

2016-11-03

A Multiple Perspective Modeling and Simulation Approach for Renewable Energy Policy Evaluation

Talal Alyamani

University of Miami, talal_2t@yahoo.com

Follow this and additional works at: https://scholarlyrepository.miami.edu/oa_dissertations

Recommended Citation

Alyamani, Talal, "A Multiple Perspective Modeling and Simulation Approach for Renewable Energy Policy Evaluation" (2016). *Open Access Dissertations*. 1741.

https://scholarlyrepository.miami.edu/oa_dissertations/1741

This Open access is brought to you for free and open access by the Electronic Theses and Dissertations at Scholarly Repository. It has been accepted for inclusion in Open Access Dissertations by an authorized administrator of Scholarly Repository. For more information, please contact repository.library@miami.edu.

UNIVERSITY OF MIAMI

A MULTIPLE PERSPECTIVE MODELING AND SIMULATION APPROACH FOR
RENEWABLE ENERGY POLICY EVALUATION

By

Talal M. Alyamani

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

December 2016

©2016
Talal M. Alyamani
All Rights Reserved

UNIVERSITY OF MIAMI

A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

A MULTIPLE PERSPECTIVE MODELING AND SIMULATION APPROACH FOR
RENEWABLE ENERGY POLICY EVALUATION

Talal M. Alyamani

Approved:

Nurcin Celik, Ph.D.
Associate Professor of
Industrial Engineering

Shihab Asfour, Ph.D.
Professor of
Industrial Engineering

Murat Erkok, Ph.D.
Associate Professor of
Industrial Engineering

Vincent Omachonu, Ph.D.
Professor of
Industrial Engineering

Moataz Eltokhy, Ph.D.
Assistant Professor of
Kinesiology and Sport Sciences

Guillermo Prado, Ph.D.
Dean of the Graduate School

AIYAMANI, TALAL M.

(Ph.D., Industrial Engineering)

A Multiple Perspective Modeling and Simulation Approach
for Renewable Energy Policy Evaluation

(December 2016)

Abstract of a dissertation at the University of Miami.

Dissertation supervised by Professor Nurcin Celik.

No. of pages in text. (95)

Environmental issues and reliance on fossil fuel sources, including coal, oil, and natural gas, are the two most common energy issues that are currently faced by the United States (U.S.). Incorporation of renewable energy sources, a non-economical option in electricity generation compared to conventional sources that burn fossil fuels, single-handedly promises a viable solution for both of these issues. Several energy policies have concordantly been suggested to reduce the financial burden of adopting renewable energy technologies and make such technologies competitive with conventional sources throughout the U.S. This study presents a modeling and analysis approach for comprehensive evaluation of renewable energy policies with respect to their benefits to various related stakeholders—customers, utilities, governmental and environmental agencies—where the debilitating impacts, advantages, and disadvantages of such policies can be assessed and quantified at the state level. In this work, a novel simulation framework is presented to help policymakers promptly assess and evaluate policies from different perspectives of its stakeholders. The proposed framework is composed of four modules: 1) a database that collates the economic, operational, and environmental data; 2) elucidation of policy, which devises the policy for the simulation model; 3) a preliminary analysis, which makes predictions for consumption, supply, and prices; and 4) a simulation model.

After the validity of the proposed framework is demonstrated, a series of planned Florida and Texas renewable energy policies are implemented into the presented framework as case studies. Two solar and one energy efficiency programs are selected as part of the Florida case study. A utility rebate and federal tax credit programs are selected as part of the Texas case study. The results obtained from the simulation and conclusions drawn on the assessment of current energy policies are presented with respect to the conflicting objectives of different stakeholders.

ACKNOWLEDGMENTS

First of all, I would like to especially express my sincerest gratitude to my advisor Dr. Nurcin Celik, for her support and encouragement throughout the completion of my doctoral degree. I would also like to thank my committee members: Drs. Asfour, Erkok, Omachonu, and Eltoukhy, for their invaluable input into my doctoral research.

Moreover, I would also like to state my appreciation to all members and friends in our Simulation and Optimization Research Lab (SimLab): Haluk Damgacioglu, Mehrad Bastani, Duygu Yasar, and Aristotelis Thanos. I have been greatly influenced by their great passion in research and pursuit of new knowledge. I will always remember my experience cooperating with them and will always appreciate our friendship.

Finally, I cannot express enough thanks to my father Mohammadghazali, my mother Nawal Melaih, my wife Hamsah Zahid, my sons Yousef and Taha, my brothers Saad, Mohammad, Abdulaziz, Wail, Ammar, Omar, Abdullah, the rest of my family, and my friends, who always give me unconditional love, and support.

TABLE OF CONTENTS

| | Page |
|---|------|
| LIST OF FIGURES | viii |
| LIST OF TABLES..... | x |
| Chapter | |
| 1 INTRODUCTION | 1 |
| 1.1. Benefits of Renewable Energy..... | 3 |
| 1.2. Barriers to Renewable Energy | 4 |
| 1.3. Renewable Energy Policies..... | 5 |
| 1.4. Renewable Energy Policy Evaluation Problems..... | 7 |
| 2 LITERATURE REVIEW | 9 |
| 3 PROPOSED SIMULATION FRAMEWORK..... | 15 |
| 3.1. Framework Components..... | 18 |
| 3.1.1. Database Module | 19 |
| 3.1.2. Preliminary Analysis Module | 20 |
| 3.1.3. Policy Elucidation Module | 21 |
| 3.1.4. Simulation Module..... | 21 |
| 4 CASE STUDY 1: RENEWABLE ENERGY IN FLORIDA | 28 |

| | |
|--|----|
| 4.1. Overview of Florida’s Electricity Market..... | 29 |
| 4.2. Preliminary Analysis..... | 33 |
| 4.3. Evaluation of Renewable Energy Policy | 42 |
| 4.4. Results and Discussions..... | 44 |
| 5 CASE STUDY 2: RENEWABLE ENERGY IN TEXAS..... | 57 |
| 5.1. Overview of Texas’s Electricity Market..... | 58 |
| 5.2. Preliminary Analysis..... | 60 |
| 5.3. Evaluation of Renewable Energy Policy | 63 |
| 5.5. Results and Discussions..... | 64 |
| 6 CONCLUSIONS AND FUTURE WORK..... | 71 |
| REFERENCES..... | 76 |
| APPENDIX A: SIMULATION JAVA CODE..... | 82 |
| APPENDIX B: SIMULATION MODULES | 93 |

LIST OF FIGURES

| | Page |
|---|------|
| Fig. 1. Overview of the proposed framework | 19 |
| Fig. 2. Electricity generation by sectors in the states of Florida as a regulated market, and Texas and California as deregulated markets | 31 |
| Fig. 3. Electricity generation from conventional and nuclear energy sources between 2001 and 2013..... | 33 |
| Fig. 4. Trend analysis on seasonal-adjusted demand data for different customer | 34 |
| Fig. 5. Residuals after trend and seasonality removal for main energy generation | 36 |
| Fig. 6. Changes in coal and natural gas prices during 2009–2013 | 37 |
| Fig. 7. Validation of simulation model | 46 |
| Fig. 8. Simulation results of hourly solar electricity generation..... | 48 |
| Fig. 9. Simulation results of minutely solar electricity generation..... | 49 |
| Fig. 10. Effect of solar energy generation from customer-owned solar panels on daily demand curve | 52 |
| Fig. 11. Solar generation for each scenario and residential demand in 2014 | 53 |
| Fig. 12. Simulated effect of energy efficiency program | 56 |
| Fig. 13. Consumption and supply of energy in the state of Texas..... | 58 |

| | |
|--|----|
| Fig. 14. Season-adjusted and de-trended data of each source using a decomposition model in Minitab®..... | 61 |
| Fig. 15. Results of validation for the demand, supply and prices..... | 65 |
| Fig. 16. Total solar capacity (MW) for each scenario | 69 |
| Fig. 17. Main module..... | 94 |
| Fig. 18. Customer sub-module..... | 94 |
| Fig. 19. Environment sub-module | 94 |
| Fig. 20. Utility sub-module..... | 95 |
| Fig. 21. Government sub-module | 95 |

LIST OF TABLES

| | Page |
|--|------|
| Table 1. Comparison of models presented in the literature for the evaluation of future policies..... | 12 |
| Table 2. Results of regression analysis..... | 40 |
| Table 3. Data for the solar program | 44 |
| Table 4. Solar capacities for each scenario | 49 |
| Table 5. Results of each scenario | 50 |
| Table 6. Cost of producing 1 MWh of electricity..... | 51 |
| Table 7. Results of energy efficiency program | 55 |
| Table 8. Results of stepwise regression model | 63 |
| Table 9. Characteristics of different scenarios considered in Texas case study | 67 |
| Table 10. Results of each case | 68 |

Chapter 1: Introduction

Electricity use is rising at a rapid speed, pacing with the growth in industrialization and urbanization around the globe. This rising demand of electricity brings out two major concerns: 1) potential reduction of fossil fuel energy sources, and 2) growing greenhouse gases (GHG) emissions, which have an undeniable impact on pollution and global warming. In fact, in the U.S., electricity generation is responsible for the greatest percentage of coal and natural gas (NG) consumption, accounting for 92% and 31% respectively [1, 2], with greenhouse gas emission accounting for 31% as of 2013 [3].

As a response to these alarming effects of electricity generation on GHG emissions as well as natural gas and coal consumption, there has been a significant rise in the global awareness of renewable energy (RE). As of 2012, the U.S. total investment in new renewable energy capacity was \$34.2 billion, and the total renewable power capacity was 164 GW [4]. Yet these investments were not solely adequate to address the adoption barriers of renewable energy technology in the electricity market, which include the higher cost of renewable energy generation when compared to the cost of conventional energy technology, lack of effective government policies and regulations, poor public concern for aesthetics of renewable energy systems, poor utility rate structures, and lack of cost-effective access to transmission [5].

With such a wide range of technical and economic barriers, there is no simple solution to adopt renewable energy technologies into the electricity market. To this end, several types of policy instruments are needed to regulate and control the electricity infrastructure and the established electricity market [5–9]. All of these various types of renewable energy policies can be grouped under two general categories: 1) financial incentives and 2) rules and regulations. Financial incentives are devised to help decrease the financial burden of

renewable energy technologies in order to make this technology competitive against other conventional energy generation methods, and include tax credits, loans, rebates, and grant programs. Besides, rules and regulations are designed to overcome technical and economic barriers in electricity infrastructure and electricity market in order to increase the role of renewable energy sources in the electricity sector. Within this context, rules and regulations include net metering, renewable energy portfolio, etc. that regulate the electricity system [10].

It is commonly agreed that in order to successfully adopt the renewable energy sources into the electricity sector, they need to be promoted with sufficient energy policies to main stakeholders in the sector [4]. To this end, in this study, a novel, comprehensive simulation framework is developed for the assessment and evaluation of different policies from the various perspectives of its stakeholders. The proposed simulation framework provides policymakers with an expedient tool to evaluate and quantify the benefits and detriments of potential policies in selection of an (near-) optimum policy considering various stakeholders including customers, utilities, environmental agencies, and public service commissions. It also demonstrates how related stakeholders act or react to implementing such policies. The states of Florida and Texas are analyzed in detail as empirical case studies to demonstrate the capabilities of the framework proposed in this research.

1.1. Benefits of Renewable Energy

Renewable energy is energy derived from natural processes that constantly replenish themselves. It can be derived from various sources: from the sun, from wind power, from

biomass, from geothermal power, and from hydropower. Biofuels are also derived from renewable resources [11].

Renewable energy offers several benefits. For one, renewable energy increases the diversity of energy supplies by limiting dependence on imported fuels, thereby creating a greater reliance on domestic, regional, and in-state resources. By reducing the use of fossil fuels, RE also provides many positive effects for the environment. It prevents air and carbon pollution, mitigates climate change, reduces waste, promotes habitat preservation, and supports the conservation of valuable natural resources. Renewable energy also leads to the creation of jobs in manufacturing, installation, and other fields, all of which further local economies. New jobs, taxes, and revenue associated with new renewable capacity all lead to local economic development. The stable (or nonexistent) fuel costs of renewables also leads to the stability of power prices [5].

1.2. Barriers to Renewable Energy

There are several barriers to renewable energy. These barriers are:

- Price Competitiveness: It is the most recognizable barrier to renewable energy advancement.
- Utility Rate Structures: Adverse utility rate structures have been a continual barrier to the increased distribution of renewable energy technologies. Rate structures are capable of increasing the cost of renewables if not monitored to encourage the development of distributed generation (for example, through standby rates and lack of net metering). Utility rate structures can also completely prevent connection to the electrical grid.

- *Lack of Interconnection Standards:* Standard interconnection rules are the procedures and technical requirements for connecting renewable energy systems to the electric utility's grid. Without such rules, it is difficult for renewable energy systems to make such a connection.
- *Barriers in Environmental Permitting:* When renewable energy generation utilizes new technology, they can be burdened with permits until the permitting officials are fully aware of the environmental effects of the generation processes.
- *Lack of Transmission:* Renewable energy resources are often located in remote areas that lack ready access to transmission. States that have not created clear utility regulations (regulations that allow investments in transmission to be reimbursable) delay the expansion of utility-scale renewable projects in their territory [5].

1.3. Renewable Energy Policies

Several types of policies are needed to facilitate investments and advancement of renewable energy technology. These policies can be financial incentives or rules and regulations. Financial incentives, such as cash incentives and tax credits, greatly help decrease the cost of renewable energy projects and make them affordable. Effective rules and regulation help regulate the electricity market, encourage utilities to participate in the employment of renewable energy technology, and benefit customers from programs such as net metering credit. States have adopted several renewable energy policies to support renewable energy technologies. The following are brief descriptions about the most common policies:

- *Net Metering and Interconnection Program*: The goal of this program is to offset the customer's electricity consumption on-site. This program is usually handled by public utilities, but governed by the state energy regulations. The net metering and interconnection program enables residential customers who install solar PV systems and generate their own electricity to connect to the grid. Electric utilities are required to ensure that customers' electric meters accurately track how much electricity is used on-site or returned to the electric grid. When electricity generated on-site is not used, it is returned to the grid. When on-site generation is not sufficient to meet the customer's needs, the customer uses electricity from the grid. In effect, excess electricity is returned to the customer at a later time, and/or customers might receive compensation for the electricity they generate.
- *Investment-Based Incentives*: This cash incentive is usually given at the beginning of the project as a direct cash incentive. This type of incentive helps customers offset the high upfront installation cost.
- *Production-Based Incentive*: This incentive is given based on the amount of energy generated by a system over the agreed upon term. With this type of incentive program, terms, number of years, and escalation rates are all specified. Unlike investment-based programs where the incentive is given at the beginning of the project, this cash incentive is distributed over the years based on the electricity generated.
- *Tax Incentives*: These include federal, state, corporate, and personal tax credits, personal and corporate tax deductions, and corporate tax exemptions. Federal tax credits are one of the biggest incentives for installing renewable energy systems.

State and local tax incentives vary among states. Thus, this incentive can have a major impact based on the state profile.

- Loans and Financing Programs: Customers can take out loans to acquire renewable energy systems. If loans are acquired, they are given to customers to facilitate the purchase of RE systems. The lower the interest rate, the better the value of the financial return of the projects [10–14].
- Renewable Portfolio Standards (RPS): It requires electric utilities and retail electric providers to supply a specified amount of customer electricity with eligible renewable resources.
- Public Funds for Renewable Energy: They are resources that are applied by states to invest in renewable energy projects and developments. Funds are usually set up by levying a small charge on customers' electricity rates.
- Output-Based Environmental Regulations: They create emissions limits per unit of energy output produced with the aim of increasing renewable energy and fuel conversion efficiency, and controlling and measuring air pollution.
- Feed-In Tariffs: They support the advancement of renewable energy by necessitating “electric utilities to pay pre-established above-market rates for renewable power fed onto the grid.” These tariffs, which may differ depending on the kind of resource used, offer renewable producers with a set stream of earnings from their projects [5, 10].

1.4. Renewable Energy Policy Evaluation Problems

There are several issues that contribute to problems with renewable energy policy evaluation. With a number of barriers that hinder the deployment, investment, and

advancement of renewable energy technology, different state energy system characteristics, and different stakeholders involved or affected by the implementation of renewable energy policy such as customers, utilities, government, and environmental agencies, there is a need for well-designed policy instruments that take into account all of these aspects. Some previous studies have only considered a single stakeholder's objective while neglecting other related stakeholders' objectives that may be affected by the implementation of such a policy. For example, RE policy that would support residential customers to install a solar PV system might neglect the utility side. Other studies have applied their analysis on small data that may be insufficient and inapplicable if implemented on a state level or in other regions. For example, a policy that may be successful in one state or region may fail in another state or region due to different state characteristics. Other studies have only considered the effectiveness of renewable energy policy based on the increased capacity of RE sources.

Therefore, in this dissertation, a state is considered as a case study as a whole. The data is collected and analyzed for the entire state's electricity system demand, supply, GHG, generation costs, and retail prices for the past few years in order to better understand and analyze the characteristics of the entire electricity system. Then, a simulation model is built to mimic the electricity system's behavior from the micro level. Furthermore, the conflicting objectives of various stakeholders—customers, utilities, government, and environmental agencies—and how each group would be affected by the implementation of such a policy are taken into account within the developed model. Lastly, several RE policies are evaluated from the perspective of different related stakeholders.

Chapter 2: Literature Review

Increasing global electricity demand, a limited supply of non-renewable energy sources, increasing cost of electricity from fossil fuels, and global warming have prompted the usage of renewable energy sources. However, technical and economic barriers are still in effect of penetration of renewable energy in greater extents [5]. Well-designed renewable energy policies play a crucial role in surpassing these barriers and dissolving the problems in the adoption of renewable energy sources to generate electric energy. Such energy policies can only be achieved via a thorough and comprehensive evaluation process that takes into account the characteristics of the entire energy system.

The studies in the literature approach the renewable energy integration problem from different viewpoints. Some studies shed light on the impacts and consequences of existing energy policies on the electricity market with an aim of understanding the response of the market to those investigated policies. These studies commonly consider each one of those existing policies as a separate case study, and compare and contrast their advantages and disadvantage using varying qualitative and quantitative tools [6–9, 15–17]. For instance, [6, 7] discuss the financial incentives and [8, 9] analyze carbon-cap, carbon trade, and carbon tax policies in conjunction with the effects of these policies on carbon emission. While [9, 15] focusing on specific policies, [16, 17] make long-term analysis of nationwide energy policies in terms of their effect on GHG emissions mitigation and energy security, respectively. However, since all of these works focus on posterior information about the electricity market, they are quite limited in modelling and inferencing on changes in the renewable energy technology, electricity market, and preferences of stakeholders.

Other studies aim to give policymakers a better understanding of the effects of future policies that would be implemented. The momentous goal of these studies is to assist

policymakers in policy design, considering current electricity system characteristics. The models presented within these studies can be grouped into three categories: analytic, economic, and fuzzy models. Analytic models in energy policy evaluation aim to measure and assess energy policies using multi-criteria decision-making methods (MCDA) [18–20]. Using these models, the effectiveness of a wide range of energy policies is investigated in terms of various criteria ranging from GHG emissions to security of electricity supply. While [18] compares the performance of an energy policy against that of an optimal policy (best one), [19, 21] give a single score to each considered policy by weighting different objectives. Even though MCDA-based studies provide quantitative analysis for each policy considering different objectives, they are quite limited in their abilities to model the system and heavily depend on expert opinion.

Economic models are also used to evaluate the effect of financial incentives on the economic burden of renewable energy technologies. Here, [21–25] study the real option technique to handle uncertainties in electricity and carbon prices. In these studies, researchers generally view the system from either the investor or government perspective, and give the results of different incentive rates. These models present precise information about the economic point of investments on renewable energy technologies. However, they lack the ability to concurrently consider other aspects of renewable energy policies and the electricity supply and demand dynamics. The last group includes fuzzy models. These models can be considered to be valuable tools for evaluating energy policies due to their capability of modeling the socio-political side of energy policies. To date, however, only a few studies have used fuzzy models in this area. Here, [26] provides a framework for the evaluation of renewable energy policies in South Africa using a fuzzy system dynamics

paradigm to help understand the interaction among energy demand and supply. The key limitation of this study is that the presented results heavily depend on transformation functions and fuzzy rules, both of which need to be optimized. Table 1 presents a brief comparison of the aforementioned analytic, economic, and fuzzy models presented in the literature.

