DESIGN AND IMPLEMENTATION OF INTERACTIVE ENERGY MODELS USING CYBER-INFRASTRUCTURE FOR ANALYZING CONSUMER AND PRODUCER BEHAVIOR

DISSERTATION

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ABSTRACT

Modern society consumes large amounts of energy; hence the energy industry is a crucial part of the economy of almost every country. High energy prices, climate change and energy security needs are the new engines driving the development of clean energy. Also, there is a major shift in public opinion towards clean energy, bolstered by the growing conviction that new policies around the use of carbon will reshape the competitive landscape of the global energy business.

Experts from the green energy industry are trying their best to educate people about the importance of green energy resources, and the need to shift from the traditional energy resources to green energy resources. The present world has also been noticing a tremendous rise in the green energy industry and a shift in the manner of utilizing energy.

In this thesis, we focuses on the cost and the environmental impact of energy consumption. Our goal is to present the user with as much information as possible so that he is capable in making smart decisions. We have divided users into two segments, consumers and producers to capture their individual behavior. We have presented a
reference system for capturing both consumer and producer behavior and a way of providing them information.

We also present two implemented applications, one for the consumer and one for the producer aimed at empowering each user with the data needed to make appropriate decisions. We also compare our implementation with a proposed reference application to understand the deficiencies of the implemented application and how can it be made better.
Dedicated to the wonderful people who have given meaning to my life...

*my Mom, my Dad, my Sister.*
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TABLE OF CONTENTS

ABSTRACT .......................................................... ii

ACKNOWLEDGMENTS .................................................. v

VITA ................................................................. vii

LIST OF TABLES ......................................................... xi

LIST OF FIGURES ......................................................... xii

1. Introduction ......................................................... 1
   1.1 Thesis Statement ................................................ 4
   1.2 Contributions ................................................... 4
   1.3 Organization .................................................... 6

2. Background and Related Work ........................................ 7
   2.1. Cyber Infrastructure ............................................ 7
   2.2. Energy Modeling ................................................ 9
   2.3. Automobiles .................................................... 12
   2.4. Households ..................................................... 14
   2.5. Related Works .................................................. 15

3. Consumer Application ............................................... 21
   3.1 Reference Application ........................................... 21
   3.2 Reference Application Architecture ............................ 24
3.3 Sample Consumer Application ................................................................. 25
  3.3.1 Sample Application Architecture ...................................................... 26
  3.3.2 Process ................................................................................................. 28
  3.3.3 Results ................................................................................................. 30
4. Producer Application .................................................................................... 34
  4.1 Reference Application ............................................................................... 34
  4.2 Reference Application Architecture ......................................................... 36
  4.3 Sample Producer Application .................................................................... 38
    4.3.1 Sample Application Architecture ....................................................... 39
    4.3.2 Process ................................................................................................. 40
    4.3.3 Results ................................................................................................. 45
5. Conclusion and Future Work ......................................................................... 47
  5.1 Conclusion ................................................................................................. 47
    5.1.1 Consumer ............................................................................................ 48
    5.1.2 Producer .............................................................................................. 49
  5.2 Future Work ............................................................................................... 51
Bibliography ....................................................................................................... 52
LIST OF TABLES

Table 1 Comparison between reference and sample consumer application .................. 49
Table 2 Comparison between reference and sample producer application....................... 50
LIST OF FIGURES

Fig. 1 Energy flow charts in the United States ................................................................. 10
Fig. 2 Energy usage of an average person ........................................................................ 11
Fig. 3 Energy utility in homes ......................................................................................... 14
Fig. 4 Reference Consumer application architecture ....................................................... 25
Fig. 5 Sample Consumer Application architecture .......................................................... 27
Fig. 6 Sequence Diagram for Consumer Application ......................................................... 30
Fig. 7 User view of the results ........................................................................................ 31
Fig. 8 Overall views ....................................................................................................... 33
Fig. 9 Reference producer application architecture ......................................................... 38
Fig. 10 Sample Producer application architecture ............................................................ 40
Fig. 11 Sequence Diagram for sample producer application ............................................. 41
Fig. 12 Sequence Diagram for sample producer application ............................................. 43
Fig. 13 Interface for user inputs and outputs ................................................................. 46
Chapter 1

1. Introduction

The energy industry is a generic term for all of the industries involved the production and sale of energy, including fuel extraction, manufacturing, refining and distribution. “Cooking a dinner, heating a house, lighting a street, keeping a hospital open, running a factory – all these activities require energy. Energy is thus at the heart of everybody's quality of life and a crucial factor for economic competitiveness as the global population and energy needs are increasing hand-in-hand, current fossil-fuel based energy system is not sustainable as it contributes substantially to climate change and depends heavily on imports from very few countries” [19]. Answers are needed that address the dual challenge of satisfying increasing energy needs and combating climate change at the same time. Energy research can play an essential role in discovering these answers.
The Short-Term Energy Outlook, by the EIA (US Energy Information Administration), helps explain the current high prices of gasoline. The major point is that gasoline inventories are low at the present time and it will take until the end of summer to bring inventories up to adequate levels. Thus, we are in a situation where supply is very tight with consequent high prices. Global clean-energy demand is poised to quadruple in the next decade, growing from $55.4 billion in 2006 to more than $226.5 billion by 2016 for four benchmark technologies (according to the sixth annual Clean Energy Trends report). This view of energy consumption shows how important it is to grow with demand while keeping an eye on the environment. An approach to achieving this is to engage the user in decision making, by showing him personalized data and some analyze to make him more conscious about his energy usage.

