Title:	Document Version:
D1.1. Energy Efficient Technologies State-of-the-art Survey	Final 1.0

Project Number:	Project Acronym:	Project Title:
649849	ENTROPY	Design of an Innovative Energy-Aware IT Ecosystem for Motivating Behavioural Changes Towards the Adoption of Energy Efficient Lifestyles

Contractual Delivery Date:	Actual Delivery Date:	Deliverable Type* - Security**:
31/12/2015	31/12/2015	R – PU

* Type:	P – Prototype, R – Report, D – Demonstrator, O – Other
** Security Class:	PU- Public, PP – Restricted to other programme participants (including the Commission), RE – Restricted to a group defined by the consortium (including the Commission), CO – Confidential, only for members of the consortium (including the Commission)

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Abstract:

This document provides an overview of the main technologies adopted within ENTROPY towards the design of the proposed mechanisms and frameworks. Therefore, it includes a state-of-the-art analysis based on existing work in the international bibliography as well as relevant projects and the description of the key mechanisms that may be adopted within the project along with their corresponding added value.

Keywords:

Survey, state of the art, energy-efficient technologies.

Revision History

The following table describes the main changes done in the document since created.

Revision	Date	Description	Author (Organization)
v1.0	1/10/2015	First version of the document	Antonio Skarmeta, Fernando Terroso-Saenz (UMU)
V1.1	30/10/2015	First input from UMU added	Antonio Skarmeta, Fernando Terroso-Saenz (UMU)
V1.2	4/11/2015	First input from UBITECH , UIBK,INTELEN,HESSO, POLO and HYPER added	Anastasios Zafeiropoulo (UBITECH), Anna Fensel (UIBK), Vassilis Nikolopoulos, Aggeliki Boussiou (INTELEN), Dominique Genoud (HESSO), Piera Iorio (POLO), Alfredo Iembo (HYPER)
V1.3	20/11/2015	Revised version from UMU	Antonio Skarmeta, Fernando Terroso-Saenz (UMU)
V1.4	9/12/2015	Revised input from UMU, UIBK,INTELEN and DNET added	Antonio Skarmeta, Fernando Terroso-Saenz (UMU), Anna Fensel, Christian Junker, Umutcan Simsek (UIBK),Vassilis Nikolopoulos, Aggeliki Boussiou (INTELEN), Maja Pokrić (DNET)
V1.5	14/12/2015	Revised input from AUEBELTR	Stavros Lounis, Cleopatra Bardaki (AUEBELTR)
V1.6	15/12/2015	Revised version from UMU	Antonio Skarmeta, Fernando Terroso-Saenz (UMU)
V2.0	23/12/2015	Revised version from UMU with HYPER reviews	Antonio Skarmeta, Fernando Terroso-Saenz (UMU)
V2.1	30/12/2015	Revised version from HES-SO	Antonio Jara and Luc Dufour (HES)
Final 1.0	31/12/2015	Final version	Antonio Skarmeta, Fernando Terroso-Saenz (UMU)

Executive Summary

The document includes a state-of-the-art analysis based on existing work in the international bibliography as well as relevant related projects and the description of the key mechanisms that may be adopted within the project along with their corresponding added value.

The examined technologies include evolvements realized in the Internet of Things (IoT) world focusing on energy efficient ICT implementations in smart cities (**Section 2**). In that sense, such evolvements are reviewed considering the different dimensions of the IoT paradigm. In addition to that, the Mobile Crowd Sensing paradigm is also studied as a suitable tool in order to extract meaningful human-centric data for an efficient energy management of buildings. Section 2 also states advances in data modelling and analysis based on Semantic Web, Linked Data and analytics extraction technologies, progress in the design and deployment of recommendation frameworks taking into account behavioural profiles of end users, novel techniques in the gamification era and the design of innovative interactive games and advanced mechanisms for the establishment of bidirectional data channels with social networks and media.

Section 3 presents an overview about solutions already available in the market that have certain similarities with the ENTROPY project approach. This way, full-blown social and personalized applications in different domains like transportation or environment management are put forward. Examples of serious games and analytics reporting are also described. Furthermore, this section also describes real and large IoT deployments for the efficient management of energy in different facilities.

Section 4 initially states how the aforementioned technologies will be applied within the ENTROPY context in order come up with innovative approaches for the efficient management of buildings in terms of energy and the intelligent processing of the feedback from their occupants.

This document will serve as an input for the architecture design. The architecture will support identified ENTROPY use cases. The contribution of this deliverable is twofold: It identifies the gap in existing solutions that need to be addressed to meet all functional and service requirements; in conjunction with the identified and analysed functionalities, approaches and solutions will serve as an input to the ENTROPY requirements definition to avoid a duplication of work.

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1. INTRODUCTION

The ENTROPY project will provide advanced tools that allow increased citizen participation, by means of Mobile Crowd Sensing (MCS), in the intelligent and efficient management of energy consumption based on Internet of Things (IoT). These tools are expected to reduce the barriers of the creation of novel energy-aware services. An important aspect is the demonstration of these tools in real world trials with communities in different cities, in order to reach a commitment and engagement of the involved communities that drives to the expected impact.

