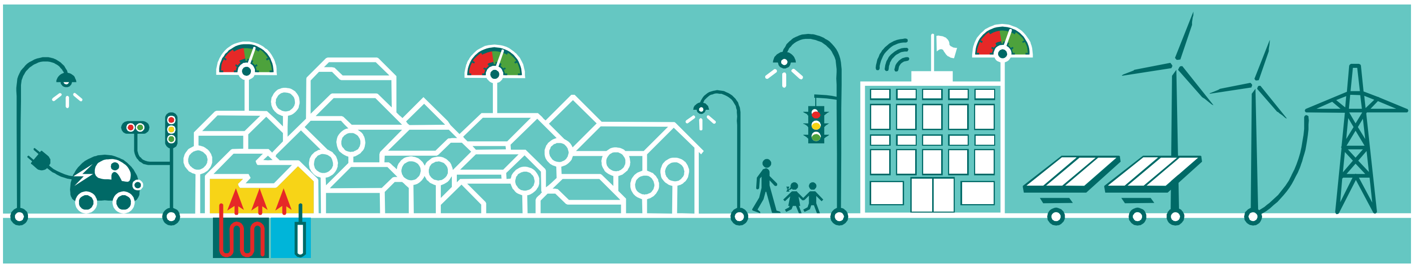
BESOS
Building Energy Decision Support Systems for Smart Cities

Publishable Summary



C O N T E N T S

Executive Summary

BESOS is an EU Research and Development project funded by the EC in the context of the 7th Framework Program that proposes **the development of an advanced, integrated, management system which enables energy efficiency in smart cities from a holistic perspective.**

The challenge

The project has targeted two main stakeholders: the owners of the infrastructure – e.g. **municipalities** – and its operators – e.g. **ESCOs and facility managers (FM)**. The former have been provided with a **Business Balanced Score Card** to audit the **Service Level Agreements** (SLA) established with the ESCOs and FM against a number of **Key Performance Indicators** (KPI). The latter have made use of the same tool to analyse new **business models**, and have been also provided with a **DSS Cockpit** to Monitor and Control (M&C) information from the infrastructure and establish **coordinated energy efficiency strategies.**
Two leading cities in Europe, **Lisbon and Barcelona,** have acted as test-beds of the BESOS approach.

B E S O S final results in short

- A common **architecture and data models for energy positive smart cities.**
- An **Open Trustworthy Energy Services Platform** integrating with the different Energy Management Systems.
- **A Energy Consumtion and production Forecast Engine.**
- **A Business Energy Balanced Scorecard**.
- **A Decision Support System Cockpit.**
- Validation in two pilot sites:
    - The Smart city of **Barcelona.**
    - The Smart city of **Lisbon.**

Executive Summary: Motivation

Energy efficient Smart cities rely on highly heterogeneous already deployed infrastructure and services- e.g. public lighting system, urban heating system, public buildings, electric vehicles, micro-generation, residential prosumers, etc. All these systems are currently managed by isolated Energy Management Systems (EMS), that hardly have capabilities to offer information and services to third parties in order to achieve advanced coordinated energy saving strategies.

This challenging scenario has motivated the extensive adoption of new business models where not only the maintenance of the public infrastructure has been outsourced, but also the management of any process leading to a saving of costs, energy or CO_2 emissions. The municipalities and facility owners responsible of public services have established contracts with specific Service Level Agreements with Energy Service Companies (ESCOs) and Facility Managers (FM) that, based on such SLAs, run the smart city trying to a) reduce costs, so they can obtain a business benefit, b) guarantee the levels of Quality of Service (QoS) established in such contracts. The latest is a key constraint of this kind of service schema since, by the end of the day, citizens will be the ones living the outcome of the approach, and they will demand to maintain similar – if not better – levels of QoS.

Project objectives

The general goals described above can be specified into a set of concrete scientific and technical objectives of the project:

1. **Specification of requirements, use-cases and Key Performance Indicators** associated to scenarios of efficient energy management in a smart city, including EMSs integration of dedicated services and applications through new business models.

2. Definition of **a common architecture and data models** for energy positive smart cities to facilitate industry deployment.

3. Development of an **Open Trustworthy Energy Services Platform** that will act as a flexible information hub that decouples.

4. **Integration with the different Energy Management Systems (EMS**) deployed in a neighbourhood to be able to interact with them in a service oriented way.

5. **Design and Implementation of end-user applications** that will help stakeholders - i.e. public authorities, ESCOs, FMs and citizens - to interact more efficiently :
    a) A Business Energy Balanced Scorecard (including new business models).
    b) A Decision Support System Cockpit (including data analysis and strategies).

6. **Validation and demonstration of the project** results in two different pilot sites:
    a) The Smart city of **Barcelona, Spain**.
    b) The Smart city of **Lisbon, Portugal**.

7. **Evaluation and Assessment** by means of a thorough methodology of the amount of energy, CO2 emissions saved through the deployment of BESOS technology.

BESOS at a glance

Building Energy decision Support systems fOr Smart cities

Project Coordinator
Name: Antonio MARQUÉS
Institution: ETRA I+D
e-mail: amarques.etraid@grupoetra.com

Project Technical Manager
Name: Pedro Jose MARRÓN
Institution: UDE
e-mail: pjmarron@uni-due.de

Partners: ETRA I+D, Universität Duisburg-Essen, Sodexo, Enercast, Portugal Telecom, LISBOA E-NOVA, HYPERTECH, Barcelona Municipality, Cobra Group and Technoflex.

Duration: 36 months
Start: 01.10.2013
Total Cost: 4,610,538 €
EC Contribution: 2,925,813 €
Contract Number 608723 - ICT

Strategic Goal: BESOS strategic goal is to develop an advanced, integrated, management system which enables energy efficiency in smart cities from a holistic perspective.

Project website:
http://besos-project.eu

The Consortium

ETRA I+D is the hi-tech unit within ETRA Group, one of the leading industrial groups in Spain. Its mission is putting in the market the most advanced solutions either directly or through the 10 companies of the Group.

Universität Duisburg-Essen covers the spectrum of Cooperating Objects and is coordinating several projects.

Sodexo España is a division of Sodexo Spain, a subsidiary of the French multinational Sodexo Aliance

Enercast GmbH is an international specialist in the field of renewable energies forecasts, based in Kassel, Germany.

Portugal Telecom Inovação, SA develops innovative and competitive services and solutions for the ICT market.

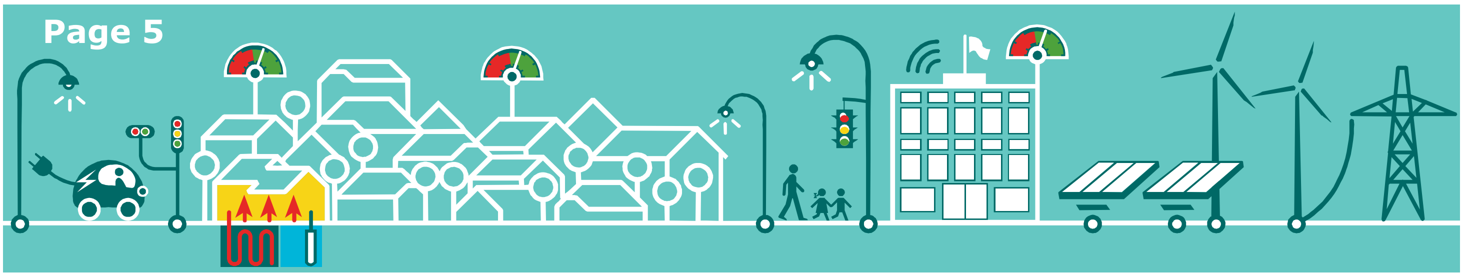
LISBOA E-NOVA seeks to contribute to the sustainable development of the city of Lisbon through good practices.

HYPERTECH provides flexible solutions for electricity consumers, electric utilities and DSM service providers.

Barcelona Municipality is the local authority responsible for services for the city of Barcelona.

Cobra Group possesses extensive experience in the development, construction, operation and maintenance of industrial facilities and power plants.

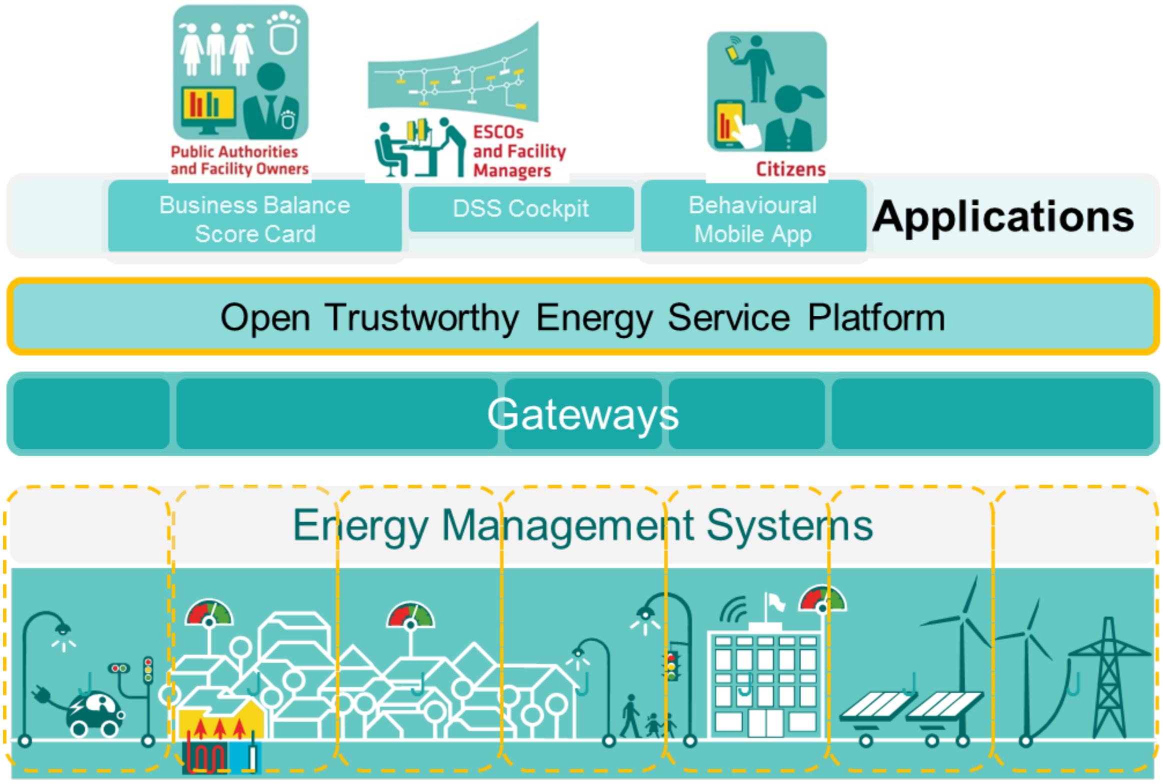
Ficosa engaged in the research, development, production and commercialization of systems and components for automobiles, commercial and industrial vehicles.