In this research, we present a high-level architecture and design of two reference applications, from a consumer and producer point of view respectively. Each application provides an interactive way of looking at the energy generation and its usage. We have also implemented two corresponding cyber infrastructure based sample applications that provide specific information to the user enabling him to make important data-driven and intelligent decisions about his energy usage (E.g. If we tell user the cost curve for the week, he might do laundry on Thursday instead of Friday to save money). The information provided to the user, (which is in addition to what he normally receives in his monthly bill, usually just an aggregated monthly chart of usage). The intent behind these applications is to investigate potential behavioral changes in the user in the patterns in the
way he goes about in using energy. Essentially, we seek to track these behavioral changes in order to observe how the user takes energy decisions based on the information provided and to examine their possible impact.

We have concentrated on two basic areas of consumption in the energy domain – automobile based transportation on the consumer side and home/household electricity consumption on the producer side. On the automobile based transportation side, the automobile industry is fast moving towards hybrid and entirely electric or plug-in vehicles. The maximum range provided by these vehicles as of now is 100 miles. Hence, there has to be a very efficient method of charging and discharging these vehicles to operate them at an optimum level. The user needs this information along-with the cost factor to decide when and how to use his car.

With respect to households, people currently tend to use the machines when they want it to. In other words, no one thinks of the actual cost factor and amount of electricity used by the community at the point of time of turning the switch on. However and for example, if everyone decided to do laundry Saturday morning at 10 am, there will be tremendous load on the infrastructure of the utility company. On the other hand if we are able to educate the first half of the community to use the laundry on a Saturday while the other half can use it on a Sunday, there will be lesser pressure on the load of the utility company and hence the user. In this way, information from the user and utility helps us in making win-win decisions.
All this said, building theses engaging solutions is only part of the solution. These applications have to be made accessible to end-users. With the advent of the Internet, the web certainly offers increasing the reach to potential users. Hence, we have designed these applications to be web-based.

1.1 Thesis Statement

“We propose reference web-based applications for consumers and producers of energy respectively. These applications aim to provide information about personalizing energy usage to the user in commonplace terms in order to effect and then track behavioral changes. Comparisons have been made between the reference and the sample application to identify gaps.”

1.2 Contributions

This thesis provides the following contributions:

1) A high-level design of reference applications for the consumer and the producer respectively.
2) Sample applications for the consumer and producer. For the consumer application (which targets automobile based transportation) we have implemented:

- A communication protocol between an embedded client (PSG) and the server to send and receive data real-time and persist it for future use.

- Collecting all the charging events and uploading them to the server using Wi-Fi connectivity and the above communication protocol to enable real-time data uploads.

- A web interface for the user to observe his charging events real-time.

- A download utility to help the user store a local copy of the past events in order to monitor his usage over time.

For the producer application we implemented:

- An interactive game to check user decisions on energy generation based on the demand.

- Various time-series and pie charts to show the effects of the above decisions.

- Interaction with a steering framework responsible for running the simulations.

3) Finally, comparisons between the reference and sample application have been presented.
1.3 Organization

The rest of the thesis is organized as follows: in Chapter 2 we present the background research and a discussion of the related work. Chapter 3 discusses consumer behavior while Chapter 4 addresses producer behavior. They both present a reference application and its architecture followed by the implementation of a sample application. Each chapter also provides a detailed view of the implementation along with the architecture, the process followed and results. Our conclusions are presented in Chapter 5.
2. Background and Related Work

2.1 Cyber Infrastructure

Cyber infrastructure consists of computing systems, data storage systems, advanced instruments, data repositories, visualization environments, and people, all linked by high-speed networks to make possible scholarly innovation and discoveries not otherwise possible. Cyber infrastructure is a term first used by the US National Science Foundation (NSF) in 2003, and it typically is used to refer to information technology systems that provide particularly powerful and advanced capabilities.
“Cyber infrastructure offers a vision of advanced knowledge infrastructure for research and education that integrates diverse resources across barriers of geography and time – and across the subtle and complex barriers of discipline, community, sector, and jurisdiction. Because it aspires to provide human-centered access to diversely controlled resources, cyber infrastructure must be open and sensitive to institutional, legal, and cultural context, especially mechanisms and procedures for collaborative research and innovation. This is critical not only for optimizing the productivity of particular research communities and initiatives but in developing public policy for advancing knowledge and innovation.” [20]

In this thesis, we use cyber infrastructure to manage, integrate and visualize data from many different sources. For the reference application, we need to gather data from the utility companies (price curves, load curves, demand curves, etc.) user-specific information (type of car used, which area he lives, etc), and US government data (policies, standards, and data from publicly available databases). For the automobile transportation project, we also used the charging events information and created a portal for the user to view the data. For the household project, we analyzed the generation and consumption curves to see how we can demand can be matched.
2.2 Energy Modeling

