جـامـعـة زايـد
ZAYED UNIVERSITY

College of Information Technology

Smart Meter: Toward Client Centric Energy Efficient Smartphone Based Solution

By

SALAM ISMAIL RASHEED KHANJI

M80006416

CIT 599 Independent Research Report

Master of Science in Information Technology Specialization in Cyber Security

Supervisor: Dr. Asad Masood Khattak

January 2016

Abstract

Smart city applications are developed to provision the urbanization streams and massive development all over the world. This can be achieved by offering real time responses to new challenges faced by different sectors, such as health, transportation, water and energy. Smart meter is one of the smart city applied solutions which facilitate to overcome the increased demand on electricity. This research examines smart meter in the context of energy sector to exploit its related features in the process of Demand Side Management (DSM) to facilitate energy efficiency. It studies the future of integrating client in DSM through developing a client centric and energy efficient Smartphone based application. The feasibility of such application is reflected on the smart meter business model adopted in Abu Dhabi. Consequently, fundamentals are established to initiate cost-benefit analysis to evaluate the rolling-out of advanced metering infrastructure.

Keywords— *smart meter; smartphone application; energy efficiency; demand side management; advanced metering infrastructure.*

This research study was supported by The Regulation and Supervision Bureau Abu Dhabi which provided expertise that significantly assisted the comprehensive concept overview of Smart Meter in Abu Dhabi.

Acknowledgement

This work indeed enlightened my knowledge and enriched my experience from different perspectives which further summarized the immense efforts achieved during the past two years in my Master's program at Zayed University. I would like to take this opportunity to express my gratitude to everyone who encouraged and supported me throughout the research process and granted me with unlimited assistance. I would like first to sincerely thank my supervisor Dr. Asad Khattak for his aspiring guidance and for his truthful and illuminating views as I would not have been able to achieve this milestone smoothly without his dedicated supervision.

I would also like to show my gratefulness to all sincere teachers and instructors at Zayed University who participated in shaping my knowledge, and supervised my academic achievements to meet the outside business needs. Furthermore, I would like to thank my colleagues in my cohort who were cooperative and supportive throughout different program courses.

My sincere appreciation goes to my supportive husband, Sameer, for his passionate and encouragement because without them I would not have accomplished this major achievement. To my little grown up kids; Omar and Ali whom I had been missing during the past two years. Thank you for being patient and always supportive in the critical time.

I would like to express my humble recognition to my inspiring model, my mother. For her infinite love and prayers throughout my whole life which helped me to overcome different obstacles. Finally, this work is totally dedicated to my soul mate, my late father Ismail Khanji, who passed away last year in the middle of the journey. All the hard work and efforts put forth in this work were merely motivated by his words and pearl wisdom.

Table of Contents

I. Introduction....................1

II. Smart Meter Background....................4

III. Smart Meter In Abu Dhabi....................7

III.1 Powerwise Smart Meter Trial....................7

III.2 Abu Dhabi Water and Electricity Authority (ADWEA)....................8

III.2.1 Smart Energy Meters....................9

III.2.2 Wireless Communication Platform....................9

IV. Smart Meter Future Trends....................10

IV.1 The proposed Solution Design....................10

IV.2 Smart Meter Simulation....................13

IV.2.1 Experimental Scenario....................13

IV.2.2 *SmartMeter* Application....................14

IV.2.3 *SavePower* Application....................14

IV.2.4 *Orvibo* WiFi Smart Socket....................14

IV.2.5 Real-time Feedback....................15

IV.2.5 Database and Readings....................15

V. Smartphone Based Solution Evaluation....................16

V.1 Smartphone Based Solution Benefits....................17

V.2 Preliminary Requirements of Cost-Benefit Analysis of Smart Meter....................20

VI. Smart Meter Security Aspect....................22

VII. Conclusion....................24

References....................25

I. Introduction

The United Arab Emirates (UAE) is an important partner country and a responsible supplier in the global energy market, as it has the world's sixth largest oil reserves and the fifth largest natural gas reserves [1]. Abu Dhabi holds dominantly 94 percent of the UAE's oil resources (92.2 billion barrels), where Dubai contains 4 billion barrels. The economic and population growth have increased a massive demand on electricity within Abu Dhabi. Residential, commercial and institutional sectors are the dominant parties with the highest electrical usage consumption estimated to be 10 times the world's average consumption per unit in 2008 [2]. Consequently, Abu Dhabi's government has launched many initiatives to identify alternative means to produce the power required to enrich its economy. One of the latest initiatives is the smart metering grid, which will help Abu Dhabi in achieving its 2030 goals by managing domestic demands on energy. Masdar, a renewable energy corporation in Abu Dhabi, and guided by Abu Dhabi's Economic vision 2030, the UAE government is currently promoting to empower its experience in the energy sector by investing in the renewable energy resources. Abu Dhabi's government has committed to secure 7% of its total energy needs from renewable resources [3].

Smart grid is one promising solution which enables the penetration of renewable resources as in solar and wind energy; hence allowing Abu Dhabi to achieve its 7% commitment. The cornerstone of smart grid technology is the smart meter (SM), which offers to communicate information (bi-directional communication) of energy consumption and production between the supplier unit and consumers. It opens the opportunity to involve effectively client roles and to transform them into 'prosumers' where they consume and produce power too. It delivers valuable information to its consumers, such as billings, electricity usage patterns and normative comparison feedback. Consequently, consumers will be able to be true agents in the energy sector by reducing their energy consumption or selling the unutilized energy back to the provider. This powerful feature in the smart meter, which favors the consumers' responsiveness and effective decisions, formulates the Demand Side Management (DSM). Consumers change their normal electric usage in response to price changes or to other mean of incentives [4].

Smart meter technology has smart-coded interfaces known as in-home displays (IHDs) which enable consumers to view and control their electrical consumption. IHDs as in OPOWER, Microsoft Hohm, and Google's now-defunct are all examples of user centric energy management applications. Moreover, through the use of Application Programming Interface (API), custom Smartphone applications can be developed to simulate IHDs and further to empower client to control home appliances. Hence, reducing power consumption based on precise recommendations suggested as feedback from the smart meter installed at the house unit. Due to the broaden use of Smartphone, and the rapid evolution in Smartphone applications, consumers can be integrated in the process easily and efficiently if some precautions are considered during the design and development phase.

The effectiveness of such applications or IHDs can be measured by the real-time feedback they support. To our best knowledge, consumers are interested in reducing their consumption but they have no rigid knowledge on how to implement, or there are no goals previously established so that they can seek after. Feedback varies from being regular which delivers the level of power consumption in total, consumption plus related cost, or consumption associated with the cost plus normative (social) comparison. More enhanced feedback might include energy tips about savings, incentive awards, educational feedback, and appliance-specific feedback which is customized to reflect the consumption of a particular home appliance as in the air conditioning (AC).

