PERSEPHONE

Improve Energy Efficiency through Personalised Energy Management Services in Small Offices and Homes

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Introduction

Energy consumption in residential and commercial buildings is estimated to account for around 40% of total energy consumption, making the need for promoting solutions that can potentially lead to significant reductions compelling. As stated by the U.S. Energy Information Administration, in 2015, about 40% of total U.S. energy consumption was consumed in residential and commercial buildings, while a similar percentage is reported by the European Commission for the overall consumption of the buildings sector in the EU. In Cyprus, at the 4th National Energy Efficiency Action Plan, it is stated that the energy intensity of households is lower than the European average level, due to the country's moderate climate, however increasing trends are observed, due to the rising standard of living and the increased electricity consumed by air conditioners.

The design and adoption of novel information and communication technologies (ICT) towards achieving higher levels of energy efficiency in the buildings sector is considered promising, as stated in the Global e-Sustainability Initiative SMARTer2030 report. ICT has the potential to enable a 20% reduction of global CO2 equivalent emissions by 2030, holding emissions at 2015 levels. The application of ICT-enabled solutions is going to provide residents with greater insight and control, and an enhanced living experience whilst saving energy and resources. However, the application of novel ICT technologies for energy efficiency has also to rely on people adjusting their energy consumption behaviour. As stated in the report of European Environment Agency, up to 20% of energy savings can be achieved through different measures targeting consumer behaviour.

Under this perspective, PERSEPHONE is proposed as an energy-aware IT ecosystem that aims to support energy efficiency in the buildings sector through behavioural change of the occupants with regards to their daily energy consumption profile as well as their preferences in terms of a personal comfort zone (e.g. range of indoor temperature levels where they feel well). The main distinguishing characteristic of PERSEPHONE is that it exploits the advantages provided by a set of novel ICT technologies for enabling the design, development and provision of personalized energy management and awareness services in smart buildings. The philosophy of the proposed approach is based on the provision of personalized services that can lead to behavioural change through energy consumption awareness and motives provided to occupants based on their behavioural profile.

Vision & Strategy

The vision of PERSEPHONE is to design and deploy an innovative IT ecosystem for motivating end-users' behavioural changes towards the adoption of energy efficient lifestyles, building upon the evolvements in the Internet of Things, Data Modelling and Analysis and Recommendation and Gamification eras. Internet of Things technologies are exploited for the proper and energy efficient interconnection of a heterogeneous set of sensor nodes (e.g. smart energy meters, sensors interacting with microgeneration infrastructure, sensors in smart phones), the collection of data based on Mobile Crowd Sensing Mechanisms exploiting the power of the collection of data from a critical mass of interested people and the application of proper communication networking schemes with regards to data collection. Advanced Data Modelling and Analysis techniques are applied for the modelling of the collected data –both from sensor networks as well as directly from end users- and the extraction of advanced knowledge by exploiting the power of Semantic Web techniques, Linked Data and Data Analytics. Focus is given on the development of personalised mobile applications and games targeted at providing energy related

information to end users, triggering interaction with relevant users, increasing their awareness with regards to ways to achieve energy consumption savings in their daily activities and adopt energy efficient lifestyles based on a set of recommendations and motives targeted to their culture and comfort zone. The engagement and direct inclusion of end users within the diverse components of the provided IT ecosystem is going to be strongly supported.

