EVALUATION METHODS FOR MARKET MODELS USED IN SMART GRIDS

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ABSTRACT

This paper investigates how demand response pilot projects for the residential sector can be evaluated. A simplified framework for how demand response pilot projects carried out for the residential sector can be designed has been developed. A review of 135 international pilot projects has been made. Interesting findings were that bill savings is the most common reason for participating and that customers tend to respond to blocks of prices instead of sudden increases in a certain hour. Also, customers tend to reduce their use of electricity when peak to off-peak price ratio is above three. Another finding concerning evaluation methods for DR smart grid projects is that a control group should be used to ensure the validity of a pilot project. The control group should be monitored simultaneously as the treatment group. This can facilitate determination of the true cause and effect relationship between variables and indicators.

1. INTRODUCTION

The European Union has set environmental targets on climate change (1). These targets are the main drivers for the change in today's power system. The targets do not only affect the production and distribution of electricity but also raise questions on how electricity is being consumed. An essential building block of an efficient power system is often referred to as the smart grid. One of the important components of a smart grid is dynamic market models that facilitate *demand response* (DR). These market models have mostly been used by large industrial and commercial customers. Residential customers account for a relatively large portion (25%) of the total electricity consumption in EU27 (1), this sector therefore offers room for potentiation.

There are several reports and articles that discuss evaluations methods for smart grid pilot projects (2), (3), (4). Pilot projects concerning dynamic market models have also been conducted (2), but there are no uniform evaluation methods of dynamic market models used in the residential sector. This paper goes through an extensive literature review concerning evaluation methods for smart grid pilot projects in the household sector and develops a simplified framework for how demand response pilot projects carried out for the residential sector can be designed and evaluated. Additionally, an international review of pilot projects for smart pilot projects has been conducted in the connection with the literature review. The results from the pilots are compiled and conclusions concerning different variables, for instance different types of market models, are drawn.

Section 2 describes important concepts within demand response. Section 3 presents the developed framework that can be used to investigate the impact that common demand response variables have on smart grid indicators. Important findings and conclusions are drawn in section 4.

2. DEMAND RESPONSE

DR can follow different principles. *Peak reduction* is the lowered use of electrical energy during hours of high total demand in the grid. Several benefits are associated with peak reduction: reduced investment costs for distribution and transmission system operators. Another principle is *electricity conservation,* which means reduced overall load curve. This indicator does also have several benefits, where one is reduced emissions of carbon dioxide. Lastly, *load shift* aims to move load from peak hours to off-peak hours. Related benefits are reduced investment costs and reduced risks of congestion in the grid.

Dynamic market models give price incentives for customers to modify their demand for electrical energy. A common dynamic market model is the Time-of-Use (TOU) model where electricity price varies for blocks of time, (commonly with two periods per day). One price level is set relatively high during times of high electricity demand. The other price level is lower and matches times of low demand for electricity. The lower rate is set below the normal price level of a fixed market model. With the Critical Peak Price (CPP) model an agreement is made which states that the electricity price is allowed to increase to a critical level a few times a year. This model is often combined with fixed market models or with TOU. It is also often combined with communication technology where the consumer is warned a day before when the critical peak will occur. The Critical Peak Rebate (CPR) market model has common characteristics with the CPP-model; however instead of increasing the costs during peak hours, customers are paid for not using electricity during the critical hours. The Real Time Pricing (RTP) model follows the price fluctuations on the spot market. This model is suitable for consumers who accept high levels of risk and for those that do not want to pay a premium price in order to be insured against price fluctuations. The models concern both electricity prices and network tariff. (2)

Consumers find dynamic models complicated. Therefore, it could be wise to accompany dynamic models with better forms of *feedback*, to increase customer awareness and to facilitate active decision making (5). Research on feedback distinguishes between *direct* and *indirect feedback*, where direct feedback is given instantly and indirect feedback is given at a later time (5).

