IoT enabled End User engagement towards energy efficient lifestyles

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Abstract – **The overall increase in number of intelligent devices and home appliances, effectively taking part in the IoT world, has led to the development of numerous innovative solutions across various domains. This paper introduces an ICT based solution for energy End User engagement towards more efficient behaviors and sustainable lifestyles. The proposed solution focuses on integration of comprehensive energy consumption monitoring platforms and/or Home Automation solutions with advanced energy services through a highly flexible cloud-based IoT platform and a service based approach. Employed energy services range from consumption data analytics and profiling over to performance evaluation and consumption prediction towards demand benchmarking and optimization. The ability to develop offer advanced energy services independently, i.e. as functional upgrade of an existing IoT platform, is used to formulate innovative business models and deliver a cost-effective solution.**

I. INTRODUCTION

A. Motivation

The overarching objective of this paper is to propose and elaborate on an ICT solution which facilitates End Users behavior change towards increased energy efficiency (EE). The current efforts in this domain are best summarized in a quality EU study produced by the European Environmental Agency "Achieving energy efficiency through behavior change: what does it take?"[1], which is based on factual data as well as an extensive literature research. As highlighted, the experience gained in previous deployments of metering and feedback technologies demonstrate that the different ICT enabled engagement platforms, strategies and methodologies lead to varying levels of behavior change and demand reduction ranging between 3%-20%, that last for varying periods of time. A similar experience is reported from the US where their Behavioural Energy Efficiency (BEE) programs are helping energy providers come up with innovative solutions, raising awareness of other EE programs, and achieving significant cost-effective savings. As indicated in the McKinsey 2013 study [2], BEE's potential is far from tapped since it revealed that behavioural interventions could reduce the total US residential energy use by as much as 20%. In this regard, a number of ICT solutions capable of capturing users' attention and generating efficient and sustainable behaviours over time, including also users with low ICT literacy, have flooded the EE market, however although proven to be effective to a certain extent, these technologies still face significant adoption barriers that can be roughly summarized into three basic aspects: a) barriers for technology acceptance, b) barriers for technology use, and c) barriers for technology effectiveness. These barriers change significantly between the commercial, residential and industrial sectors. In parallel to these, significant advances in other areas including; evolving information and communication technology infrastructures, the emergence of smart devices and the internet-of-things (IoT), the Smart Meter rollout for 2020 [3], the increase of cost-effective and novel energy storage technologies, electrification of transport, as well innovative funding, payment mechanisms and business models yield the optimal conditions for delivering innovative solutions.

B. Research questions and SoA

Inducing a behavioral change (towards EE) represents an unsolved societal challenge with potentially enormous environmental impact. But, why is it so difficult to induce a behavioral change towards EE? There are several factors: a) relatively limited perceived benefits to Users associated with EE measures. In particular, low EE associated monetary benefits to the individual (an average energy bill[1] already does not represent a significant portion of the home budget (cca. 5%)[2] and even less if we consider that only a share of it (max. 20%) can be saved), b) low capability to change energy demand patterns and energy use practices due to aspects related to lifestyle, habits, daily routines, work/family commitments, resulting in low levels of Users' demand flexibility, c) lack of global conscience related to the impact of energy generation and use on the environment (pollution, Greenhouse Gas emissions), and the tendency to perceive the individual consumption as insignificant ("My individual consumption does not make the difference"), and d) the complexity of existing ICT platforms/tools (e.g. leveraging on gamification approach) which require intensive engagement often interfering with the everyday, activities.

Additionally, there is an increased number of various Home Automation platforms present in the market which provide various services related to energy efficiency, home security, comfort regulation, remote access to home appliances etc. However, when it comes to energy

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1 https://www.ovoenergy.com/guides/energy-guides/the-average-gas-bill-average-electricity-bill-compared.html

2 http://www.deceuninck.es/blog/cual-es-el-gasto-medio-de-energia-en-un-hogar-espanol/

efficiency, they are typically focused on providing energy monitoring capabilities and supplying the End User with information related to energy consumption and, in case of advanced solutions, on providing some simple control functionalities. However, these solutions rarely provide any additional semantics attached to the captured consumption and, since the kWh (or other, e.g. kJ, calories etc.) figures may mean very little to an average End User unless attached and correlated with the actual context (e.g. number of occupants, climate conditions etc.), they stand very little chance in driving the change in the End User behavior towards more efficient lifestyles. The following is a brief overview of the solutions aiming at overcoming these barriers.