Main Results: Architecture and Energy Positive Smart Cities

Reference Architecture

The BESOS reference architecture was skilled to support the next generation functionalities envisioned for the smart city grid. The BESOS architecture can be instantiated in distributed ways and it is designed to be agnostic of EMS devices by supporting standard and extensible interfaces enabling its use in any city in the world independently of its size or location.



The Architecture is comprised by four main types of functionalities:

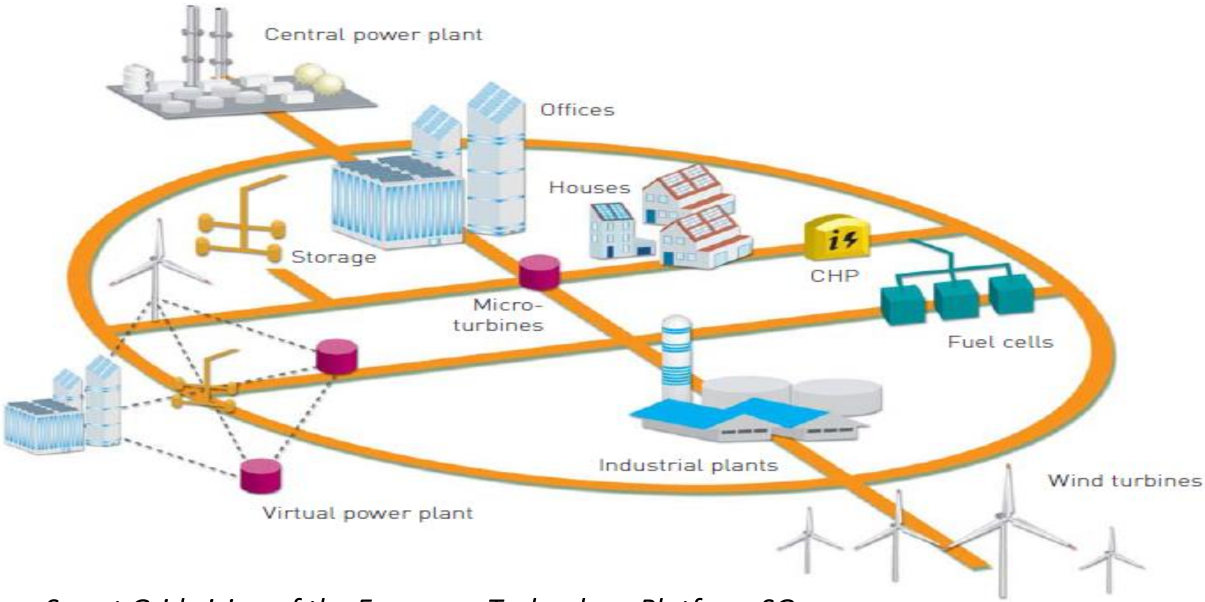
Energy Management Systems (EMS) every BESOS energy system, such as Wind farms, EV infrastructure, public lighting system, traffic lighting, public buildings, etc. is encapsulated by an EMS.
Gateways are used to integrate the EMS into BESOS service platform (OTESP). They aggregate EMS data and transform it towards BESOS standard data model that is supported by OTESP.
Open Trustworthy Energy Services Platform (OTESP) acts as an Energy Service Platform providing to BESOS Applications a set of reusable energy service enablers built on top of all EMS comprised in a Smart City.
Applications are developed on top of OTESP service enablers with all the service logic and User Interfaces needed by the different BESOS actors.

Main Results: Architecture and Energy Positive Smart Cities

Common Information model

BESOS took special focus on the definition of the common information model (CIM) among the different components that consist of the BESOS framework.

> The proper definition of a semantic framework enables the identification of an "agreement" on a common definition and structuring of the identified concepts between people/actors with different skills and expertise in related domains like ICT, energy, or building management systems.



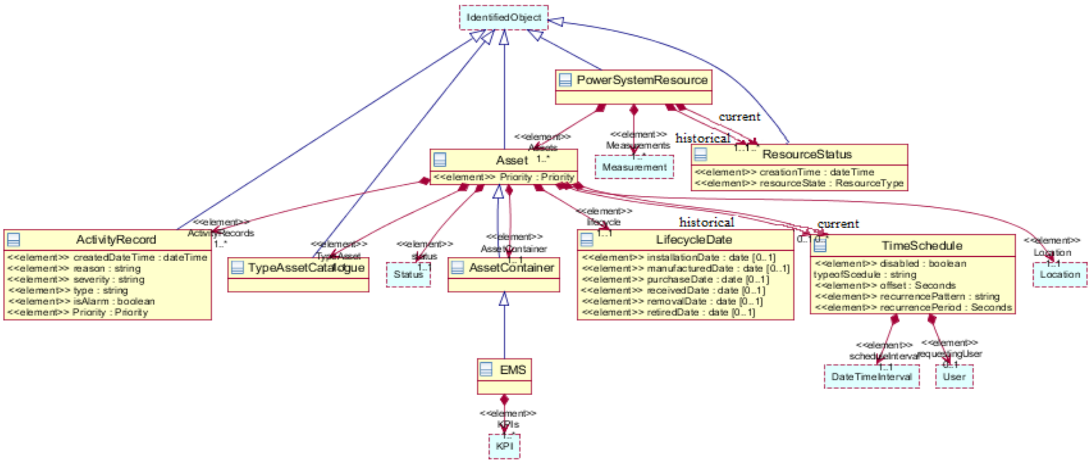
Smart Grid vision of the European Technology Platform SG

A standards-based framework acts as intersection of all local entities and it is used to facilitate reusing of concepts and mapping of local data elements. BESOS selected IEC CIM as the skeleton for adapting BESOS information model, as it defines a framework for power systems management and associated information exchange, covering communications between equipment and systems in the electric power industry. Furthermore, it added new concepts and properties coming from the project specific requirements. The decision was to go with a high level adaptation of IEC CIM concepts (global layer of BESOS model) and further extend these high level entities with BESOS specific attributes (local layer data entities).

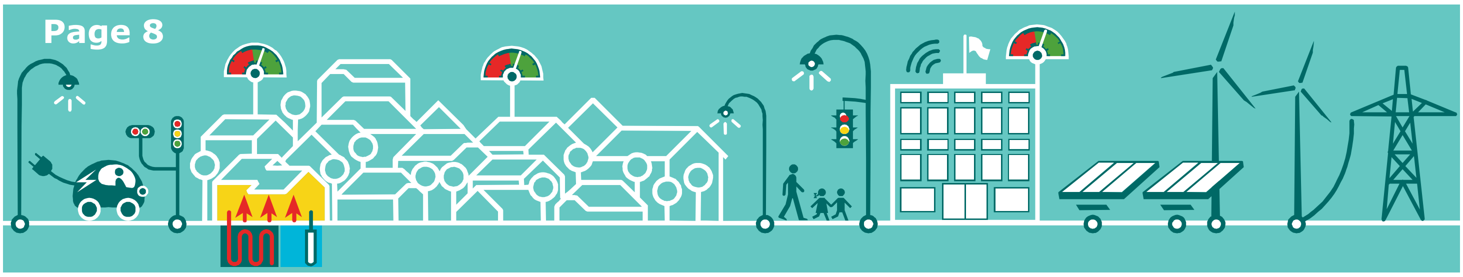
Main Results: Architecture and Energy Positive Smart Cities

BESOS CIM is broken down to 7 logical modules in order to facilitate cohesion and reusability:

Location: This module includes concepts to capture information about space location as well as the root classes required throughout the data model. This module covers the location information required by ESCOs and Manager for the optimal management of their portfolio.
Asset Structure: The module includes concepts about assets' management. This is the logical entity providing high level information, replicable at any asset type integrated in the platform and thus is considered as a cornerstone aspect of BESOS CIM.

