Cost-Benefit Analysis on smart meter projects: Lessons from case studies

Patrick T.I. Lam[1]
Wenjing Yang[2]
tsun.ip.lam@polyu.edu.hk[1]
w.j.yang@polyu.edu.hk[2]

Dept of Building & Real Estate,
The Hong Kong Polytechnic University

Abstract

Smart meters are installed in buildings as energy efficiency measures in smart cities. The benefits and costs of the smart meter projects have been evaluated in many countries, such as the monetary saving arising from Time-of-Use (ToU) pricing, the reduction of CO_2 emissions, and the facilities installation expenses. Different issues of public concern about smart meters have been discussed in the literature, including the potential health issues, the digital display problem, and the effects on energy saving and environmental protection.

This study includes case studies on smart meter projects in Great Britain (GB) and Canada, and illustrates the problems encountered in the progress of the smart meter implementation projects. Through describing the manners of evaluating the pros and cons of smart meter projects and depicting the application of relevant Cost-Benefit Analysis (CBA) framework and components, this research shows the necessity of CBA in smart city projects affecting the citizens to a large extent.

As a review study, useful experience has been gathered from the case studies for sharing, and recommendations for improvement in future projects are discussed in this paper. Further, the wide application potential of Information and Communication Technologies (ICT) should receive sufficient concern and recognition in the cost and benefits studies of smart city arena.

Keywords: Smart Meter, Cost-Benefit Analysis (CBA), Smart City, Time-of-Use.

1. Introduction

Nowadays, with the constant improvement and demand on technology, the utilization of Information and Communication Technologies (ICT) in smart city projects can make the life of citizens more convenient and efficient. Smart meters as one of the utilities using ICT are becoming increasingly popular globally. Smart meters are being rolled out to improve the electricity system and optimize the production and distribution of electricity. Smart metering is a part of smart energy management and the foundation of the smart grids [1]. As a typical smart city scenario, many countries, such as Canada, US, Australia, and UK, have been on the way of promoting their smart meter projects for a few years. For example, the first and largest smart meter project of Canada started in April 2004 in Ontario [2]. Thus, it can provide reference for other regions to obtain experiences from the pioneers. As a kind of ICT facility, the pros and cons of smart metering have always been concerned by the public with vehement controversy. The intelligent functions of smart meters present nearly real-time information of electricity-consumption clearly, and make it possible for the consumers to optimize their energy usages. Smart meters serve to reduce the consumers' energy bills by enabling them to switch the time of using electricity and transmit data directly to the energy suppliers to reduce the manpower of the supplier companies.

Despite the apparent advantages, there are still plenty of public concerns, such as the Electromagnetic Field (EMF) pollution, the threat on personal privacy and security, and the digital display problem. At times, the fees charged by the power suppliers have been reportedly higher than expected. These perceived disadvantages, coupled with the high cost of meter replacement, have cast doubts on their cost effectiveness.

As a mature decision-making tool, Cost-Benefit Analysis (CBA) has been conducted ever since the smart meter projects were mooted in some countries, but not in every case. Looking retrospectively, the smart metering initiative of Canada started in 2004, but proper CBA was not carried out, despite its high expenditure. By contrast, UK started to conduct CBA on its smart meter concept in 2008 and thereafter progressively [3]. The methodological approach of smart grids' CBA was developed by the Electric Power Research Institute [1] and guidelines for CBA of smart grids and metering development were published by the European Commission in 2012 [3], [4]. In this paper, different CBA guidelines for smart meters projects are summarized to distil the best experience. Various scenarios and problems encountered in the implementation of smart meters projects in Canada and the UK are analyzed to draw recommendations from the lessons learnt.

2. Literature Review

Smart metering system is one of the core components of smart grids, and an important element for success of smart meter projects is the adoption of Time-of-Use (ToU) pricing. ToU pricing and the related CBA guidelines will be illustrated in this part.

