An Integrated Geovisual Analytics Framework for Analysis of Energy Consumption Data and Renewable Energy Potentials

Olufemi A. Omitaomu*[1,2], Christopher S. Maness[1], Ian S. Kramer[3], Jeffrey B. Kodysh[1], Budhendra L. Bhaduri[1], Chad A. Steed[1], Rajasekar Karthik[1], Philip J. Nugent[1], and Aaron T. Myers[1]

[1]Computational Sciences and Engineering Division
Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[2]Department of Industrial and Information Engineering
University of Tennessee, Knoxville, TN 37996, USA
[3]Department of Geography
University of South Carolina, Columbia, SC 29208, USA

*Corresponding author email: omitaomuoa@ornl.gov

Abstract—We present an integrated geovisual analytics framework for utility consumers to interactively analyze and benchmark their energy consumption. The framework uses energy and property data already available with the utility companies and county governments respectively. The motivation for the developed framework is the need for citizens to go beyond the conventional utility bills in understanding the patterns in their energy consumption. There is also a need for citizens to go beyond one-time improvements that are often not monitored and measured over time. Some of the features of the framework include the ability for citizens to visualize their historical energy consumption data along with weather data in their location. The quantity of historical energy data available is significantly more than what is available from utility bills. An overlay of the weather data provides users with a visual correlation between weather patterns and their energy consumption patterns. Another feature of the framework is the ability for citizens to compare their consumption on an aggregated basis to that of their peers – other citizens living in houses of similar size and age – and within the same or different geographical boundaries, such as subdivision, zip code, or county. The users could also compare their consumption to others based on the size of their family and other attributes. This feature could help citizens determine if they are among the "best in class". The framework can also be used by the utility companies to better understand their customers and to plan their services. To make the framework easily accessible, it is developed to be compatible with mobile consumer electronics devices.

Index Terms—Energy efficiency, energy apps, energy consumption analysis, smart home, visual analytics.

INTRODUCTION

Despite notable progress in the development and deployment of energy efficient building technologies, domestic appliances, and lighting equipment, curtailing residential energy usage is still a challenge in the quest to achieve a more sustainable energy future. Residential consumers are responsible for a significant and increasing share of the nation's overall energy and electricity consumption and corresponding greenhouse gas emissions [1]. Remarkably, residential energy consumption rates consistently differ by up to 300% between identical homes occupied by people with similar demographics [2]. Reducing this large difference by engaging consumers with energy consumption information and analysis beyond their normal monthly bills could reduce energy consumption by an average of 10% [3-4].

Unfortunately, many homeowners receive no detailed feedback about their energy usage. The utility companies only provide monthly bills consisting of a total energy usage and a total price to be paid. Some utility companies include the total monthly energy usage for the previous 12 months, as a way for customers to compare their usage in the current month to the same month in the previous year. Although this approach does facilitate a quick comparison, it is far too limited in helping customers to begin to take actions. In most cases, the monthly bills leave homeowners guessing as to what might explain a higher or lower than usual bill. A typical utility bill provides no information about the relationship between weather, the household's behavior, or the age and size of the house and the corresponding energy usage, respectively. The availability of these kinds of information will help households modify their energy usage habits in ways that would be beneficial for them, their communities, and the utility companies. Furthermore, there are no metrics for individual consumers to compare their energy usage to other consumers within the same community. Consumers would like to know if their monthly energy usage is commensurate with the size and age of their homes or to other neighbors living in homes of similar size and age. The availability of metrics that allow this comparison, without undue exposure of the individual consumers, could spark some friendly competition among consumers. The gamification of energy consumption is a novel approach to achieving the sustainable energy goal through consumer involvement.

To address these problems, there have been some recent efforts to develop web-based tools for providing energy usage feedback to consumers. Some of the known tools are Opower® and TENDRIL™. These tools tend to use the same strategy for providing feedback to consumers – comparing energy usage data to average consumption for all the consumers. While this is one way to provide feedback, it is too narrow to spark friendly competition among users. Furthermore, this approach does not provide answers to some of the questions consumers are asking. Is my energy consumption commensurate with the size of my house? How does my energy consumption compare to other people that live in houses of about the same size and age as my house in my community? How can I evaluate if my energy saving practices are working? How can I take advantage of what is working for my neighbors? How can I determine if my house is a candidate for retrofit? To answer these questions and address the gap in these tools, we developed an integrated framework for energy efficient communities called CoNNECT (Citizen Engagement for Energy Efficient Communities).