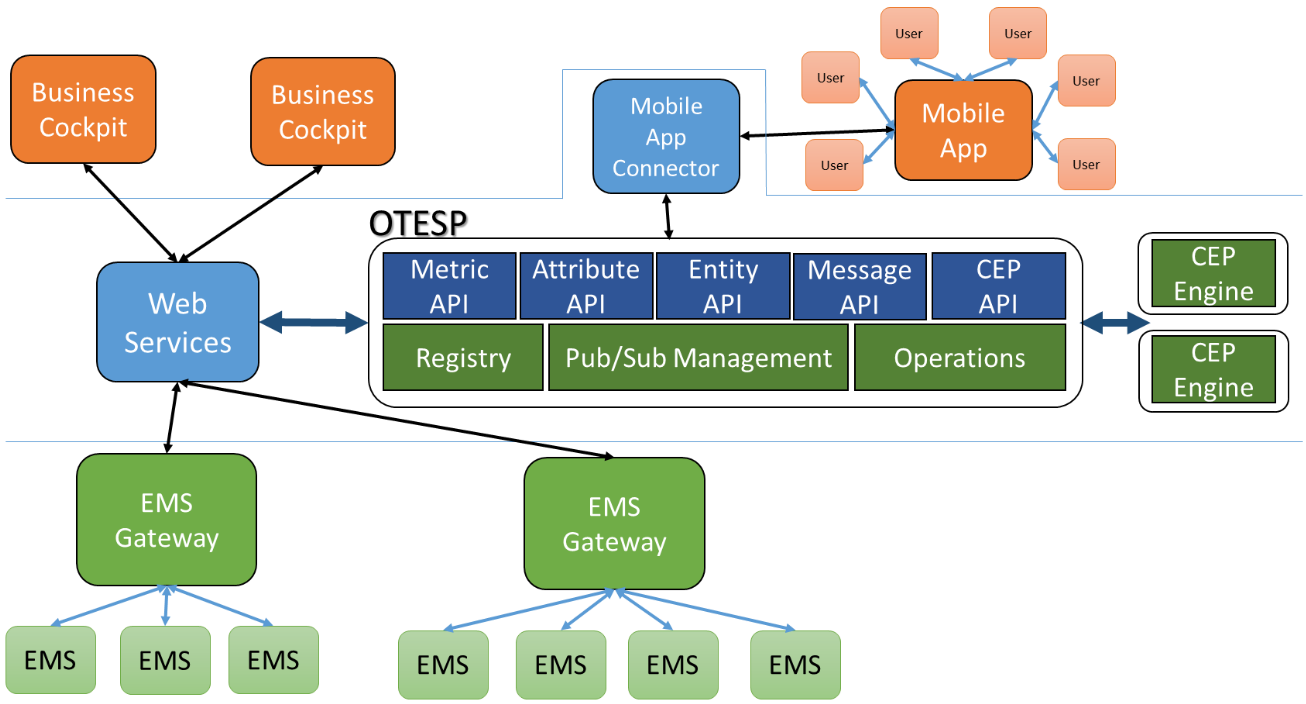


Assets Representation: This is the module providing information about the physical assets integrated in the project, namely: Public & Residential Buildings, Public & Traffic Lighting, Electric Vehicles Charging Stations, Wind & PV generation, Forecasting Engine. A modular approach is adopted for the definition of the associated classes, enabling that way the easy modification and expandability of the model.
Measurements & KPIs: This module includes concepts capturing dynamic information about raw metrics from assets and the associated Key Performance Indicators. The latest are the anchor point for the definition of high level business strategies.
Organisation & Users: This is the module for managing information about organizations and business stakeholders. The main concepts have been adopted by IEC CIM, further adapted to the business application layer of BESOS framework.
Document Types: This module specifies the business strategies and service level agreements (SLAs) examined in BESOS, covering that way the innovative business concepts and schemas at Smart Cities.
Control Structure: Along with monitoring functionalities, BESOS enables the implementation of control commands from business applications to the different EMSs. This is the module for capturing the information required for modelling these control strategies.



Main Results: Open Trustworthy Energy Service Platform

The OTESP as the middleware of BESOS project provides the developed applications capabilities to navigate through the underlying EMS infrastructure and access the supplied data from a wide range of devices located in the neighbourhood in an efficient and secure way. It thus acts as a flexible information hub, decoupling the energy applications from the heterogeneity of the smart grid and communication infrastructure. By building on the architecture and data models for energy positive smart cities, the OTESP allows for an effective processing and delivery of services while enabling the applications to dynamically express their information requirements. Thereto an information meta model has been developed, granting the means of structuring and retrieving energy related data from a heterogeneous set of energy management systems in a uniform but still flexible manner. Furthermore, the OTESP offers multiple communication paradigms to cover most use cases, supports encrypted and privacy preserving communication and allows for on-the-platform processing to efficiently manage the data flow between data sources and clients.

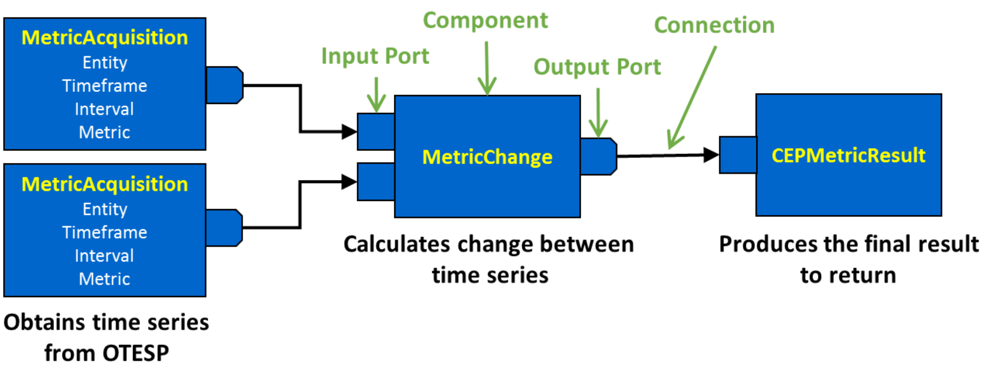


In order to organise existing infrastructures and describe arbitrary data sources, the meta information model builds on the general concept of entities. This allows a hierarchical modelling on different abstraction levels, e.g. in case of public lighting, from a single point-of-light at the lowest level over a complete street up to the whole district. Depending on the layer, the entities then can provide information with a different degree of detail and aggregation. The data itself is distinguished between metrics and attributes.

Main Results: Open Trustworthy Energy Service Platform

A metric is represented as continuously delivered data in a time series of floating point numbers as for example the energy consumption or temperature, which can be interpolated, extrapolated and aggregated, whereas an attribute describes an arbitrary complex definable property of an entity which can be read and – if applicable – also written to control the behaviour of an entity, e.g. the temperature of an air conditioning unit. Utilising this concept of modelling as a foundation, five major APIs have been defined for the OTESP to operate on the models of the energy domains (as also shown in Figure 1):

- The *Entity API* allows querying the EMSs for the available entities and their relations. Besides some general information about an entity, e.g., its ID, type (e.g., solar panel) and description, this includes primarily the supported list of attributes and provided metrics.
- The *Attribute API* allows to query the specific property values for the specified entities as well as to manage and control functionality by allowing write access to attributes if provided by the entities.
- The *Metric API* deals with the metric time series provided by the entities. As described above, this includes the capability to interpolate and extrapolate measurements.
- The *Message API* enables participants of the platform to exchange arbitrary messages. Similar to the attributes, message types can be defined depending on the requirements in the context of an energy domain.
- The *Complex Event Processing (CEP) API* allows pushing part of the application logic into the platform. Computations on specified metric data are performed directly on the platform before the results are delivered to the requesting clients. The concept of a processing graph is utilized to define the computation logic. Each processing component offers typed input and output ports as well as parameters. By instantiating these modular components and connecting them, developers are able to create reusable dedicated processing graphs optimized for their applications. As an example, the processing graph of the KPI "Change in CO_2 Emissions" graph is shown in Figure 2. Although this example is quite simple, through the cascading of multiple components, the computation logic can be defined as complex as desired.



Main Results: Open Trustworthy Energy Service Platform

To provide a compact and flexible specification of the entities, information is required from, all these APIs make use of an *EntityFilter* structure, allowing clients to either specify individual entities by their ID, based on their relationships to other entities (e.g., has-parent) or by the metrics and attributes they provide. Therefore this filter enables both node-based and data-based interaction patterns.

In addition to that, the platform also supports the publish/subscribe paradigm, notifying subscribed clients if attributes have changed or new metric values are available, allowing for an efficient distribution of information in a timely and need-based manner. For metric values, this API also supports in-network aggregation (e.g., the sum of energy consumption for a neighbourhood) to limit the required bandwidth.

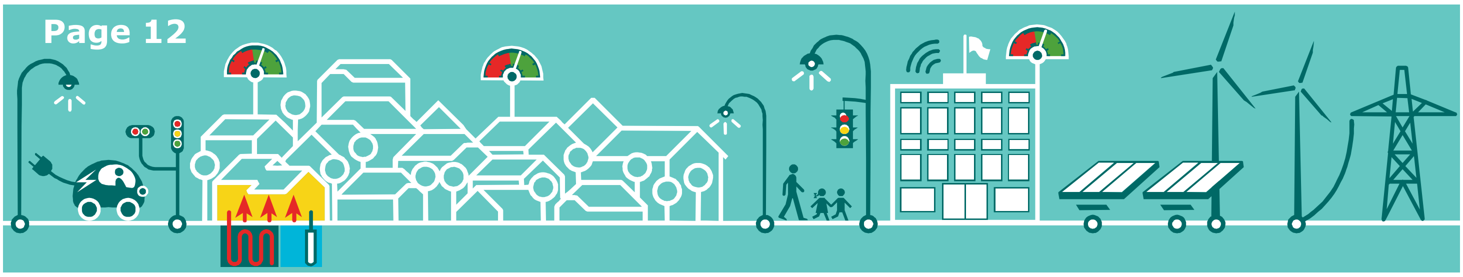
Opening the platform especially to citizens and encourage an involvement, the OTESP needs to support most of the commonly used technologies. Since almost every private person uses a mobile device for accessing information on the internet, the platform also contains a dedicated *Mobile App Connector* (see Figure 1) to meet the specific mobile requirements, allowing for asynchronous communication. Mobile users may experience a temporal unavailability of their service due to bad reception or when entering or leaving a Wi-Fi zone. Since the OTESP is relying on a permanent connection when a query is issued, a connection loss will require a re-issue of the query. Some complex queries also might need a longer execution time than what a mobile user expects. To overcome this possible problem, the *Mobile App Connector* allows to place a request to the OTESP without the need of keeping up the connection until the result is computed and delivered. Instead it immediately returns a token which can be used to obtain the result, once it has been available. Results are cached by the connector for a specifiable amount of time and can be requested as often as required during that time span. Hence the connector acts as a bridge between mobile applications and the OTESP and makes the latter available to a large field of potential users.

During the development of the OTESP, security and privacy also have been a major concern. When dealing with energy related data and providing large amounts of information and services as an EMS operator, there might also be the demand for providing customers access to protected data, e.g. data that was gathered by a smart meter at a private home or other data that may only be visible to the respective persons. In order to protect the customer privacy and ensure a secure exchange of information, the OTESP offers multiple mechanisms for achieving these goals. In general, all communication between clients (EMS, business cockpits and also users of the mobile application) and the OTESP is encrypted and authenticated in both directions using SSL/TLS (i.e. HTTPS) and the so-called “basic authentication” (HTTP-based username and password submission), which are both heavily-used internet standards.

Main Results: Open Trustworthy Energy Service Platform

Since the OTESP is querying information from multiple, independent EMS and acts as merging relay in the process of obtaining data, getting access to private data would require clients to submit credentials for each and every EMS. Apparently, the need of frequently transmitting credentials from various service providers over the platform or even caching them temporarily would be risky and not contribute to a trustworthy interaction. The OTESP avoids this problem by introducing a token based permission system, based on the OAuth protocol, which allows users to utilise third party services by using their accounts from other, trusted parties (e.g. Google or Facebook). Each EMS operator, offering protected data, has to maintain an authentication system where clients can authenticate independently of the OTESP to access their information and in return get a time-restricted token they include in their communication with the OTESP. This token is forwarded to the EMS which evaluate its validity and provide the protected information in case of an actual permission. Thus the OTESP is not involved in the process of exchanging credentials while allowing clients to access their protected data without submitting any sensitive data to the platform, preserving privacy and security.

