SMART CITY ENERGY MANAGEMENT VIA MONITORING OF KEY PERFORMANCE INDICATORS

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ABSTRACT

The combination of Smart Grid and Smart Cities concepts provides municipalities with new capabilities that will lead to better and informed decision making processes. This paper focuses on illustrating key aspects related to a holistic energy efficiency management at a city level, as well as presenting an innovative platform architecture to achieve such objectives.

The approach presented focuses on eventual consistency (fostered by the API design) instead of pessimistic locking with the possibilities of bottlenecks, allowing for improved parallelism and scalability. At the same time, such platform opens a whole new set of possibilities for better monitoring of Energy Key Performance Indicators at a city level and enforcing the decisions taken.

INTRODUCTION

Local authorities hold the key in achieving the long-term low-carbon and low-energy goals of the EU [1]. At the same time, each city or municipality has specific needs or problems to be addressed, which can be solve in many different and innovative ways, as has been demonstrated by initiatives such as Energy Cities – 30 Proposals [2].

Many of the problems faced today by local authorities with respect to energy efficiency are related to a lack of system visibility and knowledge. In most cases it is directly related to the non-existent technical tools to gather the relevant and reliable information that is to be understood and taken decision upon [3]. One of the main drivers of our future energy efficient cities is the enablement of proper measurement and data frameworks (based on ICT technologies). For this to materialize, a common platform integrating the various disparate and autonomously operating systems is needed. At the same time, such platform should provide the necessary interfaces to support the development of proper decision support systems targeted at city authorities and decision-makers [4].

The key question is how these objectives can be reached, especially with the multitude of diverse stakeholders expected to be operating in a smart city. Although each stakeholder will pursue its own goals, cooperation may result in further benefits and also assist the municipalities towards:

- Grasping a better understanding of city energy management situations (monitoring)
- Taking informed decisions based on up-to-date data and sophisticated tools
- Applying the decisions in a meaningful and timely way (control)

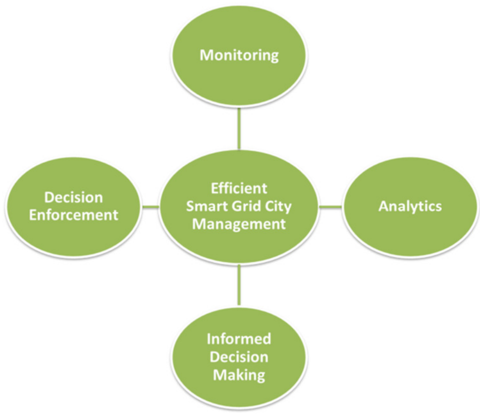

Figure 1 SmartKYE core principles for effectively managing smart grid cities

To that extent some key principles emerge on which better smart city management can be built as illustrated in Figure 1, i.e. Monitoring, Analytics, Informed Decision Making, and Enforcement of Decisions to the infrastructure. The work carried out by the SmartKYE consortium and presented here, has been based on the needs and plans for future smart cities as laid out by key European authorities, stakeholder consortia and high level strategic plans. SmartKYE follows a realistic approach by considering several of the needs of future smart grid cities and is based on a distributed query-driven model [5], [6]. The latter enables the provision of value added services to the municipal authorities without sacrificing key business aspects of the participating stakeholders, such as ownership of detailed data etc. This model in conjunction with modern cloud-based technologies and clear output of the benefit, are expected to be demonstrated within the lifetime of the project. We present an overview of some key concepts related to the architecture goals in the following.

THE SMARTKYE ARCHITECTURE

The vision behind the SmartKYE architecture is to enable improvements in the availability and quality of energy-related data. At the same time, such approach aims at enabling decision takers in a municipality or even at city-wide level, to take informed decisions that lead to a more efficient use of energy resources, contributing in this sense to a reduction in CO_2 emissions.

The energy management platform architecture proposed is illustrated in Figure 2. Such platform is an on-going effort building up on know-how of projects such as SmartKYE [7], BEAMS [8], and NOBEL [9].