1 THE CoNNECT FRAMEWORK

CoNNECT is a geovisual analytics framework that combines the power of the Microsoft Bing mapping API with that of the Protovis JavaScript API to provide a novel energy usage feedback interface for utility customers. The homepage (Fig. 1) offers a simple and straight forward introduction to the application. It also has provision for users to register and log in to use the application. Once a user has logged in, the location of the user's house is located on a map as shown in Fig. 2. This location is used later for spatial comparison of energy usage data. The blue dot on the map has the address of the user and other pertinent information about their houses. On top of this page are two links – *My energy usage* and *Compare my energy usage*. Using these links, the users are directed to interactive visualizations that begin to tell their energy usage story. In the remainder of this section, we describe the functionality of each of these areas.

Fig. 1. The homepage for the first generation of CoNNECT interface introduces the user to the system and provides user registration.

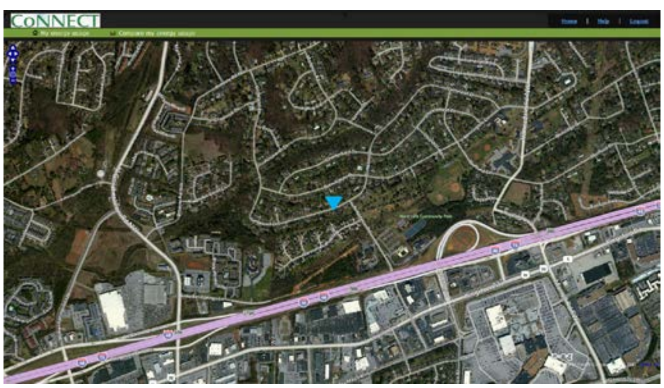

Fig. 2. After logging into CoNNECT, a map display is shown that spatially represents the user's address with a blue dot. From the two links above the map, the user is directed into a visual story of their energy usage profile.

1.1 Profile of Energy Usage

The first capability of CoNNECT is to provide users access to historical energy usage data to facilitate an understanding of temporal trends in their behaviour. This capability is achieved using the *My energy usage* link. In this framework, the word "energy" is used to include electricity, gas, and water services. The first generation of the CoNNECT application gives the user up to five-years' worth of their energy usage data. An example of the usage data for electricity is shown in Fig. 3.

The user can see usage for multiple months simultaneously. The default number of months is 13 as shown in Fig. 3. However, the user can change the size of the sliding time of interest box at the bottom of the page to see more or less months in the upper chart. The user can drag the sliding box to the left or right to see older or newer data, respectively. In addition, the user can use the data type radio buttons at the top of the page to show data for water (Fig. 4.) and gas usage.

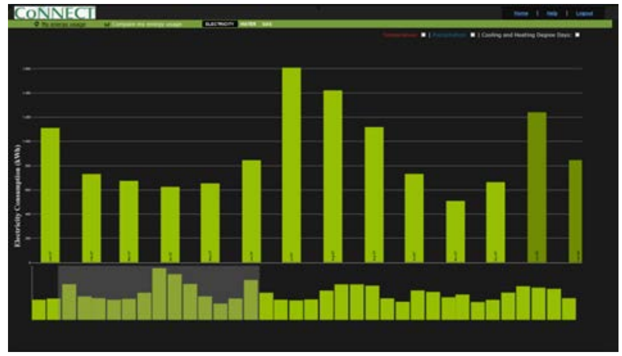

Fig. 3. An interactive chart showing historical electricity usage data from the *My energy usage* focus+context view. The sliding time-of-interest box in the bottom chart can be manipulated to examine usage patterns in greater detail in the top chart.

Fig. 4. A plot of historical water usage data from the *My energy usage* view.

In addition to viewing historical usage data, the users can overlay the average temperature and precipitation values for the geographic area of the user's residence, as well as the cooling and heating degree days for the area. An example of such overlay for electricity usage data is shown in Fig. 5. One other plot not shown is the monthly cost of energy usage which is the dollar equivalent of the energy usage.

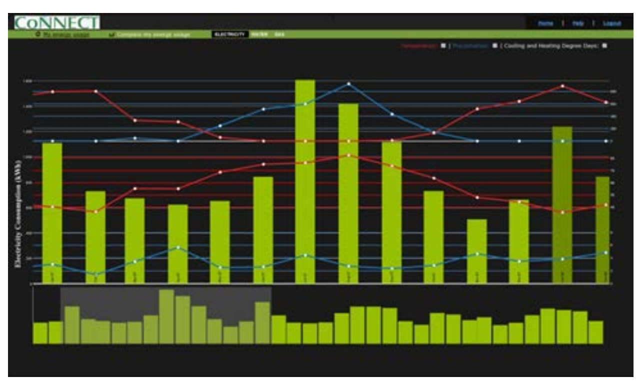

Fig. 5. An overlay of weather data on electricity usage data.

The presentation of these datasets and the associated overlays will help users to interactively read their individual energy story and facilitate deeper consideration for trends and opportunities for savings in their consumption. In addition to presenting the data, the analysis of the data using advanced approaches is discussed in Section 2.