Table 1: Comparison of models presented in the literature for the evaluation of future policies

| Model | Case Study | Benefits | Limitations |
|-----------------|--|--|---|
| Analytic Models | <ul style="list-style-type: none"> • China • Ireland • Taiwan • Turkey | <ul style="list-style-type: none"> • Quantitative analysis • Different objectives are considered | <ul style="list-style-type: none"> • Quantitative analysis is provided based on expert evaluation • Instead of evaluating policies separately within their own circumstances, they select the best one by comparing different policies • Energy system is not considered during modeling |
| Economic Models | <ul style="list-style-type: none"> • China • Germany • Taiwan | <ul style="list-style-type: none"> • Uncertainties in fossil fuel prices and other RE factors are considered • Economic impacts of the investments on RE technologies are analyzed | <ul style="list-style-type: none"> • Calculation of cost of CO₂ emission is uncertain; it is taken as constant in some studies • Some components, such as demand and capacities of existing plants, are not considered in detail |
| Fuzzy Models | <ul style="list-style-type: none"> • South Africa | <ul style="list-style-type: none"> • Supply and demand factors are considered • Uncertainties and imprecise information is handled | <ul style="list-style-type: none"> • Transformation functions may affect the result of the model • Fuzzy rules may need to be optimized |

While many studies have been presented in the literature for energy policy evaluation, only a few manage to account for the complexities that need to be considered in order to

understand the effect of policy on all stakeholders in the electricity market. In this sense, simulation is one of the most viable tools for analyzing the behavior of the electricity market for policy making. It provides a more accurate understanding of the complex interactions between different market participants and various market components.

While many studies have used simulation in order to model the electricity market [27–32], this is the first study that adapts simulation-based methodology to renewable energy policy evaluation, and considers four different stakeholders. For example, [33] proposes a comprehensive (two-level) simulation-based framework to evaluate the effectiveness of various solar PV policies related to residential customers. They mostly focus on adoption conditions and requirements for PV systems in residential areas. Their simulation models mimic the behavior of residential customers and also calculate the payback period of the PV system adoptions by different types of households. However, their analysis is only applicable on solar PV technologies and is limited to residential customers. [34] offers a complete description of scenario discovery in order to help policymakers and analysts find policy-relevant scenarios by interactively applying statistical and data-mining algorithms to large databases of simulation-model results. However, this study doesn't evaluate any renewable energy policies. [35] proposes a simulation model to examine the dynamic behavior of the photovoltaic energy sector in Spain with the goal to assist policymakers in designing energy policies. The behaviors studied are PV panel price, panel efficiency, PV power installation, subsidy value, electricity price, and PV energy investments and payback period over the last few years. The proposed model replicates the historical data trying to describe what causes the behavior and how it is reproduced. However, this study only focuses on simulating solar panels but doesn't simulate the entire

energy system nor analyze the supply and demand data. [36] proposes a simulation model for wind, and solar energies, and calculates the energy flows on an hourly basis measuring wind and solar loading and distributions in the western Sydney area. However, in this study no renewable energy policies were evaluated.

The proposed framework is also novel in simulation literature. The framework is a comprehensive energy policy evaluation tool that differs considerably from the common energy policy evaluation literature by single-handedly considering various stakeholders with conflicting objectives and modelling electricity supply and demand mechanisms. It takes each stakeholder into account separately, allowing policymakers to manage multiple objectives in policy design. It shows how each stakeholder may act or react to the implementation of financial incentives and regulation-based energy policies. Moreover, it provides a quantitative analysis for the evaluation of the policy. Unlike most of the MCDA methods in policy evaluation, it does not need subjective input including expert opinion, weights of objectives, and as such, it will help the policymakers form an objective decision in determining the most beneficial energy policies. The proposed approach gives strategic insight into the complex electricity system, and simulates the whole system based on the demand and supply mechanism from the macro level. It allows not only for the evaluation and assessment of different policies, but also for modeling the effects of electricity system changes, such as installing a new nuclear plant, closing a coal plant, etc., on the implications of energy policies. Last but not least, this study is the first to use the states of Florida and Texas as empirical studies.

Chapter 3: Proposed Simulation Framework

The aim of this study is to assess the potential impacts of different policies on their considered electricity markets. As such, their underlying electricity system and its demand-supply dynamics are concordantly modeled in this work at a macro level from the perspectives of different stakeholders. Here, the four main stakeholders considered in this study include: 1) customers, 2) utilities, 3) environmental agencies, and 4) public service commissions (PSCs). The high-level, multi-objective electricity system is formulated mathematically as the following over t_i where $i \in \{1, 2, \dots, \infty\}$.

$$\min_t Z(t) = [z_1 \ z_2 \ z_3 \ z_4]^T \text{ subject to} \quad (1)$$

where $z_1 = \sum_j \int_{t_{i-1}}^{t_i} D_j(t) P_j(t) dt \quad \forall t_i$

$$z_2 = - \sum_k \int_{t_{i-1}}^{t_i} D_j(t) P_j(t) - X_k(t) C_k(t) dt \quad \forall t_i$$

$$z_3 = \sum_g \lambda_g \int_{t_{i-1}}^{t_i} \text{GHG}_g(X_k(t)) dt \quad \forall t_i$$

$$z_4 = \int_{t_{i-1}}^{t_i} C_{PD}(D(t)) dt \quad \forall t_i$$

s.t. $\sum_k \int_{t_{i-1}}^{t_i} X_k(t) dt \geq \sum_j \int_{t_{i-1}}^{t_i} D_j(t) dt \quad \forall t_i \quad (2)$

$$\int_{t_{i-1}}^{t_i} X_k(t) dt \leq \int_{t_{i-1}}^{t_i} \text{CAP}_k(t) dt \quad \forall k, t_i \quad (3)$$

In Eq. (1), z_i is the objective of a stakeholder i where $i \in \{1, 2, \dots, 4\}$ stands for *customers*, *utilities*, *environmental agencies*, and *public service commissions*, respectively. The objectives of *customers*, *utilities*, *environmental agencies*, and *public service commissions* are to decrease their electric bill, maximize their profit (the minus sign in front of the z_2 represents the objective function being maximized), decrease the greenhouse gas emissions, and reduce the peak electricity demand, respectively. $P_j(t)$ and $C_k(t)$ are the price of electricity for each customer type j and cost of electricity generated from source k as a function of t . $GHG_g(X_k(t))$ calculates the amount of greenhouse gas u (carbon dioxide, sulphur dioxide, and nitrogen oxide) emitted from energy source k and λ_g is the weight parameter denoting the importance of greenhouse gas u for environmental agencies. $C_{PD}(D(t))$ is to capture the hourly and seasonal demand variations. Eq. (2) and Eq. (3) are to ensure that demand and capacity constraints are satisfied at all times. In these equations, the terms $\int_{t_0}^{t_1} X_k(t)dt$ and $\int_{t_0}^{t_1} D_j(t)dt$ illustrate the amount of electricity produced from source k and total demand of customer type j (residential, commercial, and industrial) as a function of t for a given time interval, and the term $\int_{t_0}^{t_1} CAP_k(t)dt$ represents the capacity of a production source k as a function of t .

It should be noted in the aforementioned formulation that all of the terms are time-dependent and highly correlated with each other and/or other markets (i.e., the price of fossil fuels directly affects the C_k). In such a system, policies and regulations may pose substantial effects on different stakeholders where capturing a specific impact of a given policy is not trivial. This issue is even intensified when the considered system operates at a highly complex (and uncertain) manner due to various interactions amongst several of its

stakeholders, making its analysis over purely analytical models impossible. In this study, as an alternative solution to solving these time-dependent functions analytically, we develop a simulation and optimization framework that incorporates these functions by reducing integrals to manageable functions for each time interval, analyzes the impact of the renewable energy policies on different stakeholders by modeling their conflicting objectives, and handles uncertainties and fluctuations in the system through the incorporation of historical data. The elimination of subjective importance weights given to objective functions by different decision makers makes the presented framework flexible and convenient for dealing with conflicting objectives of renewable energy policy design. This way, the proposed framework allows the policymakers to observe, assess, and compare the potential impacts of a given renewable energy policy on the entire system from different stakeholders' perspectives.

3.1. Framework Components

The proposed framework consists of four components: 1) a *database* providing user access to electricity market data related to electricity demand and supply dynamics, and objectives of each stakeholder, 2) a *preliminary analysis* component providing quantitative analysis for projections of internal and external factors that affect the electricity system and relationships between them, 3) a *policy elucidation* component analyzing the direct impact of selected renewable energy policies on different stakeholders and total electricity demand and supply, and 4) a *simulation* mimicking the overall system behavior considering conflicting objectives of each stakeholder. Fig. 1 shows the components of the proposed framework along with the flow of information among them.

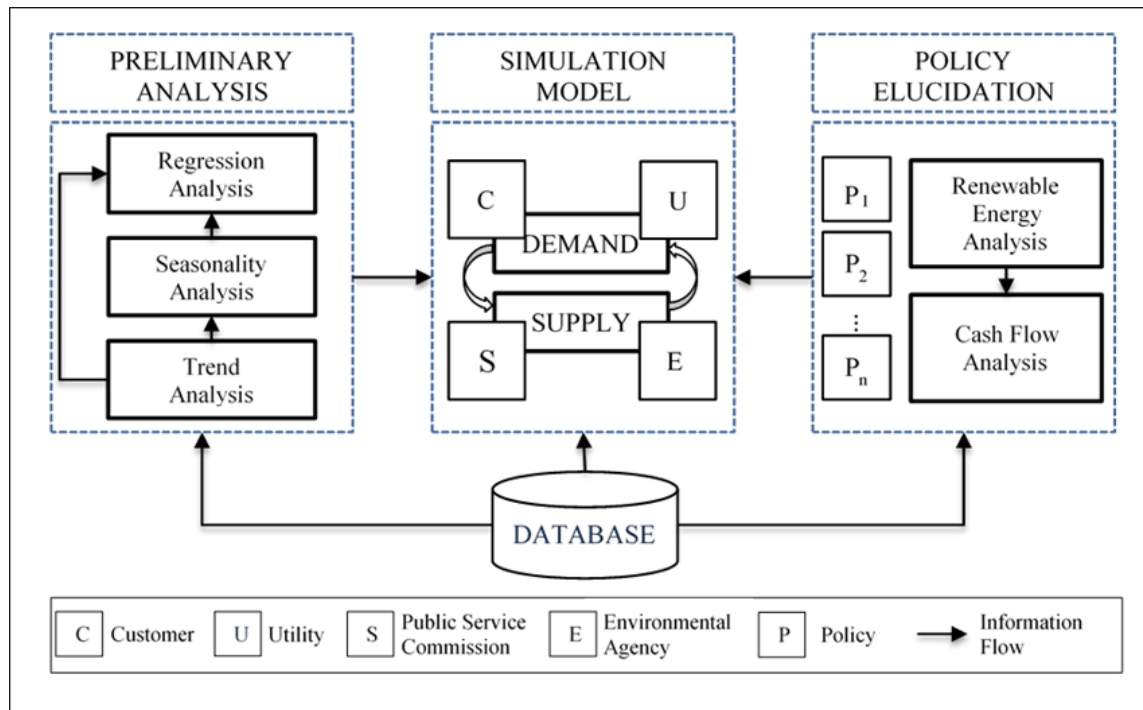


Fig. 1. Overview of the proposed framework

3.1.1. Database Module

The database collates the electricity industry data related to 1) energy economics (i.e., cost of generation from each energy generation source, fuel prices, and taxes), 2) electricity consumption (i.e., total electricity consumption for previous years, load factors, and peak demands), 3) operation (i.e., plant capacities, amount of fuel consumption in producing electricity, and greenhouse gas emissions from different energy sources), and 4) historical electricity generation data from different sources. Once collected, the database provides the collected data to other components of the framework on a need basis. Specifically for the considered case study, all of the information is imported from reliable external data sources, including the Energy Information Administration (EIA) [1, 2, 37–39], Database of State Incentives for Renewables and Efficiency (DSIRE) [40, 41], National Renewable

Energy Laboratory (NREL) [42], Florida Public Services Commissions (PSC) [33, 44], and electric utilities' reports [45–47].

3.1.2. Preliminary Analysis Module

Accurate prediction of the long-term system behavior is critical for energy policy evaluation. Hence, it is necessary to forecast the future based upon the historical data. Here, using the current electricity market data, the preliminary analysis component provides projections of electricity demand, electricity generation mix, and prices for the simulation model. In this study, a multiplicative decomposition model considering both trend and seasonality is used to forecast electricity demand of each customer type j , fossil fuel prices, and electricity supply from each source k [48]. Multiplicative decomposition model estimates the dependent variable based on the formula given in Eq. (4) where y_t shows the dependent variable, s_t indicates the seasonal indices, and d_t represents the de-trended data. In this study, the seasonal indices are determined by using centered moving average method, and de-trended data are calculated using Eq. (5) where c_0 is a constant and $T(t)$ is a trend function that may be linear, quadratic, or exponential. More details of the preliminary analysis are included in each case study.

$$y_t = s_t d_t \quad (4)$$

$$d_t = c_0 + T(t) \quad (5)$$

3.1.3. Policy Elucidation Module

There are different types of policies, some of which are focused upon financial incentives, while others are related to rules and regulations. Each policy affects at least one component in the electricity system. This module answers questions such as which and how a component (or components) is (are) affected by the policy. Since each policy has different impacts on the system, policy elucidation module has customized structure. In this way, the proposed framework is capable of modeling different types of policies. In this research, three renewable energy policies for the state of Florida are selected: a solar incentive program, a solar loan program, and an energy efficiency program. Moreover, two renewable energy policies are selected for the state of Texas: a utility rebate program, and a federal tax credit. All of these programs are related to solar energy technology because both states have great solar potentials, and the share of renewable energy from solar is very small.

3.1.4. Simulation Module

The last module is to design and build a simulation model based on the data from database and the data obtained from preliminary analysis and policy elucidation module. Simulation model mimics the system for each policy to be investigated on an individual and collective basis, and presents output results of each stakeholder to policymakers. This model is formed by a main function, four sub-modules for each stakeholder, and additional necessary functions for each policy. The main function orchestrates sub-modules, and each sub-module has its own functions for its corresponding stakeholder, and based on these

functions, effects of policies are represented. The framework then gives detailed results for each stakeholder's objective.

The system is analyzed from the four different stakeholders' perspectives: customers, utilities, environmental agencies, and public service commissions. All of these components interact with each other at the point of electricity demand and supply. In essence, the model simulates the electricity generation in an attempt to meet the demand set by customers. At the beginning of each minute, the customer sub-module begins calculating the demands of residential, commercial, and industrial customers considering the customer-owned electricity generation. Responding to this demand, utilities generate electricity from different energy sources. Each source is characterized by different factors, such as fossil fuel price, amount of demand, amount of GHG emission, cost of generation, capacity factor of each generation source, availability of renewable energy sources, and so on. After the utilities supply the newly generated demand, they start to interact with the environmental agencies. From there, GHG emissions are calculated based on the amount of energy generated from various sources.

The proposed simulation framework for policy evaluation is built using Java as a programming platform. The model runs in minutes, and the termination condition of the model is a fixed time depending on the policy under study. Next, the simulation system components are explained in detail.

Customers' Demand and Objectives: Demand is modeled in the customer sub-module. In the proposed solution, the demand of each customer is taken into account separately and calculated considering monthly and hourly variations. Here, it is assumed that the daily demand is constant for each month because, to the best of our knowledge, the

most detailed reports about the projection of demand or energy consumption for each type of customer are presented on a monthly basis.

Two main inputs are concordantly used to calculate the minutely demand for the presented model: 1) peak demand of each customer type j in month m (PD_{jm}), and 2) load factor of customer type j at hour h (DF_{jh}). First, the monthly peak demand, predicted for each customer type j using a decomposition model, incorporates seasonal fluctuations within a year and trends between years. The second input is the hourly load factor used to handle hourly variations. Moreover, when calculating the demand in minutes, noise is modeled by triangular distribution found using histogram plot of residuals, which is also used in [49]. In addition to results of preliminary analysis module, noise should also be considered while calculating the production of energy. According to histogram plots, which show the monthly deviations of results of preliminary analysis from actual data, the variability in the data associated with electricity demand and supply was modeled by triangular distribution.

$$D_{jmh} = \frac{PD_{jm} DF_{jh}}{60} \text{tri}(a, b, c) \quad \forall j, m, h \quad (6)$$

Eq. (6) calculates the demand in minutes where D_{jmh} is the minutely demand of customer j in month m at hour h . The term $(PD_{jm} \times DF_{jh})$ gives the hourly demand, and is then divided by 60 to find the minutely demand. The terms a , b , and c are the minimum, mode, and maximum values for triangular distribution, respectively. The total demand in a minute for each month and each hour is:

$$D_{mh} = \sum_{j=1}^3 D_{jmh} \cdot \quad \forall m, h \quad (7)$$

Customer objective is minimizing cost, a function of electricity demand and electricity price. Calculation of total cost is shown in Eq. (8) where D_{jm} and P_{jm} represent the total demand and price for customer j at the month m . Here, electricity prices are assumed that they are constant in a month, and the prices for each customer are predicted using a decomposition model, considering trend and seasonality based on the last ten-year monthly electricity price data provided by the EIA. [37]

$$Total\ Cost = \sum_{j=1}^3 \sum_{m=1}^{12} D_{jm} P_{jm} \quad (8)$$

Utilities' Supply and Objectives: Electricity supply is modeled in utility sub-module. The total electricity generation should exceed customers' demand. The total amount of demand that electric utilities meet (D_{mh}^u) is calculated using the following formula:

$$D_{mh}^u = \frac{D_{mh} \times normal(\mu, \sigma)}{100} \quad (9)$$

The deviations in months are represented by normal distribution, the parameters of which are calculated by using histogram plots. The terms μ, σ are the mean and variance for normal distribution, and are calculated based on the historical data. However, electric utilities generated more electricity than (D_{mh}^u), because of safety generation, energy losses, etc. Hence, the total amount of generation (G) to supply the demand is a, b percent more than (D_{mh}^u). Here, the terms U_a, U_b are the minimum and maximum values of the uniform distribution. Details of electricity demand and generation calculations are included in each case study.

$$G = D_{mh}^u \times (1 + uniform(U_a, U_b)) \quad (10)$$

The most vital part in the electricity supply is determining the electricity generation mix. The mix of electricity generation is affected by many internal and external factors, such as the availability of the energy sources, efficiency performance, dispatchability of the sources, ability of an electricity source to adopt output quickly on demand, capacity factor, and state rules and regulations, etc. For example, while nuclear cannot be changed rapidly, generation from coal and natural gas power plants can be adjusted corresponding to the changes in demand. In renewable energy sources, while electricity generation from biomass are controllable, the generation from solar and wind power cannot be controlled by operators. However, the mix of electricity generation is determined by the preliminary analysis that includes regression analysis or decomposition model. However, in simulation, the generation mix is determined by adding \widehat{X}_k where k is from 1 to 6, based on their dispatchability, until total is equal to G .

Also, to truly understand an electricity market, net interstate trade is needed to be placed into the model. If net interstate trade is negative, it means that a state imports energy from other states. If it is positive, the state exports its energy to other states. The net interstate trade (NIT) calculation is given in the following equation for each time period t :

$$NIT = G - \sum_{k=1}^6 X_k \quad (11)$$

From the utility perspective, profit maximization is one of the major concerns, especially for IOUs. Profit is calculated based on two terms: 1) revenue, and 2) cost of energy generation. Revenue (R) is equal to the total cost for customers, shown in Eq. (12). The other term, cost of generation, depends on fixed and variable operation and

maintenance (*O&M*) costs, fuel costs, depreciation costs, taxes, and administrative costs. Among them, while *O&M*, fuel, and depreciation cost terms are related to energy sources, the others are associated with total revenue. The function for calculating the total profit (*TP*) is given in the following:

$$TP = R - \sum_{m=1}^{12} \sum_{k=1}^8 (FOM_k + DC_k)CAP_k + (FC_{km} + VOM_k)X_{km} + (ACR + TR) \times R$$

where $R = \sum_{j=1}^3 \sum_{m=1}^{12} D_{jm} P_{jm}$ (12)

In Eq. (12), while fixed *O&M* cost (*FOM*) and depreciation cost (*DC*) are related with capacity of the power plant (*CAP*), fuel costs (*FC*) and variable *O&M*, costs are calculated by the amount of energy generated from source *k*. The last term calculates the administration cost and taxes using administration cost ratio (*ACR*) and taxes ratio (*TR*) based on total revenue (*R*). All of the cost parameters are taken from EIA, NREL, and utility reports [37–39, 42].

Environmental Stakeholders Objective: When it comes to environmental stakeholders, the objective is the minimization of total greenhouse gas emissions, which are calculated using the following equations, respectively:

$$GHG_g = \sum_{j=1}^8 \sum_{m=1}^{12} X_{km} GHGR_{kg} \quad (13)$$

Eq. (13) calculates carbon dioxide, nitrogen oxide, and sulfur dioxide emissions (*GHG_g*) using greenhouse gas *g* emission rate from source *k* (*GHGR_{kg}*). *GHGR_{kg}* is

calculated using the proportion between last year's energy generation from source k and last year's amount of greenhouse gas emission.

