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SUSCOM-114; No. of Pages 5
ARTICLE IN PRESS

Sustainable Computing: Informatics and Systems xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Sustainable Computing: Informatics and Systems

journal homepage: www.elsevier.com/locate/suscom

HERO: A smart-phone application for location based emissions estimates

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ARTICLE INFO

Article history:
Received 10 February 2014
Received in revised form 19 August 2014
Accepted 18 September 2014

Keywords:
Electricity
Emissions
Locational marginal price
Smart-phone
Household energy

ABSTRACT

A smartphone application has been created that provides consumers with real-time information about local air emissions resulting from their energy consumption. The purpose of the application is to provide information to enable consumers to consider emissions as they schedule their energy use. This tool provides one mechanism for demand-side optimization through optimal timing of energy use for environmental benefit. The application relies on a model that estimates air emission rates of user-selected pollutants based on real-time spatially accurate information on the electric grid. The development of this smartphone application, its potential use, and opportunities for future improvement are presented.

1. Introduction

Over the course of a day, electricity is generated by multiple types of generators. Power utilities must respond to changing demand by dispatching or shedding generator output. Each generator is associated with a unique profile of air emissions, based on the type of fuel consumed, the generator's efficiency, and installed pollution controls. Just as the demand for electricity and the generation mix evolves throughout the day, so too do the resulting air emissions. Given this, selectively timing electric load could be an effective strategy to reduce overall air emissions.

Electric generators are often significant contributors of air emissions [1] that cause environmental and human health hazards [2,3]. Air emissions rates vary widely among different power plants. Each type of fuel produces characteristic air emissions. For instance, coal naturally contains sulfur, and air emissions from burning coal generally include sulfur oxides. In contrast, nuclear power and renewable power sources such as wind and solar produce no direct air emissions per unit of power generated. The indirect and life cycle emissions from these sources are beyond the scope of this paper. Along with fuel type, plant efficiency is another factor that greatly influences air emission rates. Many older plants that are extremely inefficient (by modern standards) are still in service, and these plants produce far more emissions per kilowatt-hour (kWh) generated than their modern counterparts [4,5]. The ability to shift electric demand to times when cleaner generation sources are available can result in overall emission reductions.

The generation mix of available energy sources varies by geographic region. For instance, in the Northwestern U.S., hydropower sources supply about 70 percent of the electricity demand [6], while in the Midwestern U.S., coal is the primary fuel source. Even though the modern electric grid is even more interconnected than in the past, there are still physical transmission capacity limits that constrain the amount of power transmitted along each line. In addition, there are always power losses associated with power transmission and delivery. Therefore, energy consumed at a location can likely be attributed to generators within a local control region.

An Independent System Operator (ISO), or similarly Regional Transmission Organization (RTO), is responsible for controlling and monitoring operations of the electric power system over a specific region. One of the tools used by ISOs to efficiently manage the electric transmission system [7] is the Locational Marginal Price (LMP),

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http://dx.doi.org/10.1016/j.suscom.2014.09.001
2210-5379/

which represents the wholesale cost to serve the next incremental unit of load at a particular time and place. Researchers at Wayne State University have developed a method of estimating real-time air emissions based on LMPs [8].

In order to provide consumers with the information that this method provides, a smart-phone application called Home Emissions Read-Out (HERO) was created. HERO provides consumers real-time emissions that result from electricity use at their locations, helping them make environmentally-informed decisions about the best time (i.e. when pollutant emissions are minimized) to use their electric appliances. According to a FERC Report, the residential class represents the "most untapped potential for demand response" [9]. Rather than economic optimization, HERO addresses the similar concept of emissions optimization; that is, selectively timing energy use to reap the greatest emissions benefit. Real-time emission estimates, like those provided by HERO, are a necessary part of such emissions-based programs.

2. Approach

HERO is an Android application which provides information on the real-time emissions from the marginal generator and allow informed choices on timing of electricity consumption. This application is based on a novel energy cost-emissions link described in our earlier work [10]. This approach is supported by recent research asserting the possibility of establishing marginal emissions rates for various regions in the US [11]. However, establishment of marginal emission rates is only the first step, and HERO provides a way to utilize these marginal emission rates to optimally time electric demand, thereby reducing overall emissions.