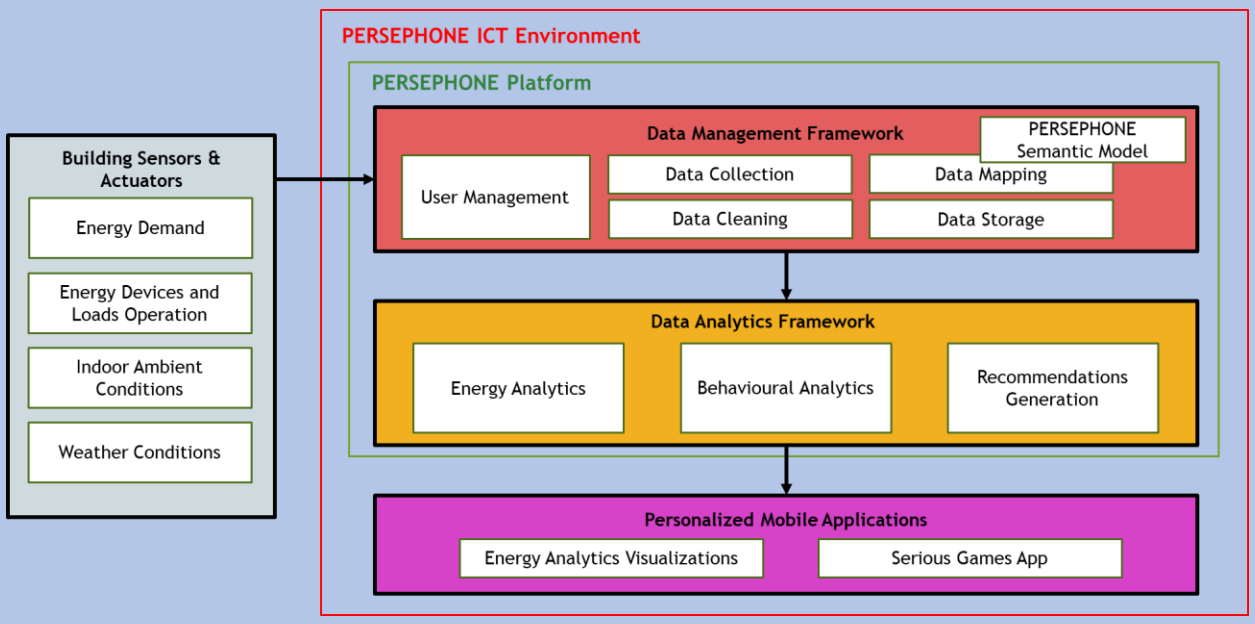
Based on the four aforementioned technology pillars, the main objectives of PERSEPHONE and the associated expected results include:

Objective	**Expected Results/Means to achieve**
- to design, implement and validate an innovative IT ecosystem for motivating end-users' behavioural changes towards the adoption of energy efficient lifestyles, leading to energy efficiency improvement levels of up to 40% (on average 25%).	- the conceptualization of the **PERSEPHONE conceptual architecture**; - the provision of the **integrated and validated PERSEPHONE platform** and set of personalised applications and games (at least **one app** and **one game**) - **25% energy consumption reduction** in the pilot site compared to a Business as Usual (BAU) scenario
- to support automated and homogeneous data collection and management through the aggregation of data streams generated from sensor networks and smart meters, as well as through the retrieval of data from mobile crowd sensing activities and their mapping to well-defined semantic models;	- the design and development of **data aggregation and homogenization mechanisms**; - the conceptualization of **two semantic models** for representing energy oriented and behavioural oriented concepts; - the capacity for management of **up to 1000 real-time monitoring data streams** per deployment.
- to support real-time monitoring and analysis of energy consumption data, capabilities for setting up thresholds, monitor, track and chart a number of quantitative and qualitative key performance indicators, as well as to design and implement powerful algorithms to disaggregate and process data from an office's or household's consumption, clients' relevant behaviour, weather and utility demand and supply information to help households identify energy "black holes" and adopt energy saving behaviours;	- the design and development of **more than 20 data analysis mechanisms** (time series analysis, clustering, forecasting, heatmaps) for supporting real-time extraction of insights as well as offline analysis and extraction of meaningful results.
- to support personalized behavioural analysis and consumption disaggregation, to provide individuals with tailor made efficiency insights and motives to adopt greener behaviours; Advanced modelling mechanisms are going to be proposed taking into	- the design and development of **personalized recommendation mechanisms** based on rules-based management systems;

account inhabitants/employees preferences with regards to the specification of their comfort zone levels. Such models should be continuously evolved and be able to identify behavioural changes.	- **more than 50% acceptance of provided recommendations** by end users, based on the targeted high efficiency of the recommendation and behavioural profiling mechanisms
- to provide consumption and cost efficiency motivation and information, including personalized retrofit suggestions and tips with estimated cost and return on investment time, peer comparison with neighbours, in terms of total and disaggregated consumption, monthly projections of consumption and savings;	- the preparation of **personalised content (e.g. tips, tasks, questions, quizzes)** based on the different type of behavioural profiles; - the **production of comparison graphs** following a campaigns-oriented approach associated with set of motives for participant users;
- to support energy characterisation of buildings and services as a means for obtaining energy certifications coherent with the European Eco-design provisions;	- the design and development of **mechanisms for buildings energy characterization**; - the energy characterization of the pilot building within PERSEPHONE
- to validate and evaluate the research results by developing a set of proof-of-concept showcases, proving the applicability and effectiveness of the proposed, innovative technologies, models and tools.	- the realisation of **set of trials in the pilot site**, the validation and evaluation of the developed mechanisms and the production of set of lessons learnt.

