concerning the demand response and the electricity industries. It may give additional insight on the proportion of government incentives that should be allocated to supply & demand and supply-side & demand-side management resources. An expanded model may also be able to answer how demand response, and government regulations may impact the generation stack. Finally, further investigation may lead to a better understanding of the current and future allocation of costs and benefits between the various stakeholders in the demand response industry.

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Appendix A : Vensim Stock and Flow Source Code

```
(01)    Adoption of Demand Response= INTEG (
                Change in Rate of DR Adoption,
                        0)
        Units: MW

(02)    Adoption of DG= INTEG (
                Change in Adoption Rate of DG,
                        0)
        Units: MW

(03)    Adoption of Energy Efficiency= INTEG (
                Change in Rate of EE Adoption,
                        0)
        Units: MW

(04)    Adoption of EV= INTEG (
                Change in EV Adoption Rate,
                        0.01)
        Units: Dmnl

(05)    "Adoption of Non-Rewewables"= INTEG (
                Change in Adoption Rate of NR,
                        0)
        Units: MW

(06)    Adoption of Storage= INTEG (
                Change in Adoption Rate of Storage,
                        0)
        Units: MW

(07)    Adoption of VER= INTEG (
                Change in Adoption Rate of VER,
                        142000)
        Units: MW

(08)    Available Supply=
                Capacity*(1-Capacity Reserve Margin)
        Units: MW

(09)    Available Supply and Demand Gap=
                Available Supply-Demand
        Units: MW
        If the Gap is +ve, then we reduce supply and increase demand. If
                        the Gap is -ve, we increase supply and reduce demand.
```

(10) Capacity=
Adoption of DG+"Adoption of Non-Rewewables"+Adoption of Storage+Adoption of VER
Units: MW

(11) Capacity Reserve Margin=
0.15+Uncertainity*0
Units: Dmnl
15% is the typical reserve to be maintained

(12) Capital Investments=
Expectation of Profits
Units: Dmnl

(13) Carbon Tax=
0
Units: Dmnl

(14) Change in Adoption Rate of DG = A FUNCTION OF(Capital Investments,Government DG Incentives
)
Units: **undefined**

(15) Change in Adoption Rate of NR = A FUNCTION OF(Capital Investments,Carbon Tax
,Price of Fuel)
Units: **undefined**

(16) Change in Adoption Rate of Storage = A FUNCTION OF(Capital Investments
,Government Storage Incentives)
Change in Adoption Rate of Storage=
Units: **undefined**

(17) Change in Adoption Rate of VER = A FUNCTION OF(Capital Investments,Government VER Incentives
)
Units: **undefined**

(18) Change in EV Adoption Rate = A FUNCTION OF(Adoption of EV,Capital Investments
,Government EV Incentives,Price of Fuel)
Change in EV Adoption Rate=
0.05*Adoption of EV
Units: Dmnl/Year

(19) Change in Expectation of Profits = A FUNCTION OF(Electricity Price)
Units: **undefined**

(20) Change in Rate of DR Adoption = A FUNCTION OF(Capital Investments,Government DR Incentives
,Money Available for DR)

Units: **undefined**

(21) Change in Rate of EE Adoption = A FUNCTION OF(Capital Investments,Government EE Incentives
)
Units: **undefined**

(22) Demand= INTEG (
Demand Change,
Initial Demand)
Units: MW

(23) Demand Change=
Economic Growth Rate*Demand + Adoption of EV*0 + Adoption of Energy Efficiency *0 + 0*Available Supply and Demand Gap/Demand Gap Closeout Time
Units: MW/Year

(24) Demand Gap Closeout Time=
1
Units: Year
Number of years to close the gap.

(25) Demand Volatility=
Adoption of Demand Response+Adoption of DG+Adoption of EV
Units: Dmnl

(26) DG Levelized Costs=
1
Units: Dollars/MW

(27) DR Levelized Costs=
1
Units: Dollars/MW

(28) Economic Growth Rate=
0.013
Units: Dmnl/Year
Average Percentage Growth, from 2009 to 2035. From Figure 93 of
EIA 2012 data. (0.72)

(29) Electricity Price= INTEG (
Price Change,
Initial Price)
Units: Dollars

(30) EV Levelized Costs=
1
Units: Dollars/MW

(31) Expectation of Profits= INTEG (
Change in Expectation of Profits,
0)
Units: Dmnl

(32) FINAL TIME = 2010
Units: Year
The final time for the simulation.

(33) Government DG Incentives=
0*Government DG Targets
Units: Dmnl

(34) Government DG Targets=
0
Units: Dmnl

(35) Government DR Incentives=
0*Government DR Targets
Units: Dmnl

(36) Government DR Targets=
0
Units: Dmnl

(37) Government EE Incentives=
0*Government EE Targets
Units: Dmnl

(38) Government EE Targets=
0
Units: Dmnl

(39) Government EV Incentives=
0*Government EV Targets
Units: Dmnl

(40) Government EV Targets=
0
Units: Dmnl

(41) Government Storage Incentives=
0*Government Storage Targets
Units: Dmnl

(42) Government Storage Targets=
0

Units: Dmnl

(43) Government VER Incentives=
0*Government VER Targets
Units: Dmnl

(44) Government VER Targets=
0
Units: Dmnl

(45) Inflation=
0.04
Units: Dmnl
Price inflation (3%/year ?)

(46) Initial Capacity=
765744
Units: MW

(47) Initial Demand=
653857
Units: MW

(48) Initial Expected Demand Growth Rate=
0.013
Units: Dmnl/Year

(49) Initial Price=
66.4
Units: Dollars
Dollars/MWh ?

(50) INITIAL TIME = 1999
Units: Year
The initial time for the simulation.

(51) Money Available for DR=
Spot Price
Units: Dmnl

(52) Price Change=
Available Supply and Demand Gap/Time Scale/1000 + abs(Electricity Price)*
Inflation/Time Scale
Units: Dollars/Year

(53) Price of Fuel=
0
Units: Dmnl

(54) SAVEPER =
TIME STEP
Units: Year [0,?]
The frequency with which output is stored.

(55) Spot Price=
Uncertainity
Units: Dmnl

(56) Supply Volatility=
Adoption of DG+"Adoption of Non-Rewewables"+Adoption of Storage+Adoption of VER
Units: Dmnl

(57) Time Scale=
1
Units: Year/Dollars*MW

(58) TIME STEP = 0.25
Units: Year [0,?]
The time step for the simulation.

(59) Transmission and Distribution Costs=
Adoption of Demand Response*DR Levelized Costs + Adoption of DG*DG Levelized Costs
+ Adoption of EV*EV Levelized Costs + Adoption of VER*VER Levelized Costs
Units: Dollars

(60) Uncertainity=A FUNCTION OF(Uncertainity,Demand Volatility,Supply Volatility
)
Uncertainity=
Units: Dmnl

(61) VER Levelized Costs=
1
Units: Dollars/MW