This deliverable presents an analysis of existing algorithms, technologies and techniques based on the information collected about research projects, platforms and commercial/non-commercial applications that provide services for either building management or citizens. In that sense, since one of the key goals of ENTROPY is to come up with real and actionable solutions encouraging the social involvement of uses, this document pays special attention to end-user applications already available on the market that follows a similar social and participatory approach.

The number of solutions targeting IoT or MCS is endlessly growing, as well as the number of existing services providing platforms. An example of these solutions that will be taken into account in ENTROPY can be found in the FP7 SocIoTal EU project. Therefore a need for mapping their different aspects in order to realize what ENTROPY can provide for existing solutions and what can be reused for the common benefit. Therefore, a detailed review of both paradigms is also put forward.

Consequently, this deliverable carries out this analysis of the state of the art, existing solutions and other running activities (such as other EU projects), in order to define the basis over which ENTROPY will define its solution.

2. TECHNOLOGICAL FOUNDATIONS

2.1 Internet of Things Communications

The Internet of Things (IoT) is nowadays one of the most important research topics in the Information and Communications Technology (ICT) field. In a nutshell, the final goal of IoT is to connect all *things* in the World to the Internet so that such things could be identified, communicative and make decisions by themselves [1].

Furthermore, during the last years, personal handheld devices (e.g. smartphones) have been steadily enriched with more functionalities and more powerful built-in sensors giving rise to the Mobile Crowd-Sensing (MCS) paradigm. This makes that such personal devices can be regarded as mobile sensors able to generate data that can be a suitable complement to the one gathered by traditional sensor nodes in IoT infrastructure deployments. Hence, a brief overview of IoT and MCS is put forward next.

2.1.1 IoT and Sensor Networking solutions

IoT is the confluence of two visions, an internet-oriented perspective and a thing-oriented perspective [1]. Whilst the former pushes towards a network-oriented vision of IoT, the latter focuses on how different objects can be integrated into a single framework. As a result, these two visions allow to seamlessly integrate classical networks and networked objects and, among other benefits, the deployment of a varied range of sensors in many different scenarios.

Internet-oriented IoT

With the rapid and varied technological development of sensors, wireless sensor networks (WSNs) have become a key technology for IoT. A WSN can be viewed as a network comprising a large number of nodes each one equipped with a sensor to detect physical phenomena. This type of network is already instrumental in several application scenarios such as healthcare, agriculture, environment monitoring, and smart metering. Compared with the wired solution, WSNs feature easier deployment and better flexibility of devices. WSNs are characterized by high heterogeneity because there are many different proprietary and non-proprietary solutions. This wide range of technologies has delayed new deployments and integration with existing sensor networks.

The current trend, however, is to move away from proprietary and closed standards, to embrace IP-based sensor networks using the emerging standard 6LoWPAN/IPv6. 6LoWPAN [2] is an acronym that combines the latest version of the Internet Protocol (IPv6) and Low-power Wireless Personal Area Networks (LoWPAN). 6LoWPAN, therefore, enables resource-limited embedded devices (often battery-powered) in low-power wireless networks to be Internet-connected by simplifying IPv6 and taking the nature of wireless networks into account. Hence, this allows native connectivity between WSN and Internet, enabling smart objects to participate to the Internet of Things (IoT).

Unlike other wireless networking solutions like ZigBee [3], 6LoWPAN can more easily communicate with other protocols providing a more suitable solution for within the IoT domain.

Thing-oriented IoT

Apart from the large deployments of sensor networks described above, other of the key goals of IoT is to link the real world with the digital world so that common objects and things have their counterpart in the digital world providing useful information. In this frame, due to their maturity, low cost and strong support from business, industrial and academic community, two of the most important enablers to achieve the aforementioned goal have been RFID and NFC.

Radio Frequency Identification (RFID) devices are wireless microchips used for tagging objects so that each one is accompanied by a rich, globally accessible virtual object that contains both current and historical information on that object's physical properties, origin, ownership, and sensory context (for example, the temperature of a room). When ubiquitous and available in real time, this information transform the way we perform everyday activities by giving applications current and detailed knowledge about our movement and behaviour. This "real-life" context can unlock the door to various business, environmental, personal, and social contexts hitherto inaccessible to Internet applications.

Apart from that, Near Field Communication (NFC) is a set of protocols that enable electronic devices to establish radio communication with each other by touching the devices together, or bringing them into proximity to a distance of typically 10cm or less. As a result, NFC has been widely installed in different handheld devices for a varied range of usages like wireless payment or smart homes. In addition to that, as will be explained later in section 2.1.2, due to the integration of this technology in mobile devices, it has been a key enabler of the mobile crowd sensing paradigm.