Key developments

As depicted in the high-level view of the PERSEPHONE energy-aware IT ecosystem architectural approach below, a layered architecture is followed with discrete layers for IoT management and data aggregation, data representation and fusion, smart energy management services and end user applications. The **Data Management Framework** is responsible for IoT nodes registration, management and data aggregation and cleaning functionalities at the edge part of the infrastructure. In addition, it is responsible for representing the collected data based on a set of defined semantic models as well as supporting a set of data fusion mechanisms over active data streams. The **Data Analytics Framework** is responsible for providing advanced analytics and recommendations to end users, as well as incorporating learning techniques for continuously exploiting the produced output by each service. The **Personalized Mobile Applications** take advantage of the set of services provided by the aforementioned frameworks. Following this, detailed information is provided for the designed and implemented mechanisms per layer.



Data Management Framework

The proposed mechanisms designed for the IoT management and data aggregation layer will follow an edge computing approach. Edge computing facilitates the processing of information, where required, in the logical extremes of a network, improving in this way the performance and efficiency of applications in terms of usage of resources. The set of mechanisms will support the easy registration, configuration and lightweight management of the infrastructure sensors deployed in the target buildings and a set of data aggregation, pre-processing and cleaning functionalities.

Upon making the collected data available through the Data Collection service, sensor data streams towards the PERSEPHONE platform will be activated. Sensor data streams will regard real-time data or aggregated data. For each of the activated data streams, the collected data will be mapped to the PERSEPHONE semantic models, the IoT-based Energy Management semantic model (IoT-Energy) and the Behavioural Intervention Semantic Model (EBIO). The IoT-Energy model aims to represent the set of concepts related to the support of energy efficiency in smart buildings. It includes conceptualization of the buildings, their structure, the deployed sensor networking infrastructure, the activation of sets of sensor data streams, as well as the realization of analysis over the collected sensor data. IoT-Energy inherits and builds upon well-known ontologies, such as the Friends of a Friend (FoaF), the Smart Appliances REFerence (SAREF), the Semantic Sensor Network (SSN), and the Linked Data Analytics Ontology (LDAO). The Behavioural Intervention Semantic Model (EBIO) aims to represent a set of concepts related to the behavioural profile of occupants in smart buildings and, thus, to facilitate the categorization of users in specific profiles and the provision of personalized content and recommendations for achieving behavioural change. The main concepts represented in EBIO regard the Agent and the Recommendation. An Agent can be a Person or a Group where personalized recommendations can be sent. A Person has a “Personality” profile for denoting personality traits, Work Engagement, socioeconomic status and gaming preferences, classification that can be proven very useful for providing the suitable content and application interaction mode (e.g., socializer, free spirit, achiever, disruptor). A Person may also have a set of comfort level or lifestyle preferences and a specific energy consumption profile that will be constantly updated depending on the end user everyday actions. EBIO model will be extended so as to include these dynamic characteristics and make possible to follow the behavioural change of the end user

as well as to adapt on real time and automatically the content of the recommendations according to his behavioural and energy needs.

Data Analytics Framework

Based on the semantically-mapped storage of the collected data in the big data repository, and through the definition of a set of REST APIs, various services will be designed and provided through the PERSEFONE platform. Such services include the recommendation engine for providing personalized recommendations to end users, as well as the data mining and analysis mechanisms for providing behavioural and energy analytics. It should be noted that these mechanisms will work in a complementary fashion, since produced output from an analysis process can trigger the provision of a new recommendation. Similarly, the feedback provided by end users based on the consumption of recommendations can lead to analysis and classification of end users in specific personality or gamer types.