2.1. Smart metering in smart city

Utilities embracing ICT are highly developed nowadays to address the demographic, economic, environmental, infrastructural and social challenges, such as Big Data, the Internet of Things (IoT), and Artificial Intelligence (AI) [5]. Thus, smart city projects based on ICT have become popular investments. According to the latest report from Bank of America Merrill Lynch (BofAML), the hottest smart city projects for investors include: (1) Smart Infrastructure; (2) Smart Buildings; (3) Smart Homes; (4) Smart Safety and Security; (5) Smart Energy; and (6) Smart Mobility [5]. Being ranked by the BofAML Smart City Index, Singapore, London, New York, Paris and Tokyo are supposed to be the top 5 of world's smartest cities [5]. The smart city projects not only help investors make a profit, but also raise the citizens' living standard and enhance environmental protection. With the high concentration of smart infrastructure and energy, smart grids integrate technologies, devices and networks to optimize the transformation of energy systems [6]. As the foundation and core component of smart grids, smart metering has become an inevitable trend globally. But the investment returns of smart meter projects are not always satisfactory or they remain controversial, even though smart metering is supposed to yield energy-saving, enhance environmental protection, and shrink consumption bills.

2.2. Time-of-Use (ToU) pricing

As mentioned, the main advantage for the smart meter projects is the ToU pricing. Smart metering possesses the functionalities of transmitting signals of real-time power consumption from the households to the power companies. With the real-time messages of electricity-consumption displayed in the meters or in-home units, consumers can optimize their power usage under the inducement of ToU pricing, especially at peak times when the system is under heavy load stress. The ToU pricing is a strategy that allows utilities to charge differential prices at different times of a day, even a year, and encourages the consumers to shift the electricity demand to avoid the peak hours, and the consumers may enjoy discount prices of electricity through the conversion of the on-peak usage to mid-peak or off-peak.

ToU pricing:

• On-peak – The most expensive and highest demand for energy;

• Mid-peak – Moderate price and demand of the energy;

• Off-peak – Bottom price for the energy with minimal energy demand.

The most important part of the consumers' benefits comes from the cost reduction with ToU pricing. The original price policy with two-price tiers depends on the different standard of power usage in summer months and winter months. If the usage exceeds the standard, the charge will be higher according to the policy regardless of electricity consumption timing. To some extent, the combination of smart meters and ToU pricing could reduce new power plants' needs and green-house gas emission. The benefits of slashing bills and environmental protection will be promulgated to the consumers via smart meter display or bills if they reduce or shift the on-peak energy use, but this entails changing the behaviors of energy use.

2.3. Cost-Benefit Analysis of the smart meter projects

There have been broader studies on the methodological approach of Cost-Benefit Analysis in utilities and transportation since the concept was proposed in 1840s by Jules Dupuit [7]. The CBA of smart metering is to conduct a cost and value assessment for the smart meter projects. The methodological approach of CBA on smart grids projects conducted by Electrical Power Research Institute (EPRI) in 2010 contains the complete contents and the systemic description of the CBA approach of smart grids [1]. The measurable and quantifiable benefits could be identified with a systematic and comprehensive evaluation using this framework. Based on this methodological approach, the European Commission developed the guidelines for CBA of smart grid projects [4] and smart metering development [3], both of these two guidelines contain the details and key components of conducting CBA applicable to EU states according to local conditions. The European Commission CBA guidelines reflect consistent standardization effort for its member states, since CBAs should be conducted according to different national characteristics [9]. For example, another generic Canadian CBA guide was published about CBA for general projects [8].

According to the Third Energy Package of EU, member countries are required to conduct CBA for the decision-making of smart meter roll-outs. After CBA analyses, 16 member states (>80%) have made the decision on roll-outs by 2020 or earlier; Poland and Romania had positive CBAs, but an official decision is pending; while 7 states (Belgium, Lithuania, Czech Republic, Portugal, Germany, Latvia, and Slovakia) had negative or inconclusive CBAs [9]. Besides theoretical research, the Department for Business, Energy & Industrial Strategy (BEIS) in the UK conducted a series of CBA on smart meter roll-out with estimation of the costs and benefits based on realistic tracking data of the meters' implementation process.

Summing up from the guidelines, the general approach to Cost-Benefit Analysis on smart meters projects should include the following contents:

Firstly, identify the boundary conditions, critical parameters, and the implementation procedures. From the insights to these smart metering guidelines [1], [3], and [4], the key parameters identified in the systematic approach of CBA on smart meter development include: project's implementation schedule, maturity of technologies implemented, electricity market prices and demand, carbon costs, peak load transfer and consumption reduction, time horizon of CBA, government macroeconomic factors, the discount rate, and impact of the regulatory framework on assumption/parameters. The integration of all these contents should be taken into consideration and applied to regional characteristics as a first step to identify the boundary and set the critical parameters.