2.1.1.1 IoT Architectures and Platforms

Bearing in mind the two aforementioned visions, when it comes to develop IoT solutions, most of them are just vertical silos that do not support interoperability and with inappropriate models of governance. For that reason, some architectures and platforms have been developed to lower those barriers.

IoT-A

IoT-A, the Internet of Things Architecture (IP EU project from 2009 to 2012) [4] defines an Architecture Reference Model (ARM) which ensures not only the interoperability but also the scalability requirements and the security and privacy in its design, which are so often neglected. This solution rests upon the creation of an architecture reference model together with an initial set of key building blocks, principles and guidelines for the technical design of the protocols, interfaces and algorithms suitable for any IoT system.

IoT-A provides a methodology to design an architecture for an IoT system. The final result of this approach is the generation a set of views, which completely defines the targeted architecture.

Webinos

Webinos [5] defines and delivers an Open Source Platform and software components for the Future Internet in the form of web runtime extensions, to enable web applications and services to be used and shared consistently and securely over a broad spectrum of converged and connected devices.

Buttler

BUTLER platform [6] is a set of enablers and services that provide means for building context-aware applications on top of smart connected objects. It provides not only generic APIs to access resources provided by IoT devices, but also additional services such as security service, localization services, behaviour prediction services and context management services that applications can reuse to enhance the user experience and security. The BUTLER Platform is specifically conceived for IoT devices and applications. It integrates different IoT devices and communication technologies in order to provide a homogeneous access to the underlying heterogeneous networks.

OpenIoT

OpenIoT [7] is a joint effort of prominent open source contributors towards enabling a new range of open large scale intelligent IoT (Internet-of-things) applications according to a utility cloud computing delivery model. OpenIoT is perceived as a natural extension to cloud computing implementations, which will allow an access to additional and increasingly important IoT based resources and capabilities. In particular, OpenIoT provides the means for formulating and managing environments comprising IoT resources, which can deliver on- demand utility IoT services such as sensing as a service. OpenIoT is pertinent to a wide range of interrelated scientific and technological areas spanning: (a) Middleware for sensors and sensor networks, (b) Ontologies, semantic models and annotations for representing internet- connected objects, along with semantic open-linked data techniques (c) Cloud/Utility computing, including utility based security and privacy schemes. From a more technical point of view the OpenIoT middleware infrastructure allows flexible configuration and deployment of algorithms for collection and filtering information streams stemming from the internet- connected objects, while at the same time generating and processing important business/applications events.

FIWARE

FI-LAB [8] conforms live instances of FIWARE [9] architecture and generic enablers, available to developers for free experimentation within this technology. The high-level goal of the FIWARE project is to build the Core Platform of the Future Internet, introducing an innovative infrastructure for cost-effective creation and delivery of versatile digital services, providing high QoS and security guarantees. Information about FIWARE Generic Enabler implementations is available at the FIWARE Catalogue [10]. In addition, specific enablers from FIWARE for the energy domain are defined under FIWARE FINESCE.

2.1.2 Mobile Crowd Sensing Mechanisms

Mobile sensors such as smart phones represent a new type of geographically distributed sensing infrastructure that enables mobile people-centric sensing. According to a forecast for global smart phone shipments from 2010 to 2017, more than 1.5 billion phones are expected to be shipped worldwide [11]. Smart phones already have several sensors: camera, microphone, GPS, accelerometer, digital compass, light sensor, Bluetooth as proximity sensor, and in the near future they are envisioned to include health and pollution monitoring sensors. Compared to the tiny, energy constrained sensors of static sensor networks, smart phones can support more complex computations, have significant memory and storage, and offer direct access to the Internet.

Consequently, Mobile Crowd Sensing (MCS) has arisen as a novel paradigm that empowers ordinary citizens to contribute data sensed or generated from their mobile devices, aggregates and fuses the data in the cloud for crowd intelligence extraction and people-centric service delivery. Similar to participatory sensing [12], MCS has sensed data from mobile devices as inputs. Nevertheless, it additionally “reuses” the user-contributed data from mobile Internet services (mostly mobile social network sites), which is often termed as the participatory media [13]. In other words, the user-contributed data are used for a second purpose. MCS further explores the integration and fusion of the data from heterogeneous, cross-space data sources providing a scalable and cost-effective alternative to deploying static wireless sensor networks for dense sensing coverage across large areas.

2.1.2.1 MCS domains of interest

Nowadays, it is possible to broadly identify three remarkable domains where the intensive processing of mobile data can be ease the development of innovative services.

Smart Cities

The general management of large and highly interconnected urban areas is usually a challenging task. For that reason, several initiatives exist that intends to leverage sensing data in order to provide better management systems. In that sense, MCS can be instrumental in order to reduce costs of large sensing deployments. As a matter of fact, ParticipAction initiative [14] intends to actively involve citizens in sensing campaigns that come up with more liveable cities.