When it comes to the user engagement, a widely adopted solution comes from the US market leader Opower/Oracle [4]. Despite the fact that they work for the utility industry, their solutions aim at helping customers understand their energy use at the first place and then better manage it. By offering a wide range of solutions ranging from Demand Response and Customer Engagement to Thermostat Management, they are focused on solving the key energy efficiency challenges. The Opower approach mainly leverages on the utilization of personalized messaging system that brings important Energy Conservation Measures (ECMs) and notifications and warnings related to the user's energy consumption, which are transferred through the means of their custom designed Web and Mobile platforms. However, the key disadvantage of the proposed solution is that the methodology that drives the personalized messaging system seems to be taking into account only the user's energy consumption and not the actual performance. The solution has the highest market penetration when it comes to the number of active users, probably owing to the fact that they not require any hardware installation at the location of each customer and offer free of charge service to the End User. However, greater energy savings and more focused energy conservation measures may only be possible if both consumption and user behavior is monitored in real-time and benchmarked against similar users. The Swedish utility E-ON recruited 10k participants for what they call "Sweden's Largest Energy Experiment" [5] in which the real-time energy consumption was presented to their customers through their Mobile App during a period of one year. The monitored consumption is visualized in five different ways, in order to investigate what would make their customers save the largest amount of energy. This approach benefited from large amount of collected data but lacks in the means for user engagement and social race between the customers. Solutions coming from Energy Aware [6] (that emerged from Neurio and Wattson), Engage and AlertMe [7] mainly leverage on the installation of additional smart metering which is used to track the users' energy consumption and Web or Mobile interface for visualization. In some cases, e.g. Neurio, advanced algorithms were employed to devise user behavior from the monitored consumption and formulate personalized messages carrying corresponding ECMs. Similarly to the previous solution, a benchmarking platform which proved to be the key factor for user engagement is missing. Simple Energy, Welectricity and Leafully [8] do not require any hardware installations but rather focus their approach on the benchmarking aspects by leveraging on proprietary social networks where people can compare and compete. However, due to the lack of detailed consumption data only broad and generic ECMs are delivered. Simple Energy [8], Welectricity [8] and Leafully [8] offer solutions that do not require additional hardware deployment but focus their approach on the benchmarking aspects. Hoping that this would lead to the critical commitment of users, they all provide proprietary social networks where people can compare and compete but also to learn from each other's. The pitfall of their approach seems to be a lack of dynamic energy consumption data (they all use energy bills), suggesting very poor resolution (monthly) which consequently lead to very broad energy conservation measures. Furthermore, the aspect of social pressure that should be coming from the employment of social networks has very low impact due to the fact they are using their own social networks which, unfortunately, has a limited number of active users. Instead, utilization of widely accepted social networks (such as Facebook, LinkedIn etc.) would allow for better user engagement, since they already use them, and unlimited dissemination possibilities.

Finally, the experience gained in previous deployment of metering and feedback technologies demonstrate that the different engagement platforms, strategies and methodologies lead to varying levels of behavior change and demand reduction (ranging between 3%-20% in kWh) that last for varying periods of time. While proven to be effective, these technologies still face significant adoption barriers that can be roughly divided into three main categories: 1) technology acceptance, 2) technology use, and 3) technology effectiveness. These barriers change significantly between the commercial, residential and industrial sectors.

II. METHODOLOGY

The proposed solution aims to spark the End User behavior change by tailoring ECMs and providing incentives to each User according to their own constraints, i.e. to provide information and advice that are relevant to the specific User and that the User can act upon without compromising comfort and convenience - the key is to understand barriers for action and target those specifically. To achieve this, features such as fair comparison (fair, as perceived and defined by the User) can enable unique social nudges (i.e., positive reinforcement in [9]) towards the behavior change. In this regard, the proposed solution seeks to evaluate the User energy social practice [10] and his energy performance, rather than (just) consumption, so as to enable fair benchmarking and competition among Users and thus create a unique social pressure capable of driving the behaviour change. The performance evaluation is used to contextualize measured energy consumption by normalizing it against a range of 'objective parameters' such as building size, construction material properties, number of occupants, climate conditions etc. The authors have opted for the User-oriented and User-tailored approaches as they are likely to improve the ICT effectiveness due to two main reasons: First, tailored advice, which fits with the user's ability and constraints, is more likely to be followed and deliver change. Second, successful actions that are visible to the User (in terms of