The **recommendation engine** will be responsible for providing context-aware and personalized recommendations taking into account the occupants' behavioural profiles. It will be implemented based on Drools, a rules-based management system. A rule will consist of a condition element and a recommendation template in the action part, which connects a context change with specific target user group criteria. When a rule is fired due to a context change (e.g., when average CO2 measurement within an hour exceeds the defined threshold), the recommendation engine selects the set of target users based on the defined user attribute filters (e.g., players who have activities at a certain location, users that are classified as highly responsive at the proposed actions through the personalized recommendations, users that satisfy specific behavioural criteria) and creates a personalized recommendation for each of them by using the defined recommendation template. Following this, the set of recommendations will be published in a publish/subscribe framework and made available for consumption by the set of personalized applications and serious games.

A produced recommendation will contain the target user, the related content, the measurement attributes that are involved in the creation of the recommendation, the possible reward for the completion of the recommendation, as well as the validation method for it. The rewards are registered to a user upon the completion and validation of a recommendation, which differs per type of recommendation. For instance, an action may be validated by checking the status of the sensors on the involved building objects (e.g., a window), while the validation of a quiz is done inherently by answering all the questions.

Another service that will be extended and provided within the PERSEPHONE platform regards the support of a set of **big data mining and analysis techniques** towards the extraction of energy and behavioural analytics. Insights provided with regards to the energy usage in smart buildings, as well as the behavioural characteristics of the occupants, may lead on one hand on increase of their energy awareness and on the other hand on targeted recommendations for reducing energy consumption. The supported set of analytics processes concerns descriptive, predictive, classification, clustering, and prescriptive analytics. Descriptive analytics will provide summary information regarding the energy usage, as well as other environmental or behavioural attributes. Predictive analytics will provide estimates for usage of energy the upcoming period, as well as examining the relationship among energy consumption and set of parameters, such as average temperature, heating or cooling degree days, day of the week, etc. The considered algorithms include linear regression, multiple linear regression, support vector regression, and principal component analysis. Classification and clustering analytics will be applied for identifying or classifying collective behaviours among the involved users. Based on the identification of groups, targeted interventions will be planned, while the produced groups will be also considered as input towards a group-aware forecasting analysis. The considered algorithms include artificial neural networks, Bayesian regularized neural networks, random forest, k-means, density-based spatial clustering, and hierarchical clustering. Prescriptive analytics will be applied for combining analytics results with automation solutions

considering the interplay among energy efficiency and comfort level of occupants. In PERSEPHONE, the R Project for Statistical Computing, and the Apache Spark fast and general engine for large-scale data processing are used for this purpose. Depending on the analysis needs in terms of big data management and performance aspects, the optimal tool per case may be selected. Interconnection of the PERSEPHONE components with the analysis toolkits will be based on the OpenCPU system for embedded scientific computing that provides a reliable and interoperable HTTP API for data analysis based on R. In the case of large-scale data processing and the need for a big data analysis framework, the Apache Spark engine can be used, where the analysis process is realized in a set of worker nodes, each one of which is hosting an Apache Spark OpenCPU Executor. The set of worker nodes are formulating a cluster orchestrated by a cluster manager. Upon the realization of an analysis, the produced results will be also made available through a set of URLs providing access to the set of results, as defined in the output parameters of the analysis template. It should be noted that analysis results are also semantically mapped to the PERSEPHONE semantic models, based on the adoption of the LDAO ontology, as mentioned before. The overall implementation facilitates the incremental addition of further analysis mechanisms, making PERSEPHONE analytic framework scalable and easily enrichable depending on the analytic needs of the future customer. The extendibility of the PERSEPHONE analytic framework is totally compatible with the market-oriented nature of PERSEPHONE project.

Personalized Mobile Applications

In addition to the set of intelligent energy management and awareness services supported by the PERSEPHONE IT ecosystem, the development of mobile applications is facilitated. Given the unified representation of data through the semantic models independently of the underlying sensor infrastructure, as well as the design and implementation of set of REST APIs for accessing and storing data to the big data repository, personalized applications and serious games development is enabled, while their applicability may regard various smart building cases. Such APIs include, among others, the provision of information for the available building spaces and their energy consumption profiles, the activated sensor data streams, latest data per sensor data stream, the recommendations provided per user along with the collected feedback, the set of actions that may be requested to be realized by an end user, the execution of queries, user demographic data, functionalities for user registration, authentication and login in the IT ecosystem, initialization and update of the user profile per application, as well as the retrieval of the top users per application. The set of applications include the development of serious games for increasing awareness and stimulating collaboration, as well as the development of personalised applications targeted to social media interaction among the involved citizens.