Abu Dhabi's climate is very hot and dry, and AC forms over 60% of total electricity consumed in the residential (domestic) sector [2]. From a consumer standpoint, it is imperative to control the AC units in times where his/her house unit is not occupied. This would indeed change the electrical usage pattern, and hence induce lower consumption. However, when no alert mechanism is deployed as an alarm to bring the consumer's attention toward manipulating the AC's set point or even to switch it off, consumers might not contribute effectively to power saving. Consequently, Smartphone applications integrate client to control and reduce energy consumption utilizing various valuable feedback communicated by the smart meter infrastructure.

This research study suggests a comprehensive overview of the current status of smart meter technology in Abu Dhabi, being the first Middle East country (or city) which has completed the phase-one rollout of smart meters in the energy sector according to Abu Dhabi Water and Electricity Authority (ADWEA). It proposes a centric and energy efficient Smartphone based solution to facilitate energy efficiency through DSM. The proposed application *SavePower* offers consumers to control AC units remotely based on real-time feedback communicated by SM. It exploits SM features efficiently with no additional infrastructure for the purpose of inducing lower electrical consumption and decreasing carbon footprint as well. The SM unit is simulated through *SmartMeter*, a Smartphone application which generates electrical readings for a particular household and communicates electrical data back to *SavePower*. The feasibility and usability of the proposed solution is evaluated according to the SM business model adopted in Abu Dhabi through quantifying the reduced electrical consumption. Moreover, its environmental implication is proved to be beneficial to Abu Dhabi's sustainability plan as it reduces around 2% of carbon emission annually in Abu Dhabi.

II. Smart Meter Background

The economic development and population growth have increased the demand on energy all over the world. Moreover, the urbanization will most likely increase the share of global energy to satisfy urban demand. Consequently, new novel, robust and cost effective methodologies are required to enable energy demand management [5]. Smart grid infrastructure represents such a methodology which is based on the interaction between consumer and provider through smart meters and control systems [6]. Smart meter offers to tackle the increased demand on electrical energy and an international exchange of experiences is required among the many pilot and demonstration projects so that to offer an excellent opportunity for the exploration and lessons to be leveraged.

Italy, which is one of the leading countries in this area, ordered to implement smart meters in 2008 in order to reduce non-technical losses rather than energy reduction reasons [7]. By the end of 2011, it was estimated that about 95% of the country had smart meter installed. Italian consumers have a web site to access their electrical energy information along with IHDs. In Spain, number of smart meters installed at the end of 2013 were estimated to 7,910,569 m, where 75% of them were integrated effectively [8]. On the other hand, Germany's decision to implement the smart meter technology was driven by a cost-benefit analysis which recommended to integrate the smart meter only to new buildings and major consumers and facilities as well. They have proposed the year 2029 as the target due date where 38,500,000 smart meters to be installed [9]. Whereas in UK, the cost-benefit analysis estimated to gain about 10.9 billion pounds by the year 2030 through utilizing smart meter technology [10]. While in France, the plan is to install a total of 35 million meters by the year 2020 [11], with features as in managing the charging of the electrical vehicles, monitoring the status of the low voltage network, and controlling the production of electricity in the low voltage network as well. Finally, in USA, and in California in particular, there have been many pilot projects between 2009 and 2011, and the deployment phase was planned between 2012 and 2015 [12]. The major concern was to engage users and to allow them to save energy and money by offering them an access to their readings as well as controlling their electrical consumption levels.

Once fundamentals of smart meter technology have been shaped, the future trends shall be addressed to allow efficient utilization of its related features. Aside from the remote billing capability, its direct contribution in DSM is related to the effectiveness of the real-time feedback the SM generates. Shultz et al. [13] identified types of feedback and their implications on user's electrical usage behavior. Feedback associated with kWs consumed, related cost, and a normative comparison between the user's last month/day/ year consumption as well as between the user's neighbor's consumption would induce low electrical consumption. These feedback can be generated by the IHD or by Smartphone based application which enables the consumer to control his/her electrical usage pattern. However, feedback alone might not be sufficient unless another useful information is considered to change the user's behavior in general toward the need to reduce electrical consumption. Nachreiner et al. [14] highlighted the psychological long term learning process where feedback must be accompanied with detailed knowledge of saving potentials along with how to perform such actions, and a motivation to keep the process ongoing. This can be achieved by enriching the Smartphone based application with energy saving tips and the push notification mechanism to alert the user when and what action to undertake.

There have been number of ICT monitoring products deployed in the electrical field, where they can be classified into solutions to monitor the entire consumption of the household, or to deliver a home appliance-specific feedback. For instance, the Onzo [15] and TED-1000 [16] are examples of visualization products using portable display. Due to the complex installation required behind the meter or in the fuse box, users might not be willing to buy or deploy. Examples of the second monitoring products are the power outlets as in Kill-a-Watt [17] and Smart Linc [18] where they offer monitoring, controlling and automating the attached device. Each time the user wants to monitor a different appliance, it requires him/her to plug it into a smart outlet or to deploy various sensors all around the house; consequently, creating extra adoption barriers. Examples are Jiang et al. [19] and Paradiso [20]. The aforementioned barriers can be overcome by utilizing the built-in features within the SM which further facilitate the process of developing IHDs or a Smartphone based application to easily integrate client in controlling the electrical consumption. Weiss et al. [21] proposed to develop a mobile-based application by which they integrate the SM web-based interface easily without the need for complex installation and configuration around the wiring. Their complete architecture had three distinct components: the smart meter along with the monitored device connected, a gateway (web-based interface) which generates the related electrical readings, and the mobile user interface which delivers the real-time feedback of the connected device. However, their proposed architecture didn't allow users to interfere with connected device in order to control its electrical consumption.

This research study discusses the prosper future of integrating the SM in UAE, Abu Dhabi in particular, positioned as one of the leading Middle East country in this field. It identifies the possibilities of engaging client to be a true agent in the energy sector through integrating smart technologies as in Smartphone based application to control AC as per it forms the highest electrical usage pattern. Moreover, the research study will also investigate the feasibility of such integration by estimating the electrical reduction as well as carbon emission through a cost-benefit analysis. The research would indeed exemplify Abu Dhabi as a successful role model for other countries in the Middle East where the deployment of SM is still in its early stages.

III. Smart Meter in Abu Dhabi

Maximum electricity usage pattern increases when everyone uses electricity on the same time of a day. This is known as 'peak demand', which mainly takes place between 2 pm till 8 pm in Abu Dhabi. For the electrical grid to generate electricity so that to meet the peak demand time, this would overload the infrastructure (power plants) and more fuel is required to meet such demand [22]. Consequently, it is imperative to everyone's interest to encourage the even use of electricity during the day. With the increased demand on energy, Abu Dhabi has started the SM initiative in 2006 through pilot and demonstration projects to overcome the peak demand dilemma and to induce lower consumption. However, aims were initially targeting remote billing capabilities, remote customer connection/disconnection, pre-paid and post-paid options and to facilitate tenants moving between apartments. Later on, consumer's engagement was considered as another objective of SMs.