In summary, the OTESP as the middleware of BESOS project provides energy related applications the capabilities of accessing and analysing information of the smart grid and the underlying heterogeneous infrastructures and communication infrastructure in a uniform and flexible way while ensuring privacy and security and supporting many different communication paradigms, making it appealing and suitable for a wide range of users and use cases.



Main Results: Forecast Engine for Energy production and Consumption

Forecasting the Energy production of Renewable Energy Resources

Motivation

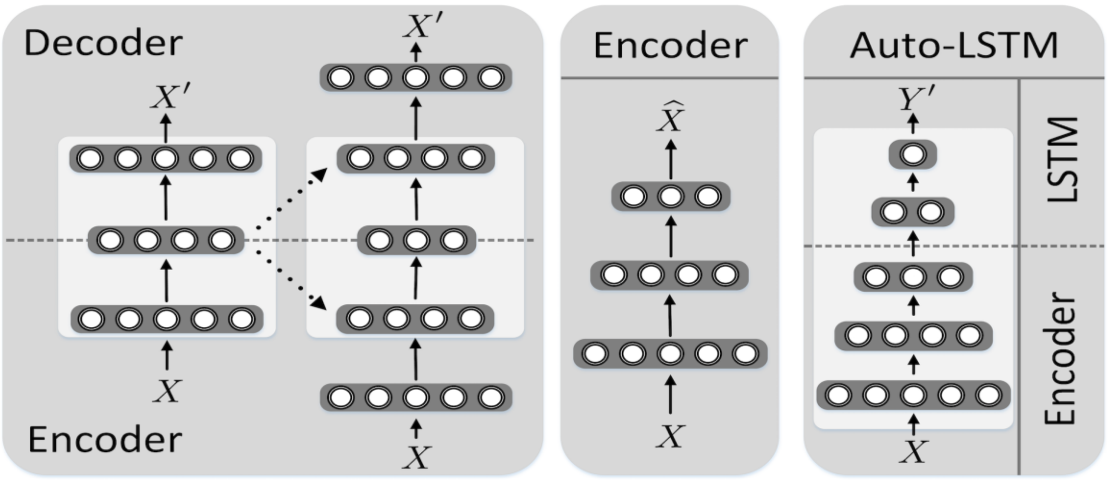
Research in techniques for regenerative power forecasting has been a major area of interest during the last decade, as more and more regenerative generators get integrated into the power grid. Regenerative generators have volatile energy characteristics, which means that they cannot be controlled such as conventional power plants.

The integration of these novel forms of power plants into the power grid is one of the big challenges that the industry currently faces. Due to the increasing portion of regenerative energy in the power mix, sophisticated algorithms have to predict the future energy generation in a reliable manner.

One of the main R&D goals of enercast was the development of new forecasting algorithms and techniques to improve the accuracy of the existing forecast algorithms. During the project, enercast has developed and tested to different kind of forecast algorithms for power production: **"The Auto LSTM"** and the "**Analog Ensemble-base Similarity Search Technique".**

The Auto LSTM

The Auto LSTM algorithm is based on an artificial neural network. It combines the feature learning of an AutoEncoder (AE) with the temporal context usage of a Long Short-Term Memory Network (LSTM). It's trained and configured with historical numerical weather predictions (NWP) and historical power production data. The NWP is the High Resolution NWP Model from the European Weather Agency ECMWF located in Reading, UK



Main Results: Forecast Engine for Energy production and Consumption

The Analog Ensemble-base Similarity Search Technique

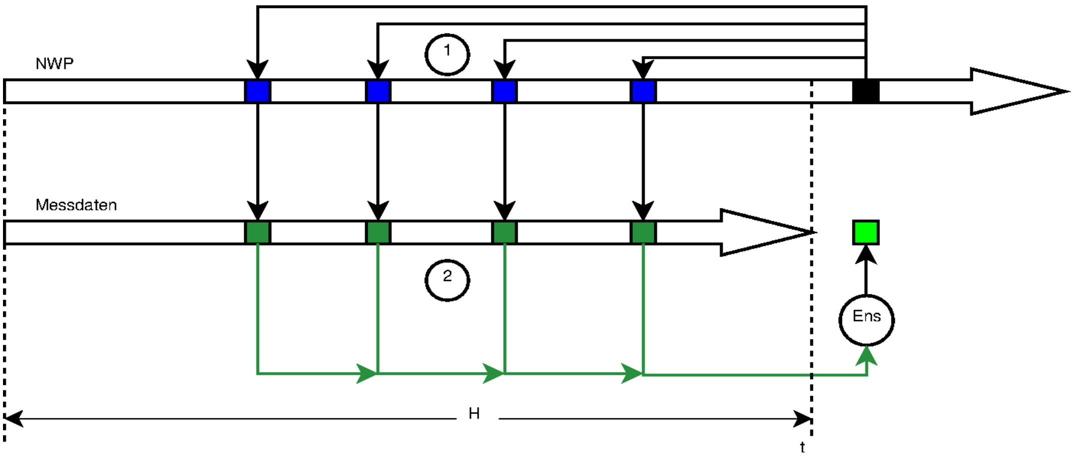
The idea of the Analog Ensemble-base Similarity Search Technique is to search in historical weather data for a number of historic situations (analog situations) which are similar to a novel situation for which a forecast has to be created. The power generation time series during the found similar historic situations are then aggregated to an overall forecast (ensemble step), e.g., by averaging the different similar situations. The historic data are typically regarded separately for each facility.

The developed Analog Ensemble Algorithm (AEA) mainly composed of three steps:

1. In a first step, the similarity of the current weather situation to each situation in the historical data is assessed using a comparison strategy. The result are so-called analogs, containing element-wise similarity scores.
2. Next, the analogs are filtered using a filter strategy to only contain the appropriate analogs for ensembling.
3. Last, the filtered analogs are used to extract the appropriate segments from the historical power measurements using an ensemble method to create the final forecast.

This AEA compares two multi-variate time series: for example a segment which represents a weather situation of the forecast-window and a segments of a historical weather situation. One of the main components of the AEA is an adaptive weighting technique of different NWP-types. These weights provide an adaption of the local weather-characteristica.

The main principle of the comparison-technique is as follows: The forecast-window with current NWP measurements is slided over a historic data set. In each step, the window content of the forecast-window is compared with the respective element of the historical NWP, and a similarity score is computed using the described measurement.



Main Results: Forecast Engine for Energy production and Consumption

The Results

The forecasting accuracy of the Auto-LSTM and Analog Ensemble Algorithm (AEA) compared to a sophisticated physical model forecasting system is very good. Each algorithm predicted the future power generation of one solar facility in Lisabon for the time range of January 2016 till May 2016. All algorithms had to predict the day-ahead forecast horizon of 24h to 48h. The predicted energy generation is compared to the measured power generation by three error measures: the root mean squared error (RMSE), mean absolute error (MAE) and BIAS. These Error Measures can be used to assess the power forecast. If RMSE > MAE the forecast has high deviations to the measured power output. If RMSE ≈ MAE the forecast has only small deviations to the measured power output. The BIAS allows assessing whether power forecast is predicting higher or lower values than the measured power output.

Conclusion and Outlook

The results showed that the Auto-LSTM has a slightly better performance as the AEA whereby both models outperform the physical forecasting model. In future work, we plan to ensemble the forecasts of each model to improve the forecasting error further. During our work, we trained multiple models but only used the best performing model. By combining the different models depending on their individual strength, we might be able to increase the forecasting quality further.

	RMSE	MAE	BIAS
Auto-LSTM	6,66 %	3,81 %	-0,95%
AEA	6.97 %	3,91 %	0,56 %
Physical Model	7.93 %	4,17 %	1,93 %

Main Results: Forecast Engine for Energy production and Consumption

Forecasting the Energy consumption

Motivation

The next goal of enercast during the project was the develop forecasting techniques to predict the power consumption of public buildings. The energy consumption of HVAC, Cooling or Air Condition is correlated by the weather, e.g. air temperature, solar radiation, wind chill, etc.

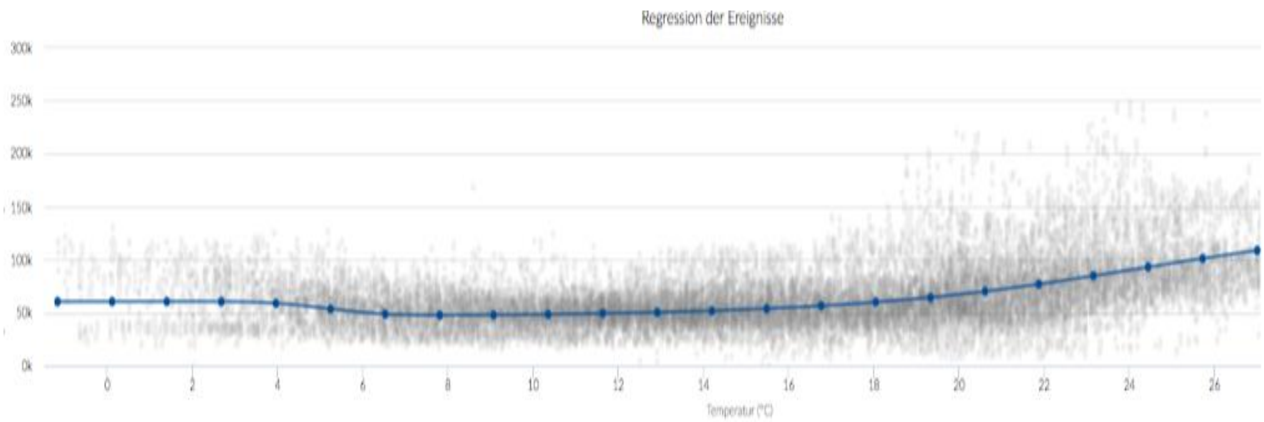
The idea is to use similar self learning algorithms such as Artifical Neuron Networks (ANN) or Suport Vector Machines (SVM), which are used in power production forecast to predict the power consumption of HVAC or cooling systems.