By “energy modeling,” we mean using computer-based tools to simulate energy use and to provide detailed views of usage) for the end user to make decision. “Energy modeling is a continuous process that gets more detailed and refined (and, hopefully, accurate) as the design process progresses. This process is used for evaluating energy efficiency, renewable energy, and sustainability.” [21]

The figure [Fig. 1] below outlines the generation and the consumption of energy for the year 2009 as given by the EnergyStar team. It also tells us how much we still depend on petroleum, coal and natural gas for our electricity and motivates the need to shift towards cleaner ways of generating electricity.
The per user energy consumption [Fig. 2] tells us how important energy is to every person. A user specific usage breakdown needs to be understood by him in order to make decisions. This means that there needs to be a way of representing a user’s energy usage in a manner that he can understand and analyze.
In this thesis, we focus on using the demand-generation information for households and real-time charging information for automobiles. These give us different viewpoints on two important fields of energy consumption: transportation and household usage.
2.3 Automobiles

The shift of automobiles to cleaner, greener fuel technology has been slow [2]. The main problems seen in this process are higher startup costs and practically no infrastructure. Actually build-out of an EV (Electric-vehicle) charging infrastructure in the US (aside from the wiring that already exists in houses across the country) would not be an issue, for two reasons [3]:

- If you buy an electric vehicle (EV) for use as your “second car”, or are willing to rent a gasoline or hybrid when you need the longer range, the chances are extremely good that the limited range (approximately 100 miles) will not be an issue.

- There is a gigantic incentive for hotels, schools, federal, state, county, and local governments, airports, malls, etc. to install free or reasonably priced chargers. Note that adding EV chargers costs almost nothing compared to adding and maintaining refueling facilities that deliver gasoline, natural gas, or hydrogen.

Charging stations for electric vehicles are expected to sprout up at 800 Walgreens stores by the end year. EV drivers who want to recharge their cars at a Walgreens will find one of two types of devices: a high-speed direct current charger, which can add 30 miles of range in roughly 10 minutes, or a Level 2 device that adds as much as 25 miles of range per hour of charge. Also, GM is upgrading OnStar to beta test a smart grid application for
EVs; and General Electric, Siemens and Schneider Electric are releasing the latest addition to their charger suites. Note that in most places in the United States, you can sell someone electrons at double the going rate for electricity and still save them at least 50% over the cost of gasoline to drive an equivalent distance [2].

“The one question users want answered about EV’s in the market right now is the range or the amount of distance they can travel on a full charge (range anxiety). The secret to avoiding range anxiety may have less to do with how or where you drive, but in deciding which car to take in the first place. According to the study, the average vehicle in the U.S. is driven 12,800 miles per year, but Mini E’s averaged only 8,639 miles driven during the year-long lease. The survey did not include information on mileage of second vehicles; however it can be assumed that the gas vehicles made up the difference. That may help explain why BMW says that range anxiety isn't an issue for experienced Mini E drivers--they're taking the EV only for short trips that they know will work for the car's 100-mile battery range” [4].

“This tells us that there is a shift in the user’s mindset about actually using an EV. Thus, if we take care of the infrastructure, most users will be more than happy to shift towards better environmental options.” [4]
2.4 Households

Buildings and households consume more energy than any other sector of our economy [Fig. 3]. They account for around 40% of the energy we consume. This accounts for a very high percent of the total energy usage. “Making the buildings we live and work in more energy efficient will bring energy and costs savings, reduce our impact on the environment, and improve living and working conditions.” [22]

![Diagram: How We Use Energy in Our Homes]

Fig. 3 Energy utility in homes
“The cost of our utility bills is the highest cost outside of the mortgage for most homeowners.” [1] A domain energy performance audit clarifies our understanding of how energy is used in the home. Combining your concerns and goals with the understanding of the home, sound, effective improvement strategies can be found. This audit is done by the Energy Star (a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy helping us all save money and protect the environment through energy efficient products and practices) team and provides us a yardstick to compare our home with others across the country.

The European Commission and US Department of Energy have several projects listed on their websites that list how the buildings and households must be built, used for efficient and clean usage.

2.5 Related Works

There are many papers and projects related to the work on consumer and producer motivations and the environmental impact of the usage of the various appliances at home and in transportation.
“Three Powerful Utility Bill Analysis Methods for the Energy Manager” by John Avina [18] presents three utility bill analysis techniques which energy managers can use to arrive at sound energy management decisions and achieve cost savings. Utility bill tracking and analysis is at the center of rigorous energy management practice. Reliable energy management decisions can be made based upon analysis from an effective utility bill tracking system. This can be incorporated in designing the reference application described in this thesis in order to make it a more powerful analysis tool.

A company, Project Better Place, [17] is developing a sustainable, environmental solution for converting country-wide transportation systems toward electricity and away from fossil fuel. Electric vehicles would be enabled through an electric recharge grid infrastructure, using charge spots and battery exchange stations. These capabilities would provide consumers with the energy to keep their cars charged and driving without the need to wait for electricity at any point. The smart grid application can be added in the reference application to tell the user where and how he can charge his car based on cost or other parameters.