The technology that is required on an appliance level for near real time DR is defined as *enabling technology*. Enabling technology dispatches instructions to the consumer or to the electrical appliance that a DR event should be initiated. For example, a washing machine could be automatically started when electricity prices are low (2).

3. EVALUATION METHODS FOR DR PILOT PROJECTS

Project evaluation concerns the comparison of realized goals with the stated and revised goals and objectives. Evaluations must not only concern an ex-post and a progress analysis but also the ex-ante prediction of project requirements. (2)
Evaluation of smart grid projects concerns:

1. The impact of chosen DR variables on smart grid indicators.
2. Design principles and data acquisition.
3. Total cost and benefits for different stakeholders.
4. Precision of costs and benefits.

To evaluate smart grid projects the impact of DR variables (such as a dynamic market model) on the smart grid indicators (such as peak reduction or electricity conservation) must be analyzed. Since external variables vary between pilot projects, both qualitative and quantitative research approaches are needed in order to make quantifiable conclusions concerning the relationship between an input and an output (2). DR variables and indicators should preferably be chosen so that total costs and benefits among the stakeholders can be calculated. The precision of benefits and costs should thereafter be evaluated with a sensitivity analysis (3).

3.1 The Impact of chosen DR Variables on Smart Grid Indicators

One of the limitations of the pilot projects relates to their heterogeneous nature making them hard to categorize. Certain research is based on historical data while others have used control groups. Sample sizes, heating systems and project duration also vary among the projects. For example, some projects have lasted for one or two months, while others have lasted for years. Additionally, some projects have several thousands of participants while others have used less than 20 participants. Problems also arise in terms of differences in demographics, geographical locations and time of execution. Therefore, due to the heterogeneous nature of the pilot project, the results gathered should be used as an indication for future estimations and assumptions regarding pilot projects. The developed evaluation framework used in this paper is presented in figure 3.1.

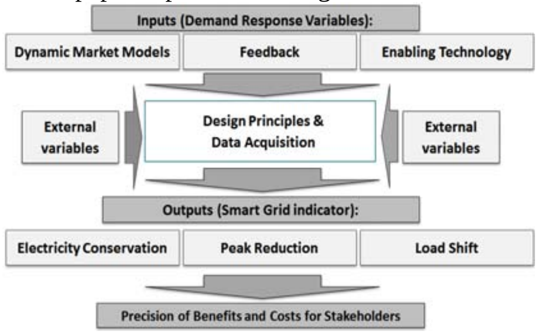

Figure 3.1: A simplified framework of DR variables impact on smart grid indicators (2).

DR indicators are not only affected by the chosen variables but could also vary due to external variables such as varying social, economic, geographical aspects (2). Furthermore, the design principles and data acquisition might influence the output of a pilot project.

3.1.1 Electricity Conservation

Quantitative and qualitative findings from pilot projects concerning the indicator electricity conservation are presented in this section. These pilots have either used feedback and/or dynamic market models. Some of these pilot projects have been combined with enabling technology. Figure 3.2 show the average electricity conservation for different feedback types.

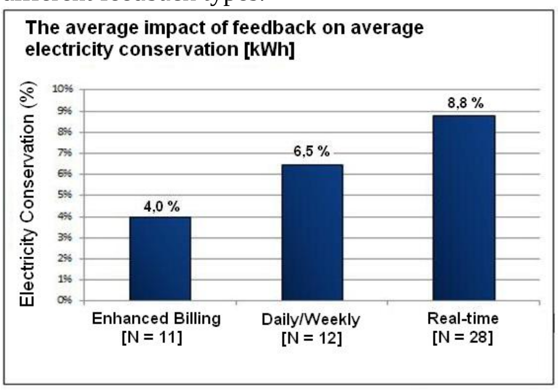

Figure 3.2: Average electricity conservation for feedback projects (2)

The use of feedback did in 46 out of 51 pilot projects led to an overall reduction in electricity consumption. The pilot projects that achieved best results used home displays with direct feedback. A reason for achieving desirable results by real time feedback can be explained by the instant connection to the actions taken by the customer.