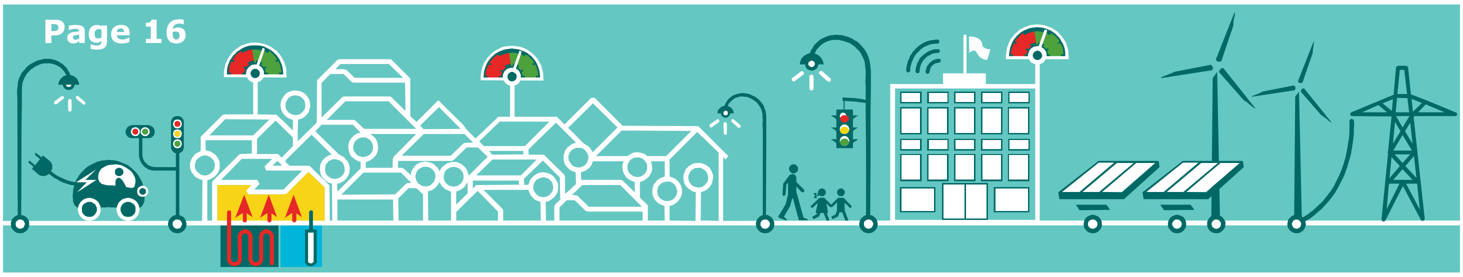
The project partners has contributed the consumption data of different building types. Enercast has used the consumption data of the HVAC, cooling and ventilation systems to develop an power consumption forecasting system.

The power consumption forecasting EMS

The historical and real time consumption data of the buildings where accessed via the OTESP gateway and transferred to the enercast SKY platform. The enercast SKY platform provides the necessary tools for filtering, training and developing the forecast algorithms. It's connected as the power consumption forecast EMS to Besos platform via the OTESP gateway.

After retrieving the data is validated by some simple validation patterns. Afterwards the cleansed data is normalized by the usage. The most of the buildings where public buildings. Public buildings got a different power consumption profile than residential buildings. So the data have to be normalized by different factors, such as "day of week", "hour of day", etc. Ensuing the normalization, the data is used the target goal for the self learning algorithms. The cleansed and normalized consumption data is used in the training process with the different NWPs of the different weather services.





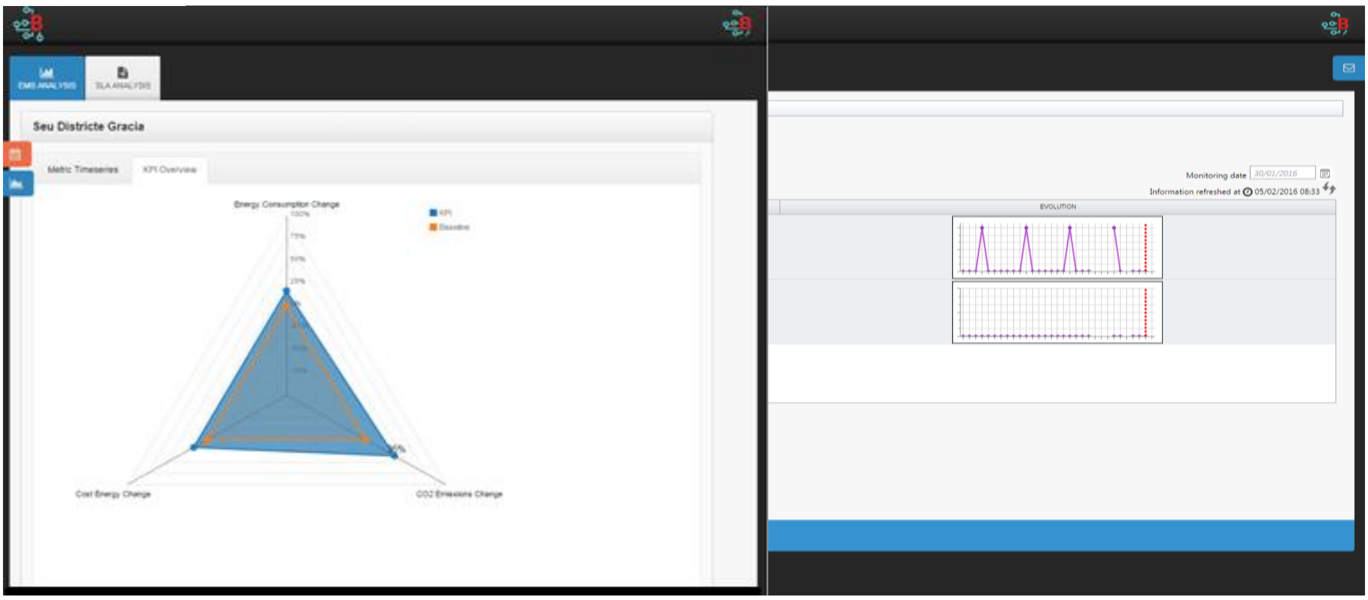
Main Results: Smart City Applications

Within BESOS two different Smart City Applications have been proposed to support municpilaities and energy service providers: a Business Balanced Scorecard (BBSC) and a Decision Support System Cockpit (DSSC).

Business Balanced Scorecard

The Business Balanced Scorecard (BBSC) aims to provide the smart city managers with the functionalities of a typical balanced scorecard with a focus on energy efficiency. The four-perspective approach of a balanced scorecard (Financial, Customer, Internal business processes, and Learning and growth) is adapted in the BBSC trying to move slightly away from the business approach and cover the management necessities of a smart city. In addition, a visual analytics tool aims to support both the facility owners in their decision process, and stakeholders in providing an informed evaluation of their strategies. Since decision makers are often not IT experts, they need to be guided via visual/interactive interfaces to be able to analyze impacts of specific options. In the same way, visual analytics techniques support tools by providing a friendly access to data.

Public authorities can find in the BSSC the tools to assess the fulfilment of their contracts with the different ESCOs that provide services to the city. These contracts can be audited in real-time by means of a series of measurable objectives and Key Performance Indicators (KPI) previously defined that will be continuously monitored. Analysis tools are also available to provide support for better understanding of the current status of the system and subsequently, assist them in the decision-making process, based on easy-to-understand data visualization.

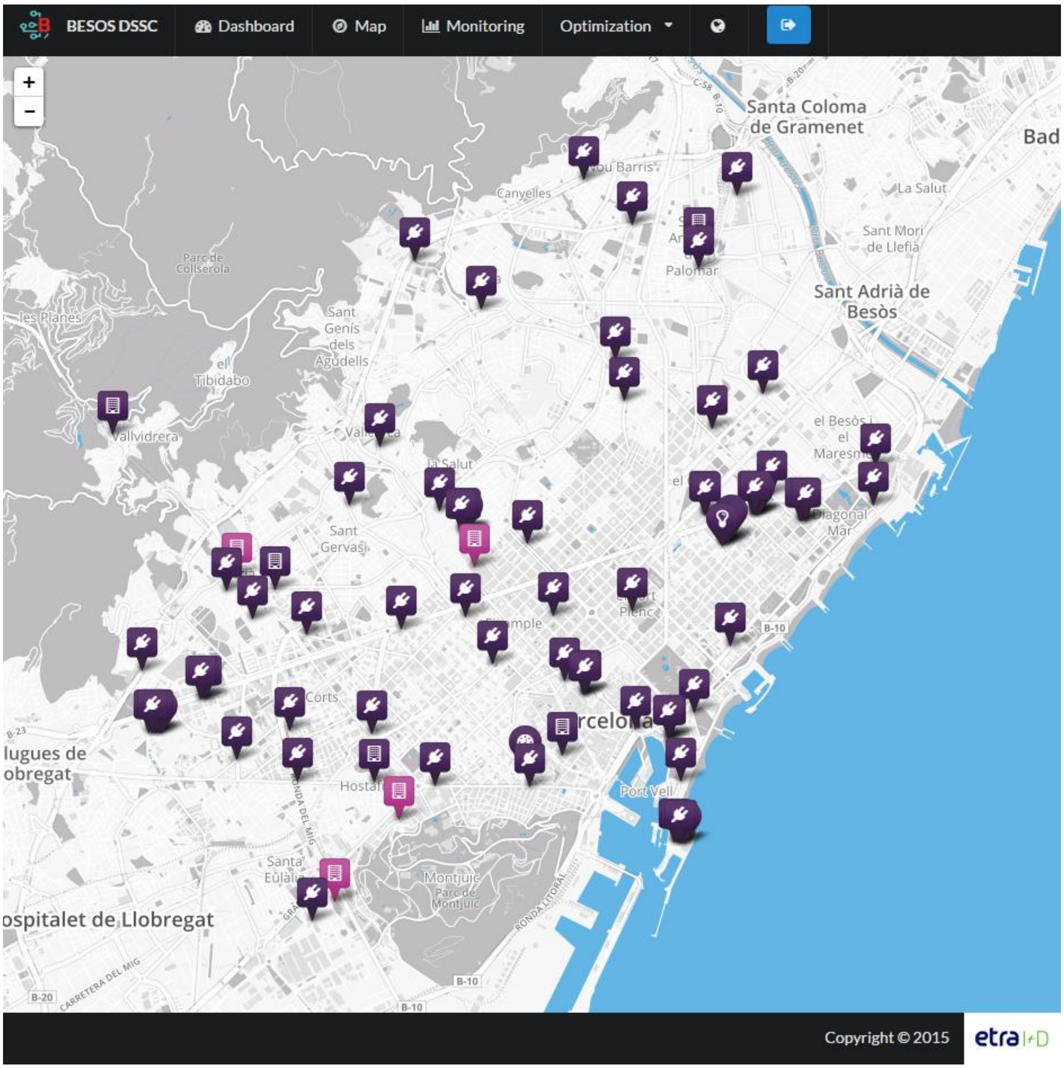


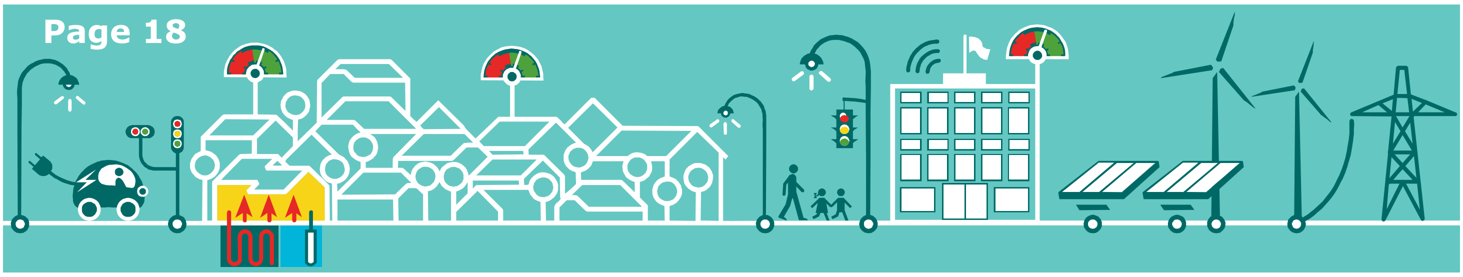
Main Results: Smart City Applications

Decision Support System Cockpit

While the BBSC focuses on the business-oriented side of the smart city management, the Decision Support System Cockpit (DSSC) goes down to a more technical level. Aimed to technical operators, the DSSC permits the monitoring of the EMS data and the actuation over the EMS both immediately and by the definition of medium-term strategies. In this context, the DSSC processes real-time data and generates valuable analytics to affect the strategies that operate a district or a subset of the energy services deployed.