1. Powerwise Smart Metering Trial

Abu Dhabi took the initiative and established a pilot project in 2012 in order to engage consumers to reduce electrical consumption during peak demand and to save them money accordingly [23]. This was achieved by Powerwise, a regulated-led initiative, launched by the Regulation and Supervision Bureau in 2011.

As part of the Powerwise strategy, the Smart Metering Trial, was launched for the purpose of: (1) disseminating awareness among consumers, (2) studying their electrical usage behavior, (3) and engaging consumers in the process of DSM by utilizing dynamic electrical pricing as incentives. The test group was composed of 400 participants living in villas and a control group composed of 200 participants with no related directions of the trial. The test group participants were subjected to two different time-of-day tarrifs; peak price and off-peak price. Where lower price is allocated to off-peak timing to the purpose of encouraging consumers to shift their electrical activities to the off-peak time. Moreover, they were supplied with P350 EcoMeter customer display units (CDUs) in order to support visualization of the current and historical consumption along with the related cost. Additionally, participants received educational material and tips on how to save electricity and how to shift consumption to off-peak time during the day.

The communication interface in the smart meter used was the general packet radio service (GPRS), though a mobile company (Etisalat) to communicate data (consumption level) to the CDU by sending readings as SMS every half an hour. The CDU visualizes the consumption level and calculates the related cost based on the tarrif (off-peak/peak). Also, it offers to compare billing costs so that consumers can be aware of his/her electrical usage pattern. Other readings are interpreted by CDU as in ambient temperature, humidity and carbon emissions.

Initial results showed that 65% of the participants were able to save electricity over the first month of the project, and this is due to the time-of-the-day pricing (off-peak/peak pricing) incentive. Moreover, the SM real-time feedback communicated to the CDU utilized different information and visualization mechanisms which contributed in the change of consumers' electrical behavioral responses. Consequently, consumers can be engaged effectively in the DSM process; however, their fidelity shall be maintained. This can be achieved through adopting more efficient solutions such as dynamic pricing and incentives, controlling appliance electrical usage, using low-cost and efficient displays such as Smartphone applications.

2. Abu Dhabi Water and Electricity Authority (ADWEA)

ADWEA[1] started to adopt the concept of smart grid since 2006, and the advanced metering infrastructure (AMI), the most visible, has been under way for some years. The 500,000 consumers in Abu Dhabi and Al-Ain have been connected to the smart grid [28]. Smart gird in the context can be applied to any situation where real-time communications are required, and ADWEA has extended this concept to control both water and electricity.

Technology Partners (TP), a market leader in the Middle East, implemented the sophisticated AMI for ADWEA [29]. They got involved when it was realized that the GPRS is no longer efficient solution to provide the bi-directional communication, where it suffered from poor data penetration and incomplete coverage. Moreover, UAE has two communication providers and they don't guarantee the coverage for all SM points plus cellular transmissions can be expensive. Other solutions, such as WiMAX and power line communication (PLC) cannot be used in UAE due to spectrum unavailability. The promising solution offered by TP was WiFi mesh network which connects multiple metering points and SCADA (supervisory control and data acquisition) measurements all over inhabited areas of the Emirate.

[1] Abu Dhabi Water and Electricity Authority http://www.adwea.ae/en/home.aspx

Lee et al. [30] compared between different wireless communication standards as in ZigBee, Bluetooth, ultra-wideband (UWB) and Wi-Fi. The comparison would help engineers choosing the appropriate communication medium when considering SM. ZigBee and Bluetooth are favored in terms of low power consumption; however, WiFi supports longer connection and devices with a considerable power supply.

1.1. Smart Energy Meters

SM as a single unit, is used for monitoring, measuring and storing meter data temporarily. Multiple SM units when connected together with set of communication protocols and network infrastructure form the AMI (Fig. 2). The Landis+Gyr[2] E-350 meter shown in Fig. 1 is used by ADWEA which has features as scheduled remote reading, automatic load shedding, remote configuration for multiple traffis and outage alerts.

Fig. 1. Landis+Gyr E-350 Smart Meter

1.2. Wireless Communication Platform

The latest generation of Machine-to-Machine network provided by the Silver Spring[3] is utilized by ADWEA [29]. It provides the wireless connectivity to create mesh network between SM units as well as the reliable bi-directional networking infrastructure. The crucial component of SM is the communication module, which uses a serial connection to communicate with the meter. It captures consumption data, demand/reset functionality, net metering, event log and remote connect/disconnect actions. The same technology has been deployed by TP and Silver Spring in many countries along with many success stories as in Australia, US, New Zealand and Brazil.

[2] http://www.landisgyr.ae/
[3] Silver Spring founded in 2002 to implement IoT all over the world http://www.silverspringnet.com/

IV. Smart Meter Future Trends

The proliferation of advances in innovations and technologies will further facilitate DSM process, where various novel solutions are fundamentally identical. However, they offer diverse options to exploit SM technology efficiently from different perspectives. The functionality of SM is expected to become prosper especially when being integrated with the development of electronic circuits, control systems, monitoring systems and communication technologies [24].

1. The Proposed Solution Design

Fig. 2 demonstrates the advanced metering infrastructure (AMI) where the proposed Smartphone based solution *SavePower* can be engaged to simulate an access point between consumers and AMI. There are multiple network layers for collecting real-time feedback and for communicating readings data, which all collaborate in designing the Smartphone application [25]:

a. Home Area Network (HAN): where IHDs or the Smartphone applications rely on to integrate the consumers in controlling and visualizing the electrical consumption. It is mainly composed of a collection of sensors and actuators. Mode of communications can be as ZigBee, cognitive radio or RF transceiver.
b. Building Area Network (BAN): where the same concept of HAN can be applied; however, the control targets the whole building unit instead of a single household.
c. Neighborhood Area Network (NAN): combination of HANs and BANs, where all information related to electrical consumption, appliances control and security alarms are interpreted to generate normative feedback. Normative or social feedback motivates the consumer to reduce consumption when comparing their readings with their neighbor readings.
d. Area Network (WAN): connects data concentrators which collect data from multiple SMs and exchange it with the main AMI head-end which is the control center unit. Communication modes may vary such as Wimax, 3G/GPRS and broadband power lines (BPL).
e. Smart Meter Gateway (SMGW): a central communication unit required to maintain the bi-directional communication between SMs and consumers, and between SMs and the control center unit.

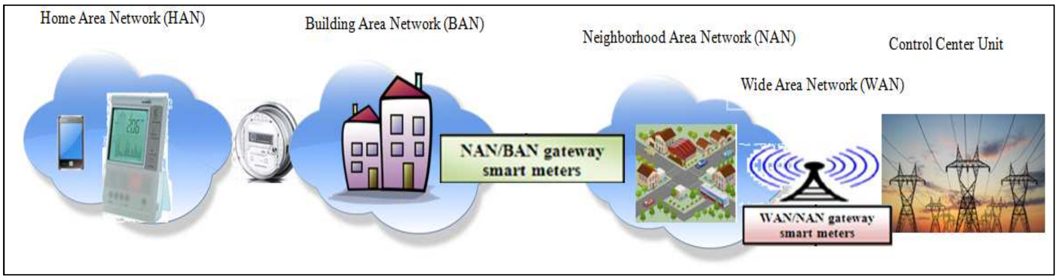

Fig. 2. Advanced Metering Infrastructure (AMI) - The proposed solution is located in HAN along with home appliances. SM works as a gateway to communicate electrical data consumption between *SavePower*, data concentrators in BAN and NAN, and the control center unit.