3.1.2 Peak Reduction

Figure 3.3 shows the average peak reduction in 57 pilot studies where dynamic market models were used. Some of these studies examined combinations of dynamic market models and enabling technology. Moreover, most of the pilot projects in the seven categories have used some sort of feedback.

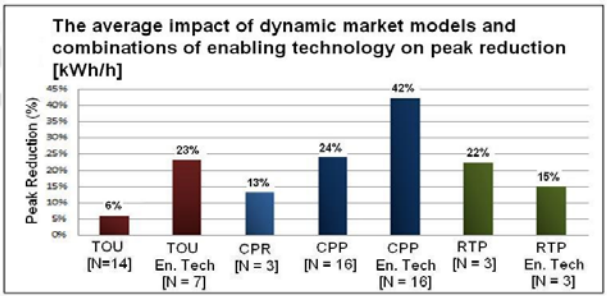

Figure 3.3: Average peak reduction of different combinations of DR variables (2)

Peak reduction occurred in all of the 57 pilot projects that used dynamic market models except in two TOU pilot projects. Lowest peak reductions were gained in the TOU pilots. The studies that used enabling technology mostly used programmable thermostats or ACs. Many of these pilot projects were either conducted in warm climate zones during summer or cold climate zones during winter. The largest reductions were achieved with the CPP model in combination with enabling technology. Important findings were that customers tend to decrease electricity consumption when peak to off-peak price ratio is above three (2) and that that customers rather respond to blocks of prices than a sudden increase in a certain hour (6).

3.2 Design Principles and Data Acquisition

In order to meet minimum requirements in DR pilots, data needs, budget, methods and schedule must be specified for the DR resource of interest. A good evaluation requires careful planning in order to meet deliverables specified for the DR resource of interest (7). DR pilot projects have different characteristics, aims and purposes and are often conducted under a variety of circumstances (2). This makes some evaluation method more or less applicable depending on the situation. For evaluation purposes it is practical to distinguish between different phases of the pilot project (3). Estimation should be made for the anticipated impact of the DR resource on total costs and benefits (3). This is called ex-ante estimations (7). Ex-post is the opposite of ex-ante and is the actual outcome of the results of the pilot project (7). It is not possible to outline all the methods that could be used for evaluation of DR pilot projects. It is however important that the evaluator has insight regarding key issues before conducting a pilot project (7). Key issues vary among indicators and variables. Examples of relevant external variables are: climate conditions, consumer preferences and the development of energy prices (2). The guidelines described below provide insight to some of the key aspects, but they are not exhaustive (7). **Customer Acceptance -** Data should not only be gathered on indicators and variables that easily can be quantified on a monetary basis but also on issues concerning the more subjective variable, *customer acceptance*. Information about customer acceptance could be gathered by surveys, focus groups or interviews. **Customer Segmentation -** The suitableness of DR alternatives varies among customer types and segments. Heterogeneity in the samples must be considered since some large customers might dominate and therefore influence the results in a pilot project (6). This might lead to uncertainties when results are being generalized to larger populations. **Design and composition of Control and Treatment Groups -** It is vital to have a control group for pilot projects concerning market models in order to ensure the internal validity of the project (7). Control groups are needed to eliminate the casual relationship between a DR resource and energy use (7). The control group and treatment group should be identical in all aspects except that the control group does not receive the experimental treatment (6). The design principle discussed above is called the *True Impact Measure* and is illustrated in figure 3.4.