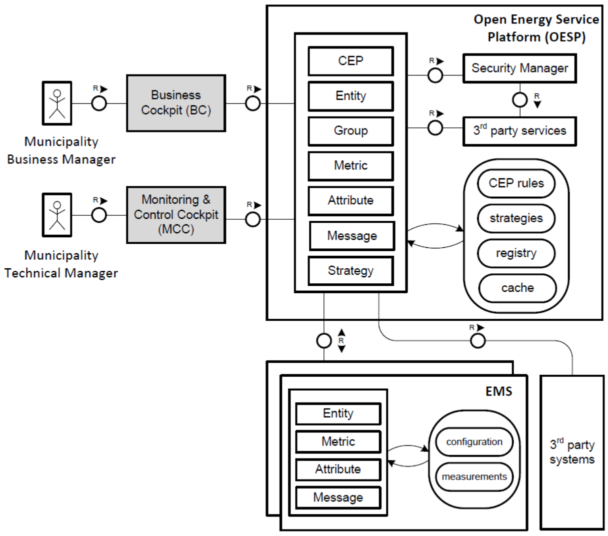

Figure 2 SmartKYE Service Architecture

The main objective is to enable the integration of the various disparate and autonomous systems operating in a city. Its main components and their interactions are depicted in Figure 2; more specifically we have:

- **Energy Management System (EMS):** These are the modules responsible for the adaptation of current existing infrastructure in a city to the SmartKYE platform. EMS modules provide data acquisition and provision of energy related information to the energy platform. It is assumed that every system e.g., wind farms, EV infrastructure, public lighting system, public buildings, etc. has such an EMS.
- **Monitoring and Control Cockpit (MCC):** This user interface allows monitoring and control aspects of a city infrastructure. This implies visualization of technical information as well as management of the infrastructure by interaction with the EMS via the OESP. Such interface is mainly targeted to technical personnel.
- **Business Cockpit (BC):** This user interface serves as visualization of business relevant information as well as additional value-added functionalities e.g., via simulation of specific situations or "what-if" scenarios. It is mainly targeted at decision takers in a city.
- **Open Energy Service Platform (OESP):** This module acts as a flexible information hub or single point of interaction that decouples the energy applications used to monitor and manage the different EMS in a neighbourhood (i.e. the BC and MCC), from the heterogeneity of the smart grid and communication infrastructure underneath.

It is clear how many heterogeneous distributed systems can interact via the cloud-based Open Energy Services Platform – OESP – depending on the data delivered for the infrastructure. Furthermore, analytics can be provided both to management and technical personnel who interact via the proper cockpits.

The following sections focus on specific details of the system.

SmartKYE Open Energy Services Platform (OESP)

The SmartKYE project has designed and is currently developing an Open Energy Service Platform (OESP) that will be able to manage system integration via energy related queries to the infrastructure's distributed systems, and will also offer other auxiliary services. The basic architectural components of this cloud-based platform are seen in Figure 2. The end-users interact via two cockpits for business and technical purposes, while various EMSs and other third party systems are also integrated via a common API, described in detail in further sections of this paper. One of the key goals of the platform is to allow scalability to cover a wide range of different deployment sizes. This goal is addressed at several layers of the platform. The API provides batching and aggregation functionality to reduce the number of roundtrips, bandwidth and latency for efficient access to the information of the infrastructure. The platform itself is partitioned into several semi-autonomous components that can be instantiated multiple times without a single point of failure. The design focuses on eventual consistency (fostered by the API design) instead of pessimistic locking with the possibilities of bottlenecks allowing for improved parallelism and scalability.

To address more use cases, the platform supports several communication paradigms. With both publish/subscribe and query functionality, the platform supports both push and pull based communication. Orthogonally, the platform also allows specifying information needs both node-centric (e.g., from certain wind mills) and data-centric (e.g., information from all energy producers). The combination of these cooperation schemes fosters the development of both history-oriented data analytics and real-time monitoring and control software.

Energy Management Cockpits (BC and MCC)

Having the right information at the right moment is indispensable for taking informed decisions. Monitoring plays a pivotal role towards achieving this. By being able to see the infrastructure state in real-time, one can react and avoid potentially future problems. To this end modern high-performance analytics are done on large amount of data. However, additional tools offering new capabilities may be used. "What-if" simulations assist towards understanding and better planning. Once a good understanding of the infrastructure is obtained (usually empirically), one can dive-in to more sophisticated options for analytics which coupled with control can further enhance the operational aspects.

Furthermore, it must be considered that the process of taking informed decisions is not trivial and solutions or strategies that are considered good at some point of time may not be so in a later timeframe. Increasingly Smart Cities will have to be able to apply economic monitoring and control strategies known from large enterprises. This assumes that apart from the technical side also the economic angle of decisions has to be fully understood and assessed. In a smart grid city infrastructure the assets will need to be managed with multiple objectives such as energy efficiency, high-priority (e.g. hospitals), economic goals (cost-driven), etc. The energy management of the Smart City is envisioned via the usage of two cockpits i.e. the BC and MCC.