HERO has four primary functions: (1) determine user location, either through the GSM cellular network or via manual selection of location from a map; (2) retrieve pricing information from an ISO server; (3) link LMP to emission rate; and (4) display information, including: marginal emissions at the user's location, supplementary information about pollutants, and emission comparisons between two different locations.

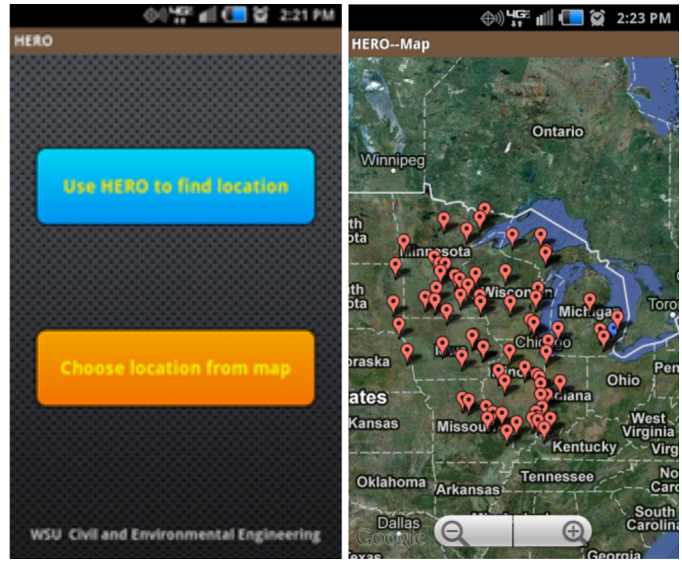


Fig. 1. HERO user selection screens.

The LMP at the closest commercial price node (CPN) is used by HERO to estimate the marginal fuel type and associated emissions. Therefore, identifying the user's location is a pivotal task. GPS (Global Positioning System) technology could be used for