Secondly, identify and monetarize the costs and benefits of the project implementation. This part uses corresponding formulas to estimate the benefits categories and relevant costs into monetary terms. The integration of this economic appraisal approach evaluates the direct and the indirect impacts about the smart meters projects [3], [4].

a. Review and describe the technology, elements, and objectives of the project;

b. Map assets into functionalities;

c. Map functionalities into benefits;

d. Establish the baseline;

e. Monetize the benefits and identify the beneficiaries;

f. Identify and quantify different categories of costs;

g. Compare costs and benefits.

Thirdly, conduct sensitivity and qualitative impact analyses. The last step illustrates the sensitivity and qualitative impacts analysis about the externalities and social impact for identifying critical variables of non-monetary appraisal affecting the CBA outcomes.

Identifications of the boundary and critical parameters are the important prerequisites for further research. Through the CBA steps, the costs and the benefits could be obtained in the tracking of the projects' implementation. CBA enables the performance of overall project design review and validation, in terms of the externalities and social effects of smart metering. Considering that smart meters project implementation is a long-term process, the evaluation criteria, timescales, and constraints may vary significantly according to different conditions, such as the technological advancements and policy changes, which should be taken into account.

3. Case Studies

In smart metering, the energy policy administration, the energy supply companies, power operators, energy services providers, metering manufacturers, meters asset providers and meters operators are all vital stakeholders and are responsible for the smart meter technical design and commercial distribution. Smart meters will replace traditional energy meters gradually to upgrade the energy system. As an intelligent facility, smart meter helps the consumers obtain the in-home service and real-time information of their energy consumption, which could affect their usage to enable their energy-saving. Smart meter could send automatic reading to the suppliers, instead of home visits for meter reading and obviate the original estimated bills to save labor costs of the energy suppliers and subsequent disputes. At the same time, the policy of ToU pricing could help to reduce the consumers' bills. Case studies on smart meter projects in UK and Canada illustrate the issues encountered in the progress of the smart meter implementation projects. Through these case studies, different public concerns about smart meters are discussed, including the potential health issues, the digital display problem, and the effects on energy saving and environmental protection.

3.1. Estimation of the benefits and costs of smart meter project: UK

From the EPRI report [1], the benefits obtained from smart meters projects should be analyzed from the perspective of benefits' categories and the beneficiaries. Total benefits could be calculated from separate perspectives in terms of the fundamental categories of benefits (economic, reliability and power quality, environmental, security and safety) and the beneficiaries' basic groups (utilities, customers, and society). Generally, the benefits to the utilities are the reduction of the operation, maintenance, and deferred capital costs, such as system security, process optimization, and investment planning improvement; the benefits to the consumers mainly come from the reduction of the energy charges, accurate consumption payment, better IT services; and the benefits to society include the reductions in negative externalities and related market failures, such as the reduction of greenhouse gas emissions. Thus, the total benefits are the sum-up of the three categories at large in monetary terms, taking into account both sensitive and qualitative impacts of possible changes.

From the report of BEIS [10], there are many categories of benefits from the aspects of economic, reliability, environmental, and security. The benefits for the consumers, composed of energy saving from the electricity-consumption reduction and the avoided cost of microgeneration metering amount to £5.30bn. Besides, the benefits from supplier companies, including the avoided costs of site visits, consumers' inquiries and overheads, reached £8.25bn. Others, combing the network-related benefits (£839m), generation benefits (£943m), carbon related benefits (£1.29bn), air quality improvements (£98m), and other key non-monetized benefits, the total benefits of smart meters project are reported to be £16,726m. The key monetized benefits in the UK's smart meter projects are illustrated as follows in Table 1 [10].

Table 1. Summary of the key monetized benefits in the UK's smart meter project

<table>
<tr><td rowspan="6">Benefits from Economic, Reliability, Environmental, Security</td><td>Type of Benefits</td><td>Sub-category of Benefits</td></tr>
<tr><td>Consumer benefits</td><td>Energy demand reduction;
Microgeneration.</td></tr>
<tr><td>Supplier benefits</td><td>Avoided site visits;
Reduction in incoming enquiries and customer service expenditure;
Prepayment cost from customers;
Better debt management;
Switching Savings;
Theft;
Remote disconnection.</td></tr>
<tr><td>Network-related benefits</td><td>Better outage detection and management for electricity DNOs;
Better informed decisions for investment in electricity network enforcement;
Avoided cost of investigating customer complaints on supply voltage quality;
Avoided losses;
Non-quantified DNO benefits.</td></tr>
<tr><td>Benefits from shifting electricity load</td><td>Generation short-term marginal cost savings from shifting electricity demand;
Savings in generation capacity investment from shifting electricity demand;
Savings in network capacity investment from shifting electricity demand;</td></tr>
</table>