In the proposed Smartphone application, two modes of communication are available: control and feedback mode. Control mode is responsible for communicating consumer's requests to the smart meter, and actions are undertaken accordingly. Fig. 3 illustrates the control mode, where parties as in the smart meter unit, control center unit and consumer's AC unit are all engaged in the Smartphone application. However, the feedback mode depicted in Fig. 4, is based on the real-time readings generated by the SM every half an hour, and readings saved at the control center unit database. Consumer sets the preferences of his/her SM and control mode is set accordingly. For instance, the consumer specifies which home appliance he/she wishes the SM to control(AC in this study) and under what criteria this control shall be undertaken. Criteria can be based on the GPS location of consumer (holder of Smartphone) or specific threshold that controls the AC's workload overuse.

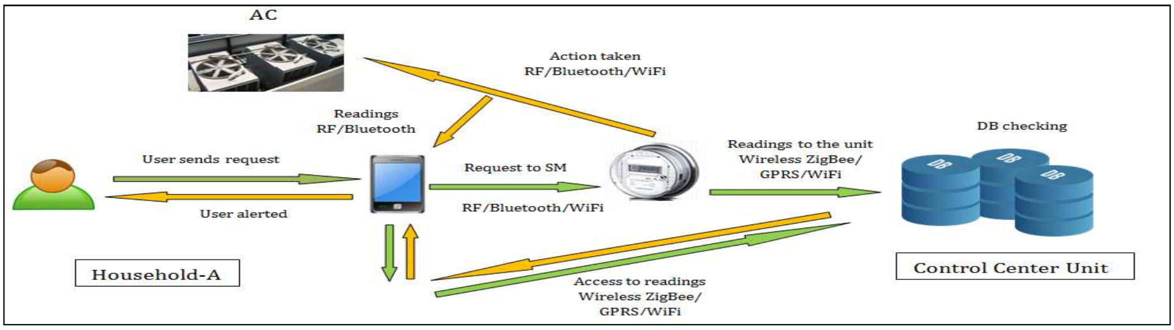

Fig. 3. Proposed Smartphone Application (Control Mode) - Consumers set their SM preferences using *SavePower* according to which SM controls AC. Preferences are sent via Bluetooth by *SavePower* and SM controls the AC via WiFi remotely. Criteria can be either GPS position or an overuse consumption threshold.

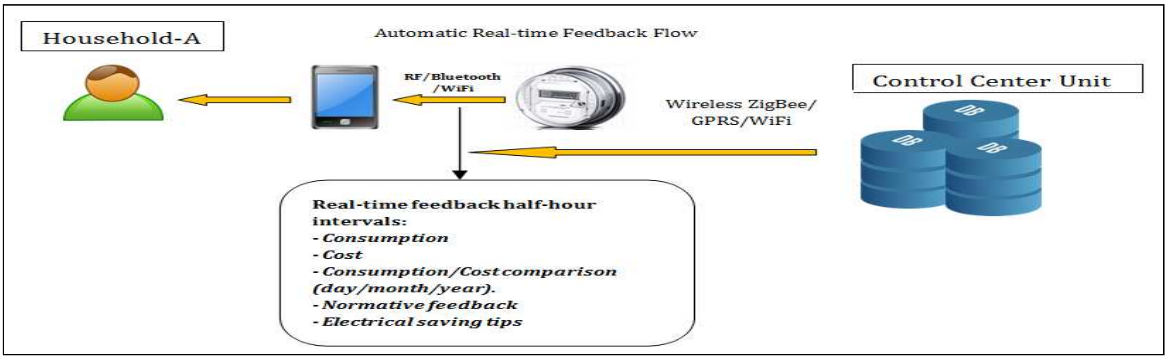

Fig. 4. Proposed Smartphone Application (Feedback Mode) - *SavePower* offers to visualize consumption related data with no automatic control of AC by SM. Real-time feedback is retrieved every half an hour from SM. Consumers may wish to control their AC randomly by requesting their SM to switch it on/off the time they select.

The proposed application has the following four main interfaces:

f. **User authentication**: Every consumer has his/her own credential maintained by the Control Center Unit. These credentials are provided from ADWEA (once registered) which identify the consumer's meter readings. Once authenticated, the user is allowed to access his/her consumption related data from the Control Center Unit database.

g. **Policy:** The consumer sets the preferences which direct the SM on what bases readings are measured and sent to the Smartphone application. Options are: what appliances to control and how to control them.

h. **Control**: Once preferences are set by policy, the SM is deployed and appliance's control is set accordingly. Control can be either manual where the consumer requests SM to turn on/off AC anytime, or automatic where SM turns on/off AC based on the criteria selected in the policy.

i. **Feedback**: Real-time feedback to better visualize consumption readings as in AC consumption, related cost, carbon emission, total consumption, total cost, total carbon emission and comparison in readings between the current and yesterday's readings, and between current readings and his/her neighbor's readings. These readings are collected from SM and consumer's related readings in the control center unit.

2. Smart Meter Simulation

SM is an embedded system which can have three cornerstone components: electric meter, processing unit and communication module [26]. Measuring electrical consumption is the responsibility of the electric meter which translates readings to the processing unit. In turn, the processing unit will process and store the information generated from both electric meter and communication module. The communication between HAN and the Control Center Unit is maintained by the communication module.

In order to simulating the structure of SM and all the surrounding AMI architecture, the design adopted in both [26] and [27] will be utilized in the proposed Smartphone based application. Faisal in [27] suggested a model where the intrusion detection system (IDS) can be either within SM box or outside the box, and readings as in consumption (kW), time duration, related cost and related carbon emission are collected from SM. In the proposed application, the same readings data are utilized to simulate the SM functionalities; however, the consumption will be customized for the AC.

1.1. Experimental Scenario

In order to demonstrate the logic of the application, two Android applications and a smart socket were used. *SavePower*, is the proposed Smartphone based application which each consumer can download from the Google play. *SmartMeter*, another Android application which simulates SM in order to generate readings every half an hour and to control the AC based on the preferences set by the consumer. To simulate controlling AC, we used Orvibo WiFi smart socket by which any electrical appliance connected through can be controlled remotely. The objective is to connect *SavePower* and *SmartMeter* applications through Bluetooth, and to control the smart socket by the *SmartMeter* application through WiFi. Consequently, the logic flow of both communication modes discussed before can be achieved.