Home Energy Management (HEM) technologies [16] enable households to remotely access and/or wisely manage their energy use, enabling lower consumption for equivalent (or better) quality of life. Microsoft’s Hohm and Google’s PowerMeter are examples of some of these technologies. Note that while, these form the basic building blocks for
user-driven energy management, the user still needs to be engaged and motivated to use these technologies.

MineFleet® Software from Agnik [15] is designed for commercial fleet owners and fleet management companies who want powerful onboard data-stream mining software for modeling, benchmarking, and monitoring of vehicle health, emissions, driver behavior, fuel-consumption, and fleet characteristics. This can be incorporated into the consumer application to get user patterns for use in decision making.

“Energy-efficient transport-Green mobility on the move” by the European commission [14] concentrates on the arts, touring activities sector and its impact. It says that the performing arts sector has not yet widely recognized or considered the environmental impact of touring activities. This shows that the touring industry, though smaller than others might have a significant impact on the environment, needs regulatory practices or policies. Opportunities for energy management are so widespread that we need to concentrate on across-the-board energy usage and consumption and not target specific sub-domains like the automobile industry.

“Consumer non-energy benefits as a motivation for making energy-efficient improvements” by Evan Mills [5] discusses consumer non-energy benefits as a
motivation for energy-efficient improvements and energy-efficient technologies that deliver equivalent energy service levels (compared to their inefficient counterparts) yet offer non-energy benefits for consumers. This work helps us define non-energy benefits that motivates or can be used to promote decisions to adopt energy-efficient technologies.

“Engaging Energy Saving through Motivation-Specific Social Comparison” by Petromil Petkov [6] builds on fundamental theories from social psychology in an attempt to shed light on how to motivate consumers to conserve energy by identifying relevant people for social comparison based on consumer's motivation to compare. To support the research process, the mobile application EnergyWiz was developed through a theory-driven design approach. This paper helps us in designing patterns for user behavior for the applications.

“One size does not fit all: applying the trans-theoretical model to energy feedback technology design” by Helen He [7] states that people do not always use technology in energy-efficient ways and that we must also focus on a people solution: understanding how and why people use energy, so we can develop technologies that can motivate sustainable energy behavior. This paper tells us how important it is to understand user behavior and capture user reactions.
“Home, habits, and energy: examining domestic interactions and energy consumption” by James Pierce [8] presents findings from a qualitative study of people's everyday interactions with energy-consuming products and systems in the home. This paper helps us in defining energy consumption by the user and tracking his energy usage.

“Power explorer: a casual game style for encouraging long term behavior change among teenagers” Anton Gustafsson [9] tells us that, engaging people in making often small – behavior changes to reduce electricity consumption and emissions of CO2 is crucial. Knowing what constitutes everyday saving behavior and what matters is therefore difficult. This paper, contributes to the discussion of using pervasive learning games to encompass long-term sustained learning and behavior changes.

“Getting to green - understanding resource consumption in the home” by Marshini Chetty [10] indicates that the users need real-time information of their usage to help reduce costs and be environment friendly. This paper emphasizes the need to have real time communication with the user.

“Strategic self-dispatch considering ramping costs in deregulated power markets” by Shrestha GB [11] studies the strategic use of ramping rates in a power producer's self-
dispatch in a power market with price and demand volatility. This paper gives us a view on the optimizing usage of ramping rates while meeting the demand.

“Advanced generating technologies: motivation and selection process in electric utilities“ by Bhavaraju M.P. [12] discusses the constant search by electric utilities for advanced methods for generating electricity to meet future demands. Also, the evaluation of the role of technologies in the future utility system, considering both quantifiable and non-quantifiable benefits and risks, is discussed from the perspective of the utility planning process. This paper helps us in evaluating the producer side of the energy industry.

“Changing energy use through design” by James Peirce [13] suggests that a new mental model is needed, and interaction designers can and should play a role in creating it. No matter how efficient an interactive product may be, a large portion of energy consumed by a digital product is often governed by user behavior. This paper tells us to how important user behavior is when tracking energy usage.
Chapter 3

3. Consumer Application

Here, we concentrate on the energy usage of a consumer. We describe a reference application and a sample implementation for collecting and showing real-time energy usage information.

3.1 Reference Application

Few benefits (e.g., environment, employment) are provided by electric power plants, coal mines, oil pipelines, or other energy-supply systems aside from the energy they produce[5]. Technologies to improve energy end-use efficiency, however, frequently offer non-energy benefits. One class of such benefits accrues at the
national level (improved competitiveness, energy security, net job creation, environmental protection) while another relates to consumers and their decision making processes. From a consumer’s perspective, it is often the non-energy benefits that motivate him or can be used to promote energy-efficient technology choices. While it is common practice to speak of the ways in which energy-efficient technologies help provide equivalent services at lower costs, non-energy benefits can add value to the energy services delivered by efficient technologies. In addition, where certain market segments are not sensitive to economic arguments (e.g., in the proverbial split-incentive, landlord-tenant situation), non-energy benefits can assume a special importance. [5] Commonly cited examples of such benefits include enhanced energy security through reduced oil imports, job creation; local economic development induced by large-scale efficiency programs, enhanced international competitiveness and reduced pollution.