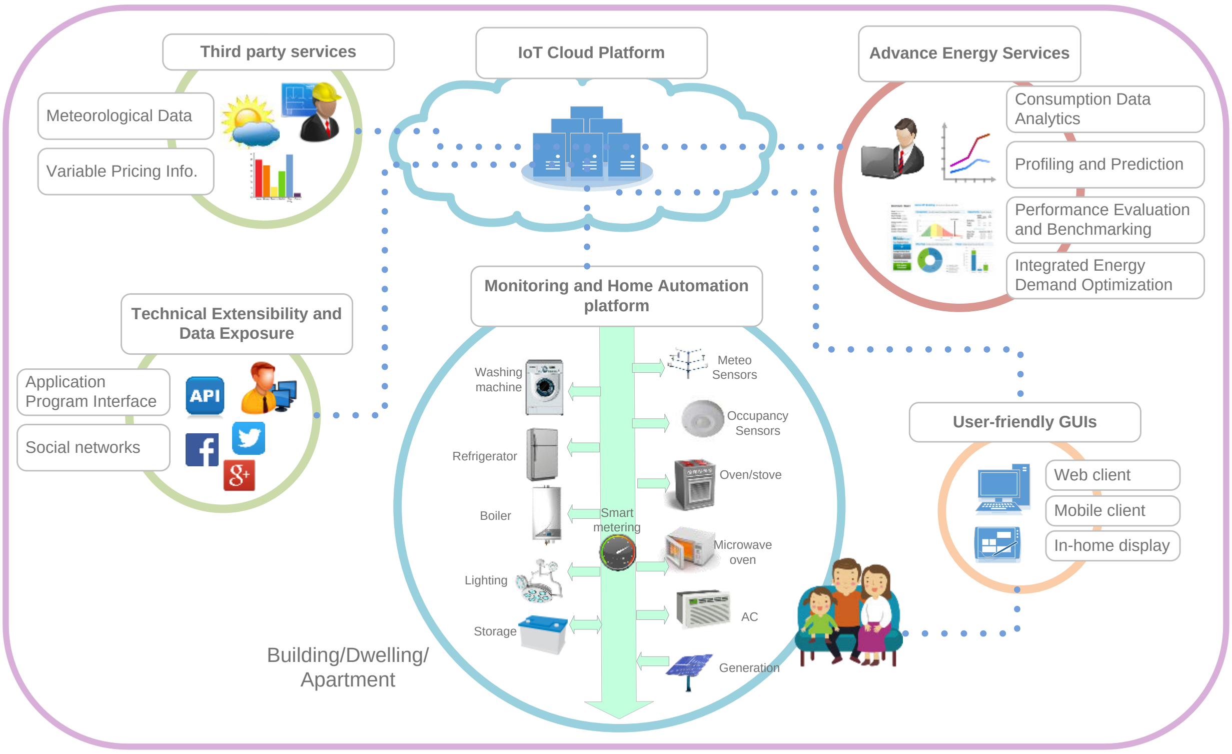

Figure 1. Overall conceptual diagram

energy and money saved or emissions avoided) will help to convince Users of the technology trustworthiness and positively reinforce the technology use.

Consequently, the proposed solution features: monitoring of energy consumption, estimation of individual energy performance out of it, detection of performance deviation and, finally, delivery of targeted and practical ECMs. Moreover, the proposed solution foresees means for End Users benchmarking against themselves and each other. These features are distributed among the following independent so called 'advanced energy services': a) consumption data analytics, b) profiling and prediction, c) integrated energy demand optimization and d) performance evaluation and benchmarking. Such modularity and flexibility in approach allows for integration of previously developed functionalities (e.g. forecasting, optimization etc.) or their reuse in similar applications.