Public Service Commission Objective: Lastly, the public service commission's goal, reducing peak demand and controlling the electricity consumption, is represented by hourly and seasonal fluctuations. Within this context, the objective of the public service commission can be minimization of daily and monthly peak demand. In this study, the impact of policies—not only on daily and monthly peak demand, but also the variations in demand throughout a day (hourly basis) and a year (monthly basis)—are represented.

Chapter 4: Case Study 1: Renewable Energy in Florida

4.1. Overview of Florida Electricity Market

Understanding the current electricity system characteristics under the umbrella of its supply and demand dynamics plays a crucial role in accurate evaluation of policies on renewable energy technologies and their incorporation to the energy market. In this study, the capabilities of the proposed framework are demonstrated on two case studies of the states of Florida and Texas, where selected renewable energy policies are evaluated from different perspectives of system stakeholders. Details of the characteristics of the state of Florida electricity market (i.e., market structure, demand, supply, currently applied renewable energy policies, and potential renewable energy sources) are provided in this section.

The electricity market of the state of Florida is ranked second in electricity demand and third in electricity generation amongst all states in 2014. The total electricity consumption in Florida was approximately 225 million MWh in 2014, with the residential sector consuming the largest portion of the produced electricity accounting for 50%, primarily due to the state's large population size and high demand for air conditioning during hot summer months, followed by heating during winter months. The commercial and industrial sector follows the residential sector accounting for 41% and 9% of electricity demand, respectively [37, 38].

From the regulations point of view, the state of Florida operated as a regulated electricity market. In regulated markets, electric utilities control the generation, transmission, and distribution of electricity, whereas in deregulated markets, utilities are primarily responsible for distribution, leaving the generation and transmission duties to other parties. Fig. 2 represents the electricity generation by sector, highlighting the

difference between the state of Florida as a regulated market, and states of Texas and California as deregulated electricity markets within the U.S. [37–39]. While independent power producers (IPPs) are primarily responsible for electricity supply in the states of Texas and California, electric utilities serve as the main electricity producers in the state of Florida by generating almost 90% of the total electricity. Given the nature of regulated markets pertaining to the considered case study, in this work, electric utilities are modeled as the main source of electric generation. In terms of ownership, these electric utilities are separated into 1) municipally-owned utilities (MOU) that aim to lower electricity rate for customers, and 2) investor-owned utilities (IOU) that aim to increase profit. Some additional power plants in Florida are co-owned by IOUs and MOUs (i.e., Scherer Coal Plant and St. Lucie Nuclear Power Plant) [45]. In our case study, both MOUs and IOUs are analyzed as their retail electricity prices change, on average, by only less than 4%, according to 2014 pricing data [47]. However, the electric utilities are modeled from the IOUs' perspective only, as they generate about 80% of the total electricity generation within the state [44].

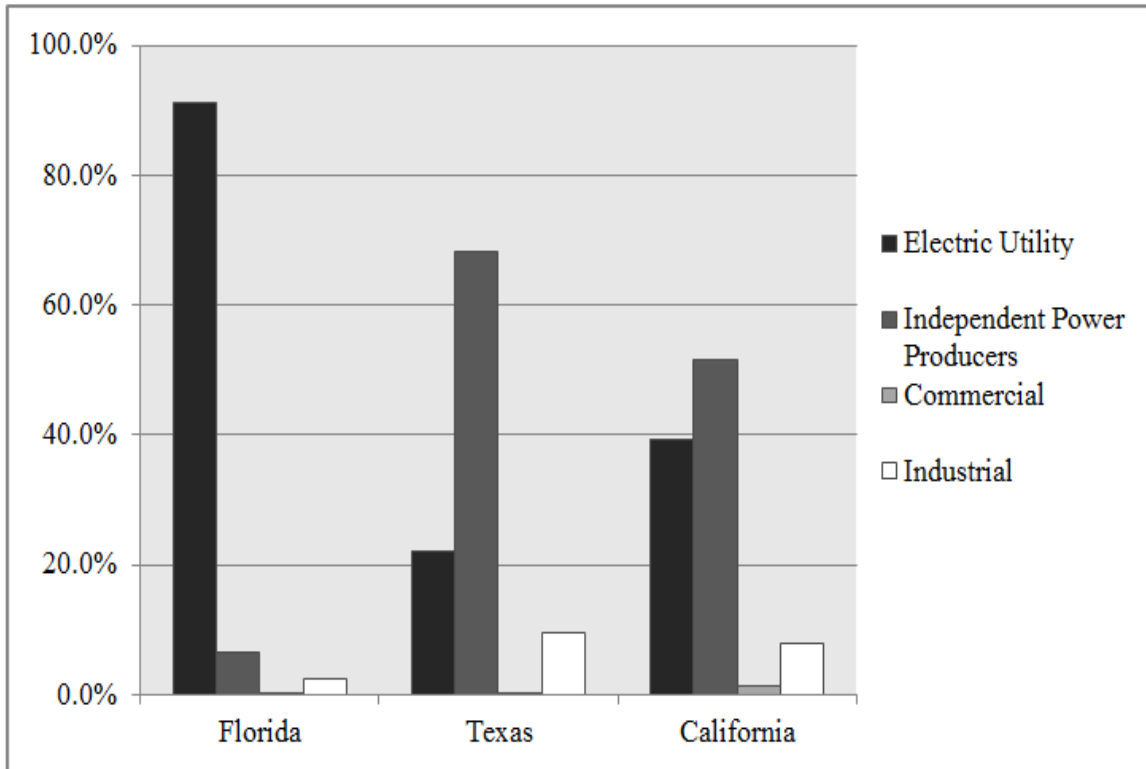


Fig. 2. Electricity generation by sectors in the states of Florida as a regulated market, and Texas and California as deregulated markets

The energy source mix for electricity generation in Florida is spread between conventional and nuclear energy sources, as shown in Fig. 3. Natural gas is the primary energy source of Florida, where its share reached from 35% in 2004 to 62% in 2013. According to the EIA reports [37, 38], the main reason behind this dramatic increase is that utilities replaced older petroleum-fired power plants with natural gas power plants. As a result, the share of petroleum in total electricity production has decreased to less than 2%. NG has also taken the place of coal, such that electricity generation from coal has decreased from 30% to 20% during the last decade [38]. On the other hand, nuclear power remains relatively constant and accounts for about 12% of Florida's consumption. It is expected that for the fuel mix to stay stable over the next few years, natural gas and coal will

contribute roughly three-fifths and one-fifth of net production, respectively. The total share of renewable energy sources in the electricity source mix of Florida is only 2%, with biomass taking the lead [37, 38]. Despite being nicknamed “The Sunshine State,” due to its high solar potential, solar energy accounts for only 0.095% of the total electricity generation in Florida as of 2013, with 137.3 MW of installed solar capacity. Low share of renewable energy source in electricity generation mix and high electricity demand are the main reasons behind high carbon dioxide (CO₂) emissions in Florida. According to EIA reports [2, 37, 38], Florida is ranked fourth in the U.S. in CO₂ emissions, where almost half of its CO₂ emission come from the electricity production.

The state of Florida has implemented a number of policies in order to encourage the advancement of solar generation and to reduce the high residential electricity demand. Amongst these policies—two incentive policies and one energy efficiency policy that were placed to reduce the high cost of installing solar panels for residential customers and decrease the high residential customer electricity consumption, respectively—are considered in this work. As part of our evaluation, the potential impacts of these policies on the electricity system are analyzed in detail from different stakeholders’ perspectives on an individual and collective basis.

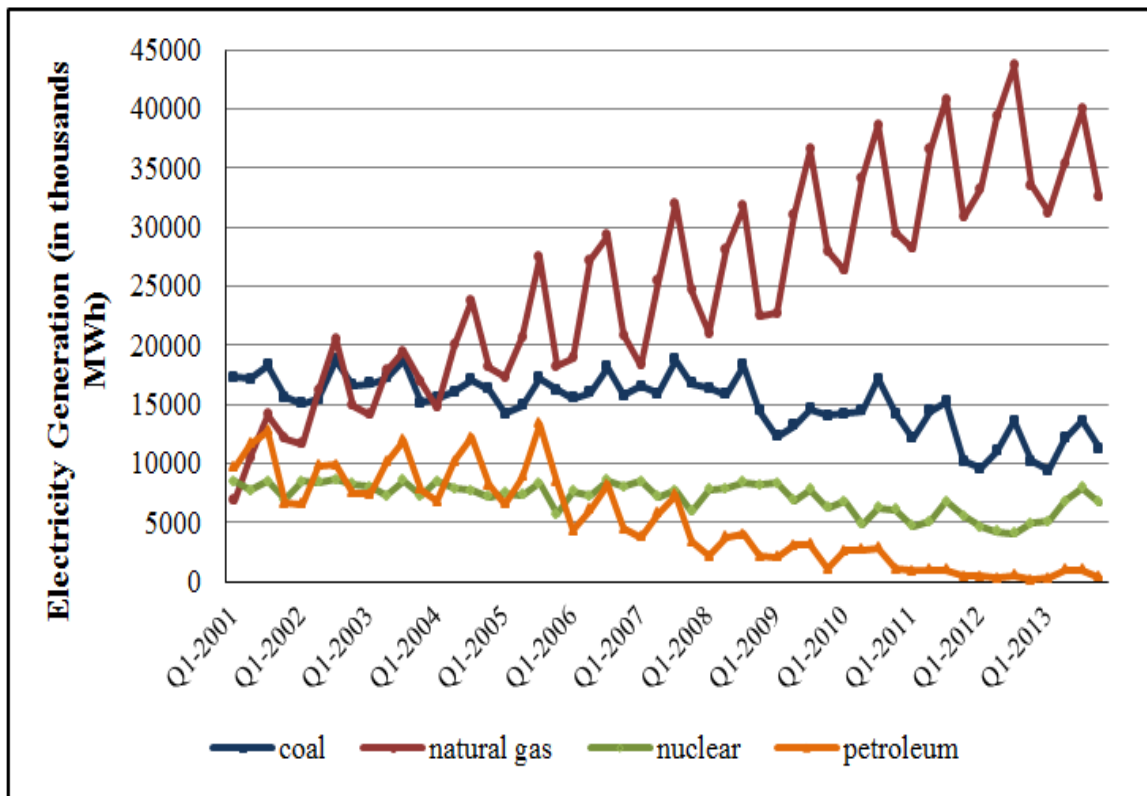


Fig. 3. Electricity generation from conventional and nuclear energy sources between 2001 and 2013

4.2. Preliminary Analysis

Electricity demand for each customer type is predicted using the decomposition model as explained above. Fig. 4 shows the seasonal-adjusted demand data and corresponding trend line for different customers in the state of Florida for the years 2011–2013. The random patterns observed around the trend lines indicated that the data can be explained by seasonality and trend. As such, the decomposition model is quite accurate in explaining the monthly fluctuations in demands of different customer types.

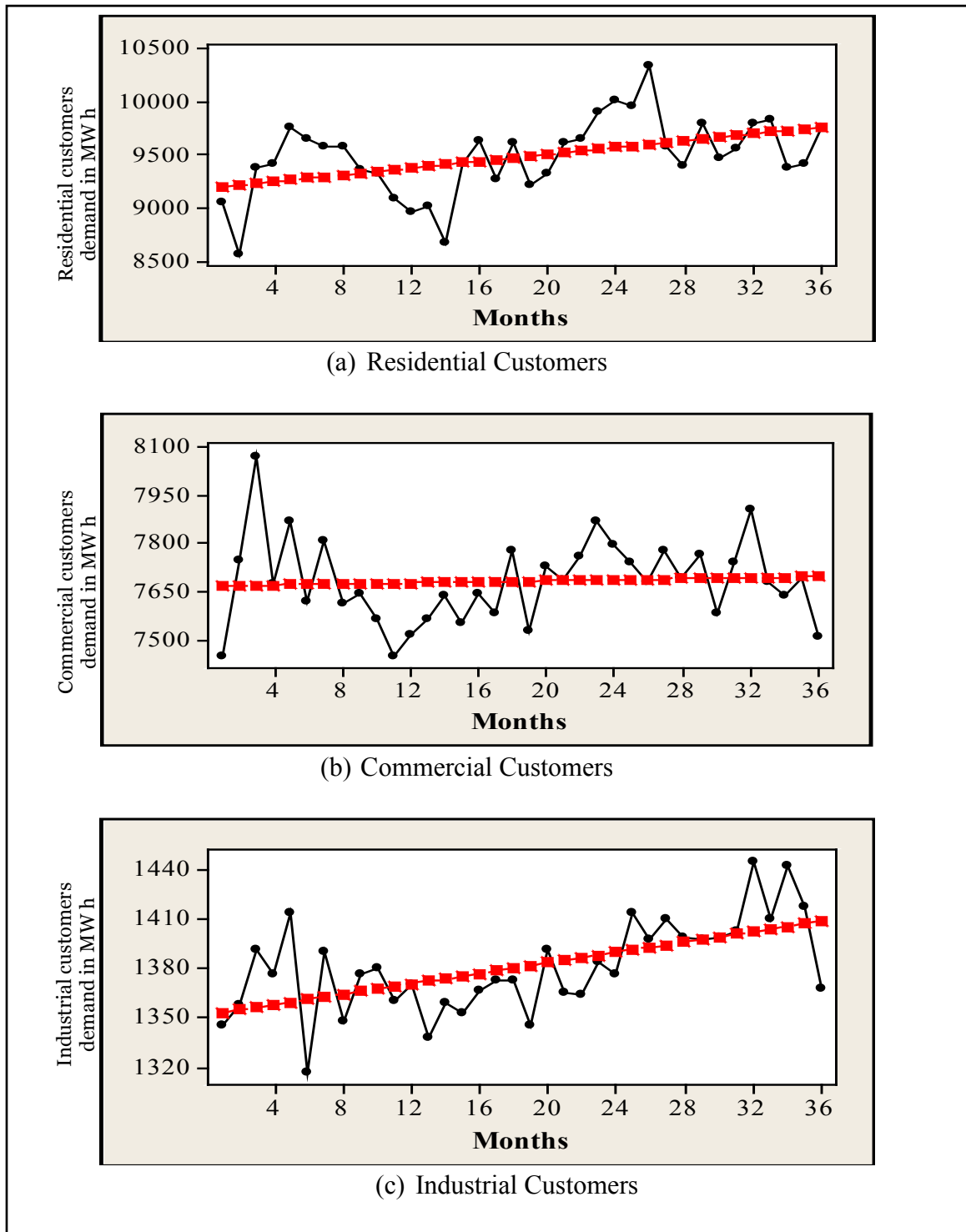


Fig. 4. Trend analysis on seasonal-adjusted demand data for each type of customers

In the preliminary analysis module, the electricity generation mix of Florida is analyzed for the years 2009–2013. Three main energy sources of coal, natural gas, and nuclear power plants are primarily modeled in this work, as the electric utilities in Florida generate nearly 98% of their electricity from these sources with negligible generation contribution from other energy sources [37, 38]. Fig. 5 demonstrates the remaining residuals when the trend and seasonal effects on these considered energy generation sources were eliminated by using our decomposition model. Here, the positive values mean that the seasonality and trend components underestimate the amount of electricity supply. On the other hand, the negative values represent the overestimation of the supply in comparison with real amount of electricity generation from the corresponding source. The very same model is also used to predict the other parameters for the simulation model such as biomass generation, solar generation, coal prices, and natural gas prices. As the data plotted for each energy source in Fig. 6 shows a non-random pattern, it is concluded that seasonality and trend are not sufficient for the modeling of variation of the electricity supply. In search for the causes of such patterns, several external factors (i.e., fuel prices, demand, etc.) are analyzed to note that the variation in coal and natural gas electricity generation is highly associated with the fluctuation in coal and natural gas prices (see Fig. 6).

Fig. 5 and Fig. 6 show that while there is a negative correlation between the price of fossil fuel and supply of electricity, there is a positive correlation between fossil fuel electricity generation and the prices of substitute energy sources of the corresponding fossil fuel. While variations in generation from coal and natural gas are explained by fossil fuel prices, the situation in nuclear electricity generation is more complicated than the others

due to more stable variable cost and electricity generation patterns of nuclear power plants. After detailed analysis on each nuclear power plant, it is concluded that power uprates in St Lucie Unit 1, St Lucie Unit 2, and Turkey Point 3 nuclear power plants have significant impact on the changes in electricity generation in 2012 and 2013.

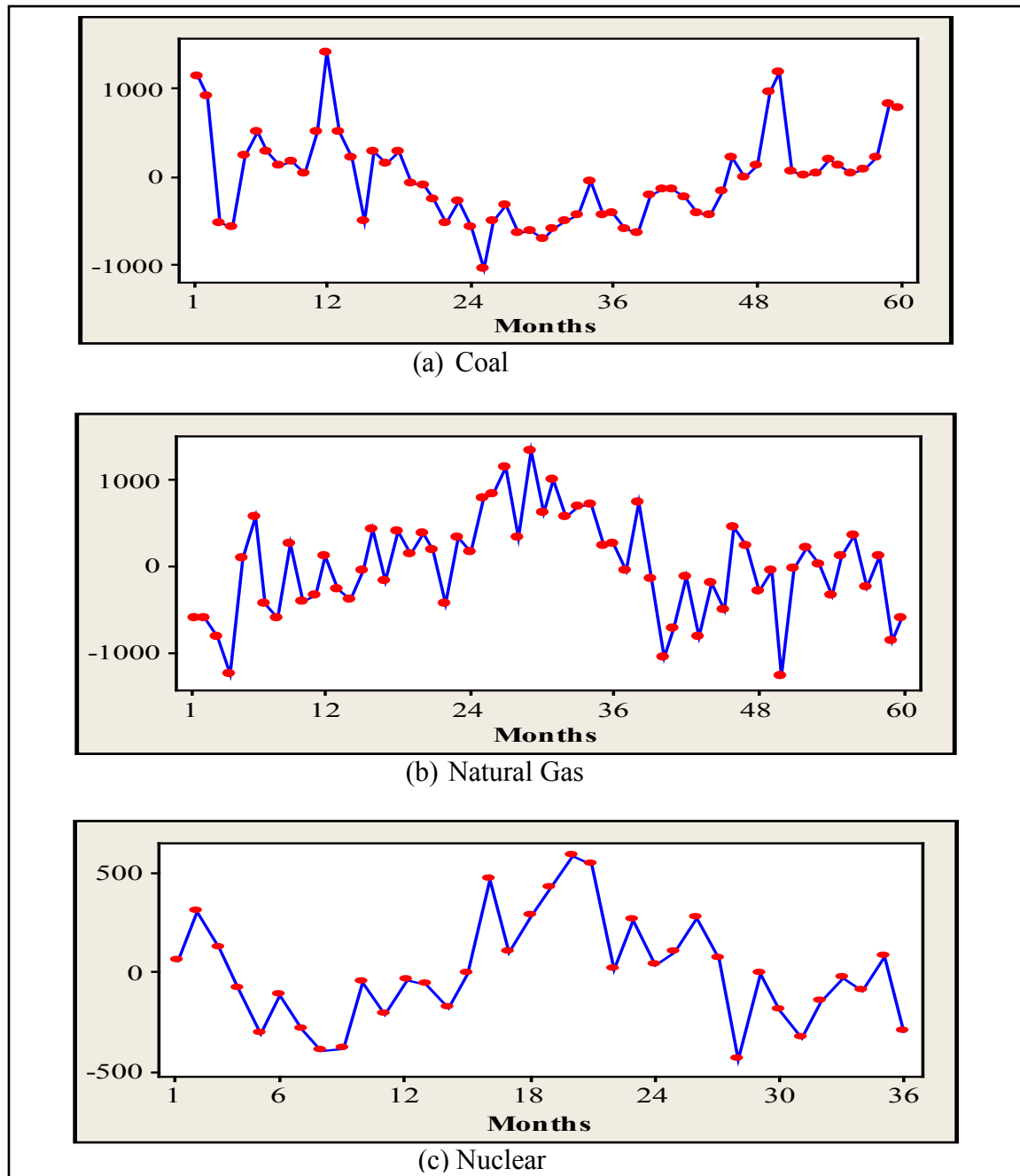


Fig. 5. Residuals after trend and seasonality removal for main energy generation sources