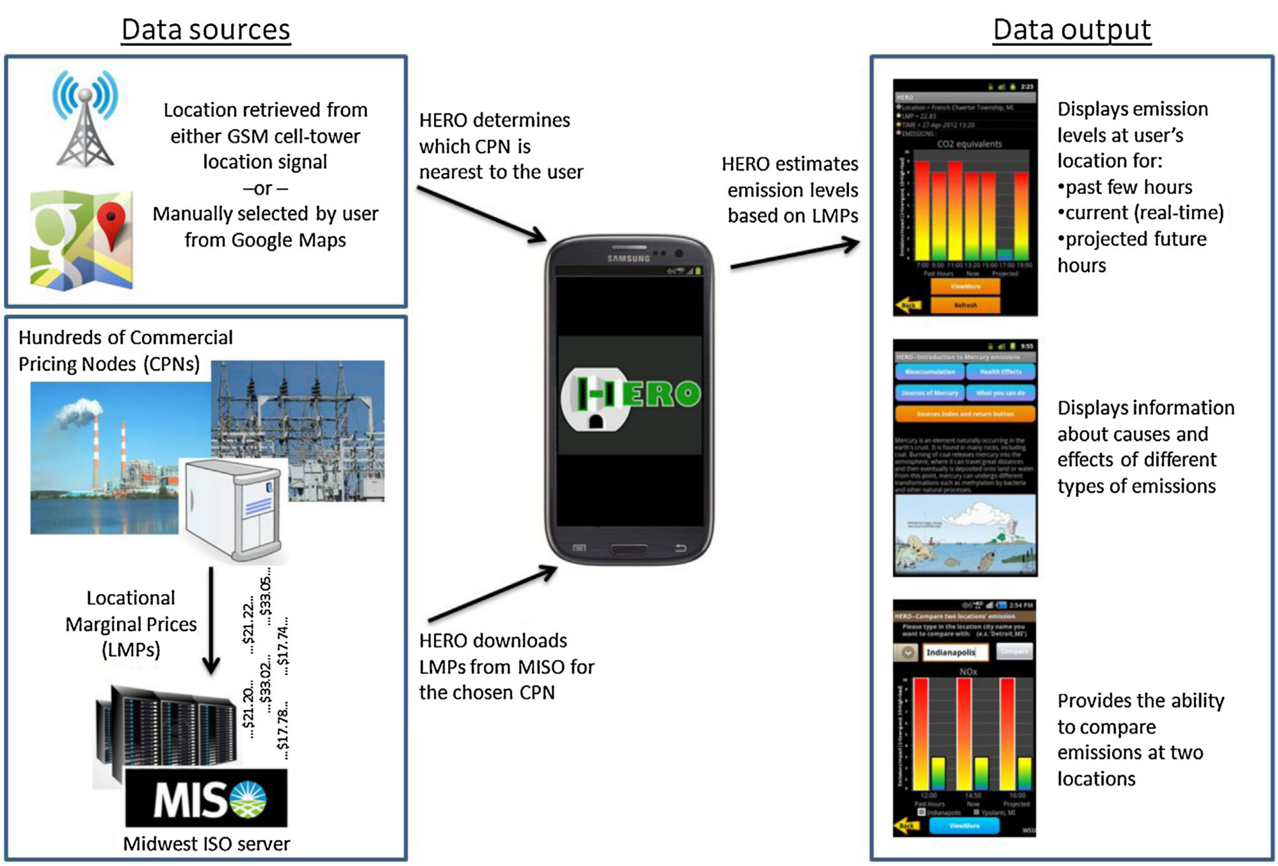
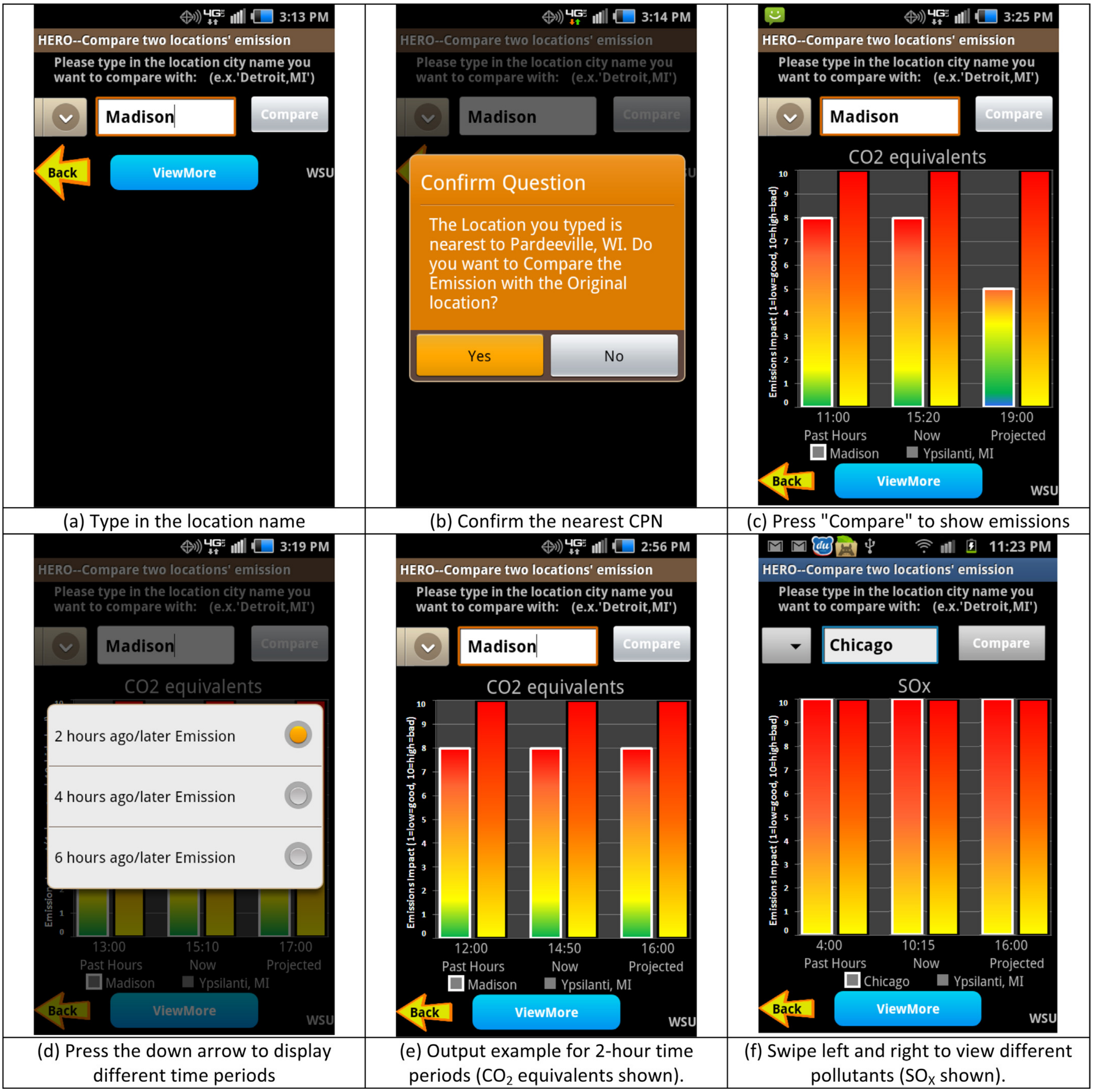


Fig. 2. HERO architecture.