Pilot description

Innovation will only be accelerated through the successful adoption of the PERSEPHONE system in real life activities of energy consumers. Evaluation of impact will be carried out based on a detailed plan, specific scenarios and methodology along with well-defined performance indicators. The pilot evaluation framework will aim at continuously monitoring critical impact aspects (e.g. energy gains, emissions reduction, cost-efficiency, cost-effectiveness, end-user acceptance and discomfort). An overview of the project pilot site is provided hereafter. The selected pilot offers a representative test-bed for properly validating the PERSEPHONE concept and solution in a setup that presents similar characteristics with the target exploitation segment (i.e. small office establishments) and will involve an experimental group of users that have committed themselves in regularly testing and evaluating new solutions for energy efficiency thus ensuring the soundness and robustness of the validation process.

The selected pilot site of PERSEPHONE project consists of a small office establishment (headquarters of Suite5) located in the centre of Limassol. The office is situated on the first floor of a three-storey

commercial building and has a hosting capacity of 13 employees in an 110 square meters total floor space. The office is powered with electricity only. Main electricity consumption is attributed to the use of air-conditioning devices (4 split A/C units are installed in the office), as well as, to office equipment (PCs, monitors and printers) used by the company employees during the typical working hours (between 9.00-18.00 during working days).
The floor plan view of the Suite5 offices is presented in the following figure:

Within the office, Suite5 has set up a fully-fledged laboratory environment, serving the research activities of the company in the domain of Internet-of-Things and Wireless Sensor Network as well as user profiling and demand side management. It is equipped with cutting-edge sensing equipment (power and environment), in-home displays, AMI gateways, smart metering devices and smart appliances/ devices that enable the validation of state-of-the-art prototypes in real-life deployments.

Methodology

The whole effort of the PERSEPHONE consortium will be market-oriented. This approach also guides the overall methodology that PERSEPHONE will follow. The PERSEPHONE methodology can be seen as a compilation of four distinct, yet highly interdependent, steps; namely (a) Market Need Recognition, mainly based on detailed state-of-play analysis, as well as user stories and technical requirements of the project's pilot cases; that, in turn, constitute representative (candidate) customers of the end product; (b) Product Development, building on existing open source (thus, contributing itself to one of the most important software trends of the last few years) and on software artifacts (developed and owned by the consortium partners) that have proven to be operational in competing environments, and following an agile approach, in order to be able to constantly ameliorate the product based on feedback received from the actual users; (c) Product Assessment, including thorough and timely technical testing and verification, as well as an iterative approach, engaging the project's pilots in the assessment and feedback loop from the very early development stages – having the verticals constantly engaged with the intermediate versions of the project's architecture, strategies, mechanisms, etc. and their feedback will be provided to the developers in order to update, parameterize and improve the product accordingly; and (d) Market Entry Preparation, carefully designing and implementing a market entry strategy. In particular, specific dissemination actions will be realized in order to build awareness around PERSEPHONE, and a detailed exploitation strategy will be devised and followed in order to prepare all the necessary channels for the

effective exploitation of the project. Finally, a closely designed and detailed business plan, accompanied by a set of lessons learnt and business cases deriving directly from the experience of the project's verticals with the product will be utilized for successful market acceptance of PERSEPHONE.

Accomplished results

Within the PERSEPHONE project, the consortium aims to demonstrate that energy waste elimination can be achieved using the developed services to a degree exceeding 90% and approaching 100%. This waste has been documented to be on average about 30% of total energy consumption. Preliminary results and findings of the H2020 UtilitEE project (where Suite5 participates as a main technology partner) already demonstrate energy wastes above 30% based on audits and measurements performed in the project pilot buildings. Furthermore about 80% of this waste can be eliminated through normative feedback and pressure – without automation – as indicated by initial UtilitEE pre-pilot trial experiments Hence, an average 25% reduction in the energy consumption of the intervention subjects is foreseen through real-time, personalized and normative feedback delivered by the PERSEPHONE applications and end-user services.

Considering wider benefits, PERSEPHONE aims to establish a solid and profitable business case whereby all involved parties will materialize significant benefits so that they are committed to following through with the commercial exploitation of the PERSEPHONE solution. These parties include the end-users, the utilities (involved as the main enablers of the PERSEPHONE go-to-market strategy and will distribute and resell the ICT infrastructure) and the consortium – in the form of a Joint Venture - that will undertake the further development, manufacturing and support of the solution.