Transportation / Mobility

The different departments and agencies in charge of the management of public and private transportation can leverage the huge amount of location data endlessly generated by mobile phones. Such data can be very useful so as to plan new infrastructures or organize traffic flows. In addition to that, end users can profit from such data by the development of real-time traffic information services. For example, the solution stated in [15] describes a distributed system that collects location and speed data from vehicles in real time so as to detect potential traffic congestions.

Healthcare

The large scale collection of different health and activity parameters by means of a varied range of wearable sensors and smart phones will help to develop new and innovative healthcare initiatives and campaigns. In addition to that, such information could be used to improve public infrastructures like creating new bike lanes or running areas.

Tourism

Tourism is one of the most common activities around the world, where people have a crucial role. Several tools such as Tripadvisor has demonstrated the value of participation, examples extending tourism experiences with Open Data, Crowd Sensing and Internet of Things integration are also defined in initiatives such as TreSight: an Innovative tourist experience in Trento.

2.1.2.2 MCS Architectures and Platforms

Recently, several mobile crowdsourcing projects tried to leverage traditional crowdsourcing platforms for mass adoption of people-centric sensing. Here we list some meaningful examples.

Firstly, Twitter [16] has been used as a publish/subscribe medium to build a crowdsourced weather radar and a participatory noise-mapping application [17]. mCrowd [18] is an iPhone based platform that was used to build an image search system for mobile phones which relies on Amazon MTurk [19] for real-time human validation. This has the advantage of leveraging the popularity of existing crowdsourcing platforms (tens of thousands of available workers), but does not allow for truly mobile sensing tasks to be performed by workers (i.e., tasks which can only be performed using sensors on mobile phones).

Apart from these particular solutions, other approaches intend to avoid a silo effect by proposing general-purpose architectures for the development of MCS systems. In that sense, some attempts to define reference architectures for MCS have been recently put forward [20]. This is the case of Medusa, a mobile crowd sensing framework that uses a high-level domain-specific programming language to define sensing tasks and workflows that are promoted with monetary incentives to encourage user participation [21]. Moreover, McSense [22] proposes architecture to link stakeholders and mobile users so that the formers can define different crowd sensing tasks and mobile users are able to choose in which one they want to participate.

Moreover, some EU projects such as SocioTal [23] and Smart Santander [24] have made use of participatory sensing solutions. While the former focused on privacy and security aspects of MCS, the latter was more related to innovative MCS-based urban services.

Despite this increasing interest and widespread usage of MCS, this paradigm is still is its early stages when it comes to formally detect the underlying behaviour of users with respect a particular domain. Examples of this usage can be found in [25] where a MCS-based approach is used to extract different types of mobility patterns within a city.

Regarding the ENTROPY project, there is a lack of solutions able to use the data collected by means of MCS in order extract energy-related human behaviour, commitment to energy efficiency apps (cleanweb approach) and engagement into their daily activities. In that sense, one of the efforts within ENTROPY intends to provide a first insight into how such mobile data could be used in such a domain.

2.2 Data Modelling and Fusion for Energy-efficient Scenarios

One of the most important questions that arise in an IoT deployment is how we convert the data generated or captured into knowledge to provide a more convenient environment to people. For this purpose, data modelling, fusion and mining technologies come into play. In that sense, the key goal of these technologies is to provide possible solutions to find out the information hidden in the IoT data and enhance the performance of the system or to improve the quality of certain services.

In an energy-efficient scenario, such processing steps become even more important mainly due to three factors, 1) the pressing need for real-time processing of data coming from a varied range of IoT devices, 2) the required interoperability among ICTs and 3) the integration of many proprietary protocols and communication standards applicable to buildings (such as heating, cooling and air conditioning / HVAC machines). In this section, a brief review of the different solutions to address these challenges is put forward.

2.2.1 Data aggregation and fusion techniques

Data aggregation is the combination of data from different sources, and can be implemented in a number of ways. The simplest data aggregation function is duplicate suppression. Other aggregation functions could be max, min, or any other function with multiple inputs.

However, in an IoT ecosystem, it is necessary to deal with a huge amount of information so that the aforementioned simple methods are not feasible. In that sense, random sampling [26] or principal component analysis (PCA) [27] are some of the foremost approaches to pre-process the incoming data before further analysis. While the former is used to pick a random sample from a larger dataset, the latter focuses on reduce the dimensionality (number of features) of the incoming data. In addition to that, new IoT deployments combine infrastructure sensors with the data coming from MCS modules.

Complex Event Processing (CEP)

In this frame, one of the most promising solutions in order to fuse and aggregate information in a timely manner is the Complex Event Processing (CEP) paradigm. CEP is a relatively novel software technology that focuses on timely processing streams of information items, so-called events, from a great number of distributed sources so as to detect certain activities of interest [28]. For that purpose, a CEP system performs different operations on its incoming event streams like filtering, aggregation or pattern discovery to make up higher-level events that represent the target activities of interest.