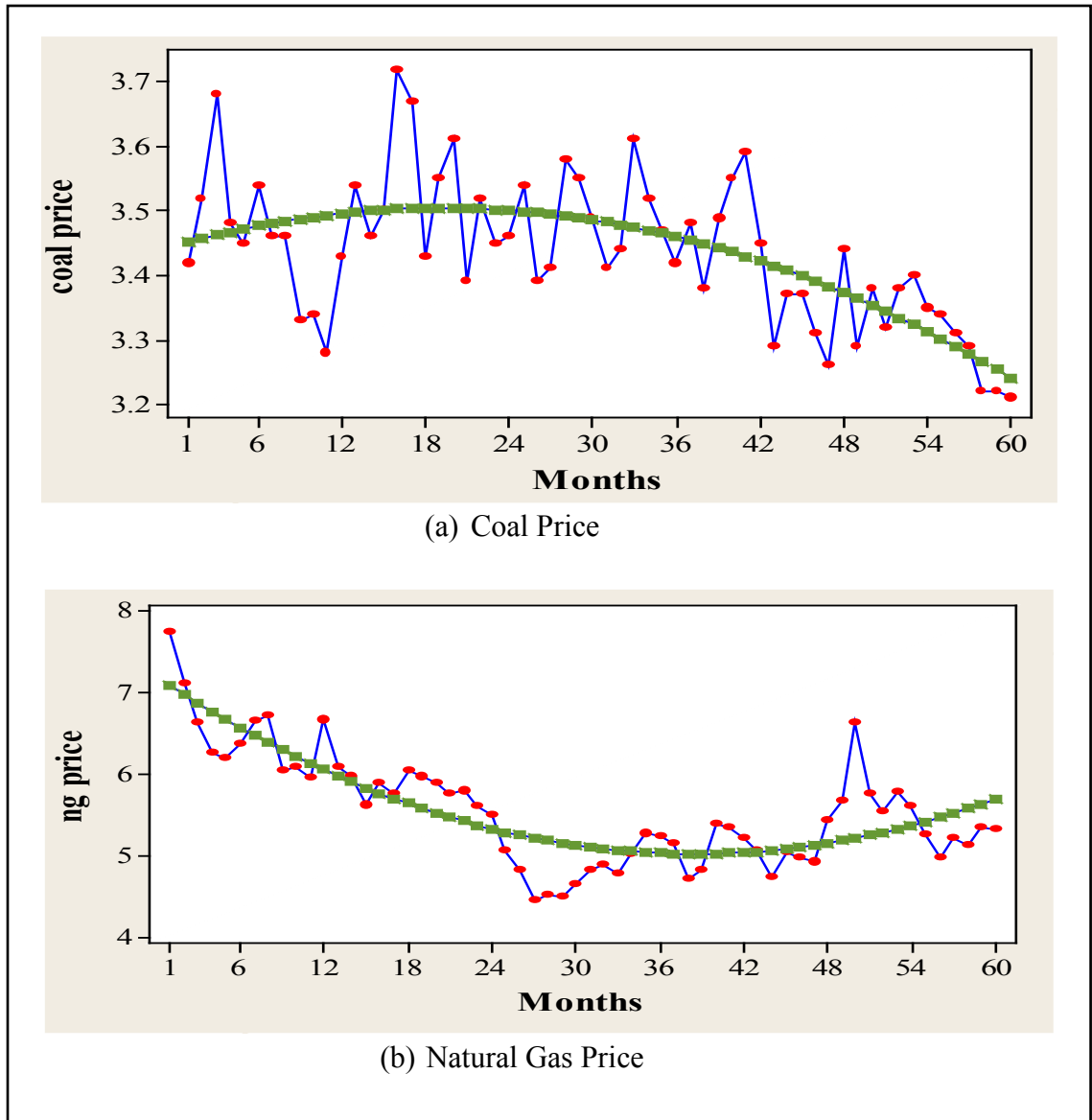


Fig. 6. Changes in coal and natural gas prices during 2009–2013

To model the variation in the supply from coal, natural gas, and nuclear power plants between and within years, a stepwise regression model is applied. Stepwise regression serves as a robust tool for determining the best combination of independent variables that best explains the dependent variable with considerably fewer computational resources than is required for all possible regressions [50]. It determines the linear regression model— $\mathbf{y} = \boldsymbol{\beta}^T \mathbf{x}$ where \mathbf{x} is the column vector of independent variables, \mathbf{y} is dependent variable,

and β is the vector of weights for the independent variables—by incorporating a selection procedure for determining predictive variables of response variables instead of entering all independent variables into regression analysis. Forward selection, backward elimination, and the combination of the two are the main selection approaches. Forward selection begins with an equation with no variables. At each step, the technique adds the variable with lowest p value until all remaining variables have greater p value than Alpha-to-Enter (α_E) to the model. Backward elimination starts with all of the variables in the equation and removes statistically insignificant variables that have p -values greater than Alpha-to-Remove (α_R) until all remaining variables have p -values less than α_R . Bidirectional elimination is the combination of the forward and backward selection techniques, testing the variables to be included or excluded at each step. Stepwise regression fine-tunes the model by adding and removing variables, and at the end, the variables ending up in the final regression model signify the best combination of independent variables to predict the dependent variable. In this study, bidirectional elimination is applied to explain the drivers of energy generation, and α_E and α_R are determined as 0.05.

The results of the developed stepwise regression model are shown in Table 2. In the regression analysis, the real electricity generation data from coal and natural gas sources and seasonal adjusted data for nuclear are designed as dependent (response) variables (see columns of Table 2). The main reason for using seasonal adjusted data for nuclear power plants, calculated by the decomposition model, is to be able to model variations (i.e., maintenance periods) within the years for nuclear electricity generation. In addition to dependent variables, the set of variables that are demand, fuel prices, trends, and upgrades for nuclear power plants are determined as independent (predictive) variables (see rows of

“coefficients” part of Table 2). The upgrades for the nuclear power plants are modeled using two variables: 1) upgrade is used to model decreasing electricity generation during upgrading of nuclear power plants, and 2) capacity is used to model increasing nuclear power capacity after upgrading. In our analysis, the variable upgrade takes “-1” for the considered year 2012, and “0” for the rest of the considered years, whereas the variable capacity is “1” for the years after 2012, and “0” for the year 2012 and before. On the other hand, demand, fuel prices, and trends variables are calculated by decomposition model. In Table 2, the coefficients part represents whether a predictive variable is selected or not, to characterize the variations of response variables. Here, if a predictive variable is chosen, then the coefficient of corresponding variable takes a value different than “0”; otherwise, it is shown by the symbol (-) in Table 2. Moreover, the output part of Table 2 represents the statistical indicators that are used to assess the regression model performance statistically. According to the *F* ratios (denoting whether the variance amongst years can be explained with the attributes of the regression model) and R-squared (denoting how close the data is to the fitted regression line), our developed regression model is able to explain the variance in the electricity generation mix within and between the given years to a significant extent.

Table 2: Results of regression analysis

| | Coal | Natural Gas | Nuclear | |
|---------------------|--------------------------|--------------------|----------------|-------|
| COEFFICIENTS | Intercept | 23.43 | -241.20 | 34.58 |
| | Demand | 0.24 | 0.62 | - |
| | Coal Price | -20.14 | 114.24 | - |
| | Natural Gas Price | 3.03 | -7.08 | - |
| | Coal Trend | 4.03 | - | - |
| | Natural Gas Trend | - | - | - |
| | Nuclear Trend | - | - | - |
| | Upgrade | - | - | 8.52 |
| | Capacity | - | - | 10.60 |
| | OUTPUT | S | 9.50 | 16.16 |
| R-Squared | | 0.81 | 0.89 | 0.64 |
| F Ratio | | 72.18 | 190.32 | 29.54 |

The results presented above are statistically encouraging. Still, it is important to note whether the results are reasonable for a real world electricity system. In the results of regression analysis, the positive correlation is demonstrated with the positive sign, and the negative correlation is shown by the negative sign. With this in mind, the meanings of regression parameters can be discussed as the following. First, the coefficients of demand are also strongly related with power plant characteristics, especially for dispatchability of power plants. In this dissertation, the electricity generation from coal and natural gas is found to be highly correlated with demand, such that the higher the demand, the higher the production. However, demand is not found to be a predictive variable of nuclear power generation, which may be due to the fact that making a change in the nuclear energy production is much harder when compared to other means of production. Also, natural gas is known as a more dispatchable electricity source than coal, and concordantly, in the

regression analysis, the coefficient of natural gas is notably higher than the demand coefficient for coal. Second, as expected, there was a negative correlation between the price of fossil fuel and the amount of generation originating from that energy source. On the other hand, the amount of generation of each source is positively correlated with the fuel price of its substitutes. Third, based on the design of capacity and upgrade variables, it is expected that the exponents of these variables are positive for nuclear power generation, just as the regression model found. Electricity generation mix may also depend on many other external factors such as utilities investment, technology, political issues, etc. As this study focuses on the analysis of the considered system at a macro level, these factors are not counted in explicitly. However, the developed regression analysis incorporates trend analysis, seasonality analysis, and variables for upgrading nuclear power plants, where only coal trend is found statistically significant.

In the case of state of Florida, in order to calculate the minutely demand in the proposed model, the monthly peak demand is first predicted for each customer type j using a decomposition model, incorporating seasonal fluctuations within a year and trends between years. Second, the hourly load factor is used to handle hourly variations. Moreover, when calculating the demand in minutes, noise is modeled by triangular distribution found using histogram plot of residuals.

$$D_{jmh} = \frac{PD_{jm} DF_{jh}}{60} \text{tri}(1 \pm 0.03) \quad \forall j, m, h \quad (14)$$

The total amount of demand that electric utilities meet (D_{mh}^u) is calculated using the following formula.

$$D_{mh}^u = \frac{D_{mh} \times \text{normal}(90.23, 15.1327)}{100} \quad (15)$$

The deviations in months are represented by normal distribution, the parameters of which are calculated by using histogram plots. However, electric utilities generated more electricity than (D_{mh}^u) because of safety generation, energy losses, etc. Based on EIA's data from the last decade, the total amount of generation (G) is 5, 5.5% more than (D_{mh}^u).

$$G = D_{mh}^u \times (1 + \text{uniform}(0.05, 0.055)) \quad (16)$$

4.3. Evaluation of Renewable Energy Policy

Two solar programs and an energy efficiency program are selected as a case in this study because of high solar potential and high residential demand in Florida. Also, it should be noted that program and policy are used interchangeably in the rest of this dissertation, since both energy efficiency and solar policies are referred to as programs in [40].

Solar Programs: These programs are based on solar electricity generation by residential customers where they serve to lessen the demand of residential customers, causing the total energy supply of utilities to decrease. Solar PV technology—which converts sunlight into electricity—is one of the fastest growing RE technologies in the world. PV is considered a clean, sustainable, renewable energy technology that can help meet the rising energy demand, lessen dependence on fossil fuels, minimize the volatility of fuel costs, and improve environmental conditions [51]. The PV system is known to have high upfront installation costs, little yearly operation and maintenance (O&M) costs, and no fuel costs. If residential customers receive adequate cash incentives that help offset the high cost of installing, many customers would consider installing PV systems. Hence, evaluating the current PV policies and designing effective policy instruments play a crucial

role in promoting solar PV technology. While residential customers that install solar energy systems on their properties pay less on their electricity bill, the high setup cost of the system makes solar systems cost prohibitive for many customers. From the utilities perspective, decreasing demand brings forth diminishing revenues as well as decreasing the energy generation costs. Moreover, increasing solar generation is preferable for both the environmental agencies and the public service commission goals.

In the cost calculation, we use net present value (NPV) analysis. The basic formula of NPV is given below.

$$NPV = \sum_{i=1}^T \frac{CF_i}{(1+r)^i} - I \quad (17)$$

CF_i shows the cash inflow during time period i , while I and r represent the initial investment and interest rate, respectively. CF_i for each time period is calculated by using the formula in the following equation:

$$CF_i = \begin{cases} P_i * G_i + PI, & \text{period } i \text{ is in the agreement} \\ P_i * G_i, & \text{otherwise} \end{cases} \quad (18)$$

In Eq. (18), PI is the incentive amount, and P_i and G_i are the price and amount of electricity produced during period. While P_i values are projected in preliminary analysis module, G_i values are simulated based on the historical data obtained from main solar plants in Florida. The data used in this study is given in Table 3.

Table 3: Data for the Solar Program

| | |
|---|-----------|
| Initial System Cost (\$/W) | \$4 - \$6 |
| Maintenance cost (% of initial system cost) | 1% - 3% |
| Interest rate (%) | 6% |
| Lifetime of solar system (in years) | 20 |

In the calculation of utility cost, loss of revenues and cost of electricity generation are considered as main factors. Hence, the additional operational costs such as equipment, transportation, etc. are not included.

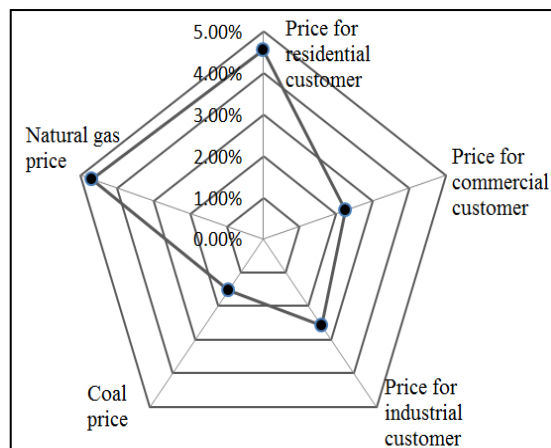
Energy Efficiency Program: The main goal of this program is to decrease summer peak demand, winter peak demand, and total annual electricity consumption. The program involves the collaboration of five major utilities and two municipal utilities whose annual sales are greater than 2000 GWh. The decreasing demand in peak hours and total annual sales will impact the electricity generation from coal and natural gas. Also, it will help the utilities to decrease the electricity from the electricity system of neighboring states or other agencies, which is called net interstate trade.

4.4. Results and Discussions

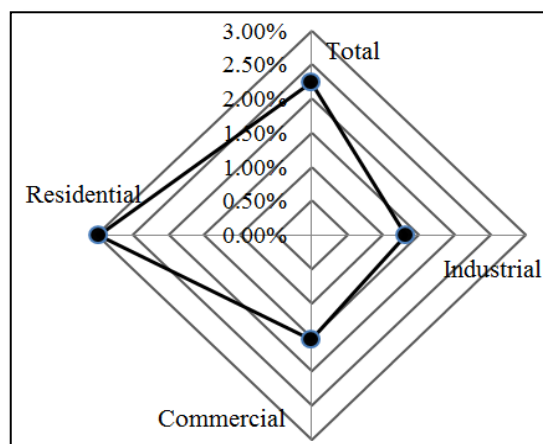
In this section, the current electricity system of the state of Florida and the effect of selected renewable energy policies on the system are empirically analyzed using the proposed framework. The effect of these energy policies on the existing system is assessed in comparison to the base scenario where “no policy” is implemented.

Base Scenario: In the base scenario, the current electricity system is simulated based on the ongoing regulations and trends. The base scenario is used not only in comparison

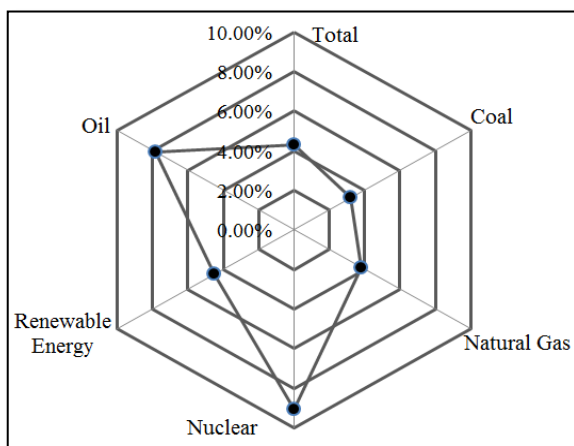
with other scenarios that include the implementation of different policies as a reference, but also in the validation of the proposed framework. To validate our approach, the system is simulated for the year 2014, and validation is made by comparing the results of the approach with the actual data obtained from EIA [40]. During validation, the results obtained from the proposed framework are evaluated under three groups: 1) pricing, which contains the electricity prices for each customer and the fossil fuel prices of coal and natural gas, 2) electricity demand, which includes the demand of each customer individually and their total demand, and 3) electricity supply, which includes the generation from conventional sources, nuclear, and renewable energy sources together, and total electricity generation. The comparisons for each group are represented in Fig. 7 based on their mean absolute percentage errors (MAPEs).



(a) Prices



(b) Demand



(c) Electricity Supply

Fig. 7. Validation of simulation model

As noted from Fig. 7, the proposed framework outputs values in the pricing and demand groups that are very close to the values obtained from the actual data. In these two groups, the difference between the simulation output and the actual data are less than 3% and 5% in all given components, respectively. In the third group, electricity supply, while good results are obtained for the supply from coal, natural gas, and renewable energy, fair results are taken from the model for nuclear electricity generation and oil power plants. However, because the oil power plants are responsible for only less than 2% of total electricity generation, its effect is considered negligible. Also, further analysis on nuclear electricity generation reveals that the seasonality pattern in 2014 is different than the pattern in the years 2011–2013. While this difference has an effect on deviations in electricity generation within a year, the annual MAPE value for total generation from nuclear power plants is only 1.48%. Once the proposed framework is benchmarked against the base scenario with promising results, its performance is demonstrated over two solar programs and an energy efficiency program, and described in the following subsections.

Solar Programs: In this study, two structurally different solar energy programs are investigated: 1) solar incentive program, and 2) solar loan program. The solar incentive program is proposed by the Orlando Utilities Commission (OUC) [46]. In this program, once the required inspections are complete on an installed solar energy system, residential customers receive a monthly credit based on the system's electricity generation read by a special meter. Within the context of the program, customers receive the credit regardless of whether the generated energy is used or sent back to the grid. On the other hand, in the solar loan program (also proposed by the OUC), customers who install a solar photovoltaic system in their property may receive a low-interest loan of up to \$20,000. Loans are repaid

with varying interest rates from 2-5.5% over a term ranging from three to ten years [41, 46]. In order to analyze the impact of both of these policies on the electricity system, the electricity generation from solar panels is simulated using the daily and hourly electricity generation data obtained from DeSoto Next Generation Solar Energy Power Plant in Florida [37, 38]. Fig. 8 and Fig. 9 represent the daily electricity generation and the generation in minutes for four days (each representing a season) for a 1kW solar panel. In this study, our analysis of the policies is conducted on the solar capacities given in Table 4.