The benefits for end-users are significant and include:

- Significant energy bill reduction using utility subsidized ICT infrastructure to remove the affordability barrier and enhance market penetration. Energy cost reduction is the most important barrier for the adoption of energy management solution. Alleviating this barrier opens the door for wide market penetration. A 25% reduction in energy consumption in a household can on average save about 1,250 kWh annually, which amounts to a reduction of energy spending by about €110 p.a. given that actual energy costs constitute about 40% of the average EU energy bill. This takes into account average electricity consumption distribution and energy prices among European households. Benefits for tertiary buildings account even more, reaching (on average) 82.5 MWh annual savings, which amounts to a reduction of energy bills by about €3,500 for a small building hosting 50 employees. As a result, the consumer can enjoy the financial benefits from the first day with zero investment for the infrastructure.
- A more comfortable and environment-friendly lifestyle. Protection of the environment is the second most popular motive for taking up energy efficiency actions among citizens. Up to now, energy efficiency measures and comfort/productivity preservation or improvement were conflicting objectives. The PERSEPHONE solution can satisfy and even maximize both. As a result, significant carbon footprint reduction can be achieved with neutral or positive impact on user perceived comfort and productivity. As a secondary benefit, such actions can be used by companies using the PERSEPHONE solution as a key constituent of their Corporate Social Responsibility programmes.
- Potential additional income sources by financially exploiting consumption and behaviour data. As stated earlier, the end-user will be the sole owner of the data regarding their energy consumption and behavioural patterns. This information, though, holds significant value both for the utility and start-ups aiming to develop value-adding services. End-users can collectively or bilaterally negotiate remuneration for usage of this information by third parties under strict privacy and security

conditions. A recent survey indicated that individuals expect about £15-£30 per month as remuneration for use of their data by third parties, but the lack of an established market makes any realistic price estimation extremely difficult.

Considering the main enablers of the PERSEPHONE go-to-market strategy, i.e. Utilities, they are also expected to materialize significant benefits from using the PERSEPHONE solution:

- Larger trackable energy savings that will alleviate political and policy pressure and, in some countries, even alleviate financial penalties stemming from Energy Efficiency Obligations. This is a key aspect for utilities as many European utilities are (partly) regulated and/or have strong links with public authorities - ranging from ownership to loose control, hence being able to demonstrate active compliance to regulations is a must. The PERSEPHONE solution will enable utilities to convincingly demonstrate savings exceeding 1,250 kWh on average per served household and 80,000 kWh per served small office building (hosting 50 employees) which contributes to the 30% binding energy efficiency target set out in the recently published Energy Efficiency Directive recast.
- Diversified utility offerings toward consumers including value-adding services on top of commodity energy supply to differentiate against the competition in a saturated commodity market. Such services are already gaining momentum in the EU. In 2014 utility offers embedding additional services rose by more than 50% compared to 2013, especially in large European cities where such differentiated offerings were about 40% of all utility offers. These services are the main way forward for utilities locked-in into a dying business model based on sale of commoditised energy. More and more, forward-looking utilities recognize the possibility of expanding beyond their current practises. PERSEPHONE can help utilities go even further and expand their market share using the unique characteristics of the project that offer mutual financial benefits for utilities and end-users among others.
- By leveraging low-cost, off-the-shelf electronic components and the Energy-as-a-Service delivery model, the PERSEPHONE solution will provide an easily replicable, robust and scalable business/revenue model for utilities. It enables steady recurring revenues, based on cloud services that can easily scale from few to thousands (or even millions) of clients, avoiding exponential costs and complexity and establishing long-term and continuously evolving customer relationships.

The PERSEPHONE consortium/ joint venture stands to gain significant financial benefits from the productization and commercialization of the solution developed within the project. Further benefits include:

- Solution development and validation within the project demonstration environment can save significant time and resources in the new product development life-cycle leading to faster time-to-market, smaller R&D investments and amortization costs and a lower product price point for market entry.
- Active involvement of the project partners in similar projects, allowing them to interact and gain insight in the requirements and business strategies of EU-wide utilities will significantly diminish risks that could make the project drift into the wrong direction in terms of future commercialization of results.