The Business Cockpit (BC) is an application bringing together a mash-up of services to deliver data to a UI, that can be flexibly customized. Since our goal is to be able to access the UI seamlessly via a wide variety of devices, the decision was taken to have the UI as a web application visible from any modern browser and any mobile or traditional device. With the current planning this translates to a cloud-hosted application while data is acquired on the fly by the OESP via queries.

The Monitoring and Control Cockpit (MCC) provides the technical experts in charge of the system with the appropriate tools for monitoring the different measures of the system and interacting with the actual assets. Besides this functionality, the MCC itself is also built with a set of dynamic strategies whose application leads to the accomplishment of a series of goals that will improve the system results. At any moment, a system administrator can specify new parameters (i.e. constraints or goals) to be followed, as well as take decisions when asked for confirmation. New data is periodically obtained from EMSs and stored, while also, real-time data can be requested by the MCC. The MCC analyses and checks current situation and assists towards taking the right decisions.

SmartKYE Smart City Energy Services

Contrary to currently overwhelmingly centralized information gathering approaches, SmartKYE considers a query-driven interaction with the vast number of stakeholders and their systems. A loosely-coupled infrastructure enables stakeholders to join or leave the SmartKYE system, and the core infrastructure data may still be owned by the respective systems. To what extend and resolutions such data is communicated to other stakeholders, depends on the queries issued and the willingness or contract-based negotiated actions. By not owning the data, and having an infrastructure handling intelligently the communication between consumers and producers of information, scalability can be achieved as well as co-evolution on both of its ends.

As already mentioned, the end-users of the platform could interact via two cockpits for business and technical purposes. Such user-interfaces will communicate with the platform via a common API, either to obtain or provide data. In the same way, the various EMS systems interacting with the platform will use the same API. Such approach aims at ease the development and deployment of the platform, as well as its re-usability.

In Figure 2 were depicted all the services that implement the SmartKYE energy API. The following list further explains each of these services:

- **Entity:** This is a general-purpose service that provides information about the attributes, KPIs and metrics being provided by an individual entity or individual physical element controlled by an EMS. The entity concept is used to represent everything from high level real systems such as a building, up to individual components within it such as a heating/cooling system, a light bulb, etc.
- **Group:** This service allows the creation of ad-hoc groups of entities (that may span one or more EMSs) and can be used for getting e.g. aggregated data
- **Metric:** This service primarily provides the basic metrics supported by individual EMS systems (e.g., energy consumption). It is designed to be extendable to future requirements or metrics. It is used also as a basis for the CEP service.
- **Attribute:** This service allows the association of arbitrary complex data – Attributes – with entities. Writeable attributes provide the foundation for control and management of the EMS.
- **CEP:** Complex Event Processing is used for calculating KPIs from simpler metrics as well as delivering the relevant information in an event based manner.
- **Message:** This service corresponds to the control part applied from the MCC to the various EMSs in the system. This, together with functionalities of the Attribute service, is used for control/management within SmartKYE platform.
- **Strategy:** Strategies can be communicated from BC to the MCC via this service which has storage and retrieval capabilities.
- **Security:** basic authentication and authorization operations.

In summary, the SmartKYE API design allows a myriad of heterogeneous systems that operate in a city to interact seamlessly and in a loosely-couple way through a unique set of API services. Furthermore, it is important to note that data or information will always remain at its source. SmartKYE will just handle intelligently the communication between consumers and producers of information.

Key Performance Indicators (KPIs)

Metrics and Indicators are essential for the evaluation and assessment of progress towards any particular energy efficiency goal. In the SmartKYE context, a KPI is an indicator that summarizes and simplifies all the data gathered with the objective to be used by the BC and MCC, in order to cover the requirements and interests of the public authorities.

It is noteworthy that the metrics and KPIs defined are basically building blocks that could be used for the definition of more complex KPIs, depending on the specific city authorities' objectives. A metric is basically any data provided by an EMS e.g., energy production by a photovoltaic system, energy consumption in a building, etc; while a KPI could be seen as a composition of metric and certain specific criteria e.g., energy consumption by square meter within a building. This approach offers certain flexibility to managers at a city level, enabling them to define specific metrics and KPIs to monitor according to their particular objectives.