Please cite this article in press as: M.M. Rogers, et al., HERO: A smart-phone application for location based emissions estimates, Sustain. Comput.: Inform. Syst. (2014), http://dx.doi.org/10.1016/j.suscom.2014.09.001



(a) Type in the location name
(b) Confirm the nearest CPN
(c) Press "Compare" to show emissions
(d) Press the down arrow to display different time periods
(e) Output example for 2-hour time periods (CO_2 equivalents shown).
(f) Swipe left and right to view different pollutants (SO_X shown).

Fig. 3. HERO emissions screens.

this task. However, using GPS consumes a non-trivial amount of energy, causing a significant reduction in a smartphone's battery life [12]. Furthermore, there is often poor GPS performance in "urban canyons," human-built canyons created by streets cutting between skyscrapers.

Therefore, HERO employs a new technology in Android called CTrack [12] which uses the GSM signature instead of GPS to accurately locate the user's current location. GSM stands for Global System for Mobile Communications. It was created as a set of standards for second generation (2G) digital networks, which have since been improved upon to create third and fourth generation (3G and 4G) networks. CTrack is an energy-efficient system for trajectory mapping using raw position tracks obtained largely from cellular GSM base station fingerprints. CTrack matches a stream of position samples to points on a known map.

By using CTrack, HERO can identify the coordinates of the user's location. After HERO loads, the user has the option to either "Use HERO to find location" or "Choose location from map"(Fig. 1). The first option signals HERO to automatically choose the nearest CPN location using CTrack. HERO computes the user's location and their distance from every CPN location within the MISO footprint. Once the nearest CPN is determined, HERO displays emission levels to the user based on that CPN.

If the user wants to manually choose a location (whether their own, or another location covered by HERO), there is an option for the user to press the "Choose location from map" button. This option shows the user a Google-map of CPN locations. The map was written using the Google Maps API. Some overlays and icons were added to the original Google map to identify the CPN locations and the user's current location. Because of security concerns, the actual location of the CPNs are not revealed; rather, the coordinates of the nearest city or town to each CPN are used.

HERO shows current real-time emission information to the user, as well as historic emissions from 2, 4, and 6 h prior, and projected emissions 2, 4, and 6 h ahead. To show the past, current and future emission information to the user, HERO estimates emission levels based on two sets of data: real-time LMP data, and day-ahead LMP data. This pricing information is available from the MISO server.

LMPs are updated on the MISO web server in near real-time five-minute increments for all CPN locations. Collecting hours of five-minute real-time LMPs for all the CPNs directly on the mobile device would consume too much of the phone's energy and resources. Therefore, HERO downloads only the most recent five-minute LMP data from the MISO web server. Then from this data set, HERO extracts the LMP of the selected CPN.

The historical and real-time LMP data are two separate documents stored in MISO server. In order to display current emissions, HERO downloads the real-time LMP document which updates every 5 min. To display future predicted emissions, HERO downloads the day-ahead LMP data. HERO provides a "Refresh" button to enable the user to update the LMP data and emission estimates for their chosen location. Each time the user either chooses a location to view, or presses the refresh button, HERO connects to the MISO server to download the latest real-time LMP data.

The five-minute current LMP and day-ahead LMP documents stored on the MISO server are in XML and CSV formats, respectively. HERO downloads the five-minute XML document from the MISO server and then uses SAX class in Java to parse the data and extract the one line of LMP information corresponding with the chosen CPN. HERO retrieves the current date and time from the Android system and uses this information to identify the correct LMP information for times 2, 4, and 6 h in the past and the future. Then HERO downloads the CSV document containing hourly LMP data of the correct date from the MISO database and parses the data to extract LMPs of the chosen location and appropriate past and future times. Fig. 2 shows the HERO architecture employed in this application.