Due to the aforementioned capabilities for timely process event-based data, such approach has proved to be a quite convenient approach when it comes to deal with infrastructure sensor data in IoT deployments. More specifically, several solutions follow a CEP approach in order to extract meaningful knowledge from RFID-based data (see section 2.1.1) [221-4, 30]

Furthermore, bearing in mind MCS deployments, the CEP paradigm has also been adapted to mobile platforms in order to fit much more constrained platforms in terms of memory and processing capabilities. In that sense, CEP has already been used as a local-processing module for handheld devices [31-32]. Basically, the goal in this case is to use CEP so as to locally fuse and aggregate information from the built-in sensors of the devices. As a result, a twofold benefit is achieved. Firstly, certain situations of interest can be detected in a more rapid manner. Secondly, the amount of data sent from the mobile devices to a central server can be significantly reduced. However, the adoption of CEP as a formal solution to fuse and aggregate data from mobile sensors is still in its early stages.

All in all, the aggregation and fusion of information in IoT and MCS environments requires solutions able to process a huge amount of raw data from static and mobile sensors both reporting uncertain and low quality data. In that sense, CEP can be a suitable solution for these steps. Hence, it will be further studied within the ENTROPY project as a tool for the pre-processing of data required for energy-efficiency monitoring.

2.2.2 Semantic Modelling solutions

It is estimated that there will be around 50 billion devices connected to the Internet by 2020 [33]. Such a stunning number of highly distributed and heterogeneous devices will need to be interconnected and communicate in different scenarios autonomously. This implies that providing interoperability among the “Things” on the IoT is one of the most fundamental requirements to support object addressing, tracking, and discovery as well as information representation, storage, and exchange. The suite of technologies developed in the Semantic Web, such as ontologies, semantic annotation, Linked Data and Semantic Web Services, can be used as principal solutions for the purpose of realizing the IoT infrastructure [34] and of solving problems of interoperability among IoT systems, caused by the heterogeneous and distributed nature of the “Things”. Towards this goal, a number of modelling approaches and ontologies used to annotate and describe the IoT data have been developed. Semantic descriptions and annotations are used to represent devices, real-world objects and events, and services and business process models. These semantic descriptions support the automated management and interaction of the different components of the IoT systems.

Semantic Modelling in IoT ecosystems

Ontologies in IoT have been developed for a number of uses, including the description of sensor and sensor networks, IoT resources and services, smart “Things”, etc.

An early work on defining common interfaces and descriptions for IoT related data is provided by the Sensor Web Enablement (SWE) group at OGC[1]. The main specifications defined by OGC are:

1. Observations & Measurements (O&M) XML Implementation[2], which defines a standard model and XML Schema for encoding real-time and archived observations and measurements of sensor data. In particular, this standard specifies an XML implementation for the OGC and ISO Observations and Measurements (O&M) conceptual model (OGC Observations and Measurements v2.0 also published as ISO/DIS 19156), including a schema for Sampling Features.

2. Sensor Model Language (SensorML[3]), which is a standard model to describe sensor systems and processes associated with sensor observations in an

1 http://www.opengeospatial.org/ogc/markets-technologies/swe
2 http://portal.opengeospatial.org/files/?artifact_id=41510
3 https://portal.opengeospatial.org/files/?artifact_id=55939

XML-based schema. The primary focus of SensorML is to provide a robust and semantically-tied means of defining processes and processing components associated with the measurement and post-measurement transformation of observations. This includes sensors and actuators as well as computational processes applied pre- and post- measurement. The main objective is to enable interoperability, first at the syntactic level and later at the semantic level (by using ontologies and semantic mediation), so that sensors and processes can be better understood by machines, utilized automatically in complex workflows, and easily shared between intelligent sensor web nodes.

3. Sensor Observations Service[4] (SOS), which is a standard Web service interface for requesting, filtering, and retrieving observations and sensor system information; The SOS standard is applicable to use cases in which sensor data needs to be managed in an interoperable way. This standard defines a Web service interface which allows querying observations, sensor metadata, as well as representations of observed features.

4. Sensor Planning Service[5] (SPS), which is a standard Web Service interface and acts as an intermediary between a client and a sensor collection management environment. More specifically, this specification defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor. The standard is designed to support queries that have the following purposes: to determine the feasibility of a sensor planning request; to submit and reserve/commit such a request; to inquire about the status of such a request; to update or cancel such a request; and to request information about other OGC Web Services that provide access to the data collected by the requested task.

5. PUCK Protocol[6], which defines how to retrieve a SensorML description and other information and can enable automatic installation, configuration and operation of sensor devices;

6. SWE Common Data Model[7], which is used in nodes to exchange sensor related data. These models allow applications and/or servers to structure, encode and transmit sensor datasets in a self-describing and semantically-enabled way.

7. SWE service model[8], which defines data types used across SWE services.

Additionally, the PubSub Standards Working Group[9] is implementing the SWE standards to enable publish/subscribe functionality for OGC Web Services and define the methods to realise the core publish/subscribe functionality for a specific service binding (e.g. using SOAP, RESTful).