1.2. *SmartMeter* Application

This application simulates the logic of the SM by using Android Studio 1.5 IntenlliJ IDEA to design and to develop. It has a simple interface which populates readings based on the preferences set by the consumer in *SavePower* application. SQLite database is created to save readings for one day, and readings are pushed to *SavePower* application each half an hour. Connection between *SavePower* and *SmartMeter* is maintained through Bluetooth, where the authenticated consumer is only obliged to connect to his/her SM unit (*SmartMeter*). It is important to note that each consumer has a unique meter ID.

1.3. *SavePower* Application

This application represents the centric and energy efficient Smartphone based solution. The consumer can be integrated efficiently in the DSM process by installing this application from Google Play. It handles the authentication mechanism where consumers use their credentials provided by ADWEA (client ID & meter ID). Once authenticated, consumer can connect to *SmartMeter* (SM unit) through Bluetooth, and to set his/her preferences which direct the *SmartMeter* on which appliance to collect readings and how to control it.

For the time being, *SmartMeter* is supposed only to control AC. Control can be either by a specific threshold which sets the AC's workload overuse, or based on the GPS location of the consumer. However, *SavePower* determines the GPS location and passes it to *SmartMeter* so that to control AC accordingly. Usually, 2 km is quite enough distance to switch AC on/off; however, for this experimental scenario a shorter distance was utilized (about 10 m).

1.4. *Orvibo* WiFi Smart Socket

Home appliances must be smart so that to control them remotely if possible. Smart socket can be used which controls the current that flows through specific appliance connected to it. In our experimental scenario, we connected a table lamp to this socket so that *SmartMeter* can switch it on/off based on preferences set by consumer in *SavePower*.

1.5. Real-time Feedback

IHDs which were used in the pilot phase, 'Smart Metering Trial' in Abu Dhabi, utilized feedback as in total consumption, total carbon emission and comparing readings with yesterday readings. To engage consumers effectively, their fidelity must be maintained through better visualization of feedback. *SavePower* populates feedback from both *SmartMeter* as well as the database of control center unit. Calculations of the related AC consumption cost, total consumption cost, AC carbon emission and total carbon emission are all done by *SavePower*. Moreover, the normative feedback is pulled from the control center unit database to further encourage consumer to save energy. Fig. 5 below illustrates the experimental scenario.

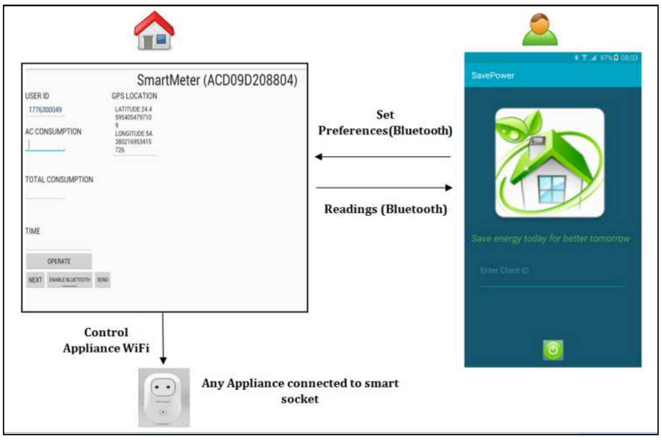

Fig. 5. Proposed Solution (Experimental Scenario) - *SavePower* hosts the control center unit database. *SmartMeter* has the GPS position the same as the consumer's household. *SmartMeter* hosts a temporary database for the specific consumer's household which is maintained for one day before being flushed with new readings.

3. Database and Readings

There are number of parameters that should be considered while measuring the total electrical consumption such as the square feet area of the house, number of occupants, what current appliances are on, ambient temperature and ambient humidity. In Abu Dhabi, summer time specially in June, July and August, records the highest consumption readings for all households. In our experiment, we have focused on collecting readings in summer time and later to study the feasibility of the proposed Smartphone based application.

Different houses were utilized and the collected readings were composed of AC consumption, total consumption, and specific time recorded (each half hour). Table 1 summarizes sample of readings used to populate the database of both control center unit and SM.

Table 1: Sample of the Experimental Database - Readings are generated reflecting summer time in Abu Dhabi (June - August). Different square feet areas are considered to reflect different electrical usage patterns. Readings are generated in both peak and off-peak time in Abu Dhabi.

House Unit	AC Consumption	Total Consumption	Time
	KWh	*KWh*	*Each 1/2 h*
Apartment 100m^2	0.94	1.18	10-10:30 am
Client ID:	1.13	1.38	11-11:30 am
1776300049	1.31	1.51	12-12:30 pm
Meter ID:	1.69	1.95	2-2:30 pm
ACD09D208804	1.88	2.15	3-3:30 pm
	1.5	2.2	5-5:30 pm
Apartment 150m^2	1.12	1.35	9-9:30 am
Client ID:	1.4	1.7	10-10:30 am
1889701050	1.68	2.1	11-11:30 am
Meter ID:	2.8	3.2	3-3:30 pm
ACD89E317502	2.24	2.92	5-5:30 pm
	1.72	2.85	7-7:30 pm
Villa 200m^2	1.37	1.81	8-8:30 am
Client ID:	1.9	2.42	10-10:30 am
2341023561	2.42	2.98	12-12:30 pm
Meter ID:	3.18	3.97	4-4:30 pm
ACD90F509010	2.5	4.23	6-6:30 pm
	2.25	4.29	7-7:30 pm

Calculations for the relevant cost of both AC consumption as well as the total consumption are carried out by *SavePower*; where each kW hour costs 0.21 AED/kWh in Abu Dhabi. However, it is estimated that each kW hour will produce in around 0.51 kg carbon dioxide. These figures will better visualize the consumption for the consumer and further facilitate the DSM. For the normative comparison, neighbors with the same square feet areas are compared so that values of consumptions are relevant.

V. Smartphone Based Solution Evaluation

The value of the proposed Smartphone based application can be reflected on two distinct aspects: clients (consumers) and control center unit (ADWEA) perspectives. Where consumers are interested in reducing electrical consumption to control their monthly bills, and ADWEA is aiming to reduce the actual cost of electricity production in Abu Dhabi. Moreover, both parties are resulting in lower carbon emission which would contribute to Abu Dhabi's sustainability plan.

Due to the flexibility offered by the proposed application to its users, they are capable of switching AC on/off remotely and based on GPS or overuse threshold criteria. Accordingly, we assumed that consumers use this application to switch AC off around 3 hours in 24 hours a day (i.e. 10%). However, there are cases where users might use it more efficiently for more than three hours a day. This assumption was used in the subsequent calculations to estimate the economical and environmental benefits returned from client and ADWEA perspectives.

1. Smartphone Based Solution Benefits

Fig. 6 illustrates the electrical consumption by sector in Abu Dhabi, where the residential (domestic) sector resulted in 31% of the total consumption in the year 2011. When further breaking down the domestic consumption, it was noted that AC formed around 65% from the total consumption (Fig. 7). This would justify the need to use the proposed Smartphone based application to control AC consumption in the residential sector.