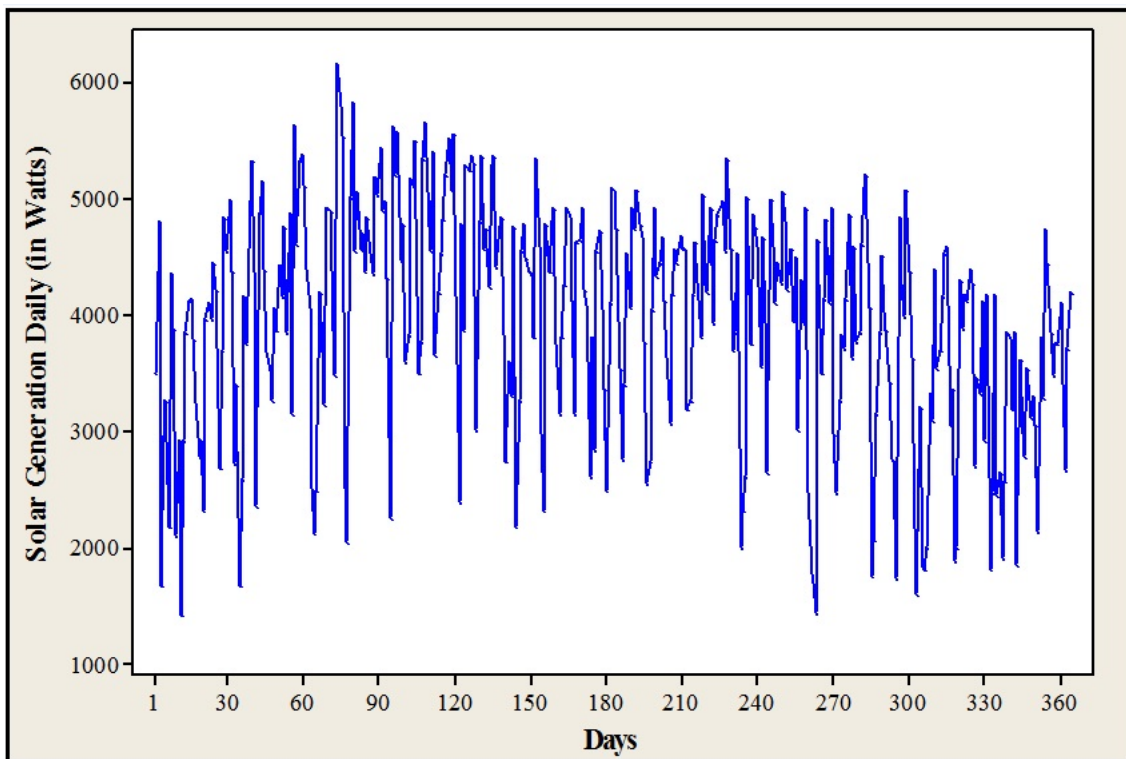


Fig. 8. Simulation results of daily solar electricity generation

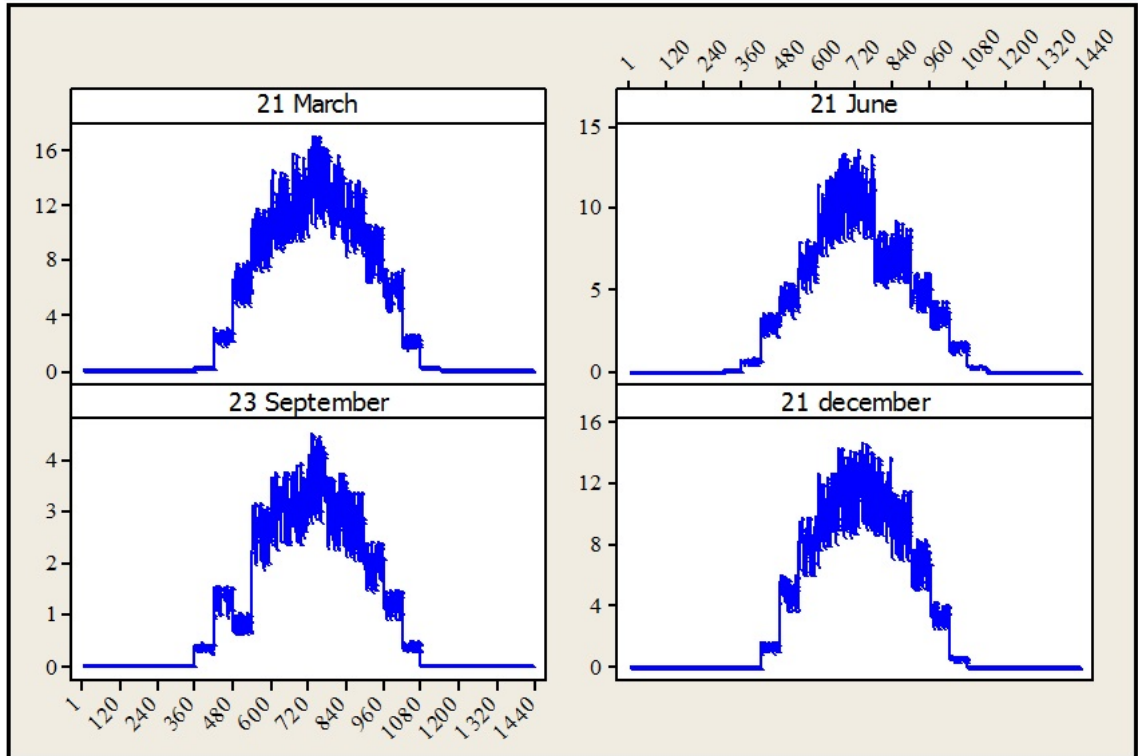


Fig. 9. Simulation results of minutely solar electricity generation

Table 4: Solar capacities for each scenario

| | Explanation | Solar capacity |
|------------|----------------------------------|----------------|
| Scenario 1 | No policy is implemented | 5 MW |
| Scenario 2 | Loan program is implemented | 11 MW |
| Scenario 3 | Incentive program is implemented | 16 MW |
| Scenario 4 | Both programs are implemented | 20 MW |

Table 4 shows the four different scenarios considered. It should be noted that the total accumulated installed solar capacity in Florida is only 40MW as of 2014 and the yearly increase in solar PV capacity is predicted to be 5MW if no policies are implemented [38]. Also, all the policy's terms and details are taken from DISIRE [40, 41]. However, the proposed framework is capable of including other scenarios, as well as other types of

policies. Table 5 represents the results of the effects of policies on the stakeholders' objectives for each scenario. The results are given with change in percentage compared to 2014 capacities. Since solar programs decrease the demand for utilities and increase solar energy generation, it is clear that they decrease GHG emissions and usage of fossil fuel in electricity generation. For instance, if both a credit and loan program is implemented, GHG emissions and usage of fossil fuel will be decreased approximately 0.01%. From a utility perspective, because of loss of revenues and cost of policies, these programs decrease the total profit, while the decrease in demand lessens the cost of total energy generation. In order to moderate the effects of these programs on profit, policymakers may consider another incentive program for utilities that is in support of solar programs.

Table 5: Results of each scenario

| | Base Scenario | Scenario 1 (%) | Scenario 2 (%) | Scenario 3 (%) | Scenario 4 (%) |
|--|------------------|-------------------|-------------------|-------------------|-------------------|
| Residential demand (GWh) | 118,430 | -0.0057 | -0.0131 | -0.0189 | -0.0228 |
| Utility profit (\$M) | 1,712 | -0.1271 | -0.1734 | -0.2185 | -0.2734 |
| CO ₂ emission (Thousand ton) | 115,875 | -0.0037 | -0.0069 | -0.0109 | -0.0121 |
| NO _x emission (ton) | 126,126 | -0.0028 | -0.0057 | -0.0091 | -0.0109 |
| SO ₂ emission (ton) | 94,874 | -0.0026 | -0.0049 | -0.0084 | -0.0096 |

From the customer perspective, both of the solar programs decrease the financial burden of solar energy systems. Table 6 shows the performances of each of the scenarios in terms of the cost of producing 1MWh of electricity in these scenarios. Table 6 shows that solar energy is not cost effective for customers, even when both loan and incentive

programs are applied. Nevertheless, these policies may encourage customers that can afford these costs to install solar energy systems. However, it should be noted that these policies decrease the cost of producing electricity from solar energy systems up to 33%. Moreover, if the electricity price goes up, and customers receive the proper loan with a low interest rate, this would help offset the high initial cost of solar PV systems, which would encourage a higher percentage of customers to install the system.

Table 6: Cost of producing 1 MWh of electricity

| | Cost (\$/MWh) |
|------------|---------------|
| Scenario 1 | 2,851.88 |
| Scenario 2 | 2,437.24 |
| Scenario 3 | 1,976.12 |
| Scenario 4 | 1,901.43 |

Installed solar panels may help decrease the peak demand and control the electricity consumption growth, both of which are the major concerns of PSC in the electricity market. In this work, the effect of the residential customer-owned solar generation on the daily demand curve is analyzed using simulation results of solar electricity generation. Fig. 10 (a) and (b) show the hourly demand curve of an average residential customer electricity consumption without solar generation, and with four different variations of solar panel installations during summer and winter, respectively. According to the figures, solar generation decreases the daily peak demand in both summer and winter up to 10%. However, its effect in winter is limited because daily demand has two peaks in winter, and solar electricity generation is negligible during the times of the second peak.

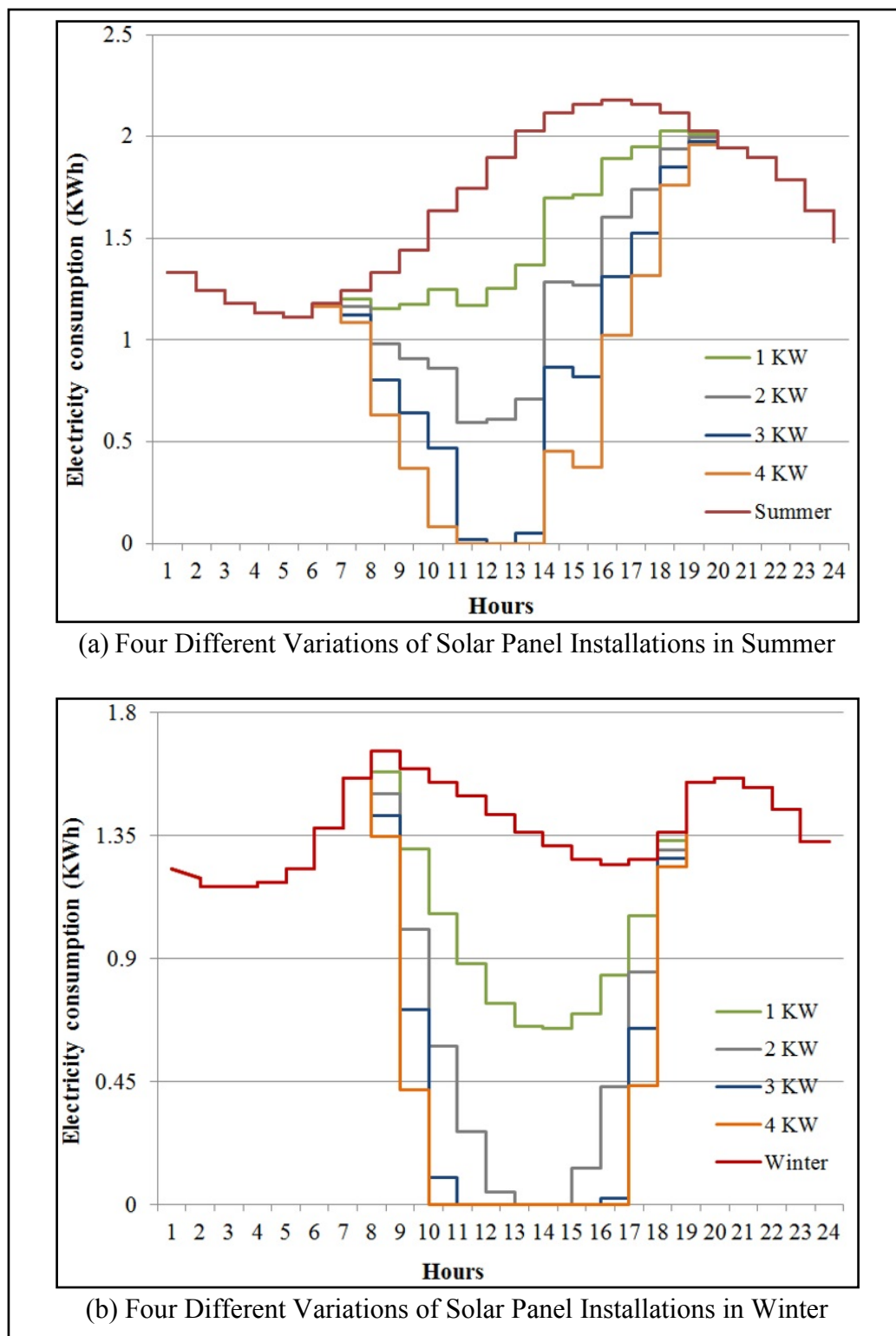


Fig. 10. Effect of solar energy generation from customer-owned solar panels on daily demand curve

The further effect of solar generation on monthly variations (for each considered scenario) is shown in Fig. 11. In Florida, March and April are the most efficient months in terms of solar generation. However, these are also the months that the residential demand is the lowest. With the incorporation of solar generation, the peak demand is expected to decrease throughout the year, yet the seasonal variations may increase. This increasing variance may have benefit in planning power plant maintenance. For example, these two months, March and April, would be the best times for scheduling the maintenance for the power plants that need annual maintenance (i.e., nuclear and coal power plants). During the periods when some power plants are offline for maintenance, solar energy can be an important backup option, and therefore, the investigated policies, which help solar energy penetration, may have significant impact on determining power plant maintenance schedules.

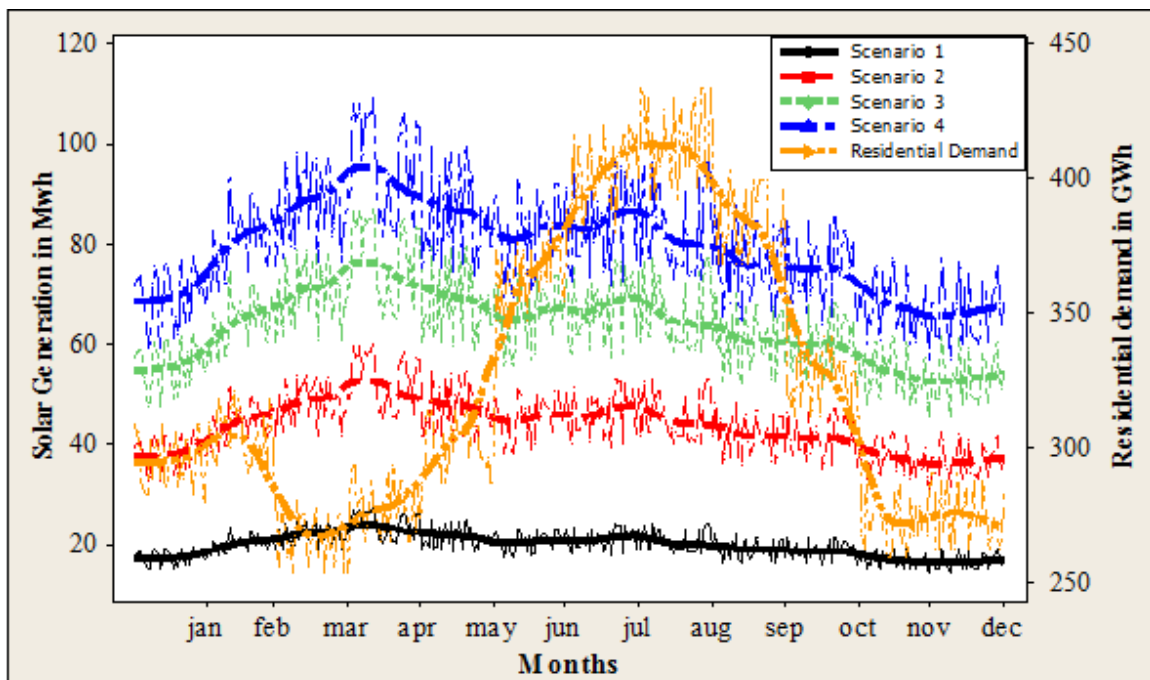


Fig. 11. Solar generation for each scenario and residential demand in 2014

Energy Efficiency Program: The main goal of the energy efficiency program is to control growth rates of electricity consumption and to decrease the summer and winter peak demands. The program involves the collaboration of five major and two municipal utilities whose annual sales are greater than 2000 GWh. Within the scope of this program, utilities propose energy efficiency goals, and these goals are then approved by the Florida Public Service Commission [40]. The goals have been set to reduce total annual sales by a total of 884.4 GWh in 2014, and 885.7 GWh in 2015, by utilities considering energy efficiency, demand response, etc [44].

Table 7 represents the results of the energy efficiency program (EEP) for 2014 and 2015. The value of the program is evaluated against the case where such a program is not implemented. In the table, the “Without EEP” column shows the exact values for corresponding system components and the objectives of stakeholders, and the ‘With EEP’ column shows the changes in percentages from the exact values when the policy is implemented.

Table 7: Results of energy efficiency program

| | | 2014 | | 2015 | |
|---------------------------|--------------------------|-----------------|--------------|-----------------|--------------|
| | | Without EEP (%) | With EEP (%) | Without EEP (%) | With EEP (%) |
| Demand | Residential demand (GWh) | 118,430 | -0.5179 | 123,048 | -0.5337 |
| | Commercial demand (GWh) | 92,231 | -0.1522 | 94,444 | -0.1560 |
| | Industrial demand (GWh) | 17,055 | -0.8228 | 17,242 | -0.8369 |
| Generation | Total generation (GWh) | 227,716 | -0.3679 | 234,714 | -0.3745 |
| GHG Emission | Carbon Dioxide (kt) | 115,875 | -0.4121 | 117,149 | -0.4231 |
| | Sulfur Dioxide (ton) | 126,126 | -0.3818 | 127,316 | -0.3973 |
| | Nitrogen Oxide (ton) | 94,874 | -0.3206 | 95,611 | -0.3291 |
| Revenue | Total revenue (\$M) | 23,397 | -0.3979 | 24,116 | -0.4082 |
| Utility Net profit | Net profit (\$M) | 1,712 | -1.7863 | 1,735 | -1.7556 |

According to the results shown in Table 7, total generation, greenhouse gases emissions, and fossil fuel consumption decrease with diminishing demand. As a consequence of this lower electricity consumption, customers pay approximately 0.4% less on average. The objective of the energy efficiency program coincides with the objectives of all stakeholders except the utilities. The results obtained from the proposed simulation reveals that the net profit of utilities decreases nearly 1.75% on average. To this end, electricity rates need to be increased in order to make this program viable for utilities. Based on the assumption that customers' consumption would only be affected significantly if the prices go up by at least 0.4%, the simulation model with increasing electricity prices of 0.2% is re-run in this case. As a result, the net profit of the utilities is still found to

decrease by approximately 1.5%, compared to the case without EEP while lowering the total electricity cost for customers. Besides the objectives of customers, utilities, and environmental agencies, Fig. 12 shows the effect of the energy efficiency program on the peak demand in 2014 and 2015. The EEP program is found to help decrease the summer peak demand up to 9% and the winter peak demand up to 6%.

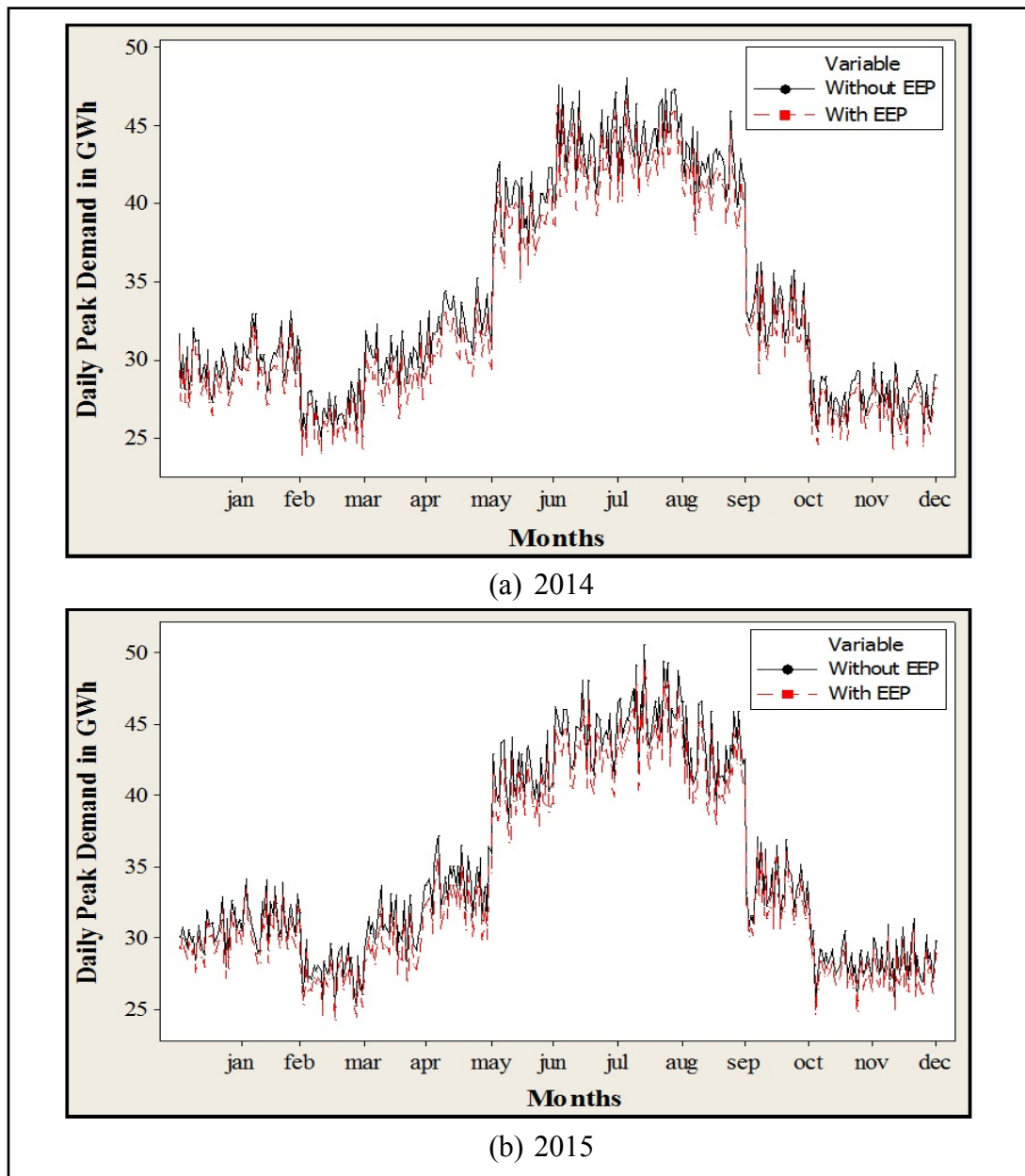


Fig. 12. Simulated effect of energy efficiency program for (a) 2014 and (b) 2015

Chapter 5: Case Study 2: Renewable Energy in Texas

5.1. Overview of Texas's Electricity Market

Each state has its own characteristics in energy supply and demand. These characteristics play an important role in the policy evaluation. In this regard, we hereby provide information about the energy consumption, electricity supply, applied renewable energy policies, and potential renewable energy sources in the state of Texas.

Texas is the biggest consumer of retail electricity sales in the U.S. The total electricity consumption by all sectors in 2013 was approximately 380 million MWh. Texas is also the biggest producer of electricity in the United States. In 2013, the total amount of electricity generated was approximately 430 million MWh, which is greater than total consumption. As a result, Texas has excess energy to export to other states and/or internationally [41].