The models and interfaces provided by OGC define a standard framework for dealing with sensor data in heterogeneous environments. The primary representation models in

4 https://portal.opengeospatial.org/files/?artifact_id=47599
5 http://portal.opengeospatial.org/files/?artifact_id=38478
6 https://portal.opengeospatial.org/files/?artifact_id=47604
7 http://portal.opengeospatial.org/files/?artifact_id=41157
8 http://portal.opengeospatial.org/files/?artifact_id=38476
9 http://www.opengeospatial.org/projects/groups/pubsubswg

SWE are encoded in XML, which has significant limitations in semantic interoperability and defining associations between different elements.

The W3C Semantic Sensor Networks Incubator Group[10] has developed an ontology for describing sensors and sensor network resources, called the Semantic Sensor Network (SSN) ontology [35 36]. The ontology provides a high-level schema to describe sensor devices, their operation and management, observation and measurement data, and process related attributes of sensors. It has received consensus of the community and has been adopted in several projects and applications[11], including the EC co-funded projects IoT.est, SemSorGrid4Envm, SPITFIRE and OpenIoT. The SSN ontology was built to describe sensors, sensing and measurement capabilities of sensors as well as the resulting observations and deployment. The ontology covers big parts of the SensorML and O&M standards. However, SSN restricts itself to a conceptual view. It does not include specific definitions for concrete sensors or domain areas. Therefore, to realise a concrete IoT system based on the SSN ontology additional domain specific ontologies must be imported. For example you would use a temperature ontology on top of the SSN ontology to model a temperature sensor. This is why, to model the observation and measurement data produced by the sensors, the SSN ontology can be used along with other ontologies such as the Quantity Kinds and Units ontology[12] and the SWEET ontology[13]. The SSN has also been used with domain ontologies to develop various smart Things ontologies, such as the smart product ontology [37]

The IoT domain, however, is not only limited to sensors and sensor networks. The physical world objects (i.e. “Things”), also referred to as “Entities of Interest,” their features of interest, spatial and temporal attributes, resources that provide the data and their related service are other important features that need to be modelled. Autonomous integration of the IoT data and resources to the business process requires machine process-able descriptions of execution requirements. In [38] a set of models for IoT entities, resources and services is described. An entity represents a ‘Thing’ in IoT and is the main focus of interactions by humans and/or software agents. This interaction is made possible through a hardware component, a ‘device’, which allows the entity to be part of the digital world by mediating the interactions. The actual software component that provides information on the entity or enables controlling of the device is called a ‘resource’. Finally, a ‘service’ has standardised interfaces and exposes the functionality of a device by accessing its hosted resources [38]. Modelling of business processes by using semantically annotated resources that take dynamicity of the IoT environments into account is described in [39].

Time, Location and Unit of Measurements

As stated above, necessary extensions with additional ontologies (e.g. for location modelling or domain specific measurements) are required to complement SSN in a scenario formally representing real world IoT deployments, like the ones in building infrastructures.

Time

Temporal aspects are essential for any system addressing real world phenomena, e.g. buildings IoT systems. Timestamps can be used to describe when a sensor reading was taken or when it was valid. Multiple readings can be ordered by the time of their

10 http://www.w3.org/2005/Incubator/ssn/
11 http://www.w3.org/community/ssn-cg/wiki/SSN_Applications
12 http://www.w3.org/2005/Incubator/ssn/ssnx/qu/qu-rec20.html
13 http://sweet.jpl.nasa.gov/ontology/

occurrence. Clients may specify that they are interested in the current state of an environment or in the state it had one week or one hour ago. To model this, an ontology for time as well as for temporal properties and relations has to be provided. A well-established ontology for this is OWL Time [40]. OWL Time allows describing of temporal properties and relationships. It also supports time intervals as well as durations, which are e.g. useful when describing imprecise measurement times as well as complex event specifications.

Location

Locations in the physical world are another basic concept that has to be modelled in realistic IoT deployment. There is a multitude of different location models and ontologies available today, including geographical and symbolic location models. WGS84[14] coordinates are used as the basic location model, since they are the de facto standard for outdoor localisation using the GPS system. To model them, the basic Geo (WGS84) vocabulary[15] is used. In addition, symbolic names are often used as locations. For example, the Linked GeoData system[16] is used to model more complex location concepts, including symbolic names, cell-based locations and inter-location relationships. To map between symbolic names and WGS84 coordinates, the GeoNames system[17] could be adopted.