The approach taken in SmartKYE project in this area has been: (i) the definition of the terms needed in order to formulate the metrics and KPIs, (ii) the description of the metrics used to calculate the KPIs and finally (iii), the methodology and formulas for each KPIs. Table 1 presents an example of a set of KPIs that could be defined and used by the SmartKYE platform:

Table 1 Sample Key Performance Indicators

KPI	Formula	Unit
Difference in asset count	$n(x_2)-n(x_1)$	
Change in production penetration	$P_{pe}(x_2)/P_{pe}(x_1)-1$	%
Difference in CO_2 emissions	$\varrho(x_2)-\varrho(x_1)$	*kg*
Change in CO_2 emissions	$\varrho(x_2)/\varrho(x_1)-1$	%
Change in energy production	$E_p(x_2)/E_p(x_1)-1$	%
Difference in energy production	$E_p(x_2)-E_p(x_1)$	*kWh*
Difference in curtailed energy	$E_{pc}(x_2)-E_{pc}(x_1)$	*kWh*
Difference in energy cost	*Ecost(x2)−Ecost(x1)*	€
Difference in weighted energy price	$p(x_2)-p(x_1)$	*€/kWh*

As it can be seen in Table 1, it is possible to define not only technical but also business-related KPIs.

EXPECTED IMPACT

A platform such as the one proposed in this paper is expected to provide the right tools to enable a holistic energy management at a city level.

Taking into consideration the results obtained from different meetings with municipal authorities, particularly in Barcelona, as well as an exhaustive review of Barcelona's energy, climate change and air quality plan 2011-2020 (PECQ) [10], the following section presents a brief summary of some key aspects related to energy management in Barcelona, and how the SmartKYE platform promises feasible solutions to some of the challenges faced.

Furthermore, the SmartKYE platform will be demonstrated in two urban pilot sites: the 22@ district in Barcelona, Spain and the Lasithi Area in Crete, Greece. However, this paper is not focused in the analysis of such results.

Application Scenarios – Barcelona, Case study

As many other cities across Europe, Barcelona authorities have been actively involved in the definition and development of actions that aim to outline Barcelona's energy commitment in the framework of the European Union's Covenant of Mayors initiative.

In particular, Barcelonas' PECQ is a plan aiming to provide strategic lines to increase energy efficiency and reduce emissions during the period 2011-2020. Besides specific actions and projects to undertake, several different challenges are also outlined. Table 2 illustrates some of the objectives envisioned by Barcelona city council:

Table 2 Barcelona objectives set up to 2020 - Energy

PECQ Objective 2020 (% vs 2008)		Units
Reduce the whole city's final energy consumption	-9.9	%
Reduce final energy consumption per inhabitant	-18.5	%
Increase local energy generation in RE	38	%
Increase the local generation of power with renewables	200	%
Increase PV + mini-wind power	400	%

In order to achieve these objectives, the municipality has defined specific actions such as the integration in one single municipal "protocol" the monitoring of the measures related to energy efficiency across the city. In particular, this will imply the collection, centralization and processing in a single platform of municipal energy consumption data.

Although the technical aspects of such platform might not be clear for the city council, from a business perspective it could help define the current situation of energy consumption in municipal facilities, as well as to use existing data to visualize impact of possible future growth in energy consumption and greenhouse gas (GHG) associated emissions.

As a result, the municipality expects to centralize and manage actions to improve the energy efficiency of facilities, track and assess energy policies and to carry out corrective actions for possible deviations from the predictions made. Such platform should be able to manage high volumes of data as well as being accessible to different stakeholders in a municipality.

Furthermore, the impact of such platform and related projects could be measured through a set of KPIs defined by the municipality, such as those listed below:

Energy:

- Local electricity generation (MWh/year)
- Total final energy saving (MWh/year)

Climate change:

- Savings of GHGs.

Relationship between economic cost and efficiency:

- Total extra cost to the Council of saving 1MWh by means of a specific measure (€ Council / MWh saved over lifespan).
- Total extra cost for the Council of saving 1t of GHG by means of a specific measure (€ Council / kg GHG reduction over lifespan).

In summary, based on the real challenges and objectives provided in the case of Barcelona city, SmartKYE platform approach can certainly offer a feasible solution to real needs of a municipalities such as those presented in this paper.

CONCLUSIONS

The SmartKYE platform approach presented in this paper offers a flexible, reliable and scalable solution to address some of the challenges municipalities face nowadays with regards to a holistic energy management of their cities. From a history-oriented data analytics to a real-time analysis and control, the platform would be able to present such information in a way that addresses particular needs of decision takers as well as technical managers in a city.

Although the SmartKYE platform development is still an on-going effort, it is expected to be validated in two real scenarios, whose results will be presented in future publications. These should present how the design, deployment and assessment of the presented infrastructure helped making effective energy related decisions in a district or at city-wide level. SmartKYE is expected to allow municipalities take informed decisions and address real challenges faced with regards to energy management, which are mostly unsolved by many of them today.

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