		Carbon savings from electricity demand shift.
	Carbon related and UK-wide benefits	**Valuing avoided costs of carbon from energy savings; Reduction in carbon emissions; Air quality benefits.**
	Non-quantified benefits	**The benefits from further energy services market development and the potential benefits from smarter energy system development.**

[Legend: DNO=Distribution Network Operator]

Costs of the smart meter projects are measured in the project implementation, relative to the baseline. Some cost information can be obtained from the investment sector, and others could be estimated from the marketplace. The costs of the capital, operation, and transition are necessary and sufficient contents to be taken into consideration. The meticulous itemization of all important costs has been depicted in the EPRI report [1] and the European Commission's smart metering guideline [3]. The capital costs of infrastructure, equipment, fuel, installation, and labor are all included. Take the supplier companies for example, the costs mainly include the purchases and implementation for the smart metering equipment and technology; data tracking, collection, and notifications for energy assumptions; the promotion and operation of the project roll-out to the public [1].

As from the EPRI report [1], the general categories of costs are mainly obtained from the projects' budget tracking processes for handing capital costs, debt, depreciation, and taxes. The costs to be tracked and estimated through the program processes, namely: Capital investment, Operation and maintenance, Environmental cost, Losses and theft, Reliability, Energy security, as well as Research and development costs. Besides, the time horizon for the costs estimation should be on the same intervals with the benefits' calculation. The capital expenditure (CapEx) and operational expenditure (OpEx), reliability, environmental, and energy security are the general categories to be tracked for roll-out and estimated for the baseline.

Taking consideration of the main affected groups, the key monetized costs of installation, operation, and the In-Home Displays (IHDs) have reached £5.44bn in the UK smart meters project by 2016. The related costs of Data and Communications Company (DCC), including the costs of communications hubs provision, are estimated at £3.13bn. Besides, the costs of industry's IT systems and energy supplier amount to £1.00bn. In addition, the industry management costs, energy, the inefficiency of bill reading and other costs reached £1.42bn. The total costs of smart meter project in UK are reported to be £10,981m [10]. The description and scale of smart meter project' key monetized costs in UK are shown in Table 2 [10].

Table 2 Summary of key monetized costs of smart meter project in the UK

General Category of Costs of CAPEX, OPEX, Reliability, Environmental, Energy Security and others.	**Meter, communications equipment, installation and consumption feedback costs**
	Data and Communication Company (DCC) related costs
	Suppliers' and other industrial contributors' system costs
	Cost of capital
	Energy cost
	Increased costs of manually reading remaining traditional meters
	Disposal costs
	Legal and organizational costs
	Costs related to consumer engagement activities
	Cost arising from uncertainty during early deployment

As for the comparison of the costs and benefits, the net benefit (Present Value) of the UK's smart meter project amounts to £10,981million, taking into consideration a discount rate of 3.5%. After the costs and benefits are estimated, there are several summarized methods to present the final results of net benefits, including annual comparison, cumulative comparison, net present value, and benefit-cost ratio. These methods make comparison of the costs and benefits and provide different insights for evaluation.

Having laid out the in-principle framework, it must be said from an academic's point of view that the data required for a full CBA of smart metering is vested with different stakeholders and data collection needs to be coordinated with governmental intervention. Power utility companies, hardware providers and distribution network operators are usually commercial organizations and their cost and benefit data is not available in the open domain. It suffices to say that a CBA is only as good as the data input allows within the capability of the analyst and its commissioning body. Guidelines, by their nature, envisage the ideal scenario.

3.2. Smart Metering in Canada

The smart meters roll out was implemented with aggressive targets, but the lack of a proper CBA is one of the main controversial issues. The responsible government agency has an inherent responsibility in the management and effective implementation of such large and complex projects with the application of ICT. With hindsight, it was the ultimate responsibility of the government to oversee and guarantee the anticipated benefits achieved and costs of implementation within the budget of the project [2], [11].

Table 3. Perceived shortfalls of the smart meter project in Ontario from the audit report on the Ministry of Energy, Canada [2].