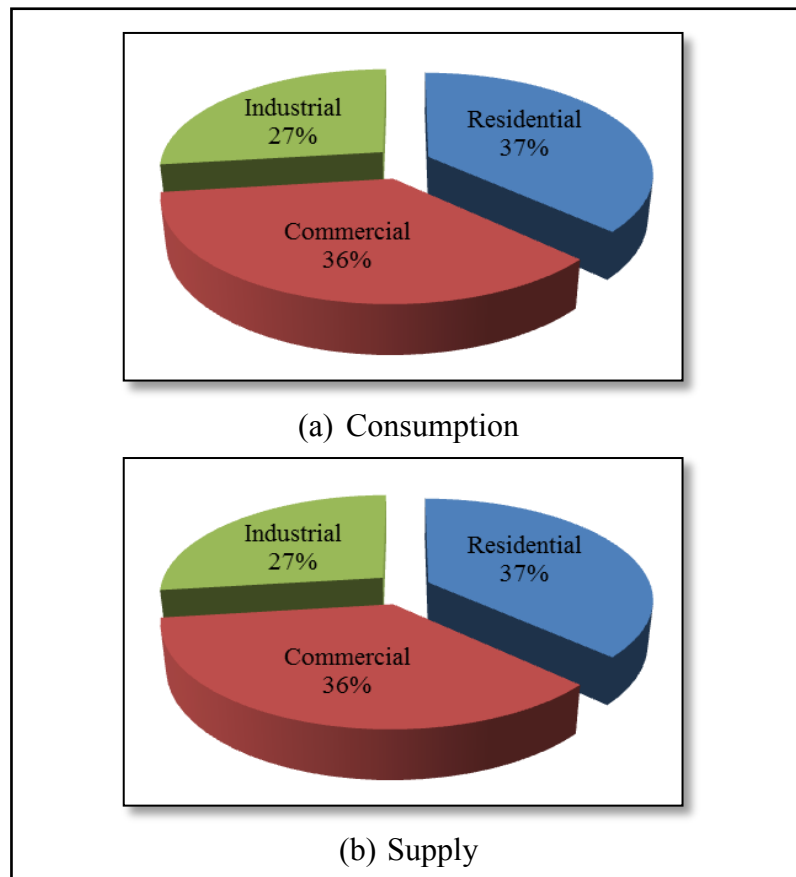


Fig. 13. Consumption and supply of energy in the state of Texas

As shown in Figure 13 (a), the residential sector consumes the largest portion of the produced electricity, accounting for 37%, which is primarily due to the state's large population size, a high demand for air conditioning during hot summer months, and extensive use of electricity as the primary energy source for home heating during winter months. The commercial sector follows residential customers, accounting for 36%. Lastly, the industrial sector has the smallest portion, with 27% of energy consumption [40]

Figure 13 (b) shows Texas's electricity generation by different energy sources in 2013. As shown, natural gas has the largest share of electricity production, and accounts for 46.82% of all electricity generated. Following natural gas is coal, which accounts for 34.5%, and then nuclear power, which accounts for 8.84%. The total electricity generated from renewable energy is only 8.99%, most of which is accounted for by wind generation. However, the state of Texas has the potential to increase renewable energy production through the usage of solar and biomass sources, due to the fact that the state is rich with solar radiation and has large agriculture and forestry areas [37, 39].

Renewable energy accounts for approximately 9.5% of Texas's total energy generation in 2013. Among all renewable energy policies, wind generation has the biggest portion of the total renewable energy sources. For example, in 2013, wind generation accounted for 86% of total renewable energy generation. On the other hand, solar generation accounts only for 0.4% of Texas's renewable energy. Although Texas has a great wind potential, one of the main reasons for the success of wind compared to other sources is implementing successful renewable energy policies. According to [52], Texas applied a well-designed and aggressive RPS policy that attracted and obliged the utilities

to install wind generation. The RPS has a remarkable effect on growing wind generation in Texas.

5.2. Preliminary Analysis

As previously explained, it is necessary to forecast the future based upon the historical data. Trend and seasonality analysis is the first step in understanding the energy supply of Texas. According to EIA reports [37, 39], the energy supply of Texas consists of four main energy sources: coal, natural gas, nuclear power plants, and wind turbines. For example, in 2013, while 99% of electricity was generated by coal, natural gas, nuclear, and wind energy sources, only 1% of energy was produced by solar, petroleum, biomass, hydroelectricity, and geothermal energy sources. Because of the negligible impacts of these energy sources, we have focused on the four main energy sources, where we consider the trend and seasonality patterns for each energy source separately. Figure 14 shows the seasonal-adjusted and de-trended data of each source by using a decomposition model in Minitab®.

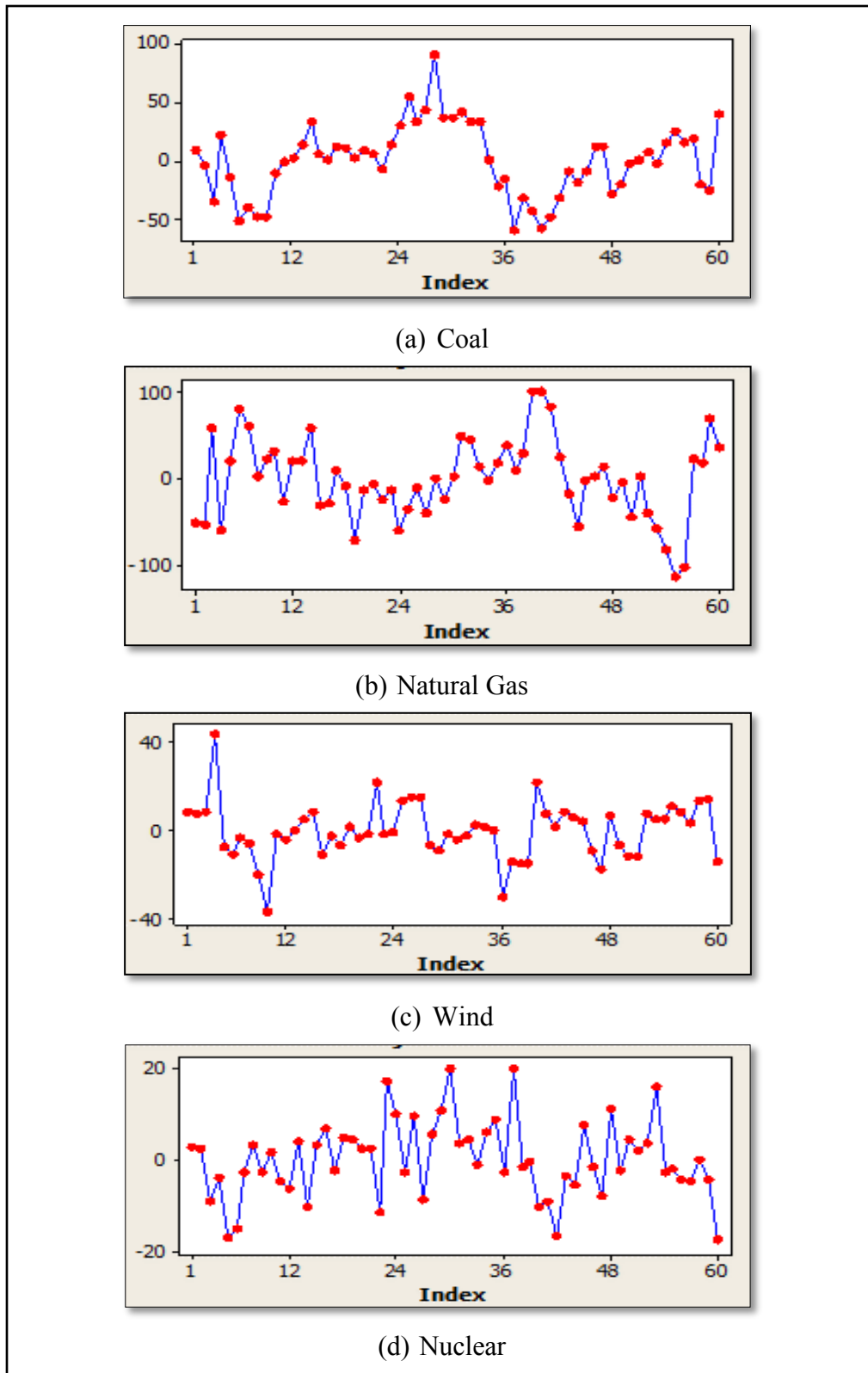


Fig. 14. Season-adjusted and de-trended data of each source using a decomposition model in Minitab®

If the data presents a random pattern around the value of zero, it is concluded that the data can be explained by seasonality and trend. Else, if the data has a pattern apart from a random pattern, seasonal effects and trend are considered not to be enough to explain the variation of the data. According to the figure, while fluctuations within years and between years seem to be good enough to be used in the modeling of the energy supply from nuclear and wind, they are insufficient to explain the variation of the supply from coal and natural gas. The overall results also make sense when different characteristics of each energy source are taken into account. For example, energy generation from wind turbines depends on installed capacity of wind turbines that can be explained by trend and weather conditions, which can be modeled by seasonality. Also, nuclear power plants are considered base load power generators, meaning that, omitting maintenance, they work continuously. Seasonality can be used for maintenance periods.

Unlike wind and nuclear sources, coal and natural gas sources do not show random patterns in their trend and seasonality analysis. This may be because coal and natural gas power plants are the generators affected by external factors such as fuel prices, demand, etc. To model the variation in the supply from coal and natural gas power plants between and within years, a stepwise regression model is used. Stepwise regression is a regression model embedded with a selection procedure for determining predictive variables to explain response variables. In this study, we have used the F-test to choose the predictive variable among the set of variables, which are demand, fuel prices, and wind generation. Wind generation is considered because increasing the amount of energy from wind turbines decreases energy demand from coal and natural gas. The results of the stepwise regression model are shown in Table 8.

Table 8: Results of stepwise regression model

| Energy Source | Coefficients | | | | Outputs | | |
|---------------|--------------|--------------|-------------------|------------|--------------------|----------|------------|
| | Intercept | Total Demand | Natural Gas Price | Wind Trend | Standard Deviation | R-Square | Mallows Cp |
| Coal | -27.68 | 0.322 | 24.2 | - | 25.9 | 79.19 | 1.9 |
| Natural gas | 11.62 | 0.764 | -43.6 | -12 | 48.8 | 86.43 | 3.3 |

5.3. Evaluation of Renewable Energy Policy

Utility rebate programs and federal tax credit programs are evaluated in this study. We focus on policies that promote solar energy because Texas has a great solar energy potential. Based on data collected from NREL on five Texas cities (San Antonio, Houston, El Paso, Fort Worth, and Austin), the average annual solar radiation in Texas is 5.8 KWh/m²/day, which makes Texas exceptional in solar energy potential [42]. To encourage the advancement of solar generation, the state of Texas launched many policies. In this work, we focus on two incentive policies among these that would lessen the high cost of installing solar panels for residential customers. The first policy we evaluate is a utility rebate program. The second policy is a federal tax credit. Lastly, we examine the effect of combining these two policies together.

Utility rebate program: In order to encourage the installation and advancement of renewable energy technology, states, local governments, and utilities offer rebates. Most rebate programs that support renewable energy are managed by states, municipal utilities, and electric cooperatives. These programs usually provide funding for solar photovoltaic and other renewable technologies. Rebate amounts vary widely based on technology and

program administrators. In general, utilities offer residential customers who install solar photovoltaic rebates ranging from \$0.75 to \$2.50 per watt installed.

Federal tax credit: Customers who install a solar system in their homes receive a 30% federal tax credit. In general, the major solar photovoltaic system expenses happen upfront, and the system savings happen over the lifespan of the system. Thus, this incentive available to residential customers helps offset the high setup installation cost of the photovoltaic system and makes it affordable.

5.4. Results and Discussions

Base Scenario: We demonstrate our proposed approach by first simulating the current system using our forecasted data without implementing any policy. The system is simulated for the year 2014, and validation has been made comparing the results of the approach with the actual data taken from EIA [37, 39]. In validation, we have compared the results under three groups: 1) demand, which includes the demand for each customer separately and total demand, 2) energy supply, comprised of energy generation from main sources and total generation, and 3) prices, which contain electricity prices for each customer and the fossil fuel prices of coal and natural gas. All comparisons are shown in Fig.15.

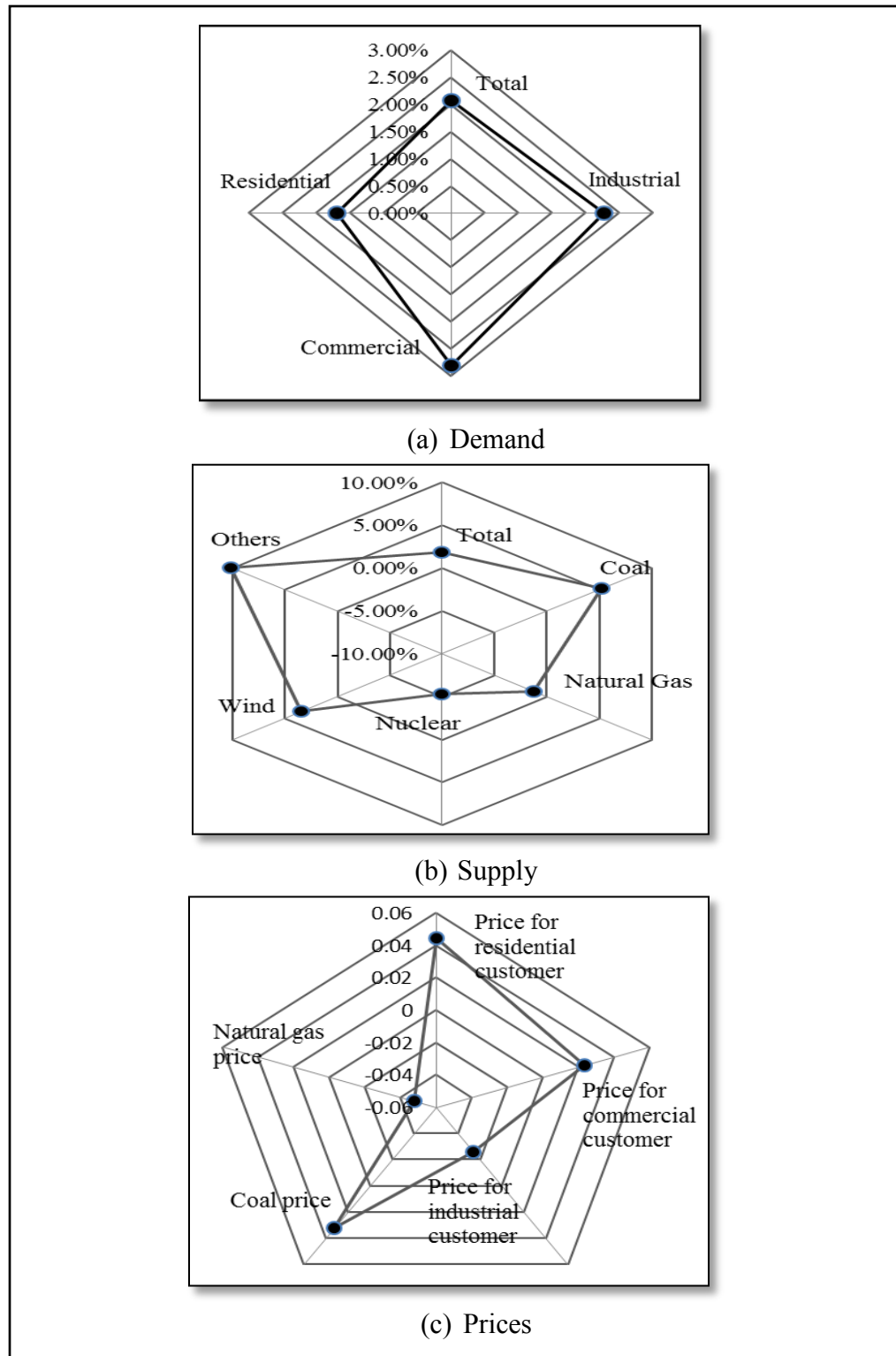


Fig. 15. Results of validation for the demand, supply, and prices

According to Fig.15, the framework simulates the system with acceptable errors. The differences of all components are in the range of $\pm 5\%$, apart from the supply from other energy sources, which is 10.09%. The effect of the error is negligible because of the small amount of energy generation from these sources. Details of our experiments are explained in the following section.

Table 9 shows characteristics of each scenario that is a different combination of a rebate policy with changing rebate rates and a federal tax credit. Each row in the table shows a different scenario, except the base scenario of Case 0, in which no policy is applied. Each column under “Rebate Policies” shows different rebate rates per watt for installed PV cells. Federal tax credit is another policy that encourages residential customers to install solar panels on their properties. The last column represents the expected solar capacity to be installed if the corresponding policy or policies are implemented (and to what extent). Since determining the exact values of solar capacities is out of the scope of this study, it is assumed that they are provided priori.

Table 9: Characteristics of different scenarios considered in Texas case study

| Case Number | Rebate Policies | | | | | Federal Tax Credit | Expected Solar Capacity |
|-------------|-----------------|------|------|------|------|--------------------|-------------------------|
| | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 | | |
| Case 0 | | | | | | | 2 MW |
| Case 1 | ✓ | | | | | | 6 MW |
| Case 2 | | ✓ | | | | | 7 MW |
| Case 3 | | | ✓ | | | | 8 MW |
| Case 4 | | | | ✓ | | | 9 MW |
| Case 5 | | | | | ✓ | | 10 MW |
| Case 6 | | | | | | ✓ | 7.5 MW |
| Case 7 | ✓ | | | | | ✓ | 11 MW |
| Case 8 | | ✓ | | | | ✓ | 11.5 MW |
| Case 9 | | | ✓ | | | ✓ | 12 MW |
| Case 10 | | | | ✓ | | ✓ | 12.5 MW |
| Case 11 | | | | | ✓ | ✓ | 13 MW |

The aim of both policies is to increase the willingness of customers to install solar panels through decreasing high installation costs. Increasing the capacity of solar will affect the energy supply, and the changes in energy supply would have an impact on all stakeholders. In this regard, we demonstrate the results of each case for basic components in Table 10. The results are given based on their deviations from the base case of Case 0.

Table 10: Results of each case

| Case | Total Revenue (\$1,000) | Variable cost of generation (\$1,000) | Greenhouse Gas Emissions | | | Fossil Fuel Consumption | | Total solar panel output (MWh) |
|---------|-------------------------|---------------------------------------|-------------------------------|------------------------|-----------|-------------------------|-------------------|--------------------------------|
| | | | CO ₂ (metric tons) | SO ₂ (tons) | NO (tons) | Coal (short tons) | Natural gas (Mcf) | |
| Case 0 | 34,112,141 | 7,251,467 | 241,437 | 298,582 | 168,883 | 119,680,444 | 1,498,759 | 3,219.96 |
| Case 1 | -754.67 | -146.11 | -4.17 | -3.96 | -2.70 | -1,583.28 | -37.27 | 6,469.74 |
| Case 2 | -941.55 | -182.37 | -5.20 | -4.94 | -3.36 | -1,975.52 | -46.50 | 8,072.58 |
| Case 3 | -1,130.86 | -218.84 | -6.24 | -5.93 | -4.04 | -2,372.27 | -55.84 | 9,693.82 |
| Case 4 | -1,323.25 | -256.20 | -7.30 | -6.94 | -4.73 | -2,776.15 | -65.35 | 11,344.18 |
| Case 5 | -1,512.91 | -292.94 | -8.35 | -7.93 | -5.41 | -3,174.12 | -74.72 | 12,970.40 |
| Case 6 | -1,039.85 | -201.46 | -5.74 | -5.45 | -3.72 | -2,182.05 | -51.36 | 8,916.52 |
| Case 7 | -1,713.36 | -331.73 | -9.46 | -8.98 | -6.12 | -3,594.77 | -84.62 | 14,689.30 |
| Case 8 | -1,794.29 | -347.54 | -9.90 | -9.41 | -6.41 | -3,764.38 | -88.61 | 15,382.38 |
| Case 9 | -1,890.47 | -365.99 | -10.43 | -9.91 | -6.76 | -3,966.04 | -93.36 | 16,206.43 |
| Case 10 | -1,989.62 | -385.25 | -10.98 | -10.43 | -7.11 | -4,174.15 | -98.26 | 17,056.83 |
| Case 11 | -2,072.37 | -401.14 | -11.44 | -10.86 | -7.41 | -4,347.63 | -102.34 | 17,765.74 |

According to our findings, increasing installed solar capacity decreases demand of residential customers and energy generation. As a result, revenues of utilities as well as the variable cost of energy generation decreases. However, since the loss in revenue is greater than the gain from generation cost, utilities may want to cover the difference by increasing the selling price. Moreover, increasing solar energy generation will lead to a decrease in energy generation from natural gas and coal. In this study, we have not considered the changes on wind and nuclear generation and other energy sources, which generate a very small portion of total demand. Decreasing generation from coal and natural gas may cause both greenhouse gas emission and fossil fuel consumption to diminish. Therefore, installation of more solar panels is encouraged by environmental agencies and

governments. Also, because of the enforcement of green energy, utilities may take advantage of these policies in spite of decreasing total revenue.