The DSSC is as well provided with a knowledge basis to propose corrective actions. This knowledge can come from a common strategy identified from a new business model analysed with the BBSC – e.g., matching loads and production, proposing shifts on the consumption profile for a particular EMS –, or from a specific innovation affecting an EMS – e.g., usage of a more aggressive policy for energy saving in public lighting or traffic lights –, among others.





Project Impact: Demonstration and Evaluation Results

The demonstration activities validated and hosted, in the smart cities of Lisbon and Barcelona, the different systems developed in the first half of the project. These activities allowed to activities to enlarge the impact of the project and to raise the attention of the main stakeholders.

In summary, the objectives of the demonstration of the results were:

- To use the **Business Balanced Score Card and DSS Cockpit** under the supervision of the end-users (Barcelona municipality, Lisbon E-Nova and Lisbon Municipality – stakeholder, Sodexo and ETRA);
- An android mobile **application** for the school community;
- To test the **use cases** in the different EMS involved;
- To host the **public demonstration** activities, to enhance the dissemination and impact of the project.

Two different test campaigns were planned (Trial 1 and Trial 2). This provided two different datasets for comparison in two different seasons, and enabled an incremental deployment of the solutions being provided by the project. It is

Led by the pilot site leaders (Lisboa E-Nova, the Ajuntament de Barcelona, SODEXO, Cobra and Ficosa), and in close collaboration with the user group supporting the pilots (eg. Lisbon Municipality and Lisbon University Campus), the different systems were deployed in the test sites with the support of the technical partners ETRA, PTIN and ENERCAST.

Project Impact: Demonstration and Evaluation Results

EMS in Barcelona:

- Ficosa Power Plant
- Public lighting
- Electric Vehicles
- Barcelona Municipality Buildings
  - Centre Cívic Orlandai
  - Biblioteca Agustí Centelles
  - Biblioteca Les Roquetes
  - Arxiu Municipal Contemporani
  - Centre Cívic Can Déu
  - Centre Cívic Tomasa Cuevas
- Catalan Gorvernment Buildings (I.cat)
  - I.Cat Headquarters
  - IES Can Margarit
  - CAP Cervelló
  - Film Library (Filmoteca)
- BCN Traffic Level
- BCN Traffic Consumption
- Cobra CECOVI Wind Farm (Viudo
- Energy production forecast
- Energy consumption forecast

EMS in Lisbon:

- Campo Grande 25 Building – managed by Lisbon Municipality and ISA
- Olivais School - managed by Lisbon Municipality and ISA
- Mechanical and Electrical Department from the Municipality managed by Lisbon Municipality and ISA
- University of Lisbon PV Park energy production – managed by Conergy/CAPA
- Cobra CECOVI Wind Farm (Montegordo) – managed by Cobra
- EV Charging points
- Traffic lights, managed by EDP and Lisbon Municipality
- Public lighting managed by Philips and Lisbon Municipality
- Social Services' building managed by LMIT and Lisbon Municipality
- Energy production forecast
- Energy consumption forecast

Project Impact: Demonstration and Evaluation Results

It was not the intention of the project – due to obvious budgetary constraints – to propose a full-scale smart city deployment. On the contrary, it was preferred to involve as many different energy management systems in a city as possible, with a limited – but relevant -number of monitored and controlled resources per EMS.

In the above mentioned EMS, different use cases were tested according to the following table:

USE CASES		Public building system	Energy generation system	Electric Vehicles	Public lighting system	Traffic lighting system	Public building system & Energy generation system
UC1	Visualization and Monitoring of energy data	x	x	x	x	x	x
UC2	Data analytics on historical information of Prosumer Flexibility-	x	x	x	x	x	x
UC3	Energy demand optimization of the public lighting based on light environment				x		
UC4	Energy management for the use of electric vehicle fleet			x			
UC5	Electrical Vehicles (EV) local optimization and storage capacity forecasting			x			
UC6	Energy demand curve optimization based on traffic conditions				x	x	
UC7	Energy demand monitoring and optimization in public buildings	x					x
UC8	Smart city Energy demand curve optimization	x	x	x	x	x	x
UC9	Optimal Alignment of KPIs with SLAs	x	x	x	x	x	x
UC10	Service platform for Public Authorities and ESCO's to access to public tenders information	x	x	x	x	x	x
UC11	Modification of user behaviour	x					x
UC12	Measurement of the renewable energy produced and predicted in the distribution network		x				x
UC13	Predict the energy consumption on weather data	x					x
UC14	Measurement / control of the electric energy quality (in the distribution network)	x	x	x	x	x	x
UC15	Preventive Maintenance Alarm	x	x	x	x	x	x

Project Impact: Demonstration and Evaluation Results

There is a tight interconnection between the demonstration and evaluation activities performed in BESOS, as the demonstration of the different case scenarios further enables the evaluation of the platform in Lisbon and Barcelona pilot areas. Two rounds of evaluation were performed following the two periods of pilot implementations.

Overall, there are four main pillars that consist of the evaluation framework of BESOS project:

BESOS **impact assessment analysis** considering the different business scenarios and use cases identified and further demonstrated in the project

BESOS **end users' experience** evaluation considering the development of the different applications for the business stakeholders: Public Authorities, ESCOs, citizens and EV users

BESOS **technical evaluation**, handling that way the evaluation of the software components that consist of the final platform

BESOS **business evaluation** towards the evaluation of viability and further commercialization of the different applications developed in the project: BESOS Business Balanced Scorecard, BESOS Decision Support Cockpit and BESOS forecasting Engine.

Special focus is delivered at the impact assessment analysis of BESOS platform, further addressing the list of use cases tested in pilot premises. Different evaluation scenarios were performed to evaluate:

- The optimal management of **Public & Traffic Lighting** taking into account contextual and traffic density data for demand reduction
- **Public Buildings** assets' management considering the evaluation of new dynamic pricing schemas
- The coordinated management of **Electric Vehicles Charging** points by taking into account EV users' needs and preferences → demand shifting at night low cost and low CO2 emissions hours
- The **smart city management** scenario where different types of assets are integrated and demonstrated under a common management framework→ coordinated management by taking into account the aforementioned control strategies at the different asset types
- The innovative production and consumption **forecasting engine** developed within the scope of BESOS framework

In addition, the reliable and uninterrupted monitoring of numerous asset types and further the identification of abnormal situations (by monitoring energy quality) were also evaluated as part of impact assessment analysis.

Project Impact: Demonstration and Evaluation Results

It must be pointed out that before the actual deployment in pilot sites, an ex-ante analysis was performed to "screen the landscape" at pilots, further allowing for the definition of a point of reference for the conduction of the project assessment. A summary of the results from the evaluation process performed at the two pilot sites and reporting periods are presented in following tables, with the list of performance indicators defined as part of BESOS evaluation plan. In, addition a detailed commentary about the different evaluation scenarios performed is provided to clearly highlight the impact of the DSS strategies, considering the diversity of assets that consist of the portfolio at each pilot site.

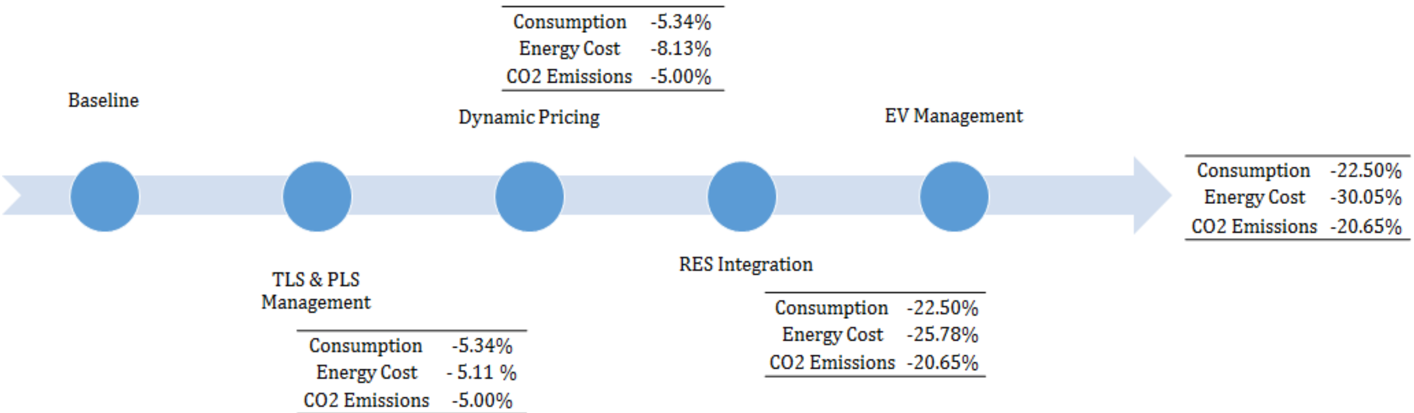
ID	Evaluation Criteria	Barcelona Site		
		1st Period	2nd Period	Comments
1	Efficient Monitoring of the Facility (EMF)	93.80%	96.23%	The evaluation is associated with efficient and reliable monitoring of assets
2	Increase RES generation utilization (IRU)	5.40%	17.16%	Smart City management scenario: Increased **RES integration** during the 2nd round of trials
3	Cost reduction (CR)	-10.51%,	**-30.05%**	Smart City management scenario considering integration of different asset types (*)
4	Peak Demand Reduction (PDR)	-	-26.32%	Smart City management scenario considering the integration of different asset types (*)
5	Increase in Building Efficiency (IBE)	-2.50%	-3.10%	Public Buildings Management Scenario: Evaluation of alternative tariff schemas
6	Energy Efficiency in Neighbourhood Level (EEN)	-2.00%	**-22.50%**	Smart City management scenario considering integration of different asset types (*)
7	Increase of Public lighting efficiency (IPLS)	-1.43%	-5.92%	PLS & TLS energy efficient strategies considering environmental and traffic density
8	Efficient EV Management Fleet (EEVM)	-	-19.01%	Coordinated EV & Building Management → Cost reduction by shifting at night hours
9	EVs hosting capacity (EVHC)	-	210%	Electrical Vehicles (EV) local optimization and increase on total storage capacity for EV fleet management
10	CO2 reduction of the system (CORS)	-6.05%	**-20.65%**	Smart City management scenario considering integration of different asset types (*)
11	CO2 reduction via EV management (COREV)	-	- 4.47%	Coordinated EV & Building Management → Charging at night hours
12	CO2 reduction through EV penetration	-	-44.48%	Electric Vehicles replacing Conventional Vehicles → Impact on CO2 emissions
13	CO2 reduction due to optimal RES exploitation	-5.29%	-16.41%	Electrical Vehicles (EV) local optimization → Charging when CO2 emissions ratio is low
14	Electrical Power Quality Factor	95.75%	97.22%	Measurement / control of the electric energy quality evaluation scenario
15	Forecasting Performance (FOPE)	19.30%	17.75%	Generation and Consumption Forecasting Engine Evaluation
16	Predictive Maintenance Accuracy Index	-	100%	Predictive Maintenance Analysis Engine Evaluation