Criticisms leveled at the Program	**Decision to roll out smart metering not preceded by an appropriate cost-benefit study**
	Subsequent Cost-Benefit Study flawed
	Smart Metering costs to-date exceeding estimated costs and benefits
	Significant Smart Meter system development and integration difficulties encountered
	Peak-demand reduction targets not met
	Ontario's surplus power sold to other jurisdictions at loss
	Electricity billing levels varied by distribution companies
	Time-of-use (ToU) Pricing Model has had little effect on reducing peak demand
	Significant impact on ToU rates due to Global Adjustment not transparent to users
	Users complaint on Time-of-use (ToU) rates and billing errors
	Duplicatedprocessing by Provincial Data Centre and local distribution companies' in-house systems
	Inefficient smart meter data processing by Provincial Data Centre and distribution companies
	Unclear contract conditions for Provincial Data Centre's operating fee
	Inadequate monitoring of fire safety risk supposedly related to smart meters

Undeniably, smart metering is one of emerging technologies and applications of ICT to develop Ontario into a smarter society. The 4.8 million smart meters installed have contributed several benefits to Ontario, including the real-time consumption information, avoided site visits, and reduction in carbon emissions [11]. But, the stakeholders and the users were unhappy about lacking CBA on the smart metering initiative in Canada because of its complex and challenging characters, especially that Ontario was one of the first country in North America to roll out smart meters [2]. It was reported that the Ministry of Energy of Canada overstated some CAD 600 million net benefits over 15 years, which should be blamed on the lack of CBA. The majority of distribution companies reported no operational saving, but the operating costs relating to smart metering actually rose. Users' savings were also limited, with more than 50% of the distribution companies receiving high volume of complaints from the smart metering and TOU rates, and most of the households could not find any reduction in their bills. Thus, the main benefits for the distribution companies and users were not achieved [2]. It was recommended that Canada needed to conduct CBA to monitor the net benefits through tracking the actual benefits and costs of the implementation process urgently, and the coordination of smart metering and ToU pricing in optimizing the electricity usage should be improved to switch the peak demand and reduce the infrastructure costs [11].

3.3. The pros and cons of the smart meter projects: Canada and UK

The main difference between the original meters and the smart ones are the consumers' usage information being sent to the utility companies automatically through the data communications company's (DCC) networks. The pros of the smart metering system include better customer information, higher reading frequency and quality of billing data, as well as improved load profiling and forecasting [3]. From the consumers' perspective, the pros of smart meters include: real-time information of energy consumption instead of the estimated billing; optimization of energy usage to reduce the power fees and emissions; and switching suppliers can be easier and smoother. Smart meters roll-out hope to fulfill the needs of the UK by the end of 2020 to be achieved by the energy companies [12]. Consumers should receive an in-home display, which shows how much gas and electricity is being used in near real time. The technology offers consumers a modern service that puts them in control, helps them to save money and use less energy with up-to-date information on their energy as they use it.

Smart meters and the charging policy of ToU can help consumers manage their electricity consumption through using electricity at different times of the day. According to the Ontario Energy Board's (OEB) report, the average electricity consumption of a typical Ontario consumer amounts to 750 kWh per month, with 2/3 of the overall amount during off-peak hours and the remaining consumption distributed between mid-peak and on-peak [13]. In the UK, the latest findings from Smart Energy Outlook indicate that nearly 80% of smart meter users agree that they are taking steps to reduce their energy use, and over 80% hold the opinion that they could manage their energy costs better with smart meters [14]. The British welcome this smart energy facility with the purpose of reducing energy consumption and convert UK into smart country, and they should thank largely the Government for successful promotion of smart city.

On the downside, smart metering is facing a series of challenges, including the potential health issues, the digital display problem, privacy leakage, cost overrun, and cybercrime, which are among the top concerns of the public.

Before the smart meter projects rolled out, there were public concerns of the potential health issues due to Electromagnetic Field (EMF) pollution, which used to be voiced out at the beginning of project promotion in the UK. The worry about potential health issues was that radio-frequency microwave radiation of the system may lead to EMF pollution. But the public health professionals and scientists have emphasized that the human exposure to this type of low-level radiation is even less than the smart phones which are being used commonly in daily life. And the digital-divide problem of smart city projects also exists in smart metering, which has long faced complaints that the facilities are unfriendly to the ageing, lower-income, or lower-education populations. The digital-divide is a global phenomenon with the internet development, but the enthusiasm of bridging digital-divide is making improvements gradually. For example, Siemens are developing a new smart metering facility with simple, stable, and friendly user interface. Meanwhile, the big fear of personal information disclosure still exists, although information security system of public security has been in place to prevent the possibility of hacking and ensure the security of users' information in the design of meters and the back-office system in most jurisdictions. Worse still, however, was the worry about safety of the smart metering facilities, ending up in a lot of equipment being removed, because some fires were thought to be caused by smart meters in Canada.