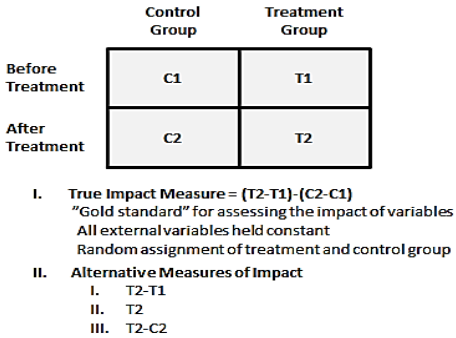

Figure 3.4*: Evaluation design according to the "The true impact measurement" (6)*

From a statistical point of view, it is essential to have a substantial amount of participants. At least 100 customers are recommended for the control group and for the treated group respectively as results are meant to be used in a large scale implementation (6). **Persistence -** One important evaluation criterion is whether expected impacts will persist during and after the pilot project (7). **Weather and Climate Impact -** It could be relevant to measure the magnitude of peak reduction in relation to weather conditions since it is important to know the exact levels of DR for some stakeholders (2). Daily variations are often important and should be considered when an evaluation plan is being developed (7).

3.3 Costs and Benefits for Stakeholders

There are several tests to evaluate the cost effectiveness of pilot projects (2), (8). There are two tests for electricity consumers: the first one is the participant test, which measures Net Present Value (NPV) for participating in a pilot project. The pilot should not be conducted if the pilot is not economically beneficial for the participants. The second test for the consumers is the Ratepayer Measurement Impact (RIM) test. It measures how the rates for customers who are not participating (non-participants) changes as a consequence of the pilot project. If the rates do not increase for the nonparticipants, the RIM test is passed. There is also the Total Resource Cost (TRC) test that measures the combinations of the effects for the energy company and participants. If the benefits exceed the total costs for both the energy company and the participants the test is passed. The last test is the Program Administrator Cost (PAC) test. It measures costs and benefits for the ones conducting the pilot, which is usually the energy company. The pilot is cost effective if the benefits exceed the costs.

3.4 Sensitivity Analysis and Precision

The socio-technical nature of the smart grid imprints the level of uncertainty for estimated outcomes. This makes it important to associate costs and benefits with its precision level. The Electric Power Research Institute (EPRI) suggests a broad set of categories as a reasonable way of estimating risks for benefits and costs (3). One way of doing so is to combine types of benefits and corresponding level of precision with the different beneficiaries of a smart grid project as shown in figure 3.5.

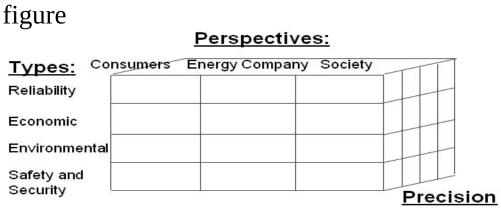

Figure 3.5: Perspectives, types and precision level for costs and benefits among stakeholders in DR pilots (3)

It is important to understand that the magnitude of a benefit is not always necessarily related to the precision of that estimate (e.g. potential cost reduction with lower emission levels). Uncertainty concerning the cost for conducting smart grid projects is in general lower than the uncertainty related to its estimated benefits (3).

4. CONCLUSIONS

The developed framework, which is based on an extensive literature review, shows that dynamic market models, feedback, and enabling technology are the most common variables used in DR projects. To properly measure the impact of the specific variable alone on the smart grid indicators (peak reduction and electricity conservation) the pilot project should use a control group. The control group should be monitored simultaneously as the treatment group. This establishes the true cause and effect relationship between variables and indicators. It also ensures the validity of a pilot project and the results can more securely be used in a large scale implementation. The compilation of international projects shows that dynamic market models should be simple; this could be achieved by providing customer feedback. Customers generally had a high acceptance for dynamic market models and the most common reason for participating was the potential for bill savings. The review of international pilot projects also found that customers tend to respond to blocks of prices instead of sudden increases in a certain hour. This raises questions about RTP; if fluctuations occur often it could become tiring and if the fluctuations are not large enough, the incentive to change behavior might be inhibited or lost. These findings are important to consider when a pilot is planned to be conducted. Furthermore, it is important to design pilot projects with a long term perspective in order to allow financial predictions needed for the different stakeholders, the primary way to express these test results is by using the NPV.

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