Up to this point, even though increasing solar capacity may seem to satisfy stakeholders overall, policymakers should also consider the total budget. Since states or other stakeholders need to be willing to pay to increase installed solar capacity, a policymaker should have to select the most effective one. To put this into perspective, we propose a solar budget index given in Eq. (19).

$$SBI = \frac{\text{Total Solar Output}}{\text{Total Payment}} \quad (19)$$

In the calculation of this index, we use average electricity generation from solar panels in a year and total payment given to the customers who install the solar panels. Policymakers prefer higher SBI values to determine the energy policy related to solar energy source. The SBI of each case is demonstrated in the Fig. 16.

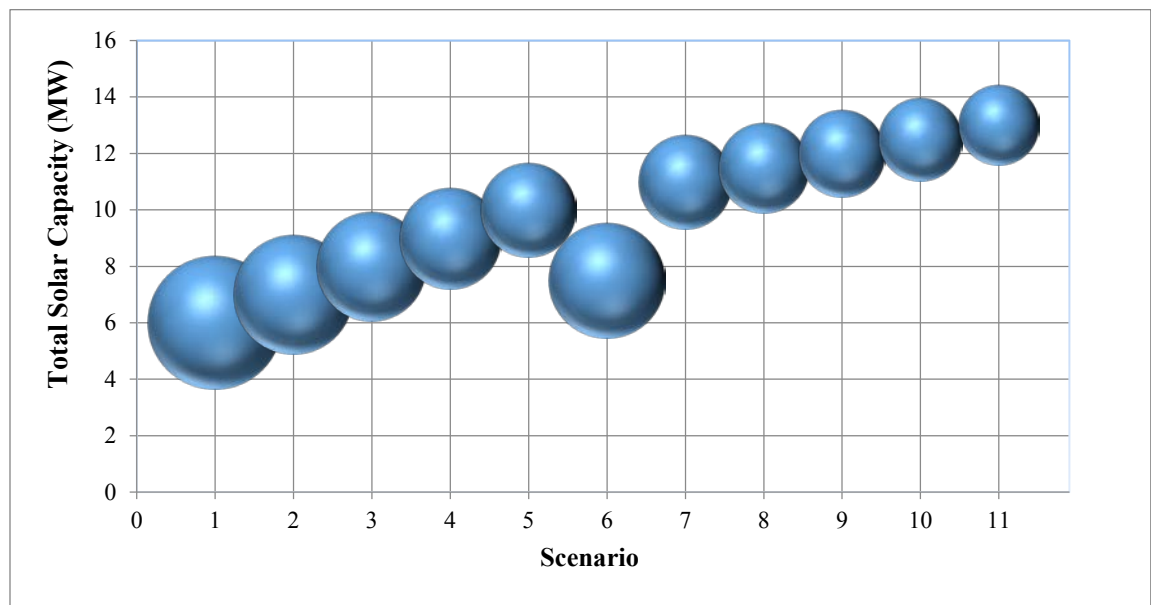


Fig. 16: Total solar capacity (MW) for each scenario

In Fig. 16, the X-axis shows each scenario, whereas the Y-axis indicates the solar capacity of the corresponding scenario. The bubble size represents the SBI of each scenario. It should be noted here that SBI relies heavily on the assumption of installed solar capacity for each scenario. Based on our assumption, Scenario 1, Scenario 2, and Scenario 6 have better SBI results than the others.

Chapter 6: Conclusion and Future Work

Renewable energy has many benefits, including environmental and economic benefits, reliable supplies, and energy security. In order to promote and ensure the efficient advancement of renewable energy, policymakers should consider economic, social, technological, and environmental factors associated with the complex electricity market. In this research, a policy evaluation framework that provides policymakers a priori understanding of the effect of the policy on the general demand and supply system, and the objectives of different major stakeholders is proposed. Trend, seasonality, and regression analyses are embedded in this framework in order to capture the electricity generation mix and forecast demand and fossil fuel prices. Also, the policy elucidation module allows for the modular incorporation of different renewable energy policies with varying characteristics. The simulation model simulates the system based on the data from preliminary analysis, policy elucidation, and database modules. This study is novel in its development of a simulation model with multiple stakeholders in the policy evaluation problem.

The state of Florida has a great potential to increase the use of renewable energy, specifically from solar technology. The implementation of effective renewable energy policies may significantly help advance this condition. In this research, three renewable energy policies/programs for the state of Florida are evaluated: a solar incentive program, a solar loan program, and one energy efficiency program. The results reveal that these programs help decrease customers' demand, causing the total utilities generation and greenhouse gases emissions to decrease. Likewise, the state of Texas has a great solar energy potential, but the state's electricity generation from solar is still very small. However, with the support of effective and efficient policies targeting to decrease the high

capital cost of solar technology, the advancement of solar energy would increase significantly. In this study, two solar/renewable energy policies are evaluated for the state of Texas: a utility rebate program and a federal tax credit. The model results reveal that these financial incentive policies may greatly decrease the installation cost of solar energy for residential customers, which in turn leads to a decrease in the total demand and GHG. Moreover, combining utility rebate incentives and federal tax credits is a more efficient option than implementing one type of policy alone. From a budgetary standpoint, when viewed through the SBI index, it may prove more beneficial to apply one of the following incentives: utility rebates of \$1-\$2 per watt of solar energy installed, or a 30% federal tax credit of total installation cost, rather than implementing a combination of the two.

The proposed framework simulates the entire state electricity market from the macro level. Therefore, this work is mainly presented to state regulators or policy makers in the States of Florida and Texas. Also, in this study, multiple policies are evaluated and involve different parties and stakeholders. For example, the first two solar incentives programs evaluated in Florida, the solar incentives program and the solar loan program, and the first policy evaluated in Texas, the solar rebate program, are given to residential customers from utility companies. The third policy evaluated in FL, the energy efficiently program, is enacted by state regulators and implemented by five major utility companies in FL. The second policy evaluated in Texas, the 30% federal tax credit, is given by the federal government to residential customers. As can be seen, multiple types of policies that involved different parties are considered. Hence, all of these parties or stakeholders can benefit from this study, especially state regulators. Moreover, as can be seen from the results and discussions, the policies met all stakeholders' objectives except the utilities.

However, policymakers or state regulators can look for other solutions to make these policies viable for utilities. These solutions include adopting a funding program that adds a fee to customers' electricity bills with the purpose of collecting funds to support and incentivize RE technologies. Moreover, state regulators can also provide utilities that support RE with tax deduction to compensate their loss. If none of these options are appropriate or available to utilities, the proposed framework would still help utilities to evaluate or select the best policy to minimally decrease their profit and/or avoid other more costly options such as a penalty price imposed on utilities who don't participate in the advancement of RE technology or comply with the state regulations.

The proposed framework provides a faster and a more accurate way to evaluate RE policies while considering various stakeholders with conflicting objectives. First, the simulation model mimics the entire State electricity systems' supply and demand from the macro level. Second, all the data is collected from reliable sources, including EIA, DSIRE, NREL, PSC, and electric utilities' reports. Third, the policy elucidation module is capable of evaluating multiple RE policies without affecting the simulation model. Fourth, the preliminary analysis module predicts all the electricity supply and demand data, electricity prices, fossil fuel prices, and generation costs based upon historical data by using trend, seasonality and regression analysis.

While the states of Florida and Texas are considered as case studies in this work, various other states and countries can be evaluated using the same framework by inputting the associated system data. The proposed framework can also be extended to include other renewable energy policies and alternative substitutes of energy sources including wind turbines, depending on the case studied. Other renewable energy generation sources (i.e.,

wind for Minnesota, etc.) may prove more beneficial. Additionally, different geographic characteristics and evolution of renewable energy sources can affect the efficiency performance of renewable energy sources and can impact the results of the proposed framework. The approach is described in a generic manner where it could be applied to other geographic regions or states by fine-tuning the corresponding parameters used in the simulation model. Also, different forms of trend and regression analysis (i.e., fuzzy models) can be embedded into our proposed framework as part of future venues of this work for designing a policy and for microanalysis purposes. Moreover, details regarding the distribution system can be added to this evaluation. For instance, the impact of the newsworthy Senate Bill (HB 1077) that is currently being discussed by the state of Florida to authorize customers and third parties to produce and sell renewable energy [53] can be evaluated over the Floridian energy system. To this end, different contracts between utilities and customers can be evaluated considering conflicting objectives such as minimizing the cost and maximizing the renewable energy generation and energy surety. Furthermore, price elasticity of demand and customer preferences are two separate but related wide areas, both of which are beyond the scope of this study. These can affect the analysis and evaluation of renewable energy policies. Evaluation of such policies considering different energy substitutes and varying price elasticity of demand scenarios from the perspectives of different stakeholders will be considered as an extension of this research.

References

- [1] Energy Information Administration (EIA), 2014. US Coal Consumption by End-Use Sector, 2008 - 2014. Accessed Aug. 13, 2015. <http://www.eia.gov/coal/production/quarterly/pdf/t32p01p1.pdf>.
- [2] Energy Information Administration (EIA), 2015. Natural Gas Consumption by End Use. Accessed Oct. 13, 2015. http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm.
- [3] Environmental Protection Agency (EPA), 2014. U.S Greenhouse Gas Emission Sources. Accessed Oct. 14, 2014. <http://www.epa.gov/climatechange/pdfs/usinventoryreport/US-GHG-Inventory-2015-Chapter-Executive-Summary.pdf>.
- [4] Renewables 2013: Global Status Report. Accessed Oct. 18, 2014. http://www.ren21.net/Portals/0/documents/Resources/GSR/2013/GSR2013_lowres.pdf.
- [5] Environmental Protection Agency (EPA), 2014. Benefits and Barriers of Renewable Energy. Accessed Oct. 14, 2014. <https://www.epa.gov/statelocalclimate/state-renewable-energy>.
- [6] Zhou, Y., Wang, L., and McCalley, J. D., 2011. Designing effective and efficient incentive policies for renewable energy in generation expansion planning. *Applied Energy*, 88(6), 2201-2209.
- [7] Gouchoe, S. M., Everette, V. S., Haynes, R., 2002. *Case studies on the effectiveness of state financial incentives for renewable energy*. National Renewable Energy Laboratory.
- [8] He, Y., Wang, L., & Wang, J., 2012. Cap-and-trade vs. carbon taxes: A quantitative comparison from a generation expansion planning perspective. *Computers & Industrial Engineering*, 63(3), 708-716.
- [9] Almutairi, H., & Elhedhli, S., 2014. Modeling, analysis, and evaluation of a carbon tax policy based on the emission factor. *Computers & Industrial Engineering*, 77, 88-102.
- [10] Database of State Incentives for Renewables & Efficiency (DSIRE). Renewable Energy Policy Programs. Accessed Nov. 28, 2014. <http://www.dsireusa.org/>.
- [11] Chen, Y., 2004. *Promotion of Renewable Energy Globally: Based on Johannesburg Follow-up*. Nordic Council of Ministers.
- [12] Burns, J. E., & Kang, J. S., 2012. Comparative economic analysis of supporting policies for residential solar PV in the United States: Solar Renewable Energy Credit (SREC) potential. *Energy Policy*, 44, 217-225.

- [13] Price, S., Margolis, R., 2010. 2008 Solar Technologies Market Report. *Lawrence Berkeley National Laboratory*. <https://escholarship.org/uc/item/5f24h660>.
- [14] U.S. Department of Energy. Power Saver Loan. Accessed Dec.15, 2014. <http://energy.gov/eere/buildings/maps/powersaver-loans>.
- [15] Gan, L., Eskeland, G. S., Kolshus, H. H., 2007. Green electricity market development: Lessons from Europe and the US. *Energy Policy*, 35(1), 144-155.
- [16] Chen, C. C., 2011. An analytical framework for energy policy evaluation. *Renewable energy*. 36(10), 2694-2702.
- [17] Yao, L., Chang, Y., 2014. Energy security in China: a quantitative analysis and policy implications. *Energy Policy*, 67, 595-604.
- [18] Browne, D., O'Regan, B., Moles, R., 2010. Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. *Energy*, 35(2), 518-528.
- [19] Kabak, M., Dagdeviren, M., 2012. A MCDM model for energy policy evaluation. In *Uncertainty Modeling in Knowledge Engineering and Decision Making: Proceedings of the 10th International FLINS Conference*, Istanbul, Turkey, 26-29 August 2012 (Vol. 7, p. 131). World Scientific.
- [20] Trappey, A. J., Wang, D. Y., Ou, J. J., Trappey, C. V., Li, S. J., 2014. Evaluating renewable energy policies using hybrid clustering and analytic hierarchy process modeling. In *Computer Supported Cooperative Work in Design (CSCWD), Proceedings of the 2014 IEEE 18th International Conference on* (pp. 716-720). IEEE.
- [21] Zhang, M., Zhou, D., Zhou, P., 2014. A real option model for renewable energy policy evaluation with application to solar PV power generation in China. *Renewable and Sustainable Energy Reviews*, 40, 944-955.
- [22] Scatasta, S., Mennel, T., 2009. Comparing Feed-In-Tariffs and Renewable Obligation Certificates-the Case of Wind Farming. *Preliminary version*.
- [23] Lee, S. C., Shih, L. H., 2011. Enhancing renewable and sustainable energy development based on an options-based policy evaluation framework: case study of wind energy technology in Taiwan. *Renewable and Sustainable Energy Reviews*, 15(5), 2185-2198.
- [24] Reuter, W. H., Szolgayová, J., Fuss, S., Obersteiner, M., 2012. Renewable energy investment: Policy and market impacts. *Applied Energy*, 97, 249-254.
- [25] Zhang, D., Chai, Q., Zhang, X., He, J., Yue, L., Dong, X., Wu, S., 2012. Economical assessment of large-scale photovoltaic power development in China. *Energy*, 40(1), 370-375.

- [26] Mutingi, M., Mbohwa, C., 2014. A framework for analysis and evaluation of renewable energy policies. Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management.
- [27] Sáenz, J. P., & Celik, N., 2014. Simulation-Based Interactive Modelling of barrier option pricing. *International Journal of Modelling and Simulation*, 34(1), 23-35.
- [28] Thanos, A. E., Bastani, M., Celik, N., & Chen, C. H., 2015. Dynamic Data Driven Adaptive Simulation Framework for Automated Control in Microgrids.
- [29] Sáenz, J. P., Celik, N., Asfour, S., & Son, Y. J., 2012. Electric utility resource planning using continuous-discrete modular simulation and optimization (CoDiMoSO). *Computers & Industrial Engineering*, 63(3), 671-694.
- [30] Zhang, T., Siebers, P. O., Aickelin, U., 2011. Modelling electricity consumption in office buildings: An agent based approach. *Energy and Buildings*, 43(10), 2882-2892.
- [31] Li, G., Shi, J., 2012. Agent-based modeling for trading wind power with uncertainty in the day-ahead wholesale electricity markets of single-sided auction. *Applied Energy*, 99, 13-22.
- [32] Richstein, J. C., Chappin, E. J., de Vries, L. J., 2014. Cross-border electricity market effects due to price caps in an emission trading system: An agent-based approach. *Energy Policy*, 71, 139-158.
- [33] Zhao, J., Mazhari, E., Celik, N. and Son, Y.J., 2011. Hybrid agent-based simulation for policy evaluation of solar power generation systems. *Simulation Modelling Practice and Theory*, 19(10), pp.2189-2205.
- [34] Bryant, B.P. and Lempert, R.J., 2010. Thinking inside the box: a participatory, computer-assisted approach to scenario discovery. *Technological Forecasting and Social Change*, 77(1), pp.34-49.
- [35] Movilla, S., Miguel, L.J. and Blázquez, L.F., 2013. A system dynamics approach for the photovoltaic energy market in Spain. *Energy Policy*, 60, pp.142-154.
- [36] Mitchell, K., Nagrial, M. and Rizk, J., 2005. Simulation and optimisation of renewable energy systems. *International Journal of Electrical Power & Energy Systems*, 27(3), pp.177-188.
- [37] Energy Information Administration (EIA). 2014. US States Electricity Data Browser. Accessed Dec. 6, 2014. <http://www.eia.gov/electricity/data/browser/>.
- [38] Energy Information Administration (EIA). 2014. Florida State Energy Profile and Energy Estimate. Accessed Dec. 6, 2014. <http://www.eia.gov/state/analysis.cfm?sid=FL>.

- [39] U.S. Energy Information Administration (EIA). Texas State Profile and Energy Estimate. Accessed Jan. 24, 2015. <http://www.eia.gov/state/analysis.cfm?sid=TX>.
- [40] Database of State Incentives for Renewables & Efficiency (DSIRE). Florida Renewable Programs. Accessed Dec. 10, 2014. <http://programs.dsireusa.org/system/program?state=FL>.
- [41] Database of State Incentives for Renewables & Efficiency (DSIRE). Texas Renewable Programs. Accessed Dec. 10, 2014. <http://programs.dsireusa.org/system/program?state=TX>.
- [42] National Renewable Energy Laboratory (NREL). Accessed Dec. 05, 2014. <http://www.nrel.gov/>.
- [43] Florida Public Service Commission (PSC). Electric Restructuring Activities. Retrieved Sept. 4, 2015. <http://www.psc.state.fl.us/Publications/ElectricRestructuring>.
- [44] Florida Public Services Commission (PSC). Commission Approved Goals. Accessed Jan. 15, 2015 <http://www.psc.state.fl.us/library/filings/10/03539-10/03539-10.pdf>.
- [45] NextEra Energy. Nextera Energy - 2014 Annual Report. Accessed Aug. 13, 2015. <http://www.nexteraenergy.com/pdf/annual.pdf>
- [46] Orlando Utilities Commissions (OUC). Solar Incentives. Accessed Jan. 12, 2015. <http://www.ouc.com/environment-community/solar/solar-incentives>.
- [47] Florida Municipal Electric Association (FMEA). Florida Electric Bill Comparisons - Florida Municipal Electric Accessed Sept. 4, 2015. <http://publicpower.com/electric-rate-comparisons/>.
- [48] S. Makridakis, S.C. Wheelwright, and R. J. Hyndman., 1998. *Forecasting: Methods and Applications.* Wiley.
- [49] Richstein, J. C., Chappin, E. J., & de Vries, L. J., 2014. Cross-border electricity market effects due to price caps in an emission trading system: An agent-based approach. *Energy Policy*, 71, 139-158.
- [50] Campbell, M. J., 2006. *Statistics at square two.* Blackwell.
- [51] Pearce, J. M., 2002. Photovoltaics—a path to sustainable futures. *Futures*, 34(7), 663-674.
- [52] Langniss, O., and Wiser, R., 2003. The renewables portfolio standard in Texas: an early assessment. *Energy Policy*, 31(6), 527-535

[53] The Florida Senate, 2015. HB 1077: Renewable Energy. Accessed Dec. 05, 2015.
<http://www.flsenate.gov/Session/Bill/2015/1077/?Tab=BillHistory>.