Unit of Measurements

Different properties in IoT data models represent physical magnitudes like "length" or "weight". Each one of these properties should be associated with an unambiguous unit of measurement, e.g. "metre" or "kg". Otherwise, cultural differences may lead to clients interpreting values incorrectly, e.g. by assuming a length is given in "feet", while it is actually given in "metre". While RDF allows specifying the type of a given property value by tagging it with a special type identifier, it does not support tagging values directly with a unit of measurement. A number of potential ontologies were found to model units of measurements in linked data:

(a) **Quantities, Units, Dimensions and Data Types Ontologies**[18] (QUDT) is a family of ontologies developed by TopQuadrant and sponsored by NASA designed to formalize quantities, units of measurement, dimensions and types in RDF/OWL formats. Due to this ambitious goal it is incredibly broad and precise. It models base types such as length and time and builds derived types as a hierarchy (e.g. Velocity = Length / Time, Kilometres Per Hour = Kilometres Travelled / Time taken). Where appropriate, it also references similar ontologies with sameAs and exactMatch relationships as well as DBpedia entries where appropriate. This gives items associated with QUDT types a huge amount of semantic information.

(b) **Units of Measurement Ontology**[19] (UO) establishes a hierarchy of base and derived types. It contains a large number of types but is missing some common derived types such as "Kilometres Per Hour". It also fails to link to external resources such as DBpedia where relevant which makes it less useful that QUDT.

14 http://spatialreference.org/ref/epsg/4326/
15 http://www.w3.org/2003/01/geo/
16 http://linkedgeodata.org/
17 http://www.geonames.org/
18 www.qudt.org/
19 https://code.google.com/p/unit-ontology/

(c) **Ontology of Units of Measure**[20] (OM) stands out from the other evaluated ontologies by using URIs as the value for the majority of each type's information. This immediately gives feedback to the user that values are unique. Thanks to each type using the same signature, this lets the user easily compare types for similarities using simple methods such as string comparison rather than needing to traverse the type hierarchy. Each of these URIs (e.g. om:kilometre, om:dimension, om:length-dimension) can be followed to obtain more information including other users of this value. OM has a large number of derived types available but – just as UO – lacks links to external resources such as DBpedia and other ontologies.

(d) **Measurements Unit Ontology**[21] (MUO) aims to solve the same problem as the other evaluated ontologies by establishing a hierarchy of base and derived types.

Delivery Context

The Delivery Context Ontology[22] provides a formal model of the characteristics of the environment in which devices interact with the Web or other services. The Delivery Context includes the characteristics of the Device, the software used to access the service and the Network providing the connection among others. The Delivery Context is an important source of information that can be exploited to create context-aware applications, thus providing a compelling user experience.

Linked Sensor Data

Semantic annotations can describe IoT resources, services and related processes. However, often there is no direct association to the domain knowledge in the core models that describe the IoT data. Different resources, including observation and measurement data, also need to be associated with each other to add meaning to the IoT data. Effective reasoning and processing mechanisms for the IoT data, and making it interoperable through different domains, requires accessing domain knowledge and relating semantically enriched descriptions to other entities and/or existing data (on the Web). Linked Data is an approach to relate different resources and is currently adopted on the Web. Providing automated mechanisms for semantic tagging of the resources using the concepts available as linked data (e.g. such as those available on the Linked Open Data cloud), and defining automated association mechanisms between different resources (e.g. based on location, theme, provider and other common properties) make the IoT data usable across different domains.

Kno.e.sis linked sensor data; Linked Sensor Data is an approach to representing and publishing sensor descriptions and sensor observations on the Web using the Linked Data best practices. Publishing sensor data as Linked Data enables discovery, access, query, and interpretation of sensor data. With a view of making sensor data publicly accessible on the Linked Open Data (LOD), the Kno.e.sis research centre has generated two datasets, the LinkedSensorData and the LinkedObservationData. On the one hand, LinkedSensorData is an RDF dataset containing expressive descriptions of ~20,000 weather stations in the United States. The data originated at MesoWest[23], a project within the Department of Meteorology at the University of Utah that has been aggregating weather data since 2002. On average, there are five sensors per weather

20 http://www.wurvoc.org/vocabularies/om-1.6/
21 http://idi.fundacionctic.org/muo/muo-vocab.html
22 http://www.w3.org/TR/dcontology/
23 http://mesowest.utah.edu/index.html

station measuring phenomena such as temperature, visibility, precipitation, pressure, wind speed, humidity, etc. In addition to location attributes such as latitude, longitude, and elevation, there are links to locations in Geonames near the weather station. The distance from the Geonames location to the weather station is also provided. The data set also contains links to the most current observation for each weather station provided by MesoWest. This sensors description dataset is now part of the LOD. On the other hand, LinkedObservationData is an RDF dataset containing expressive descriptions of hurricane and blizzard observations in the United States. The data again originated at MesoWest. The observations collected include measurements of phenomena such as temperature, visibility, precipitation, pressure, wind speed, humidity, etc. The weather station's observations also include the unit of measurement for each of these phenomena as well as the time instant at which the measurements were taken. The dataset includes observations within the entire United States during the time periods that several major storms were active - including Hurricane Katrina, Ike, Bill, Bertha, Wilma, Charley, Gustav, and a major blizzard in Nevada in 2002. These observations are generated by weather stations described in the LinkedSensorData dataset introduced before. Currently, this dataset contains more than a billion triples.