We should address motivation of the particular user, especially during the design phase by deriving motivation-specific design suggestions for comparative feedback [6]. We also need to motivate sustainable energy usage behaviors by people. One approach is the development of technologies that provide real-time, continuous feedback of energy usage [7]. Most technologies use a "one-size-fits-all" solution, providing the same feedback to differently motivated individuals at different stages of readiness, willingness and ability to change. The development of energy-efficient technology (e.g. cars, homes, appliances) is one such approach. While important, this is only a partial solution as people do not
always use these technologies in energy-efficient ways. We must also focus on a people solution: understanding how and why people use energy, so we can develop technologies that can motivate sustainable energy behavior. One approach to motivating sustainable energy usage behaviors is the development of technologies that provide real-time, continuous feedback of one’s energy usage.

Studies of home electricity consumption have shown that people’s behavior plays an important role when it comes to excessive energy usage [8]. Engaging people in making small behavior changes to reduce electricity consumption and emissions of CO2 is therefore crucial.

Knowing what constitutes everyday saving behavior and what matters is difficult [9]. For e.g., with teenagers, this problem description is particularly true since the knowledge level regarding energy conservation in this group is generally low. This group is also often less cost-motivated since they rarely pay for their own use of electricity. So, when it comes to motivating teenagers towards energy awareness, new approaches need to be considered. One such is the use of pervasive games connected to the players own energy consumption. Earlier work has confirmed this to be a highly effective approach. The question however remains whether effects on behavior can be retained. The hypothesis is that a more casual game play and a richer learning interaction enabled by building the game on a real time sensor system could stimulate more lasting effects.
3.2 Reference Application Architecture

The figure below [Fig. 4] shows the architecture of the reference application. The control system acts as the heart of the system that interacts with the various modules and is responsible for collecting and displaying the information. The control system basically has three modules working together as described below.

The data collector module collects data from various sources. It uses the USGIS (US Geological Survey) to get routing information and the location of the public energy outlets, information from the utility to get the price and demand-response information, policy information from the DOE (Department of Energy), inputs from the user directly or indirectly to track his usage and reactions and finally it also gets data from the user social network that allows us to create a user behavior pattern.

The data aggregator module is responsible for longitudinal analysis of the data. It takes all the data and applies pattern generation algorithms to find user behavior pattern and track his energy usage. It is also responsible for checking user reactions to the information he is receiving and adapt to the user based on his patterns. The views creator forms the interface to the system for the user. It hides all the complexities of the system and provides an easy to understand and interpret interface. It creates different views for very user based on his access rights.
3.3 Sample Consumer Application

The consumer application aims at the energy consumption side of the energy domain. This consumer application concentrates on giving the user information about his charging events so that he can make decisions about his charging pattern.
3.3.1 Sample Application Architecture

Every consumer/charging station needs to talk to the data collector module of the control system. The sample application we designed uses a mobile device called the Plug Smart Go (or the PSG) for this purpose. The PSG has a Wi-Fi chip inside it that connects to a nearby local router. The username and password must be set using a web interface. Once the credentials are provided, it can successfully send and receive real-time data.

The control system contains three main modules [Fig. 5]. The data collector module is responsible for interacting with the PSG. It collects all the data sent up by it and also sends updates/configs to the PSG using the Hyper-Text Transfer Protocol (HTTP) protocol. A data aggregator is responsible for maintaining the data in a particular pre-defined schema. The data aggregator is an instance of the MySQL database that holds the data coming from the PSG as well as some bookkeeping information about the user, utilities, vehicles, etc.

The views creator module is responsible for creating the interface to the different types of users. The Administrator view gives the user access to all the information. An admin can add or delete any data. The Fleet view gives the user data about his fleet, so he can observe how his vehicles are performing on the road and whether they are performing up
to expectations. The Utility view enables utility companies to see which vehicles have performed charging events in their area and when. This helps them in doing capacity planning, energy generation, etc. The utilities also provide price and demand-response (DR) information to the PSG that automatically checks with the pre-defined user controlled thresholds that decides if and when the car needs to be charged. The price and DR thresholds have a default starting value and can be set by the user. The DR events inform the users about demand peaks. Thus, based on the price and DR information the user can decide when to charge the car.

We also have the User view catering to a single user. This will provide information only about his PSG and his car and the events associated with them.

Fig. 5 Sample Consumer Application architecture
3.3.2 Process

The key aspect of plug-in vehicles is the amount of charge the battery has and the range the vehicle can cover on that charge. Thus, there needs to be information provided to the user about the amount of charge, how much range the charge can provide. This fundamental piece of information can go a long way in helping the user decide on his trips. This information may be supplemented by information on the main non-energy benefit of using the plug-in/electric vehicle, which is the impact on environment by using the vehicle. That is, we can calculate the amount of charge used by user and use this to calculate other values that will tell us about the environmental impact of his driving.