Without bias, new public concerns about the significant over-budget cost for smart meter projects have been raised in UK and Canada recently. The delay of smart metering roll-out and the initial equipment's out-of-service account for a significant proportion of the exceeded budgets in the UK, and even worse the costs are continually increasing. According to the latest research from BEIS [10], most British support the smart meter roll-out, but with the delay of implementation and a batch of initial smart metering equipment failing to work effectively for technical reasons, the smart meter project's cost will reach £12 billion, with £1 billion exceeding government's pervious budget. For Canada, the smart meter project in Ontario was confronted with serious postponement and overspending, and the public was anxious about the safety and security of smart metering, coupled with continually rising.

4. Conclusion and Recommendations

This paper describes the manner of evaluating the costs and benefits of smart meter projects, depicting the application of relevant Cost-Benefit Analysis (CBA) approaches as advocated in related guidelines.

CBA assist in validation of the externalities and social effects of the smart metering. Considering that smart meter project implementation is a long-term process, the evaluation criteria, timescales, and constraints may vary significantly according to different conditions, such as technological advancements and policy changes, which should be taken into account. In CBA, the costs and the benefits of smart meter projects can be itemized and monetarized. From the case studies, useful experience has been gathered for sharing, cumulating in the following recommendations for improvement of future smart meter projects.

Firstly, proper and efficient coordination of smart metering and ToU pricing is necessary, so that electricity-usage can be optimized to reduce the peak demand and related infrastructure costs.

Secondly, the application of maturity and improvement of technologies should ease the public's anxiety about the safety of smart meters.

Thirdly, People are paying more and more attention to personal privacy in modern society, with opponents hold the view that data of smart metering will be used indiscriminately by the supplier companies. Thus, seeking consumers' consent is essential, together with explicit information on the future usage of collected data.

Last but not the least, it is necessary to conduct Cost-Benefit Analysis or establish a business case for evaluation prior to implementing a smart metering initiative to assess benefits, costs, and associated risks to ensure value for money. Besides, the wide application potential of ICT should receive sufficient recognition (for its upside) and concerns (for its downsides) in cost and benefits studies.

References

[1] "Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects," Electric Power Research Institute 2010.

[2] "2014 Annual Report," Auditor General of Ontario 2014.

[3] "Guidelines for Cost Benefit Analysis of Smart Metering Deployment," European Commission, Joint Research Centre, Institute for Energy and Transport 2012.

[4] "Guidelines for conducting a Cost-benefit analysis of Smart Grid projects," European Commission, Joint Research Centre, Institute for Energy and Transport 2012.

[5] P. Tsarchopoulos, "21st Century Cities: Global Smart Cities Primer,"

[6] V. T. V. Lam, "Smart Metering – An Enabler for Smart City," presented at the Joint Symposium 2016 BUILDING A SMARTER CITY VIA LATEST TECHNOLOGIES, Hong Kong, 2016.

[7] E. Q. R. Toh, Cost-Benefit Analysis: Cases and Materials. 2011.

[8] "Canadian Cost-Benefit Analysis Guide Regulatory Proposals," Treasury Board of Canada 2007.

[9] P. Josef Žádník, "Cost-benefit studies(CBA) for smart metering roll-out in the EU Overview and way forward," presented at the SMART GRIDS IN PRACTICE, Hotel Double Tree by Hilton Bratislava, 2015.

[10] "SMART METER ROLL-OUT COST-BENEFIT ANALYSIS," Department for Business, Energy & Industrial Strategy 2016.

[11] "2016 Annual Report," Auditor General of Ontario 2016.

[12] "smart meters: a guide, January 2017," Department for Business, Energy & Industrial Strategy2017, Accessed on: 24 January 2017.

[13] "Ontario Energy Report Q1, 2017", Ontario Energy Board, 2017

[14] "Smart energy outlook (August 2016)," in "The voice of the smart meter rollout," SMART ENERGY GB 2016.

Acknowledgment

The work described in this paper was fully supported by a grant from the General Research Fund of the Research Grants Council of the Hong Kong SAR Government (Project no. PolyU15233116).