ASSESSING RESILIENCE AS A CO-BENEFIT OF SUSTAINABILITY IN URBAN ENERGY SYSTEM: AN INTEGRATED FRAMEWORK AND TWO CASE-STUDIES

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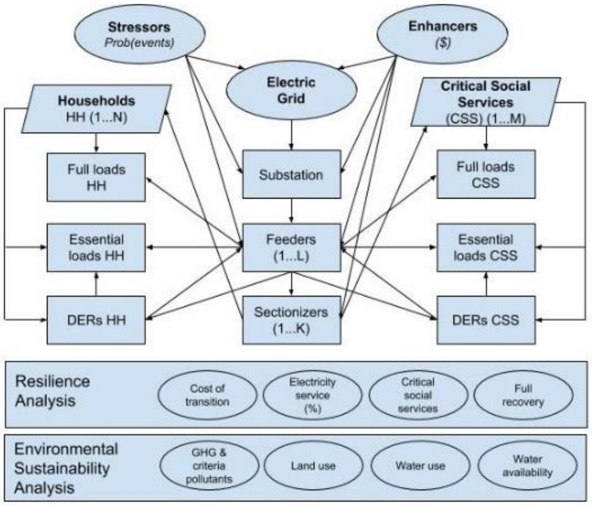
Overview

Resilience is gaining more significance as a performance goal for electric power system. This trend is driven by the growing importance of electricity to critical social services and to vital urban infrastructure (e.g., transportation, telecommunication, water, natural gas), rapid urbanization, and more extreme weather events caused by climate change (Wender et al, 2017; Evans and Fox-Penner, 2014). Measures to enhance resilience have implications to other important goals including affordability and sustainability. Marchese et al (2018) identify three perspectives for the joint implementation of resilience and sustainability: system sustainability increases as resilience increases but not vice versa, sustainability as a component of resilience being the ultimate goal of the system, and they being separated goals. In practice, these goals and their trade-offs are defined by political process and shaped by technology progress. This paper presents a relational conceptual-framework for integrated study of technologies and policy instruments that have potentials in improving sustainability and resilience of urban energy system. It is followed by two case studies on the resilience as a co-benefit of sustainability, one in the context of Long Island, New York, and another one in Riyadh, Saudi Arabia.

Methods

Our framework is based on two conceptual frameworks in the literature. Desouza and Flanery (2013) conceptualize city as a complex adaptive system comprising of five elements (i.e., resources and processes of the physical system; and people, institutions, and activities of the social system), and consider four types of stressors: natural (e.g. hurricanes, earthquakes), technological (e.g., failures of complex technical systems), economic (e.g., deteriorating infrastructures), and human (e.g., deliberate acts). A framework by EPRI (2015) for studying the impacts of distributed energy resources (DERs) on electric grid includes the key physical elements and DERs, and five major analysis activities including characterization of DERs, energy analysis, and reliability analysis. Existing literature also reports a variety of indicators to measure the sustainability and resilience performance of energy system. They range from simple economic indicators (Mejia-Giraldo et al, 2012), to structured and comprehensive metrics that factor in behaviour under changing conditions and complex interactions among sub-systems (Roege et al, 2014).

Guided by this framework, we assess the resilience benefits of two technologies that are rapidly deployed in urban energy system: distributed PV systems and electric vehicles (EVs). Their values to urban sustainability have been well studied. This study asks, What are their impacts on the resilience of urban systems, and What are the implications of this co-benefit to their adoption and use?



This study estimates their resilience benefits in a hypothetical urban/suburban community (Narayanan and Morgan, 2012; Shang and Sun, 2017) that is served with one electricity feeder. Our scenario is that (1) this community loses power supply from the grid and will have an extended period of power outage; (2) it is technically ready to island, and can deploy DERs in the community including PV systems and EVs to power the critical electricity services. The critical electricity services include critical social services (e.g., police station, grocery store, gas stations, schools, cell towers, streetlights (Narayanan and Morgan, 2012)), and essential household services (e.g., lighting, basic cooking, heating boiler, and air conditioning). We use the System Advisory Model (SAM) developed by National Renewable Energy Lab and real weather data during four time periods (three in the Long Island case, and one in the Riyadh case) to estimate the electricity output.

Results

Figure 1 shows our relational framework for studying the sustainability and resilience performance of urban energy system. This framework reflects the trend that electricity is becoming more central and critical to future cities. It includes stressors as probabilistic events and enhancers representing resilience-enhancing investments. It is designed to carry out analysis at feeder to substation levels. The demand for electricity services is divided into two sectors (i.e., household, and critical social services) and two levels (i.e., essential loads, and full loads). Our sustainability analysis is limited to environmental sustainability and considers emissions of greenhouse gases (GHGs) and criteria pollutants, water use and availability, and land use. The four major indicators in resilience analysis are cost and time for full recovery, recovery process of electricity services, and availability of critical social services.

Preliminary results show that electricity generated by PV systems in the aftermath of selected catastrophic weather events are very low comparing to the total loads. But they are sufficient to power critical loads at households and critical social services during the days. EVs with vehicle-to-grid (V2G) capability extend the electricity services to the nights. With their gas tanks, plug-in hybrid electric vehicles (PHEVs) bring more resilience benefits to the community during the extended power outage.

Conclusions

This paper presents a framework for integrated assessment of technologies and policy instruments to enhance the resilience of urban energy systems, and two case studies on the resilience as a co-benefit of sustainability. This framework can be applied to evaluate and compare a variety of options, from hardening the physical system to incentivizing customers to adopt technologies with the co-benefits of sustainability and resilience. From this relational conceptual-framework to operational model, a number of challenges exist. Major ones are: (1) the integration of many different modules of the physical systems, and then with the human/social systems; (2) the availability of reliable data to accurately characterize the technologies and situations; and (3) address policy/decision problems salient to policymakers and stakeholders. The two case studies demonstrate the significant resilience benefits of PV systems and EVs with V2G capabilities to a urban community. For these two technologies, resilience benefits augment their values as sustainable technologies. For community with distribution grid that is capable of dynamic islanding, PV systems and EVs offer a viable option to maintain power supply for critical loads during extended period of outage, and can hence improve the community resilience to stressors and the wellbeing of its members.

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