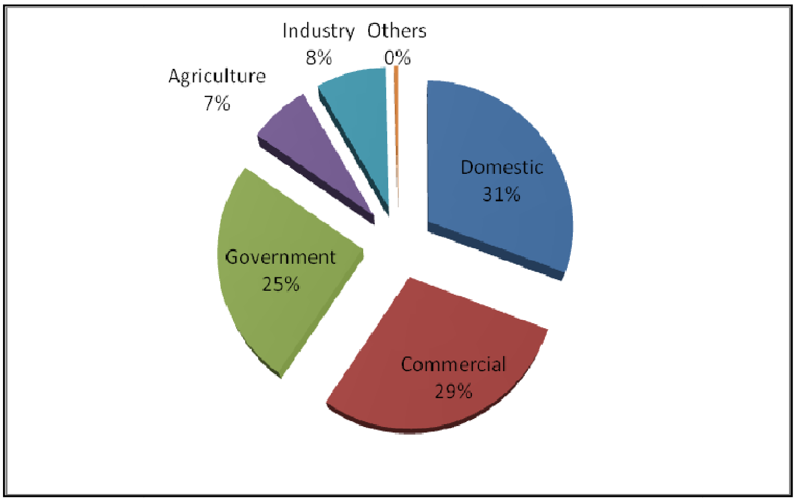

Fig. 6. Electricity Consumption By Sector in Abu Dhabi (ADWEC, 2011)[4]

[4] ADWEC (2011) Statistical Report 1998-2011 http://www.adwec.ae/report2011.html

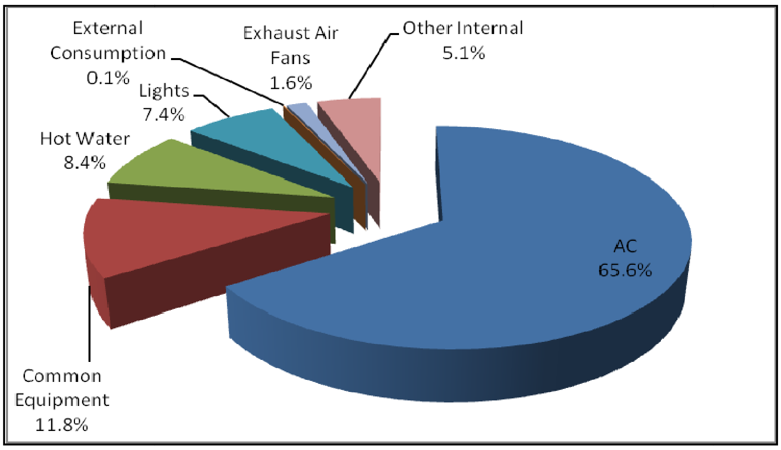

Fig. 7. Domestic Sector Electrical Consumption Breakdown (ADWEC, 2011) [5]

In 2011, the annual consumption of electricity in Abu Dhabi was estimated around 43.3 TWh [32]. Based on the assumption we utilized before, using *SavePower* would result in around 10% (3 hours in a day) savings in consumption per day. When reflecting this percentage on AC's consumption in the residential sector of Abu Dhabi, the total saved electricity can be calculated as follows:

*(TWh **annual consumption** * % **consumption of residential sector** * TWh **total AC consumption in residential sector** * % **savings due to SavePower**).*

Table 2 shows the electricity savings due to *SavePower* application which was around 0.863 TWh annually. To calculate the cost benefit resulted from this saving, electricity tarrif must be considered where there are three tariff types in Abu Dhabi: UAE national tarrif 0.05 AED/kWh, non-UAE national 0.21 AED/kWh, and the actual unit cost 0.288 AED/kWh. It worth mention that the actual cost is the cost required to produce electricity by energy plants. Both UAE and non-UAE national tarrifs reflect the client side savings whereas the actual cost tarrif is related to ADWEA savings perspective. Table 3 demonstrates the economical benefit estimation when utilizing *SavePower*.

[5] ADWEC (2011) Statistical Report 1998-2011 http://www.adwec.ae/report2011.html

Table 2: Annual Saved Electricity (TWh) in Abu Dhabi Due to *SavePower* - Considering the domestic electrical consumption in Abu Dhabi as well as emphasizing on AC's electrical consumption.

Sector	Abu Dhabi Annual Consumption in 2011 (TWh)	% of residential sector	% of AC consumption in residential sector	Total AC consumption in residential sector (TWh)	% of Savings due to use save power	Total saved electricity (TWh)
Electricity (TWh)	43.3	31%	65%	8.63	10%	0.863

Table 3: Annual Monetary Saving (AED) in Abu Dhabi Due to *SavePower* - Considering the annual electrical reduction resulted in Table 2. Tarrifs are national, non-national and the electrical production tarrif.

Sector	Total saved electricity (TWh)	Selling Unit Cost (AED/KWh)	Actual Unit Cost (AED/KWh)	total Selling Monitory Saving (Million AED)	Actual Monitory Saving (Million AED)
Electricity	0.863	0.05 - 0.21	0.288	(43.2-181.3)	248.6
Total Annual Monitory Saving (Million AED)					**248.6**

As depicted, *SavePower* would save around 43.2~181.3 million AED annually from client perspective, and around 248.6 million AED annually from Abu Dhabi perspective. Since electricity tarrif is subsidized in Abu Dhabi, the economical benefit reflected on the actual cost is more valuable than the benefit reflected on client perspective.

Aside from the annual cost benefits resulted by utilizing *SavePower*, other environmental implications can be major outcome, aligned with Abu Dhabi's 2030 vision which is to reduce carbon footprint by encouraging individuals to embrace environmental friendly habits. To better illustrate *SavePower* environmental implications, we calculated the estimated amount of carbon emission for the total electrical consumption in Abu Dhabi, and the total carbon emission reduced after utilizing *SavePower*. Table 4 shows that *SavePower* would result in 2% reduction in carbon footprint annually. Where each kWh unit results in around 0.51 kg CO2.

Table 4: Annual Reduction in Carbon Emission (Kg) in Abu Dhabi Due to *SavePower* - Comparison between carbon emission of the total electrical consumption in Abu Dhab in 2011 (43.3 TWh) and the carbon emission resulted after utilizing *SavePower*. Each kWh results in 0.51 Kg CO2.

Sector	Amount of Savings at demand side	CO2 Emissions intensity (kg CO2 eq/ KWh)	Amount of CO2 Reduction (thousand ton CO2 eq)
Saved electricity	0.86	0.51	440.27
Total electricity	43.3	0.51	22063.07
% of carbon reduction from total carbon produced			**2.00%**

2. Preliminary Requirements of Cost-Benefit Analysis of Smart Meter

Smart meters can help in promoting incentives for consumers to be engaged in energy efficiency improvements, along with enabling the introduction of smart grid systems to penetrate renewable energy resources. However, this would definitely lead to significant costs, risks and new technical challenges. Consequences of such rolling-out of SM stipulates considerations as in data protection and system interoperability in the long term. Rolling-out SMs must be examined in the context of cost-benefit analysis (CBA) in order to evaluate various parameters of benefits related to different sectors as in residential, commercial and industrial sectors as well. Moreover, CBA findings exemplify SM model to other utilities sector such as gas and water.

