***UNCERTAINTY IN BENEFIT-COST ANALYSIS OF SMART GRID DEMONSTRATION PROJECTS IN THE U.S., CHINA, AND ITALY***

Nihan Karali, Lawrence Berkeley National Laboratory, Phone: +1 510 495 8185, email: [NKarali@lbl.gov](mailto:NKarali@lbl.gov)

Gianluca Flego, European Commission JRC, Phone: +39 332 785689, email: [gianluca.flego@jrc.ec.europa.eu](mailto:gianluca.flego@jrc.ec.europa.eu)

Jiancheng Yu, State Grid Corp. of China, +86 22-24408671, [Jiancheng.Yu@tj.sgcc.com.cn](mailto:Jiancheng.Yu@tj.sgcc.com.cn)

Silvia Vitiello, European Commission JRC, Phone: +31 224 565182, email: [Silvia.Vitiello@ec.europa.eu](mailto:%20Silvia.Vitiello@ec.europa.eu)

Dong Zhang, State Grid Corp. of China, Phone: [+86.22.24408671](mailto:+86.22.24408671), email: [jackzhangua@sina.com](mailto:jackzhangua@sina.com)

Chris Marnay, Lawrence Berkeley National Laboratory, Phone: +1 510 486 7028, Email: [ChrisMarnay@lbl.gov](mailto:ChrisMarnay@lbl.gov)

## Overview

Early in this century, it became clear that the technology embedded in the developed world’s electricity supply system had become seriously inadequate to cope with the challenges that we are facing today, and to generally meet rising expectations for grid performance, often assumed necessary to support the emerging *digital economy* (Tapscott, 1995). *Smart Grid* emerged as an umbrella term to describe a number of technologies that had mostly already been proposed or actually developed separately, but which had failed to gain broad deployment. The notable example is advanced metering infrastructure (AMI), whose capabilities had been recognized as necessary for several decades. The motivations for smart grid can be boxed into three types. The first involves establishing an appropriate AMI infrastructure to enable price-elastic demand, and hence an efficient market. The second concerns improved operation of the legacy centralized grid. And the third, and perhaps most radical, leg of the smart grid stool is decentralized control of the power system, i.e. microgrids and community power (Marnay and Lai, 2012).

Given the substantial investments required, there has been keen interest in benefit cost analysis, i.e., quantifying and monetizing the performance of smart grid technologies. Analysis to calculate and publicize these results has been a central objective in many jurisdictions. Smart grid projects are typically characterized by high initial costs and uncertain benefit streams over the long-term. Making a decision with long-term implications requires a thorough understanding of likely or possible future situations and also the ability to balance a large number of controllable and uncontrollable parameters (Bhushan and Rai, 2009). Thus, there is a need for common method development and application. In this study, we compare two different approaches; (1) Electric Power Research Institute (EPRI)’s benefit-cost (B-C) analysis method, and (2) the Analytic Hierarchy Process (AHP) decision making method. These are applied to three case study projects executed in three different countries; the U.S., China, and Italy, considering uncertainty in each case. This work is conducted under the U.S.-China Climate Change Working Group, Smart Grid, with an additional contribution by the European Commission.

## Methods

As seen in the figure, the EPRI method defines smart grid technologies, or assets, and their technical functions. The mechanisms by which they generate benefits are specified and monetized. Benefits are allocated to the utility, consumers, and society. The EPRI method defines benefit as a monetized value of the impact of a smart grid project to a firm, a household, or society in general.

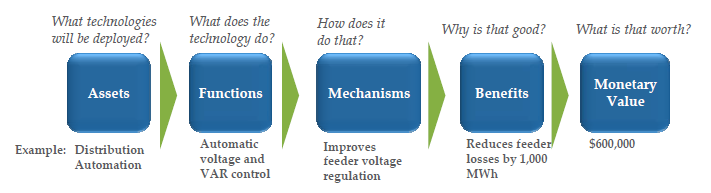
 *(Source: EPRI, 2010)*

Figure 1 The logic flow of SGCT

The AHP method converts subjective expert evaluations into numerical values and ranks each alternative on a numerical scale. The method starts with establishment of a general indicator system based on all the benefits generated by each smart grid sub-project. Then, each indicator, e.g., reliability, efficiency, economy, and environmental friendly, is assigned a relative weight according to expert opinion. These weights are integrated and used to calculate an overall dimensionless benefit of the smart grid project.

## Results

In this paper, aspects of the three actual demonstrations are analyzed: (1) the Irvine Smart Grid Demonstration (ISGD) Project in Southern California, (2) the Tianjin Eco-city project in China, and (3) the Malagrotta demonstration in Rome.

Lawrence Berkeley National Laboratory (LBNL) used the $80M ISGD Project to test the EPRI method by using its DOE funded implementation in the Smart Grid Computational Tool. ISGD is a comprehensive demonstration that spans the electricity delivery system and extends into customer homes. The three subprojects evaluated are: (1) a 39 unit home energy efficiency demonstration including some deep zero net energy retrofits, (2) a utility scale battery installation, and (3) a distribution voltage and volt-ampere reactive (VAR) control demonstration.

The 31 km2 Tianjin Eco-city is planned to ultimately accommodate 350,000 residents and is the site of multiple smart grid demonstrations. Three subprojects were evaluated by the State Grid Corporation of China (SGCC) using AHP, (1) a microgrid with energy storage, (2) a smart substation, and (3) distribution automation.

EU’s Joint Research Center (JRC) adapted the EPRI method to the European context and made it more relevant by using project specific factors such as geography, typology of consumers, and regulations. JRC applied the first application of benefit-cost analysis to the Malagrotta demonstration project in Rome. Three subprojects evaluated are, (1) advanced grid automation, (2) monitoring and remote control grid, and (3) new network management criteria.

In each sub-project, factors contributing to uncertainty and complexity surrounding smart grid technologies and their future benefits are explored. Results and performance of the EPRI and AHP methods are compared, and ability to accommodate uncertainty explored.

## Conclusion

This exercise was performed within a joint research effort by LBNL, SGCC, and JRC and aims to demonstrate, compare, and evaluate B-C analyses conducted for three actual smart grid demonstration projects. A deep understanding of B-C analysis methods and their strengths and weaknesses will be critical to smart grid deployment decision-making by governments and industries. Evaluating these methods from a multi-country perspective will facilitate future assessments and comparisons of results internationally.

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