III. SOLUTION

The proposed solution aims at employing and adapting existing technologies and integrating them into a unique ICT platform capable of capturing users' attention and generating efficient and sustainable behaviours over time. More precisely, it considers integration of comprehensive energy consumption monitoring (including electricity and gas meters, calorimeters, smart plugs, smart meters, etc.) and environment sensing (comprising occupancy, temperature, illuminance, humidity, CO/CO_2 etc.) with the advanced energy services through a highly flexible cloud-based IoT platform, Figure 1. Moreover, utilization of existing pre-fabricated Home Automation solutions, capable of seamless integration of a wide range of home appliances and actuators, is envisioned through service based integration with the advanced energy services which are, in short, responsible for delivering user-tailored ECMs and, whenever possible, "translating" them into applicable control/management actions which are to be conducted by the automation part of the system and the corresponding actuators. The following is a brief overview of the employed energy services and their interrelation.

A. Consumption Data Analytics, Profiling and Prediction

When it comes to retrieval of energy consumption data, the proposed solutions is primarily leveraged upon a comprehensive monitoring platform which offers detailed consumption breakdown but also upon the single smart meter and employment of consumption data analytics service which enables disaggregation of load, e.g. by leveraging on the non-intrusive load monitoring (NILM) paradigm, e.g. in [11], to estimate appliance-level energy consumption. Once consumed, the data will be forwarded towards the advanced analytical services. The employed data processing will be based on machine learning and statistical methods to build models with as little human intervention as possible. The following functionalities are required:

- Data cleaning and preparation
- User classification and profiling (based on machine learning methods, namely automatic preparation and clustering of monitoring time series)
- Apartment building or multi-family house classification and profiling (based on historical energy consumption enriched with building parameters, climate conditions, etc.)
- Individual building consumption prediction (based on historical data, weather, building usage, year of construction and similar metadata, e.g. using a user-centric energy consumption modelling in [12])

Listed functionalities will be used to devise a unique analytics engine which will have a twofold objective, i.e. to look for performance deviation by comparing current with previous performance based on measured consumption, which will enable generation of specific and User-tailored Energy Conservation Measures (ECM) communicated to the User (e.g. User may consume more energy under the same outdoor conditions and occupancy due to an opened window, malfunctioning HVAC device etc.), and, to anticipate wasteful practices based on User-centric energy consumption modelling and consumption forecast combined with pricing/load/stability information received from ESCOs (e.g. User consumption is approaching contracted power peak, electricity tariff will change in next X minutes, grid is approaching its limit etc.)

B. Performance Evaluation and Benchmarking

Calculating User energy performance and using it later for benchmarking, instead of using only energy consumption for benchmarking, is a pivotal energy service that the proposed platform aims to offer. Therefore, adopting methodologies that will enable fair comparison and benchmarking of Users against themselves and others with similar profiles is at the cornerstone of proposed approach. Energy consumption data, *per se*, represents required, but not sufficient, information to estimate someone's performance or to enable fair comparison. For example, Users may consume more energy due to change of outdoor climate conditions, change in occupancy, specific work / family requirements or events, or else, while still keeping the same level of performance. The performance evaluation will consider normalization of consumption against a range of relevant parameters such as applicable climate conditions and number of occupants, but also building size and construction material thermal properties etc. This will allow for setting realistic and achievable goals for the Users, rather than unrealistic ones, that discourage further engagement and reduce the effectiveness of the technology over time. In particular, the proposed solution will integrate the performance evaluation approach from the Energy Star's Portfolio Manager [13], [14], developed by the US EPA which represents the industry-leading, free of charge online tool that allows users to benchmark, track, and manage energy and water consumption and greenhouse gas emissions against similar users/buildings nationwide. It is based on the calculation of the so called Energy Star Score [15], which is expressed as a number on a simple scale of 1 – 100 and rates the User's performance on a percentile basis: buildings with a score of 50 perform better than 50% of their peers; buildings earning a score of 75 or higher are in the top quartile of energy performance. Although the comprehensive methodology behind score calculation takes into account normalization of building type, number of inhabitants, type of their activity etc., it lacks in delivering means for better User engagement through the means of social web that unleashes the full capacity for achieving positive social pressure.

C. Integrated Energy Demand Optimization

Apart from detecting User's wasteful practices through a set of analytical services, the proposed solution also offers energy conservation and cost reduction measures which are found as output from an integrated energy dispatch optimization. As a result of such optimisation, an optimal demand profile (highlighting the deviation from the regular practices) is suggested together with optimal dispatch (allocation in time) of multiple energy supply options and available energy assets. For this purpose, an optimisation framework based on the Energy Hub concept [16], [17], further extended conceptually during the Epic-HUB project [18], will be employed.