CBA highlights objectives which align with economic and environmental competence, and can be summarized as follow:

a. SM rolling-out economic assessment must be positive in general by minimizing additional costs of AMI introduction.
b. Client benefits are the cornerstone in CBA where SM rolling-out must guarantee a gradual pay off the additional costs and in parallel to exploiting its useful features as in electricity savings and load-shifting.
c. SM features must contribute to energy efficiency by inducing low electrical consumption by integrating innovations to facilitate the effective use of its functionalities.
d. Decentralization and integration of renewable resources into the supply system.

e. Exploit the existing communication infrastructure to offer the bi-directional communication channels, and to avoid double investment in this sector.

According to ADWEA, Abu Dhabi is currently rolling-out around 500,000 SM units all around Abu Dhabi and Al Ain. Based on the latest report of the Northeast Group, the capital expenditure of smart meters in the Middle East is estimated to reach $3.6 billion with 16.1 million units installed by the year 2020[33]. For Abu Dhabi to shorten the payback period of installing the AMI and SM in particular, it is imperative to integrate the ICT field in order to exploit SM existing functionalities to reduce both electrical consumption and carbon footprint as well. Based on the assumption in Table 3, the annual savings of utilizing *SavePower* application three hours a day would result in around 248.3 million AED annually. Consequently, it is estimated that Abu Dhabi would need around 2 years as a payback period when installing the AMI and SM all around Abu Dhabi Emirates. However, the feasibility of such proposed application is driven by different vectors starting from Abu Dhabi's regulations and how they are planning to penetrate electrical dynamic pricing to encourage individuals to change their electrical habits. Other factor is to decrease electricity subsidies which would suggest a smooth adoption of the SM model.

Moreover, a survey was conducted to assess the usability of *SavePower* and how much consumers are aware of its related benefits aside with SM. The sample included diverse consumers with diverse knowledge about electricity consumption and SM concept. Around 50% of the participants agreed on the increased demand on electricity in Abu Dhabi and awareness is required to be disseminated among Abu Dhabi's citizens to control high electrical consumption. However, 35% of the participants related carbon emissions to electrical consumption which would suggest that environmental awareness is required to be emphasized on to address the concept of sustainability.

The survey results illustrated that consumers are willing to reduce their electrical consumption but there are no direct means of incentives to encourage them to do so; around 68% of the participants considered AC's consumption is the highest. However, less than 60% of them encouraged using *SavePower* or SM features due to either its related security and privacy risks or due to electricity subsidy by which the government paid around 53% of its costs directly in 2012 [2]. Consequently, decreasing electrical subsidy is one factor to maintain positive exploitation of

SM features and all its related trends. Abu Dhabi's government has recently increased electricity tarrif from 0.15 to 0.21 kWh per unit. When considering the benefits achieved by utilizing *SavePower* and SM features and their reflections on the government, the actual cost can be decreased as demonstrated in Table 3 by 248.6 million AED annually. Consequently, though utilizing our proposed solution might not affect Abu Dhabi's consumers directly, Abu Dhabi's government still can decrease the cost needed to produce energy to meet its increased demand. Moreover, the environmental implications are addressed from both consumer and government perspectives as well where decreased carbon footprint is resulted which supports Abu Dhabi's sustainability plan.

VI. Smart Meter Security Aspect

Smart Meter provides bi-directional communication to offer time-of-use (TOU) dynamic pricing between consumers and the control center unit. Readings can be generated at fine-grained intervals ranging in seconds to fifteen minutes. Consequently, it is critical to protect the AMI so that to maintain effective SM functionalities. As discussed before, AMI has various communication technologies which depend on several factors as in business model and the local environmental conditions. Each technology introduces security challenges which is unique and requires special countermeasures to overcome. Sharma et al. [25] defined four distinctive security requirements to be fulfilled by SM: device authenticity, data confidentiality, data authenticity and integrity and consumer privacy and security. Throughout AMI applications, it is imperative to maintain consumer data and transaction privacy as well as their integrity. Moreover, accessing the SM unit features must be authenticated to avoid manipulations. With new technologies being integrated as future trends in Smart Grid and in AMI in particular, SM should be flexible enough to handle new security threats.

Despite the benefits of the proposed Smartphone based solution illustrated before, new security threats will be introduced all around the AMI. These can be highlighted based on the four security requirements defined by Sharma et al.[25] as follow:

a. Ensuring consumer's authentication is the key to preserve SM authenticity. A rigid authentication mechanism shall be considered aside from the consumer ID and meter ID provided by ADWEA.

b. Empowering consumer to set preferences which control the SM functionalities would increase the probability of manipulations by inauthentic parties. Moreover, sniffing on SM readings will invade consumer's privacy when appliance's usage signature is exposed.
c. Manipulating generated SM readings would affect consumer's billing integrity since readings are communicated to the control center unit database. Genuine readings must be protected by both the control center unit and prevention mechanisms utilized in AMI.
d. GPS positioning is used as a criterion to facilitate DSM; this would increase the risk of consumer being traced since his/her position is required to be updated and reflected back to the application.
e. Traditional attacks as in Man-in-the-Middle (MIM) and Denial-of-service (DoS) attacks can now target the proposed application to gain access to consumer's SM unit. Consequently, SM services might not be available and consumer's privacy and security might be exposed.

The aforementioned security threats are resulted from a combination of different security vectors; Smartphone security, communication network protocols security and SM security. The cornerstone vector is the SM and ensuring its resilience against such threats would assist to overcome security concerns from consumers and communities perspectives. Shuaib et al.[31] experimented the impact of different common attacks on the SM namely DoS and ARP cash poisoning attacks. Results demonstrated the need of packet filtering mechanisms, encryption capabilities and intrusion prevention and detection functionalities to be integrated in the AMI. Designing a robust SM with considerations focused on security countermeasures would encourage consumers to smoothly embrace new technologies as in the proposed Smartphone based application. Consequently, it would ensure consumers fidelity and increase the feasibility of integrating such technology in the process of DSM.

VII. Conclusion

Smart metering is a pioneering technology and a beneficial tool for utilities sector as in gas, water and energy to meet the increased demand due to the drastic economic and population growth. However, its adoption globally and in the Middle East in particular, was slowdown as a consequence of the global recession. SM benefits in the energy context include but not limited to reductions in electrical consumption especially in the peak demand. Consequently, the flexibility in introducing new electrical tarrifs and decreasing subsidies in electricity would indeed guarantee smooth adaption of smart metering technology. Also, this would suggest integrating SM related future trends efficiently as in the proposed Smartphone based solution. The proposed application introduced the straightforward step to help engaging consumers efficiently in the process of DSM to induce low electrical consumption and to reduce carbon footprint as well.

