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Overview

The U.S. is unusual in that a definition of the term "smart grid" was written into legislation, appearing in the Energy Independence and Security Act (2007). When the recession called for stimulus spending and the American Recovery and Reinvestment Act (ARRA, 2009) was passed, a framework already existed for identification of smart grid projects. About $4.5B of the U.S. Department of Energy's (U.S. DOE's) $37B allocation from ARRA was directed to smart grid projects of two types, investment grants and demonstrations. Matching funds from other sources more than doubled the total value of ARRA-funded smart grid projects. The Smart Grid Investment Grant Program (SGIG) consumed all but $620M of the ARRA funds, which was available for the 32 projects in the Smart Grid Demonstration Program (SGDP, or demonstrations).

Given the economic potential of these projects and the substantial investments required, there was keen interest in estimating the benefits of the projects (i.e., quantifying and monetizing the performance of smart grid technologies). Common method development and application, data collection, and analysis to calculate and publicize the benefits were central objectives of the program. For this purpose standard methods and a software tool, the Smart Grid Computational Tool (SGCT), were developed by U.S. DOE and a spreadsheet model was made freely available to grantees and other analysts. The methodology was intended to define smart grid technologies or assets, the mechanisms by which they generate functions, their impacts and, ultimately, their benefits. The SGCT and its application to the Demonstration Projects are described, and actual projects in Southern California and in China are selected to test and illustrate the tool. The usefulness of the methodology and tool for international analyses is then assessed.

Methods

The main motivation behind the SGCT methodology is that technologies (i.e., assets) provide a set of functions that can generate Smart Grid benefits, which can be quantified and monetized. After identifying the assets, the SGCT maps (1) assets into functions, (2) functions into mechanisms (i.e., impacts), (3) mechanisms into benefits, and (4) benefits into monetary values. Benefits are allocated to the utility, consumers, and society.

SGCT provides a list of assets with definitions that will be considered while assessing costs and benefits of smart grid projects. In this manner, the methodology establishes a widely known set of definitions that provide a common basis for comparison between projects and thus provides a key contribution to the smart grid costs and benefits analysis literature. There are 22 smart grid benefits in the SGCT, which are grouped into four main benefit categories: economic, reliability, environmental, and security. All costs and benefits that can be expressed in monetary terms, including a societal perspective (e.g., environmental costs) are considered in the analysis.

The $80M Irvine Smart Grid Demonstration (ISGD) Project is used as an example to demonstrate how the SGCT can be applied in practice. ISGD involves assets on both sides of the customer meter. On the utility side, grid-scale batteries are deployed, capabilities to identify and segregate faults are installed, and upgrades are made to the local control center. On the customer side, a block of 39 modern homes were equipped with three different levels of smart equipment, energy storage units and PV generation. The most extremely efficient homes, about one third of the total, have local storage, smart appliances and controls, etc., intended to show compliance with California's future zero net energy (ZNE) target. First established in 2007, the goal is for all new residences to be ZNE by 2020, and all new commercial construction by 2030. Another third of the homes have an intermediate level of efficiency and smart grid technology, while the final third is a control group of standard homes meeting energy codes circa 2003. Since the project is entering its last year, a considerable amount of metered results are now available.

Results

Outcome of the ISGD project is assessed against the baseline, which reflects the parameter values without the ISGD project (i.e., values based on historical performance data prior to the operation of the smart grid technologies). Figure 1 shows an example standard SGCT output, illustrating the annual costs and benefits related to the “Customer Electricity Use Optimization” function. Benefits related to this function are “Reduced electricity cost” and “Reduced CO_2 emissions.”

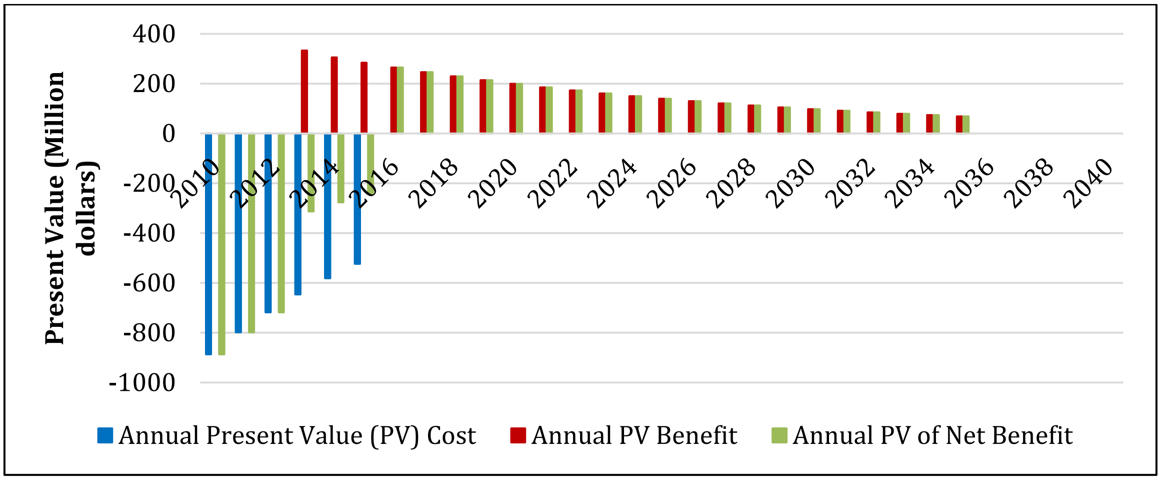

Figure 1 Annual Present Value Cost Benefit Graph

Net present benefit (i.e., summing the bar values shown in Figure 1) is close to zero in this rudimentary case. Overall results show that total benefits exceed total costs around 2016 (the break-even point), and persist through the study period. The SGCT is also applied to a commercial building section of the Tianjin Eco-City (TCE) demonstration in China. The results and experiences from these analyses are combined with general evaluation of benefits analysis and tools, and lessons learned for international comparisons shared.

Naturally, uncertainty is a major challenge for benefits analysis. The uncertainty comes from multiple sources, the relationship of technologies to impacts, equipment performance, future costs and economic conditions, etc. A strong tension exists between the desire to address the sources of uncertainty versus the need to offer a simple comprehensible method that that can be widely and consistently applied. The challenge of addressing uncertainty and the usefulness of the SGCT will be explored and addressed in the paper. Possibilities for representing uncertainty while maintaining a transparent analysis will be discussed.

Conclusion

This paper presents the SGCT and its application to a demonstration project in the U.S., and aims to show the effectiveness of SGCT methodology for evaluating the impact of smart grid investments. In addition, results from a small scale SGCT application in China are compared with the ISGD project to form a basis for future international comparisons of smart grid projects.

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