1.2 Comparison of Energy Usage Data among Peers

To help users understand how their energy usage compares to other utility customers, the link *Compare my energy usage* presents a comparative view based on what is known about the user's energy consumption and assessment of their property. The property assessment data used for this purpose includes the year the house was built, the square footage of the house, the number of rooms in the house, and other property-specific data as available through the county property assessors' office. The motivation for our approach is that it is not very informative to the utility customers, if their energy usage is compared to the average usage in their community. As an illustration, comparing energy usage for a 1000 sq. ft. home to other houses, including houses of average size of about 4000 sq. ft. is misleading and unfair. Therefore, we try to compare apples to apples. Furthermore, we also compare usage in space and time. The spatial boundaries used for comparison are those customers are readily familiar with – subdivision, zip code, and county. So, with our approach, a 1000 sq. ft. home is compared to other houses that are between 800 sq. ft. and 1200 sq. ft. in the user's subdivision, zip code, and county. Furthermore, we also compare data based on the age of the house. Therefore, the above criterion is modified as follows – a consumer living in a twenty-five year old house of size 1000 sq. ft. is compared to other houses aged between twenty-three and twenty-seven years old and between 800 sq. ft. and 1200 sq. ft. All the houses that satisfy this criterion are classified as the user's peers. This criterion is then used in the customer's subdivision, zip code, and county respectively. A collection of the outputs of such a comparison for a consumer is shown in Fig. 6.

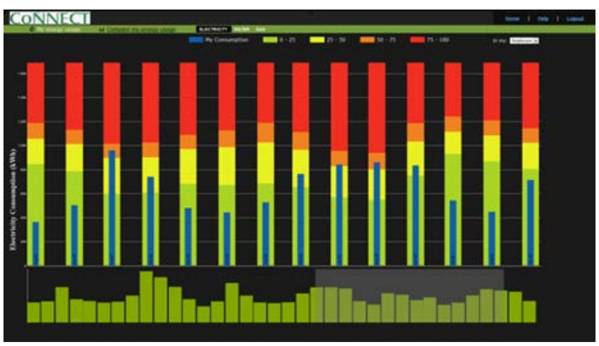

Fig. 6. An interactive visual comparison of electricity usage of a consumer to peers in the same subdivision.

Looking at the outputs in Fig. 6, the "blue overlay" represents the consumer's electricity usage for each month. The "green block" represents consumption for the lower 25 percent of their peers; the "yellow block" represents the next 25 percent (or 25 to 50 percent) of their peers. The "orange block" represents the 50 to 75 percent mark for their peers; and the "red block" represents the upper 25 percent of their peers. Again, users can drag the sliding time-of-interest box to see how her comparison has changed over time. From the snapshot shown in Fig. 6, this user's consumption is usually below the 25 percent mark, except for the 4th, 8th, and 11th bar in Fig. 6 where the user is between the 25 and 50 percent mark; as well as in the 3rd, 9th, and 10th bar in Fig. 6 where the user's usage is within the 50 and 75 percent mark. These dynamic visual queries will help consumers to understand why their consumptions have changed, and they can begin to take actions to maintain greater consistency with their "comparison class" or even reduce their consumption over time. Furthermore, they can also begin to identify the months they are one of the "best in class". For example, in the month of August over two consecutive years (that is, the 1st and 13th bar in Fig. 6), the consumption for this user is about half of the consumption for the lower 25 percent of her peers. This user may be interested in what might have resulted in the lower bills in these months; and could then recognize these months as examples of best practices. These best practices could then be shared with the other users through the CoNNECT blog site established for social networking among users.

In addition to comparison based on the location, age, and size of the consumer's house, users can also compare their consumption based on the size of their household. This metric can be used for comparison by itself or used in conjunction with the location, age, and size of his/her house. In all cases, the outputs are presented in the same form as shown in Fig. 6.

2 Advanced Analysis For energy consumption

The advanced analysis component of the CoNNECT framework includes the ability of the consumer to "tag and track" their consumption pattern and perform some basic consumption data analysis. This "tag and track" capability enables users to keep a diary of known events during each month that could have resulted in a higher or lower overall energy consumption in that month. When consumers compare their consumption in, for example, August 2010 to August 2011, they have no re-collection of activities around the house that could have resulted in extremely higher or lower bill in August 2010. With this capability, they can select the month of interest and make a note for their own use. They can make such notes as, "hosted more guests", "on vacation", "replaced an old appliance", "sealed the windows", etc. With notes like these, comparison between months is made easier and more informative while the user personalizes their energy consumption story.