The environmental impact can be measured by the number of carbon dioxide other greenhouse gas emission. In order to keep the information concise and easy to understand, we are using a metric called "emissions avoided" that is a consolidated metric of the entire emissions of the user. We also tell the user the number of gallons he/she saved as compared to a gasoline car. This tells the user how he is doing compared to a normal gasoline car for the same number of miles. These calculations are done using government released information and information released by the Original equipment Manufacturers (OEM) of electric cars.
We are using HTTP authentication to authenticate the user and then HTTP communication to send or receive data. Every user has a private key associated with the PSG (i.e. every PSG has the key and not the user). We are keeping data based on the PSG being used. So, the information is PSG-specific and not user specific. The PSG has a microchip that continuously monitors external power being driven through the PSG. If any energy is consumed, it is calculated and stored. All the values like the emissions and the gallons equivalent, time duration, etc are also stored. The processor calculates these values just after measuring the power intake and before storing [Fig. 6].

A communication interface provides a way for this PSG to connect to a web server. The PSG is an embedded device and works on a processor designed by Microchip Inc. Note that we used the Microchip IDE and the C programming language to program the chip. We used JSON as the primary data exchange format. The server end is completely based on the Java enterprise edition (Java EE) framework.

The processor continuously checks if there is any new data (new data implies that the data has been recently collected in the EEPROM and not yet sent to the server.) When the processor finds any new data, and if it can successfully connect to the Internet, it forms a TCP connection with the server and sends the data in the form of a JSON file. When the server receives a new file, it will open and parse the file, and store the values in the database. The server uses freely available Java based JSON parsers (Douglas JSON libraries - https://github.com/douglascrockford/JSON-java) to parse the file.
The user can view this data on the server whenever he/she wants to. Every user is associated with a PSG which is in turn associated with a username. The user can use this associated username and password to login to the interface. The interface is completely written using Java server Pages (JSP). Once the user logs in, he can view a summary of all the statistics [Fig. 7]. This gives him complete details on the current and lifetime
events. He can also view the current energy statistics and the total lifetime statistics. A
detailed description of the current or past event is also displayed. Since the
communication happens every 2 minutes, the data is updated in almost real-time. So, the
user can view the data as he is performing the charging event or after the event. The view
also shows the price of charging at that time, the total cost for the event and lifetime
costs. The user can also view the history of all his events in the history page. Thus, he can
get a complete view of their current/past event and also a history of all the events on the
PSG.

Fig. 7 User view of the results
There is also an Administrative view [Fig. 8] for the interface. An administrator has control over all the information. In addition to the user-PSG information, the Administrator view also has the utility and the vehicle information. Assuming every vehicle will be associated with a PSG, the PSG will have connecting vehicle information. The location of the PSG is used to provide us with the utility information. All this information is fed to the server and can be seen only by the administrator.

The Fleet view allows the fleet owners to view when and where their fleets are being charged. Finally, the Utility view provides the utility companies with a view of the users that charged within their service radius. These can be useful information to the utility companies and fleet owners respectively. Using this information, they can decide on future policies, offers, etc. based on all this information.
Fig. 8 Overall views
Chapter 4

4. Producer Application

Here, we concentrate on the energy production side. It involves the consumers, government policies, generation methods, etc. and provides all the information and analytics associated with it.

4.1 Reference Application

Rising global energy demands, increasing costs and limited natural resources mean that householders are more conscious about managing their domestic resource consumption [10]. Based on their current management practices around water, electricity and natural gas systems in the home, we find that in-the-moment resource consumption is mostly
invisible to householders and that they desire more real-time information to help them save money, keep their homes comfortable and be environmentally friendly. "Designing for domestic sustainability therefore focusses on improving the visibility of resource production and consumption costs as well as supporting both individuals and collectives in behavior change"[10].

Power demand and price in deregulated power markets have shown a tendency of sudden wide excursions over short intervals of time. The ability to adapt can be very rewarding [11]. The generation scheduling based on conservative ramp rates of the generators may not be optimal as they limit the ability of a generation unit to provide energy. So, the ramp rates should be more aggressive in meeting the demand.

The primary goal is to generate electricity with minimum damage to the environment and to use resources that are abundant [12]. The evaluation of the role of these technologies in the future utility system, considering both quantifiable and non-quantifiable benefits and risks, has to be discussed from the perspective of the utility planning process.

No matter how efficient an interactive product may be, a large portion of energy consumed by a digital product is often governed by user behavior [13]. Sometimes using less energy requires only small changes in behavior while at other times; it requires radical shifts in lifestyles and values. When designing for sustainability in everyday life, we need to find ways to design products that create needed behavioral and intellectual
change and are easily adapted into daily routines. Finding ways to meet both of these
criteria is among the most fundamental challenges for sustainable interaction design.

4.2 Reference Application Architecture

The figure below [Fig 9] shows us a architectural view of the reference application. This
application has various modules that concentrate on different functionalities. The
producer needs to understand the consumer behavior and practices to know where and
how the consumer is using energy. The consumer application developed previously fits in
nicely to know the consumer behavior. The utilities or various stakeholders will have
some rules or constraints while producing the energy which need to be incorporated into
the application.