The optimizer is based upon a mathematical algorithm for integrated optimisation of energy supply and demand of the target building, while taking into account available energy assets, multiple carriers at the supply side (both conventional and renewable energy sources), fixed and variable pricing tariffs, type of the load (critical, reschedulable and curtailable load), comfort levels, etc.

D. IoT-based integration platform

Once developed, advanced energy services are integrated with the corresponding data sources and devices able to perform energy conservation measures as well as third party services. In other words, the technological prerequisite for deployment of the proposed platform is to ensure connection of sensors, actuators, and devices to a network and enabling the collection, exchange, and analysis of generated data. The described constellation will indeed form an IoT network characterized by many devices (i.e. things) that will use dedicated gateways to communicate through a network to the platform back-end server which will be running on an open-source IoT platform and utilized to enable integration of the deployed sensors with advanced energy services. The integration platform will indeed represent an IoT Cloud Platform and will be leveraged by an open-source communication middleware enabling data exchange of underlying systems and services required to enable an IoT solution.

The proposed platform will operate on a cloud infrastructure (e.g. OpenShift, AWS, Microsoft Azure, and Cloud Foundry) or inside an enterprise data centre, and will be able to scale both horizontally, to support the large number of devices connected, and vertically to facilitate deployment of different IoT solutions. The IoT Cloud Platform will ensure the following core features, as indicated in Figure 2:

- It will be leveraged upon middleware responsible for orchestration of system components and services
- It will be able to interact with very large numbers of devices and gateways using different protocols and data formats. Moreover, it will provide a framework for utilization of a common data format (e.g. Canonical Data Model) so as to allow for easy integration into the rest of the platform.

- It will provide means for maintaining a central registry to identify the devices/gateways running in an IoT solution and the ability to manage the devices.
- It will provide a scalable data store that supports the volume and variety of IoT data.
- It will account for scalable event processing capabilities, ability to consolidate and analyse data, and to create reports, graphs, and dashboards.
- It will have the ability to use API for application integration.

Depending on the specific technical and functional requirements developed during the platform specification phase, the decision on the actual open-source IoT Cloud platform will be made (e.g. Eclipse Kapua, or Eclipse OM2M).

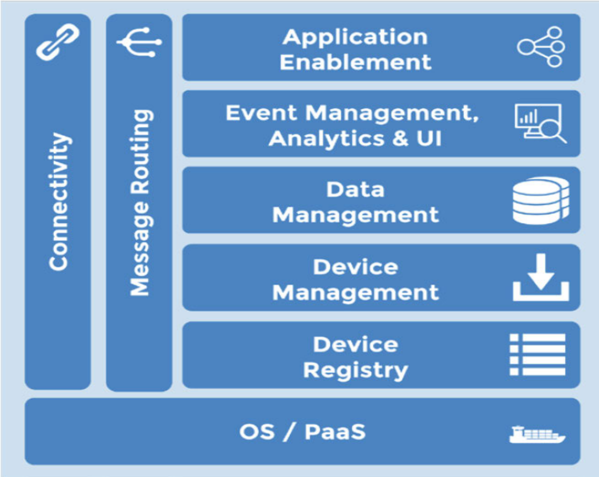

Figure 2. IoT Cloud Platform functionalities (source: IoT Eclipse website)

IV. CONSLUCION

The flexible technological platform relying on IoT integration and independent, yet complementary, energy services aiming at increasing energy efficiency of individual consumers is proposed. The elaborated approach focuses towards cost-effective solutions and sustainable business models accounting for different levels of equipment and service deployment.

The underlying algorithms aims to estimate user regular behavior and anticipate wasteful practices, both in terms of energy and costs. Moreover, in order to support advanced wasting scenarios, the data collected at user premises are combined with the corresponding pricing/load/stability information received from the third party services (e.g. from ESCO, meteorological data service). In addition, integrated energy demand optimization is used to detect sub-optimal energy management of available energy assets in the multi-carrier environment. The integration of energy services is achieved through an IoT Cloud Platform and an open-source communication middleware enabling seamless data exchange of underlying systems and services.

The availability of professional, open-source, IoT solutions yields the opportunity for affordable and easily deployable energy management solution offered through innovative business models (e.g. SaaS) allowing for faster return on investment and higher benefits for the end Users.

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