3. Hero emissions output

HERO uses the LMP data from the MISO server to estimate marginal emission rates. An algorithm that was originally developed by Carter et al. [8] and later improved upon by Rogers et al. [10] is used to link ranges of LMPs to likely marginal fuel types such as nuclear/renewable, coal, natural gas, and fuel oil. These are the primary fuel types found in the MISO. Average emission rates for each fuel type are based on the U.S. Environmental Protection Agency's (EPA) Emissions & Generation Resource Integrated Database (eGRID), and Toxic Release Inventory (TRI) [13,14]. Emissions of carbon dioxide (CO_2) equivalents, nitrous oxides (NO_X), sulfur dioxide (SO_2), lead (Hg), and mercury (Pb) are reported for individual power plants. HERO uses average emission rates for eGRID subregions, which are defined using power control areas and North American Electric Reliability Corporation (NERC) regions as a guide [15].

Fig. 3 provides an example of the emissions screen shots displayed within the HERO application.

4. Conclusions and recommendations

HERO provides one part of an environmental feedback loop by carrying the LMP-emissions estimation method into the hands of consumers. It is a tool that contributes to a greater goal of reducing air emissions from power generation.

HERO presents data to consumers in a convenient format, and also provides some relevant information about the consequences of air emissions. This information is provided with the aim that HERO will lead some consumers to the next part of a feedback loop: action. For now, since HERO has no way to track actual habits, it mainly serves to educate people and perhaps let them take on a sense of personal responsibility for the emissions that result from their energy use. However, it is not hard to imagine that in the near future, HERO can be coupled with smart metering technology. Real-time information about emissions *and* home energy, combined, would allow HERO to complete the last part of a feedback loop: measurement of the desired action and quantification of results. Ultimately, the complete feedback loop would then show users how much pollution they have reduced over time by optimizing their electricity use.

In the future, there are a few modifications to HERO that would make it a more powerful tool. Our goal is for HERO outputs to be as informative and easy to use as possible so that it promotes action. As a result, will continue to enhance the user interface and enhance the information presented. With this aim we plan to aggregate emissions into a common index to provide users with a means of assessing the impact of multiple pollutants simultaneously. From a functional perspective, another immediate objective is to move HERO to a server so that it can handle a larger number of users. This would allow coverage of more locations across the US, more background information about appliances, and eventually, the possibility of connecting emissions data to real-time energy use information from smart meters.

Acknowledgement

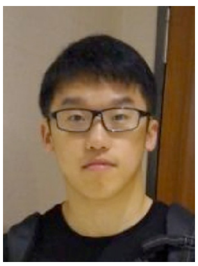
We would like to acknowledge the support of Great Lake Protection Fund (GLPF) that through funding the project 881 helped us to conduct this research and create HERO.

References

[1] R.D. Tabors, B.L. Monroe III, Planning for future uncertainties in electric power generation: an analysis of transitional strategies for reduction of carbon and sulfur emissions, IEEE Trans. Power Syst. 6 (4) (1991) 1500–1507.
[2] B. Schutz, R. Stuger, Electric power generation from various sources, particularly from coal, and the health hazards, Elektrotech. Maschinenbau 98 (12) (1981) 495–504.
[3] A. Rabl, J.V. Spadaro, Public health impact of air pollution and implications for the energy system, Annu. Rev. Energy Environ. 25 (2000) 601–627.
[4] D.S. Cohan, C. Douglass, Potential emissions reductions from grandfathered coal power plants in the United States, Energy Policy 39 (9) (2011) 4816–4822.
[5] EIA, 27 gigawatts of coal-fired capacity to retire over next five years, U.S. Energy Information Administration, 2012.
[6] EIA, State Electricity Profiles 2010, U.E.I. Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, 2010.
[7] H. Louie, K. Strunz, Locational marginal pricing in north american power systems, Netzregelung und Systerrifuhrung (ETG-FB109) Vortriige der 9 (2008).
[8] T.H. Carter, C. Wang, et al., Modeling of power gen pollutant emissions based on locational marginal prices for sustainable water delivery, IEEE Energy Tech, Cleveland, OH, 2011.
[9] FERC, A National Assessment of Demand Response Potential. Staff Report, Federal Energy Regulatory Commission, 2009.
[10] M.M. Rogers, Y. Wang, C. Wang, S. McElmurry, C. Miller, Evaluation of a rapid LMP-based approach for calculating marginal unit emissions, Appl. Energy (2013), http://dx.doi.org/10.1016/j.apenergy.2013.05.057 (in Press).
[11] K. Siler-Evans, I.L. Azevedo, et al., Marginal emissions factors for the U.S. electricity system, Environ. Sci. Technol. 46 (9) (2012) 4742–4748.
[12] A. Thiagarajan, L. Ravindranath, et al., Accurate, low-energy trajectory mapping for mobile devices, in: 8th USENIX Symp. on Networked Systems Design and Implementation (NSDI), MIT Computer Science and Artificial Intelligence Laboratory, Boston, MA, 2011.
[13] EPA, Emissions & Generation Resource Integrated Database (eGRID), U.S. Environmental Protection Agency, 2012, Version 1.0.
[14] EPA, Toxics Release Inventory (TRI), U.S. Environmental Protection Agency, 2012.