The control system is the heart of the system. It has the main modules that perform the
functionality and give out the required information. The system interface module creates
an interface for the various stakeholders involved with the application. It creates an
abstraction hiding all the complexities of the models involved. The population model
gives a population graph based on current population and the growth rate. The demand
model takes the population graph and creates a demand curve for that population. It uses
publicly available government datasets about energy consumption and user demand. The policy model takes into account all the government policies and rules that form the constraints for energy generation. The generation model takes the policies and the demand curve uses a least cost optimization algorithm to decide how generation meets the demand based on its current capacity.

All the various models are connected through the steering framework. This framework acts a central location that handles all the communication between the models and the system interface. It takes care of formatting the inputs and outputs for the various models. The models after running their respective simulations send their outputs to the steering framework. The framework then formats the output and sends it to the system interface. The system interface then creates different charts based on the usage, costs, emissions, etc., and shows them to the user.
Fig. 9 Reference producer application architecture

### 4.3 Sample Producer Application

The sample application producer application simulates the generation capacity of the producer and gives information on its usage costs and emissions. It also provides us with some graphical views to analyze the information.
4.3.1 Sample Application Architecture

The figure below [Fig. 10] shows the architecture of our sample producer application called the CDI project. The system basically takes inputs from the stakeholders, simulates various aspects of generation and produces the required output. The modules in the system are:

- CDI system interface: Provides an interface to the stakeholders and creates an abstraction that hides the internal complexities of the models. It also creates and presents various charts for analysis and making decisions.
- Steering framework: Acts as a central controlling module for the various internal modules and their interactions.
- Population Model: Finds the current population growth and the growth rate and gives the population graph for the time of simulation.
- Demand Model: Takes the current population as input and outputs the demand curve for that population.
- Generation Model: Takes the demand curve of the population from the demand model and the generation capacity for generation of electricity. It then uses a least cost optimization model and provides a demand-generation curve, emissions value, costs on a per-plant basis.
4.3.2 Process

Every stakeholder that wants to use the application has a username and a password for authentication. He basically interacts with a node on the glenn cluster at the Ohio supercomputer center (OSC). After he logs in, the system interface checks if he is a recurring or a new user. If he is a recurring user, his most recent information is displayed while for a new user, some default information is displayed. This is done to ensure that the user starts at some starting point of generation and not at zero generation capacity. The web server is an Apache tomcat instance. There is a Java Server Pages (JSP) script
that reads user inputs and creates a file that it sends to the steering framework through a socket.

The stakeholder provides the amount of increase in the number of generators based on some plant-specific information like build time, build cost, maintenance cost, etc. [Fig.11]. The system interface will then create a JSON file based on the input and send it to the steering framework. We are using JSON as the primary data exchange format and socket communication to send/receive data between the system interface and the framework.

Fig. 11 Sequence Diagram for sample producer application
The steering framework then starts the various models and produces an output JSON file from the outputs of the various models. It then sends it back to the CDI system interface through the socket. There is also another JSP file that listens on the socket. This will read, parse the output file and store it in session variables [Fig. 12].

The simulations for the various models are run for a year of data. The output file has data values for the demand-generation, population, costs and GHG emissions for running the generators on a yearly basis. This file also contains representative weeks for the best, worst and average week based on how the current amount of generators met the demand. When the user asks for a particular plot, the appropriate variables are used and a chart is created dynamically. We are using jfreeChart – a freely available JSP based charting utility to draw the charts as it very easy to use and has well explained APIs. This chart is then shown to the user in the interface page.
Fig. 12 Sequence Diagram for sample producer application

There are several main processes involved while running this application. These include:

- **Showing current information**: Every user that logs in to the system has a username. If he is a recurring user, his most recent information is displayed while for a new user, some default information is displayed.

- **Creating the input file**: The user, based on the plant details selects amount of increase in each of the generators (plants). This information is put into a pre-decided JSON file format and sent over to the steering framework.
- Executing the information: The steering framework parses all the values from the input file and starts the models. The models simulate the exact working of the electricity demand and generation. They then output all the details about the simulations including the demand-generation gap, GHG emissions, etc.

- Creating the output file: The steering framework takes all the outputs from the models and creates a JSON file that provides the information in a structured manner to the CDI system interface. It has the best, average, worst week from the demand-generation graph and also gives yearly information for the rest of the time user simulated.

- Charting the output: The CDI system interface then parses all the output data from the output file and creates various charts for different options. The user can select to view the chart for the population growth, demand-generation curve, GHG curve, etc. These charts give the user a graphical view based on his inputs. These can drive the producer decisions and provide usage information.

4.3.3 Results

The figure below [Fig. 13] shows us the interface of the application for the stakeholder. He can see some static values like the population and the growth rate per year on the right hand side while user inputs are taken from the list on the left hand side. This shows the
current generation capacity and asks for the number of increase in the generators he is interested in.