Moreover, it proved to exploit SM features effectively with no added infrastructure by controlling ACs or any other home appliance remotely through utilizing the real-time readings communicated in AMI. The successful of embracing new technology trends as in the proposed solution depends on the robust business model of AMI. Hence, the proposed solution is proven to be beneficiary to utilities sector as in ADWEA where SM rolling out is still in its early stages in the Middle East.

References

[1] Energy in the UAE, Energy Factsheet (2010). Date Accessed: November 2015. Retrieved from: http://www.uae-embassy.org/sites/default/files/pdf/LH-Energy-factsheet_2010-03.pdf.

[2] Smith, B. (2015). Demand Side Management in Abu Dhabi and the UAE; Challenges and Opportunities (PowerPoint Slides). Date Accessed: Decemeber 2015. Retreived from: http://www.cleanenergyministerial.org/Portals/2/pdfs/GSCN_Energy_Efficiency_in_Abu_Dhabi_Challenges_and_Opportunities.pdf

[3] Abu Dhabi: Investing in an Evolving World Energy Market. Masdar (2015). Date Accessed: November 2015. Retrived from: http://www.masdar.ae/en/media/detail/abu-dhabi-investing-in-an-evolving-world-energy-market.

[4] Siano, P. (2014). Demand response and smart grids—A survey. Renewable and Sustainable Energy Reviews, 30, 461-478.

[5] OECD (The Organisation for Economic Co-operation and Development), OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing. Date Accessed: December 2015. Retrieved from: http://dx.doi.org/10.1787/9789264122246-en, 2012.

[6] Savić, D., Vamvakeridou-Lyroudia, L., & Kapelan, Z. (2014). Smart Meters, Smart Water, Smart Societies: The iWIDGET Project. Procedia Engineering,89, 1105-1112.

[7] Hierzinger R et al. Smart Regions Project Deliverable 2.1: European Smart Metering Landscape Report 2012. Vienna: Austrian Energy Agency; 2012.

[8] Gomez AG. Without information there is no revolution : The impact of the adoption of Royal Decree 216/2014 (VBAC) on the trading activity . Journal of Energy 2014; 42: 79-85 .

[9] Edelmann H, Kästner T. Cost-benefit Analysis for the Comprehensive Use of Smart Metering, on behalf of the Federal Ministry of Economics and Technology. EY:Düsseldorf; 2013.

[10] United Kingdom Government. Household Energy: Smart Meters; 2015. Date accessed: December 2015. Retrieved from: https://www.gov.uk/government/publications/2010-to-2015-government-policy-household-energy/2010-to-2015-government-policy-household-energy#appendix-7-smart-meters.

[11] Leiva, J., Palacios, A., & Aguado, J. A. (2016). Smart metering trends, implications and necessities: A policy review. Renewable and Sustainable Energy Reviews, 55, 227-233.

[12] Cooper A, Wood L. Summary of Customer-Funded Electric Utility Efficiency Savings, Expenditures, and Budgets.Washington:The Edison Foundation Institute for Electric Innovation; 2014.

[13] Schultz, P. W., Estrada, M., Schmitt, J., Sokoloski, R., & Silva-Send, N. (2015). Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms. Energy, 90, 351-358.

[14] Nachreiner, M., Mack, B., Matthies, E., & Tampe-Mai, K. (2015). An analysis of smart metering information systems: A psychological model of self-regulated behavioural change. Energy Research & Social Science, 9, 85-97.

[15] Onzo Ltd. Date Accessed: December 2015. Retrieved from: http://www.onzo.co.uk.

[16] Energy Inc. Date Accessed: December 2015. Retrieved from: http://www.theenergydetective.com.

[17] P3 International. Date Accessed: December 2015. Retrieved from: http://www.p3international.com.

[18] SmartLabs, Inc. Date Accessed: December 2015. Retrieved from: http://www.smarthome.com

[19] Jiang, X., Dawson-Haggerty, S., Dutta, P., & Culler, D. (2009, April). Design and implementation of a high-fidelity ac metering network. In Information Processing in Sensor Networks, 2009. IPSN 2009. International Conference on(pp. 253-264). IEEE.

[20] Paradiso, J. A. (2006). Some novel applications for wireless inertial sensors. InProc NSTI Nanotech.

[21] Weiss, M., Mattern, F., Graml, T., Staake, T., & Fleisch, E. (2009, November). Handy feedback: Connecting smart meters with mobile phones. In Proceedings of the 8th international conference on mobile and ubiquitous multimedia (p. 15). ACM.

[22] Program & Projects. Smart Metering Trial. Date Accessed: December 2015. Retrieved from: http://www.powerwise.gov.ae/en/research/programmes-projects/time-of-day-trial.html.

[23] Alaileh, R., Yousif, M., Fadul, A., & Preece, M. (2013, November). Energy efficiency and demand side management in Abu Dhabi. In GCC Conference and Exhibition (GCC), 2013 7th IEEE (pp. 559-564). IEEE.

[24] Siano, P. (2014). Demand response and smart grids—A survey. Renewable and Sustainable Energy Reviews, 30, 461-478.

[25] Sharma, K., & Saini, L. M. (2015). Performance analysis of smart metering for smart grid: An overview. Renewable and Sustainable Energy Reviews,49, 720-735.

[26] Costache, M., Tudor, V., Almgren, M., Papatriantafilou, M., & Saunders, C. (2011, September). Remote control of smart meters: friend or foe?. InComputer Network Defense (EC2ND), 2011 Seventh European Conference on (pp. 49-56). IEEE.

[27] Faisal, M. A. (2012). Securing Advanced Metering Infrastructure (AMI) in Smart Grid using Intrusion Detection System (IDS) (Doctoral dissertation, Masdar Institute of Science and Technology).

[28] The smart grid gets even smarter (2011). Technical Review: The Middle East. Vol 27, no. 5. Date Accessed: December 2015. Retrieved from: http://www.tpfz.com/pdfs/SmartGrid_Gets_Even_Smarter.pdf

[29] Next generation smart meters and AMI communications (September 2013). Data Accessed: December 2015. Retrieved from: http://www.tpfz.com/pdfs/TP%20AMI%20Solution%20WP%20092413.pdf

[30] Lee, J. S., Su, Y. W., & Shen, C. C. (2007, November). A comparative study of wireless protocols: Bluetooth, UWB, ZigBee, and Wi-Fi. In Industrial Electronics Society, 2007. IECON 2007. 33rd Annual Conference of the IEEE (pp. 46-51). IEEE.

[31] Shuaib, K., Trabelsi, Z., Abed-Hafez, M., Gaouda, A., & Alahmad, M. (2015). Resiliency of Smart Power Meters to Common Security Attacks.Procedia Computer Science, 52, 145-152.

[32] Assaf, S., & Nour, M. (2015). Potential of energy and water efficiency improvement in Abu Dhabi's building sector–Analysis of Estidama pearl rating system. Renewable Energy, 82, 100-107.

[33] Very clever meters: Recent developments suggest that smart meters may soon be hotly in demand across the region (2012, Oct.17). *ConstructionWeekonline.com.* Retrieved from: http://www.constructionweekonline.com/article-19096-very-clever-meters/.