APPENDIX A: Simulation Java Code

Main Functions

Initialize

```

Customer temp=add_customers();
temp.customer_type="Residential";
temp=add_customers();
temp.customer_type="Commercial";
temp=add_customers();
temp.customer_type="Industrial";
Utility temp1=add_utilities();
Government temp3=add_governments();
Policy temp4=add_policies();
temp4.policy_type="policy_1";
temp4=add_policies();
temp4.policy_type="policy_2";
temp4=add_policies();
temp4.policy_type="policy_3";
temp4=add_policies();
temp4.policy_type="policy_4";
set_generation_sources_table();
set_cost_table();
set_customer_cost_table();

```

myFunction

```

generation_sources_out=new double[10];
generation_sources_out[0]=utilities.get(0).coal_total;
generation_sources_out[1]=utilities.get(0).oil_total;
generation_sources_out[2]=utilities.get(0).natural_gas_total;
generation_sources_out[3]=utilities.get(0).wind_total;
generation_sources_out[4]=utilities.get(0).solar_total;
generation_sources_out[5]=utilities.get(0).other_total;
generation_sources_out[6]=utilities.get(0).hydroelectric_total;
generation_sources_out[7]=utilities.get(0).geothermal_total;
generation_sources_out[8]=utilities.get(0).nuclear_total;
generation_sources_out[9]=utilities.get(0).biomass_total;

```

set_customer_total_cost

```

customer_sum_cost=0;
for (Customer i:customers)
{
customer_sum_cost+=i.customer_cost;
}
customer_sum_total+=customer_sum_cost;

```

set_fuel_prices

```

fuel_prices=new double[12][3];
for (int a=0; a<3; a++) {
    for (int b=0; b<12; b++) {

        fuel_prices[b][a]=excelFile.getCellNumericValue("Fossil_Fuel_Cost",b+(input_year*12)+2,a+2);
    }
}

```

set_generation_sources_table

```

generation_sources_table=new double[10];
generation_sources_table[0]=utilities.get(0).coal_total;
generation_sources_table[1]=utilities.get(0).oil_total;
generation_sources_table[2]=utilities.get(0).natural_gas_total;
generation_sources_table[3]=utilities.get(0).wind_total;
generation_sources_table[4]=utilities.get(0).solar_total;
generation_sources_table[5]=utilities.get(0).other_total;
generation_sources_table[6]=utilities.get(0).hydroelectric_total;
generation_sources_table[7]=utilities.get(0).geothermal_total;
generation_sources_table[8]=utilities.get(0).nuclear_total;
generation_sources_table[9]=utilities.get(0).biomass_total;

```

set_days_in_month

```

number_of_days=new int[12];
number_of_days[0]=31;
number_of_days[1]=28;
number_of_days[2]=31;
number_of_days[3]=30;
number_of_days[4]=31;
number_of_days[5]=30;
number_of_days[6]=31;
number_of_days[7]=31;
number_of_days[8]=30;
number_of_days[9]=31;
number_of_days[10]=30;
number_of_days[11]=31;

```


generation_sum_total_calc

```

generation_sum_total=utilities.get(0).coal_total+utilities.get(0).oil_total+utilities.get(0).natural_gas_total
+utilities.get(0).nuclear_total+utilities.get(0).wind_total
+utilities.get(0).solar_total+utilities.get(0).biomass_total+utilities.get(0).other_total+utilities.get(0).hydroelectric_total+utilities.get(0).geothermal_total;

```

total_demand_each_customer_calc

```

total_demand_each_customer=new double[4];
total_demand_each_customer[0]=customers.get(0).demand_residential_total;
total_demand_each_customer[1]=customers.get(1).demand_commercial_total;
total_demand_each_customer[2]=customers.get(2).demand_industrial_total;
total_demand_each_customer[3]=customers.get(0).demand_residential_total+customers.get(1).demand_commercial_total+customers.get(2).demand_industrial_total;

```

calculate_sum_demand

```

demand_sum_now=0;
for (Customer i:customers)
{
if (i.customer_type=="Residential") demand_sum_now+=i.demand_residential_now;
if (i.customer_type=="Commercial") demand_sum_now+=i.demand_commercial_now;
if (i.customer_type=="Industrial") demand_sum_now+=i.demand_industrial_now;
}
demand_sum_total+=demand_sum_now;

```

cost_of_each_customer_calc

```

cost_of_each_customer=new double[4];
cost_of_each_customer[0]=customers.get(0).customer_cost;
cost_of_each_customer[1]=customers.get(1).customer_cost;
cost_of_each_customer[2]=customers.get(2).customer_cost;
cost_of_each_customer[3]=customers.get(0).customer_cost+customers.get(1).customer_cost+customers.get(2).customer_cost;

```

Demand Function

```

monthly_peak_demand_residential
peak_demand_residential=new double[12];
for (int i=0; i<12; i++){
peak_demand_residential[i]=get_Main().excelFile.getCellNumericValue("Base_Demand",i+2,2)*demand_projections[i][0];

```

```

}
monthly_peak_demand_commercial
peak_demand_commercial=new double[12];
for (int i=0; i<12; i++){
peak_demand_commercial[i]=get_Main().excelFile.getCellNumericValue("Base_Demand",i+2,3)*demand_projections[i][1];
}

```

monthly_peak_demand_industrial

```

peak_demand_industrial=new double[12];
for (int i=0; i<12; i++){
peak_demand_industrial[i]=get_Main().excelFile.getCellNumericValue("Base_Demand",i+2,4)*demand_projections[i][2];
}

```

set_demand_projections

```

demand_projections=new double[12][3];
if (Main.input_year==0)
{
for (int a=0; a<3; a++) {
for (int b=0; b<12; b++) {

demand_projections[b][a]=get_Main().excelFile.getCellNumericValue("Demand_Projections",b+2,a+2);
}
}
}
if (Main.input_year==1)
{
for (int a=0; a<3; a++) {
for (int b=0; b<12; b++) {

demand_projections[b][a]=get_Main().excelFile.getCellNumericValue("Demand_Projections",b+14,a+2);
}
}
}
if (Main.input_year==2)
{
for (int a=0; a<3; a++) {
for (int b=0; b<12; b++) {
demand_projections[b][a]=get_Main().excelFile.getCellNumericValue("Demand_Projections",b+26,a+2);
}
}
}

```

```

    }
}
if (Main.input_year==3)
{
for (int a=0; a<3; a++) {
    for (int b=0; b<12; b++) {

        demand_projections[b][a]=get_Main().excelFile.getCellNumericValue("Demand
_Projections",b+38,a+2);
    }
}
}
}

```

calculate_demand

```

double mu;
if (customer_type=="Residential")
{
mu=peak_demand_residential[get_Main().month]*power_factor_residential/60;
demand_residential_now=mu*triangular(0.95,1.05,1)-Policy.pv_generation;
demand_residential_total+=demand_residential_now;
}
if (customer_type=="Commercial")
{
mu=peak_demand_commercial[get_Main().month]*power_factor_commercial/60;
demand_commercial_now=mu*triangular(0.95,1.05,1);
demand_commercial_total+=demand_commercial_now;
}
if (customer_type=="Industrial")
{
mu=peak_demand_industrial[get_Main().month]*power_factor_industrial/60;
demand_industrial_now=mu*triangular(0.95,1.05,1);
demand_industrial_total+=demand_industrial_now;
}
}

```

set_customer_cost

```

if (customer_type=="Residential")
{
customer_cost=get_Main().cost_per_mwh_table_for_customer[0]*demand_residential_n
ow;
}

if (customer_type=="Commercial")
{

```

```
customer_cost=get_Main().cost_per_mwh_table_for_customer[1]*demand_commercial_
now;
}
```

```
if (customer_type=="Industrial")
{
customer_cost=get_Main().cost_per_mwh_table_for_customer[2]*demand_industrial_no
w;
}
```

Utility Functions

set_generation_by_source

```
generation_by_source=new double[10];
for (int i=0; i<10; i++) {
    generation_by_source[i]=get_Main().generation_sources_table[i]/total_generation
;
}
```

satisfy_demand

```
current_generation=0;
current_demand=0;
total_peak_demand=0;
for (Customer i:get_Main().customers)
{
    if (i.customer_type=="Residential") {current_generation+=i.demand_residential_now;
        total_peak_demand+=i.peak_demand_residential[get_Main().month]*get_Main().
time_interval_length/60;}
    if (i.customer_type=="Commercial") {current_generation+=i.demand_commercial_now;
        total_peak_demand+=i.peak_demand_commercial[get_Main().month]*get_Main(
).time_interval_length/60;}
    if (i.customer_type=="Industrial") {current_generation+=i.demand_industrial_now;
        total_peak_demand+=i.peak_demand_industrial[get_Main().month]*get_Main().t
ime_interval_length/60;}
}
```

```
current_demand=current_generation;
```

```
total_power_factor=current_generation/total_peak_demand;
current_generation=current_generation*(1+triangular(0.092,0.099,0.094));
division_factor=get_Main().number_of_days[get_Main().month]*60*24/1000;
nuclear=((861+287*2.25)/division_factor+0.0378*current_demand)*triangular(0.98,1.02
,1);
```

```

coal=(1012/division_factor+0.242*current_demand-
(870/division_factor*get_Main().fuel_prices[get_Main().month][0])+(131/division_factor*get_Main().fuel_prices[get_Main().month][1]))*triangular(0.98,1.02,1);
hydroelectric=0*triangular(0.98,1.02,1);
geothermal=0*triangular(0.98,1.02,1);
biomass=normal(28,11782)/(60*24)*triangular(0.98,1.02,1);
other=normal(32,8072)/(60*24)*triangular(0.98,1.02,1);
natural_gas=-
10420/division_factor+(4935/division_factor*get_Main().fuel_prices[get_Main().month][0])-
(306/division_factor*get_Main().fuel_prices[get_Main().month][1])+0.624*current_demand;
oil= (-
117/division_factor+40.3/division_factor*get_Main().fuel_prices[get_Main().month][1])-(
17.3/division_factor*get_Main().fuel_prices[get_Main().month][2])+0.027*current_demand;
solar=0.2/60*nameplant_capacity[4]*triangular(0.95,1.05,1);
wind=0*triangular(0.98,1.02,1);
total_generation_now=nuclear+coal+hydroelectric+geothermal+biomass+other+natural_gas+oil+solar+wind;
interstate=current_generation-total_generation_now;
coal_total+=coal;
oil_total+=oil;
natural_gas_total+=natural_gas;
nuclear_total+=nuclear;
hydroelectric_total+=hydroelectric;
wind_total+=wind;
solar_total+=solar;
geothermal_total+=geothermal;
biomass_total+=biomass;
other_total+=other;
total_generation+=current_generation;
interstate_total+=interstate;

```

nameplant_capacity_set

```

nameplant_capacity=new double[10];
for (int i=0; i<10; i++){
nameplant_capacity[i]=get_Main().excelFile.getCellNumericValue("Capacity",i+2,2);
}

```

capacity_factor_set

```

capacity_factor = new double[10];
for( int i=0; i<capacity_factor.length; i++ ) {

```

```

capacity_factor[i]=get_Main().generation_sources_table[i]/nameplant_capacity[i]*100/3
65/24;
if (capacity_factor[i]==0) capacity_factor[i]=0.1;
}

```

set Capital and OM costs

```

Capital_and_OM_costs=new double[10][3];
for( int i=0; i<10; i++ ) {
for( int j=0; j<3; j++ ) {
Capital_and_OM_costs[i][j]=1;
}
}
}

```

cost_calc

```

for (int i=0; i<10; i++) {
depreciation_cost+=get_Main().generation_sources_table[i]*Capital_and_OM_co
sts[i][0]/capacity_factor[i]*0.12;
OM_cost+=get_Main().generation_sources_table[i]*(Capital_and_OM_costs[i][1
]/capacity_factor[i]+Capital_and_OM_costs[i][2]);
cost_by_source[i]+=get_Main().generation_sources_table[i]*Capital_and_OM_c
osts[i][0]/capacity_factor[i]*0.12+get_Main().generation_sources_table[i]*(Capital_and_
OM_costs[i][1]/capacity_factor[i]+Capital_and_OM_costs[i][2]);
cost_by_source[i]=cost_by_source[i]/(get_Main().generation_sources_table[i]+0.
1);
}
taxes=total_revenue*triangular(0.10,0.12, 0.113);
administrative_other_cost=total_revenue*(0.09972+0.00683*6)*triangular(0.998,
1.002, 1);
cost_total=fuel_cost+depreciation_cost+taxes+OM_cost+administrative_other_co
st+purchased_power;
profit_total=total_revenue-cost_total;
cost_distribution=new double[6];
cost_distribution[0]=fuel_cost/total_revenue;
cost_distribution[1]=purchased_power/total_revenue;
cost_distribution[2]=OM_cost/total_revenue;
cost_distribution[3]=depreciation_cost/total_revenue;
cost_distribution[4]=taxes/total_revenue;
cost_distribution[5]=administrative_other_cost/total_revenue;
profit_portion=profit_total/total_revenue;

```

new_cost_calc

```

for (int i=0; i<10; i++) {
new_cost+=get_Main().generation_sources_table[i]*new_costs[i];
}

```

```

}
new_cost+=total_revenue*triangular(0.098,0.12,0.113);
new_cost+=purchased_power;
new_profit=total_revenue-new_cost;
new_profit_portion=new_profit/total_revenue;

```

revenue_calculate

```

revenue_now=get_Main().customer_sum_cost;
total_revenue=get_Main().customer_sum_total;

```

Environmental agent Functions

set_emission_rates

```

emission_rates=new double[4][3];
for( int i=0; i<4; i++ ) {
    for( int j=0; j<3; j++ ) {

```

```

emission_rates[i][j]=get_Main().excelFile.getCellNumericValue("GHG_emission",i+2,j+
2);
    }
}

```

calc_emissions

```

for (Utility i:get_Main().utilities)
{
    carbon_dioxide=
i.coal_total*emission_rates[0][0]+i.natural_gas_total*emission_rates[1][0]+i.oil_total*e
mission_rates[2][0]+i.other_total*emission_rates[3][0];
    sulfur_dioxide=
i.coal_total*emission_rates[0][1]+i.natural_gas_total*emission_rates[1][1]+i.oil_total*e
mission_rates[2][1]+i.other_total*emission_rates[3][1];
    nitrogen_oxide=
i.coal_total*emission_rates[0][2]+i.natural_gas_total*emission_rates[1][2]+i.oil_total*e
mission_rates[2][2]+i.other_total*emission_rates[3][2];
}

```

Governmental agent Functions

```

calculate_coal_consumption
short_ton_of_coal_total=0;
short_ton_of_coal_total=get_Main().generation_sources_table[0]*coal_per_mwh;

```

calculate_natural_gas_consumption

```
mcf_of_natural_gas_total=0;  
mcf_of_natural_gas_total=get_Main().generation_sources_table[2]*natural_gas_per_mwh;
```

calculate_oil_consumption

```
barrels_of_oil_total=0;  
barrels_of_oil_total=get_Main().generation_sources_table[1]*oil_per_mwh;
```


APPENDIX B: Simulation Modules

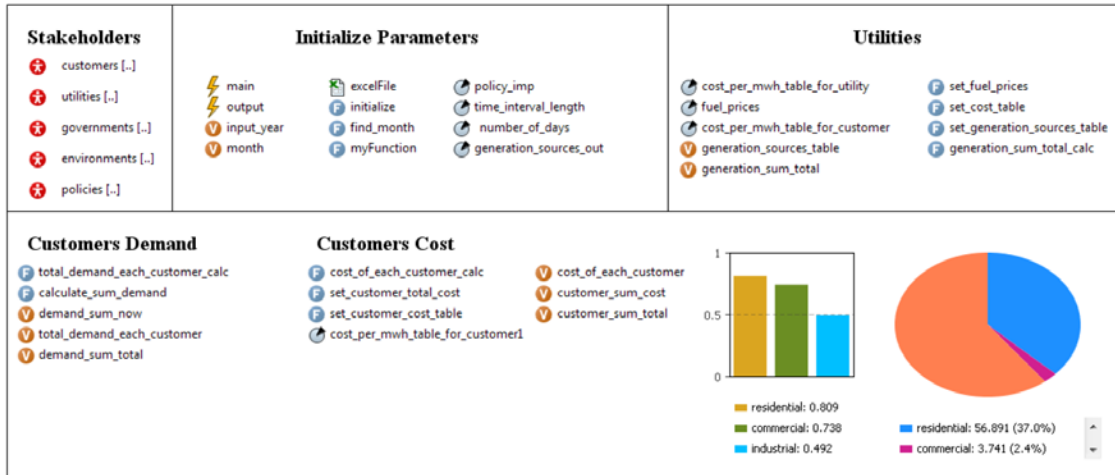


Fig. 17. Main module

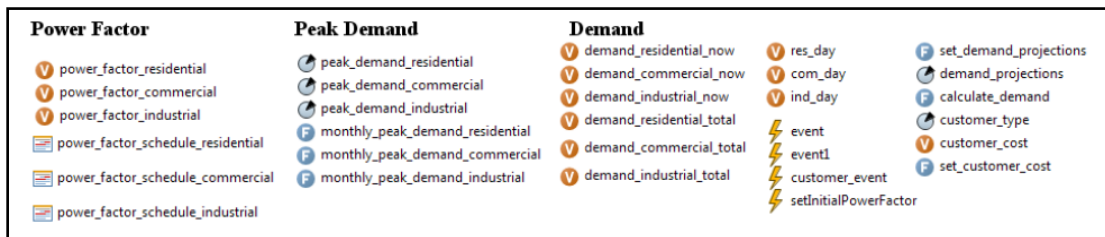


Fig. 18. Customer sub-module

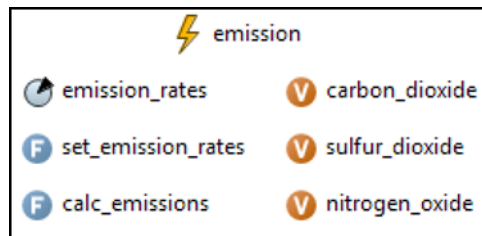


Fig. 19. Government sub-module

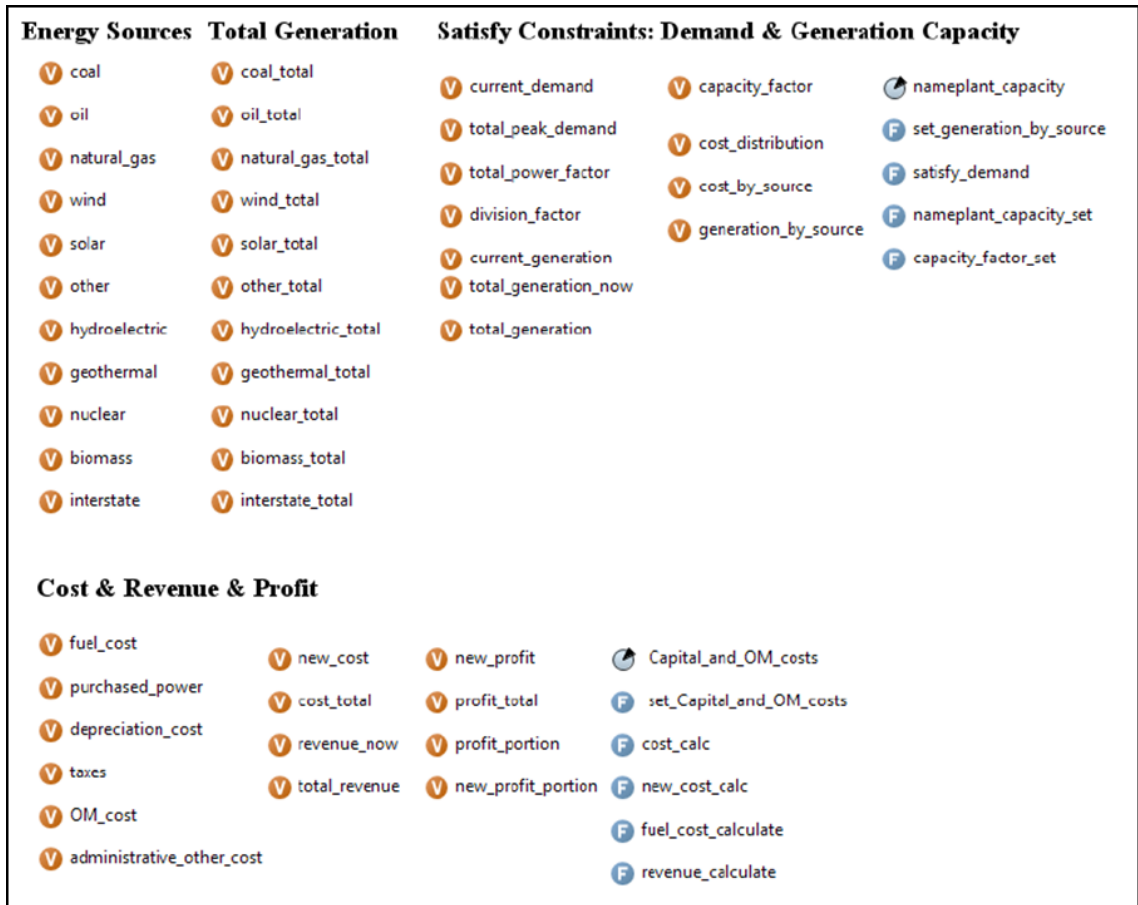


Fig. 20. Utility sub-module

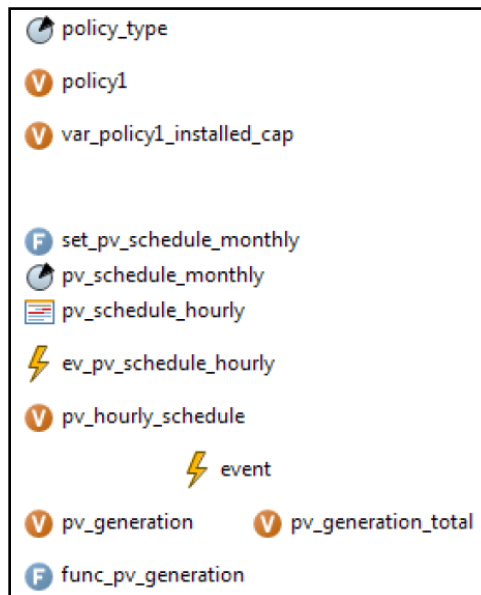


Fig. 21. PSC sub-module