After the simulations, system interface receives the output file. It parses and stores values in session variables. Now, he can view the chart on the same page. There are many options the user can select based on his requirements. So, if he is a community planner and interested to see if he is meeting the population demands, he will just look at the demand-generation curve while the DOE (Department of Energy) might be more interested in looking at the emissions and the environmental impact of running the generators. The interface provides chart-views for all the options based on what the user wants to see.

The output data is shown in a pictorial view and hence easy to understand. The output data has been divided into yearly view and weekly view. The weekly is a representation of the best, worst, average week in meeting the demand for that year of simulation. This gives a better understanding of how you have been performing for that time period. The yearly data gives an approximate estimate of all the other aspects of running the generators like the cost, emissions, etc.
Fig. 13 Interface for user inputs and outputs
Chapter 5

5. Conclusion and Future Work

5.1 Conclusion

The sample application presents some aspects of the reference system if not all. It lacks in some areas but gives us an overall understanding of the entire picture. Though it has a target population, it gives us a pretty good representation of the overall picture.

5.1.1 Consumer

The table below (Table 1) gives us an account of the comparison between the proposed consumer reference application and the consumer sample application that we created.
<table>
<thead>
<tr>
<th>Reference Consumer Application</th>
<th>Sample Consumer Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time information to be provided</td>
<td>Efficient client-server communication implemented for real-time updates.</td>
</tr>
<tr>
<td>Relevant data shown to the user</td>
<td>Communication provides up-to-date and relevant usage information</td>
</tr>
<tr>
<td>Environmental impact information to be provided</td>
<td>Environmental impact calculated based on government published and industry accepted standards and shown to the user</td>
</tr>
<tr>
<td>Data Analytics need to be shown</td>
<td>Not provided. User needs to analyze his usage data and make decisions</td>
</tr>
<tr>
<td>Entire demographic should be considered</td>
<td>Only for people with electric vehicles</td>
</tr>
<tr>
<td>Recommendations to help user make changes</td>
<td>Not provided. Lacks the intelligence</td>
</tr>
<tr>
<td>User Feedback to create a learning model</td>
<td>Not added. Lacks the learning.</td>
</tr>
</tbody>
</table>
5.1.2 Producer

The table below (Table 2) gives us an account of the comparison between the proposed producer reference application and the sample producer application that we created.

Table 2 Comparison between reference and sample producer application

<table>
<thead>
<tr>
<th>Reference Application</th>
<th>Sample Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time information to be provided</td>
<td>Efficient communication using sockets implemented. Data is from simulations and not real-time usage</td>
</tr>
<tr>
<td>Relevant data shown to the user</td>
<td>Communication provides relevant event information from the models. Gives an accurate representation of energy generation</td>
</tr>
<tr>
<td>Environmental impact information to be provided</td>
<td>Environmental impact calculated based on government published and industry accepted standards and shown to the user</td>
</tr>
<tr>
<td>Data Analytics need to be shown</td>
<td>Many options like costs, emissions provided for energy production</td>
</tr>
<tr>
<td>Entire demographic should be considered</td>
<td>Only for stakeholders interested in capacity planning like utility companies,</td>
</tr>
</tbody>
</table>
5.2 Future Work

The sample applications have some gaps that need to be addressed to come closer to the reference application. The reference application in turn needs to be refined to meet user needs by doing surveys and interviews with both consumers and producers. Social networking analysis of the user can be added in the learning process as it gives us a better idea of user behavior. We need to find patterns in user behavior that will help us in keeping the user engaged and check his motivation.

Also, users reactions need to be recorded and their behavioral changes need to be tracked. We should analyze these changes in user behavior and have a constant learning application. The user needs to have a sense of achievement and motivation in using the interface. We can use a game-like approach to target the users and keep them engaged and participating actively.
Bibliography


[5] Consumer non-energy benefits as a motivation for making energy-efficient improvements by Evan Mills and Art Rosenfelds


[7] One size does not fit all: applying the transtheoretical model to energy feedback technology design by Helen He, Saul Greenberg, Elaine M. Huang

[8] Home, habits, and energy: examining domestic interactions and energy consumption by James Pierce, Diane J. Schiano, Eric Paulos

[9] Power explorer: a casual game style for encouraging long term behavior change among teenagers by Anton Gustafsson, Magnus Bang, Mattias Svahn

[10] Getting to green: understanding resource consumption in the home by Marshini Chetty, David Tran, Rebecca E. Grinter

[12] Advanced generating technologies: motivation and selection process in electric utilities by Bhavaraju M.P.

[13] Changing energy use through design by James Peirce, David Roedl

http://ec.europa.eu/energy/index_en.htm

[15] Minefleet by Agnik, a protected distributed data mining technology
http://www.agnik.com/minefleet.html

[16] Home energy technologies
http://energy.gov/articles/homeowners-using-smart-technology-save-energy-money

[17] Project Betterplace
http://www.betterplace.com/


http://ec.europa.eu/research/energy/intro_en.htm

[20] Committee for Economic Development, Council on Competitiveness, National Science Foundation, Science Commons, and University of Michigan

[21] USGBC (US Green building Council), 510 Rosenbaum PA 128