[15] S.S. Rothschild, Total, Non-baseload, eGRID Subregion, State? Guidance on the Use of eGRID Output Emission Rates, E.H. Pechan & Associates, Inc. for the U.S. Environmental Protection Agency, Springfield, VA, 2009, pp. 4.

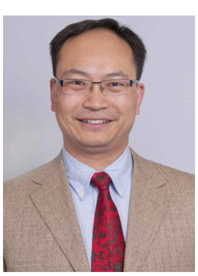
Michelle Rogers worked to develop LEEM and HERO as graduate student research assistant in the Wayne State Department of Civil and Environmental Engineering. After she earned her Master's degree, she moved on to work for the State of Michigan Department of Environmental Quality, in the Air Quality Division. When she can, Michelle still likes to be involved with the project team.



Guoyao Xu is a Ph.D student of Electrical and Computer Engineering at Wayne State University. He is responsible for the system architecture and technique part of LEEM and HERO project. His research interests include the resource management of big data architecture systems, green computing, cluster computing and cloud computing.

Professor Carol Miller of the Department of Civil and Environmental Engineering, Wayne State University, is the Principal Investigator for the project that has created this environmentally responsive electricity tool. Dr. Miller has research interests spanning urban water sustainability, environmental pollutant transport, and the energy/environment interface. Dr. Miller is the previous Chair of the State of Michigan Board of Licensing for Professional Engineers and the current U.S. Chair of the bi-national Great Lakes Science Advisory Board of the International Joint Commission. Her research has been funded by numerous agencies including the Great Lakes Protection Fund (sponsoring the present project), US Army Corps of Engineers, National Science Foundation, US EPA, DTE Energy, the Great Lakes Commission, and others.

Dr. Shawn McElmurry, Associate Professor of Civil and Environmental Engineering, is one of the original developers of the LEEM technology. Shawn has a broad range of skills related to contaminant transport, air quality, and computational modeling that support product development. Dr. McElmurry's research has been supported by a wide range of agencies including the US EPA, the International Joint Commission, and others. He is a well-known expert in heavy metal deposition and transport.



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Stephen S. Miller, P.E., is a Section Manager, TRANSMISSION 2000® at Commonwealth Associates, Inc. Commonwealth provides expertise and data to drive LEEM. Commonwealth was involved in conceiving the methodology and continues to consult with the project team as the method is refined. Commonwealth's proprietary algorithms uniquely allow disparate data sources to be related to produce granular and actionable results.

Dr. Caisheng Wang is leading the power flow modeling aspects of the research presented in this paper. Caisheng is a professor of Electrical and Computer Engineering at Wayne State University and is the Principal Investigator of two ongoing National Science Foundation projects, including "Optimal Distributed Control of Power Grids with Multiple Alternative Energy Distributed Generation Micrograds: Towards Reliable, Sustainable and Clean Power Generation". He has been collaborating with researchers nationally (e.g. from PNNL) and worldwide (e.g., from TU Berlin in Germany, National Institute of AIST in Japan and Zhejiang EPRI in China) on various interdisciplinary topics related to sustainable energy development.

Cheng-Zhong Xu is a professor of Electrical and Computer Engineering at Wayne State University and the Director of the Institute of Advanced Computing and Data Engineering of Shenzhen Institute of Advanced Technology of Chinese Academy of Sciences. His research interest is in parallel and distributed systems and cloud computing. He has published more than 200 papers in journals and conferences. He was the Best Paper Nominee of 2013 IEEE High Performance Computer Architecture (HPCA), and the Best Paper Nominee of 2013 ACM High Performance Distributed Computing (HPDC).