Project Impact: Demonstration and Evaluation Results

(*) In order to establish a concrete smart city demonstration scenario, we are defining an indicative testbed with part of the portfolio assets:

- Public Buildings: 4 Barcelona Municipality public buildings with aggregated power demand at 210 KW and an average of **70 KW**
- EV fleet: A total of 250 EVs from the existing charging points with a maximum charging point at 32 KW and an average of **9.8 KW**
- PLS portfolio : A number of 5 PLS cabinets with a nominal power at **25 KW**
- TLS portfolio: Part of transport zone (20 zone areas) integrated in the project, taking into account the available traffic patterns. The nominal power for the selected zone is **25 KW**
- RES integration: Both PV and Wind integration with an average of **18 W** nominal power of covering that way **~ 15 %** of energy consumption from RES generation

The impact of each control strategy in Smart City management scenario is:



Project Impact: Demonstration and Evaluation Results

The same analysis is performed for Lisbon Pilot Site:

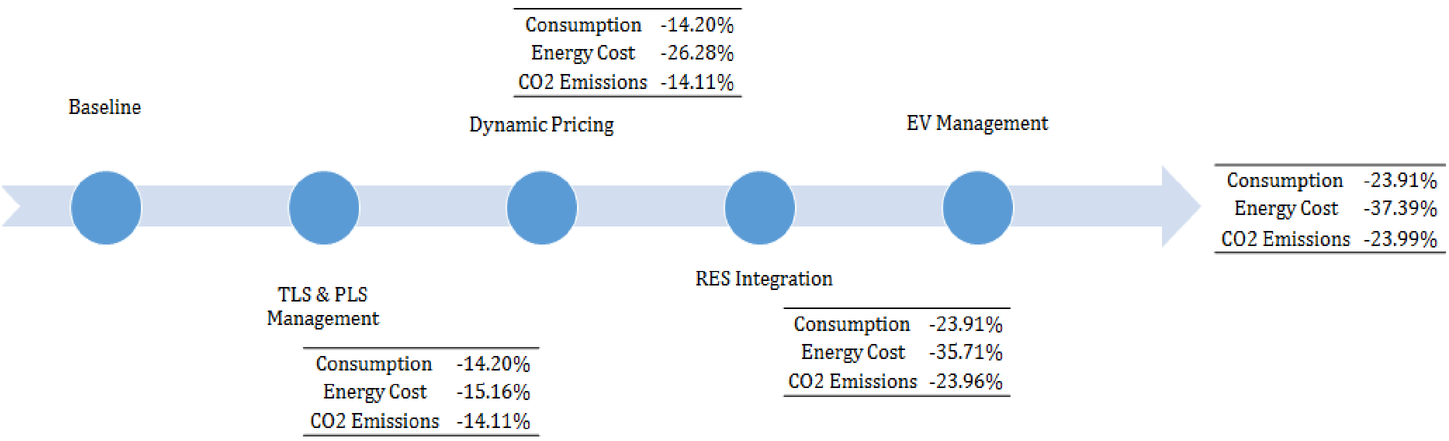
	Evaluation Criteria	Lisbon Site		
		1st Period	2nd Period	Comments
1	Efficient Monitoring of the Facility (EMF)	94.03%	96.04%	The evaluation is associated with efficient and reliable monitoring of assets
2	Increase RES generation utilization (IRU)	5.00%	9.71%	Smart City management scenario: Increased **RES integration** during the 2nd round of trials
3	Cost reduction (CR)	-21.60%	**-37.39%**	Smart City management scenario considering integration of different asset types (**)
4	Peak Demand Reduction (PDR)	-	-12.32%	Smart City management scenario considering the integration of different asset types (**)
5	Increase in Building Efficiency (IBE)	-18.50%	-23.84%	Public Buildings Management Scenario: Evaluation of alternative tariff schemas
6	Energy Efficiency in Neighbourhood Level (EEN)	-	**-23.91%**	Smart City management scenario considering integration of different asset types (**)
7	Increase of Public lighting efficiency (IPLS)	-	-13.34%	PLS & TLS energy efficient strategies considering environmental and traffic density
8	Efficient EV Management Fleet (EEVM)	-	-22.94%	Coordinated EV & Building Management → Cost reduction by shifting at night hours
9	EVs hosting capacity (EVHC)	-	147%	Electrical Vehicles (EV) local optimization and increase on total storage capacity for EV fleet management
10	CO2 reduction of the system (CORS)	-6.09%	**-23.99%**	Smart City management scenario considering integration of different asset types (**)
11	CO2 reduction via EV management (COREV)	-	-0.58%	Coordinated EV & Building Management → Charging at night hours
12	CO2 reduction through EV penetration	-	-61.82%	Electric Vehicles replacing Conventional Vehicles → Impact on CO2 emissions
13	CO2 reduction due to optimal RES exploitation	-6.09%	-9.85%	Electrical Vehicles (EV) local optimization → Charging when CO2 emissions ratio is low
14	Electrical Power Quality Factor	98%	97.26%	Measurement / control of the electric energy quality evaluation scenario
15	Forecasting Performance (FOPE)	19.03%	16.51%	Generation and Consumption Forecasting Engine Evaluation
16	Predictive Maintenance Accuracy Index	-	100%	Predictive Maintenance Analysis Engine Evaluation

Project Impact: Demonstration and Evaluation Results

(**) In order to establish a concrete smart city demonstration scenario, we are defining an indicative testbed with part of the portfolio assets:

- Public Buildings: Olivais & DRFM & LMIT buildings taking into account data with nominal power demand at 50 KW and an average of **15 KW**
- EV fleet: A number of 25 EVs is selected for evaluation, by taking into account data from available EVs, nominal power demand at 20 KW and an average of **2.5 KW**
- PLS portfolio, considering data as coming from Philips lighting system integrated in BESOS platform with an average nominal power of **14 KW**
- TLS assets: considering energy consumption and traffic density simulation data from PT traffic lighting system (a total number of 5 traffic lighting points is considered for the evaluation process) with an average nominal power of **14 KW**
- RES integration: Olivais PV (3 x) and Montegordo (0.1 x) wind park in order to examine an integrated case scenario. Average of **3.5 W** nominal power, covering that way **~ 10 %** of energy consumption from RES generation.

The impact of each control strategy in Smart City management scenario is:

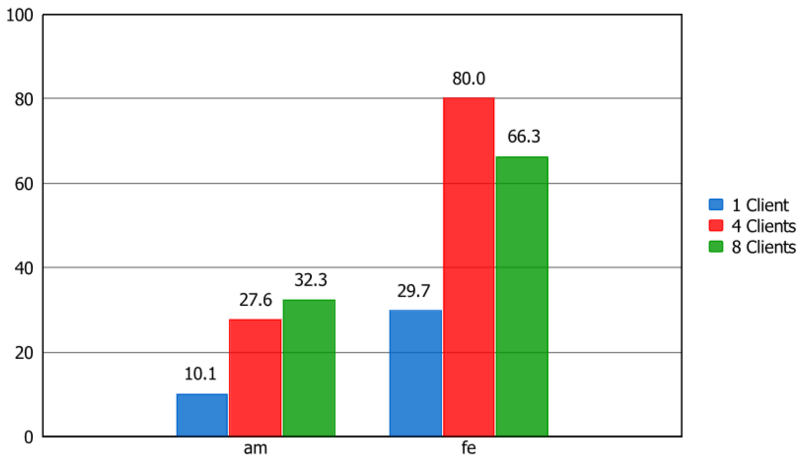


Project Impact: Demonstration and Evaluation Results

Along with impact assessment analysis, the evaluation of the business applications by the end users/system stakeholders was performed. A total number of 150 users were involved at testing and further evaluating the functionalities and the look & feel of the applications. A summary of the results is reported:

- The dynamic management and renegotiating of SLAs by monitoring KPIs values at different spatiotemporal granularity is an important feature offered by BESOS BSC. The innovative analytics and the enriched visualizations provided added value to the tool
- BESOS Decision Support Cockpit is integrating heterogeneous asset types under a fully automated management framework, enabling that way the coordinated management at smart cities. Special interest was delivered about the integration of BESOS forecasting engine as an innovative feature of BESOS DSS.
- The behavioral mobile application, as a simple and intuitive app, provides useful information and personalized messages to the citizens.
- The EV management framework was delivered in a non-obtrusive way, promoting the efficient management of the charging process by taking into account the parameters from contextual environment.

Following the evaluation of the main functionalities offered by the tools, special interest was delivered about the Technical Dissemination and Business Exploitation of BESOS outcomes. The technical evaluation analysis covers the different layers of BESOS architecture by evaluating business applications, EMS gateway but most important the OTESP platform. The role of the platform is fundamental for BESOS, standing as the central entity that manages several assets and business applications and thus an extensive evaluation is performed. To obtain reproducible and controlled results, we conducted different lab tests with the OTESP to evaluate its performance under various settings.