Furthermore, with the information tagged in each month, they can elect to monitor their energy consumption trend starting in a particular month using tagged information. This capability is especially useful when energy savings initiatives are implemented, such as installing an energy efficient appliance. For example, if an energy-efficient clothes washer is installed, the information can be tagged to the appropriate month, and the savings in energy consumption, if any, can then be tracked beginning with that month. This tracking process could help consumers identify energy efficient initiatives that are either working or not working. The trend analysis for the tracking assumes that the in-house behavior remain the same as in the previous months before the tracking began.

3 Exploration of Renewable Energy Potentials

Another capability is the ability for users to analyze the renewable energy potential available to them through their house in case they are interested in developing that opportunity. The first generation of CoNNECT currently has solar energy potential integrated into the application. Future generations will extend this capability to ground heat pump technologies.

To achieve this capability, high resolution LiDAR data at about 1-m horizontal resolution and at about 0.3-m vertical resolution is used to model solar energy potential on individual rooftop using upward-looking hemispherical algorithm. For a detailed description of the modeling algorithm, see [5]. The methodology used can be summarized as shown in Fig. 7.

A schematic implementation of the methodology is shown in Fig. 8. The outputs from the implementation of the methodology is made available to CoNNECT users for different reasons – for comparing the current usage to solar energy potential on their rooftop and also for identifying the so-called "solar panel sweet spots" on their rooftop. An example of the presentation of the outputs of the model is shown in Fig. 9. The "red" polygon on each roof is the identified sweet-spot based on the output of the solar energy potential modeling.

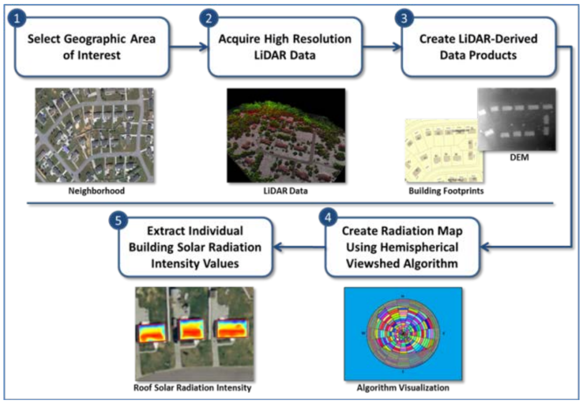

Fig. 7. An overview of the methodology for estimating solar energy potential on building rooftops.

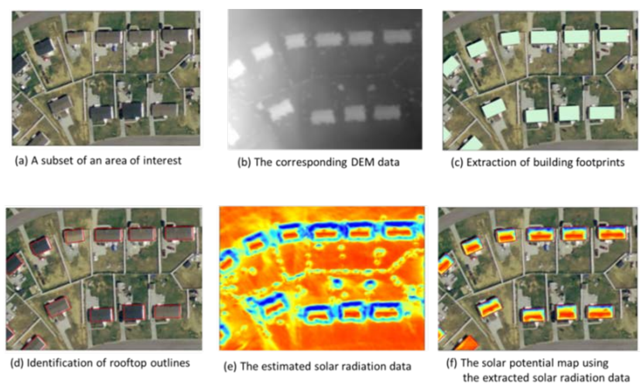

Fig. 8. The sequence of implementation of the methodology.

Fig. 9. Identification of solar sweet-spot (red polygons) on building rooftop and evaluating solar energy potentials.

The user can click on each roof to determine how a conversion of the monthly solar energy to electricity production compares to their current monthly consumption.

The users can also visually evaluate the impact of shading and building orientation on the solar energy potential for their building. Buildings with taller structures, such as trees, closer enough tend to have smaller area of solar sweet spot as shown in Fig. 10 (image "M"). Buildings with no taller structures and with a south facing roof tend to have larger solar sweet spot area; hence, higher solar energy potential (image "N" in Fig. 10). The CoNNECT application also includes a computation of a variant of the return on investment for information purposes only.

Fig. 10. A comparison of solar radiation estimations for two different residential areas.

4 Conclusion

Many factors drive the need for utility companies to engage their customers. One of such factors is the need to promote energy-saving initiatives. This initiative encompasses the need to reduce peak load, meet energy efficiency mandates, and reduce CO_2 emissions. The ability to fulfil this factor is necessary for engaging customers for demand response. To help the utility companies achieve this factor, we have developed a new geovisual analytics framework called CoNNECT. The developed framework takes the need to provoke a change to a new level by advancing the state-of-the-art in home energy report and feedback system. The system can be used as a paper report or interactive support and engagement tool. It is designed to preserve the privacy of the data owners, while they explore the benefits of the statistics in all the available data. The interactive tool can be accessed over the web or using mobile devices.

Acknowledgments

This work is supported by the Laboratory Directed Research and Development (LDRD) Program of the Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract DE-AC05-00OR22725. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

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