Project Impact: Demonstration and Evaluation Results

The main factors (successfully tested for OTESP adaptation) are related to scalability, reliability, interoperability and latency. Additional tests were performed to evaluate the ease of deployment as we need to ensure the transferability of BESOS platform to other Smart Cities.

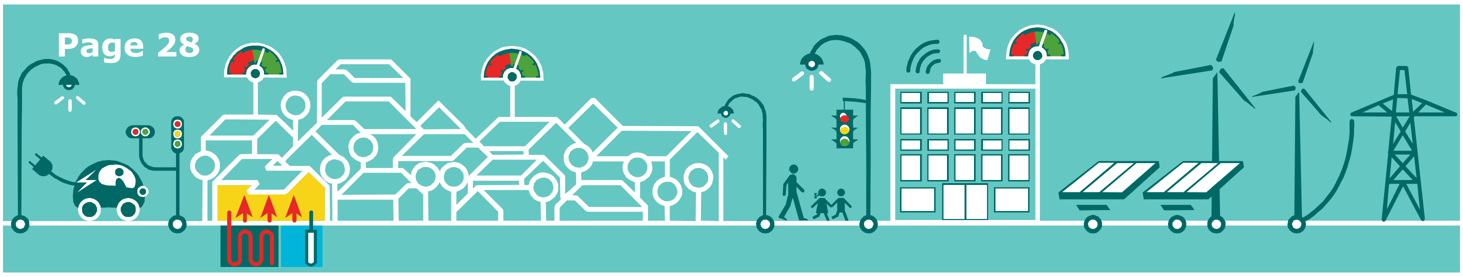
Finally, the business-wise evaluation of the different BESOS applications was performed to further complement the exploitation analysis of the project. A detailed business evaluation process was conducted at the early beginning of the project, defining the cost benefit analysis indicators: NPV, IRR and Payback period. The outcomes from the evaluation of the different system components that can be further exploited as standalone applications are presented hereafter:

Application / CBA Indicator	Visual Analytics	BESOS BSC & DSS Cockpit	Forecasting Engine
Internal Rate	18.70%	19.44%	8.60%
Payback Period	3.2	3	4.2

Along with the business evaluation of the different system applications, a business evaluation for the holistic platform is performed taking into account the results from impact assessment analysis. Different evaluation scenarios were defined (Scenario A: optimistic, Scenario B: most likely), and the outcomes from the evaluation are presented in the following table:

Pilot Site	Scenario A	Scenario B
Internal Return Rate (%)		
Lisbon	16.90	12.30
Barcelona	17.60	11.50
Payback Period (years)		
Lisbon	3.4	4.1
Barcelona	3.1	4.4

The cost benefit analysis is further complemented by the cost effectiveness and SWOT analysis to highlight the business perspective of BESOS platform. The results from BESOS evaluation process show that the proposed platform can reach the goals set by the project *"to enhance existing neighborhoods with decision support system to provide coordinated management of public infrastructures in Smart Cities, and at the same time provide citizens with information to promote sustainability and energy efficiency".*



Project Impact: Dissemination actions

In addition to the technical activities developed within the project, special attention has also been given to the suitable dissemination of results to the most relevant stakeholders (public authorities and Facility Owners; ESCOS and Facility Managers and citizens.

Key figures

- **4** Public Workshops.
- **33** Events.
- **10** Publications
- **4** Newsletter
- **1** Video
- **150** Interviews with end-users
- **1** Poster and Brochure
- **4** Publishable Summaries

The project has organised 4 public Workshops, involving in all cases other R&D projects with ongoing activities in at least one of the pilot sites at BESOS – Lisbon or Barcelona.

BESOS public workshops have been organised in the context of the European Sustainable Energy Weeks (EUSEW), from 2014, when the project started, to 2016.

The workshops were structured as an Energy Day, as defined by EUSEW: an Energy Day is a not-for-profit event, activity, project, exhibition or display that promotes energy efficiency or renewable energy. Activities such as exhibitions, conferences, online events, performances, guided tours, open door days, workshops, media campaigns and concerts are all eligible.

Therefore, since the project activities fully matched the areas of interest of an Energy Day, it was decided to organise three main activities, looking always for the collaboration of local partners, potential users and other EU projects.

In addition to the three EUSEW events organised, a fourth meeting was hosted in Portugal, promoted by Portugal Telecom in the context of the Lisbon Smart City initiative.

Project Impact: Dissemination actions

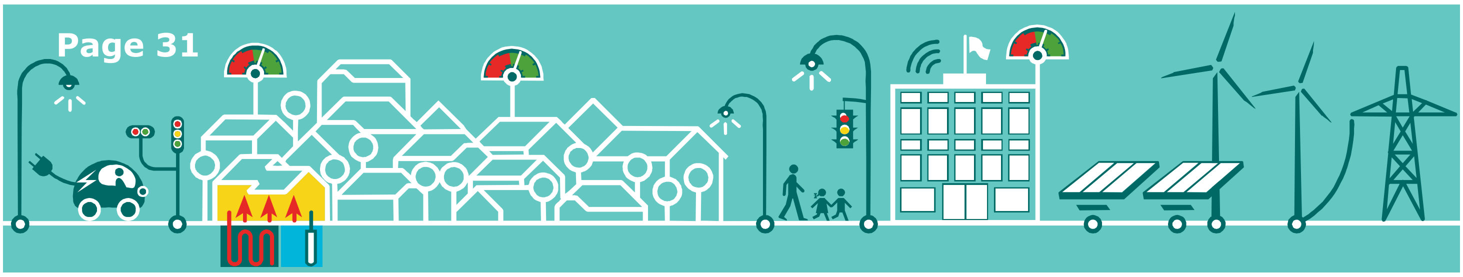
In addition to the four workshops organised by the project, the progress and achievements have been presented in more than 30 congresses and events, in some of them incorporating also a publication as part of the dissemination effort. In total BESOS has appeared in 10 publications, some of them scientific – peer reviewed – others tackling more commercial and specialied media.

From the list of events where BESOS has been presented, it is noteworthy mentioning the participation of BESOS at the launching conference of the EUROPEAN Innovation Partnership on Smart Cities, and the participation at the Smart City World Congress, both at the 2013 edition – with a paper – and at the 2015 edition, with a stand supported by the EU projects with pilot activities in the city of Barcelona.

Project Impact: Exploitation

Having achieved all the objectives originally set for the project, the BESOS consoritum has clearly established during the life time of the project the next steps to market the project results. In total 9 potential products have been identified as exploitable, with a complete analysis on profitability (Internal Rate of Return and Return on Investment) for some of the key results covered also at this publishable summary.

Type of Exploitable Foreground	Description of exploitable foreground	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	Common Information Models	NA	BESOS CIM based on IEC CIM	J62.0.2 - Computer consultancy activities	Last Quarter 2016	NA	HYPERTECH
General advancement of knowledge	Open Trustworthy Energy Service Platform	NA	Platform for federated and secured access to energy data	J62.0.1 – Computer programming activities Smart Cities	First Semester 2017	AGPL	UDE (owner); ETRA, PTIN, COBRA, Enercast (EMS owner)
Commercial exploitation of R&D results	***Forecast Algorithms***	***NA***	**Forecast Engine**	**J62.0.3 - Computer facilities management activities**	**First Semester 2017**	**commercial license agreement**	**ENERCAST**
Commercial exploitation of R&D results	**Business Balanced Score Card**	**NA**	**BSC for real-time monitoring and management of KPI**	**J62.0.3 - Computer facilities management activities**	**Last Quarter 2016**	**NA**	**ETRA, HYPERTECH**
Commercial exploitation of R&D results	**DSS Cockpit**	***NA***	***Integrated Energy Management System***	**J62.0.3 - Computer facilities management activities**	***First Semester 2017***	**NA**	**ETRA**
General advancement of knowledge	Reference Architecture for a Positive Energy Smart City	*NA*	BESOS Reference Architecture	*J:Information and communication*	*Last quarter 2016*	NA	All
Commercial exploitation of R&D results	ETSI compliant IoT Component	*NA*	IoT Application Enablement Component	*J:Information and communication*	*2017*	commercial license agreement	PTIN
Commercial exploitation of R&D results	Mobile application for behaviour modification	*NA*	*Mobile Application to promote a sustainable usage of energy*	*J:Information and communication*	*First Quarter 2017*	commercial license agreement	PTIN
General advancement of knowledge	System to collect energy data from in the field devices and deliver them to energy applications	*NA*	*Lisbon EMS integration*	*J:Information and communication*	*2017*	NA	PTIN, Lisboa ENova



Conclusions and next steps

Back in 2013, when the project initiated its activities, and even before, when the project started to be planned among the core partners of the BESOS consortium, the concept of a Smart City was something still under definition, without any practical implantation of any of the Smart Platforms that nowadays are being deployed in most of European cities. Thus, the project was forced to specify – with the support of Lisbon and Barcelona – its own architecture of what was going to be needed to act as an Energy-oriented Smart City Platform. The outcome of this effort is the BESOS architecture and CIM that has served the project to evaluate two independent – though collaborative - Smart-City Applications in two pilots that were not provided yet with Smart City Platforms and that nowadays are world wide examples – lighthouse projects – of the benefits of a well-defined Smart City approach.

Obviously, the objective of BESOS was never the definition of a high level ICT urban platform – extensively tackled in other bigger projects – but to provide an open reference of the framework needed to attend one of the main pillars of any Smart City: the energy management. It is in this context, that the project produced back in 2014 its first reference architecture and CIM, implemented, deployed and validated later in BESOS pilot sites.

Once the main objective of the project architecture – support the validation of BESOS developments – was fulfilled, the consortium started looking at what could be the future for the architecture defined in the project. Not being a full Smart City Platform – only the energy area is covered – the options were to escalate the solution trying to become one of the many urban platforms that are competing in Europe – with some major players already marketing its property solutions – or to use the know-how gained in order to affect future standards and especially the definition of a common open reference architecture promoted by the Smart Cities EIP. The second option has finally prevailed, much more, the project has ensured that the developments validated in Lisbon and Barcelona are seamlessly integrated with the Urban Platforms being deployed at each city, and the Smart City applications developed are first examples on the benefits that such platforms can bring to European cities.

BESOS

Building Energy Decision
Support Systems
for Smart Cities