Sense2Web linked sensor data platform; Sense2Web[24] supports flexible and interoperable sensor data description. Sense2Web associates different sensor data ontologies to domain data and resources on the semantic Web and the Web of data. Linked data is one way to publish, share and connect data via URIs on the Web. It focuses on interconnecting data and resources on the Web by defining relations between ontologies, schemas and/or directly linking the published data to other existing resource on the Web. The linking process can be done manually or (semi-) automatic mechanisms can be used to create the associations. Publishing data as linked data enables discovering other related data and relevant information and facilitates interconnection and integration of data from different communities and sources. Sense2Web publishes sensor device and node descriptions as linked data and makes it available to other applications via SPARQL endpoints. The Sense2Web demo also provides a mash-up application to demonstrate reasoning and interpretation of linked sensor data using Linked Open Data resources. Sense2Web provides graphical user interfaces to annotate the IoT data (i.e. resource description, real world entities and services) using concepts obtained from linked open data cloud (e.g. DBPedia and GeoNames) and also other local domain ontologies.

Linked Sensor Middleware; The Linked Sensor Middleware[25] (LSM) brings together the live real world sensed data and the Semantic Web. It provides many functionalities such as: i) wrappers for real time data collection and publishing; ii) a web interface for data annotation and visualisation; and iii) a SPARQL endpoint for querying unified Linked Stream Data and Linked Data.

Behavioural Semantic Modelling

Using ontologies for human activity can overcome some issues of probabilistic methods such as scalability, data scarcity and static models [41]. Ontologies are able to represent complex relationships among concepts and instances thus, they provide more expressivity for environments. As it is widely studied in [42], there are several context

24 http://personal.ee.surrey.ac.uk/Personal/P.Barnaghi/Sense2Web.html
25 https://code.google.com/p/deri-lsm/

modelling ontologies that support human activity representation. An overview of the ranking of the most representative human activity ontologies is provided in Fig. 1.

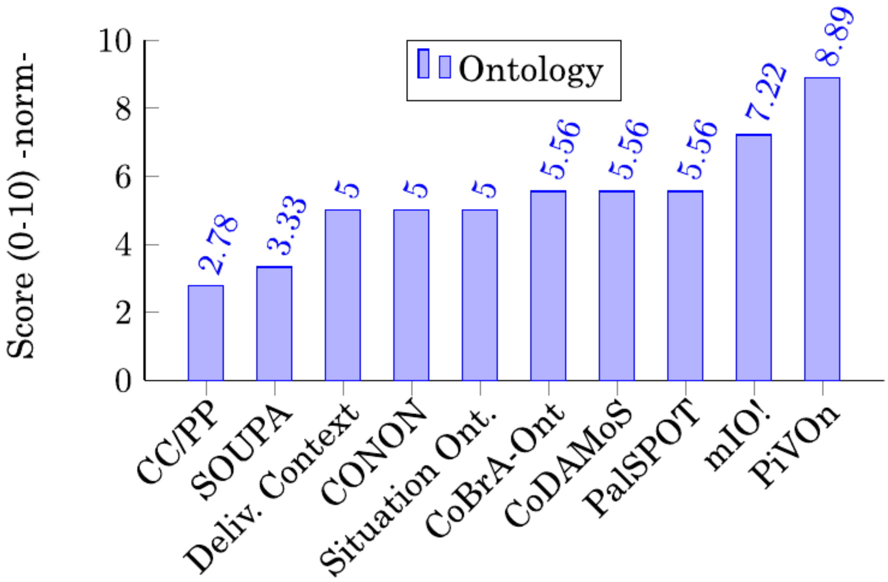

Figure 1: Overall ranking for the most representative human activity ontologies

SOUPA ontology [43] is a context ontology, that aims to save time on ontology development process, by combining several common ontology concepts. These are, namely FOAF for person profiles, DAML –Time for modelling time entities (instant times and intervals), OpenCyc spatial ontologies and Regional Connection Calculus for spatial context modelling; Cobra-Ont and MoGATU for Belief-Desire-Intention (BDI) modelling and Rei ontology for policies.

SOUPA consists of two parts: SOUPA Core and SOUPA Extensions. The core part defines more generic concepts that can fit in various scenarios. SOUPA Extensions module is more specific to different domains.

SOUPA Core describes Person, Agent & Action & BDI, Policy, Time, Space and Event concepts. These concepts can be extended to different domains by application developers.
One of the extensions of SOUPA is CoBrA – Ont. CoBrA (Context Broker Architecture) is a pervasive system especially dealing with places. eBiquity application utilizes this ontology and system. It manages the environment for a group meeting at a location and at a time based on the context described with CoBrA-Ont and SOUPA ontology.

CoDAMoS Ontology [44] ontology mostly focuses on adaptability and dynamic code generation for devices according to environment and user preferences. It contains for main concepts: user, platform, environment and service. CoDAMos emphasizes that, environment changes in an ambient system only relevant if it affects to user. Therefore it defines various aspects for a user, for example, a user can have different tasks and moods. It also considers that one users might have different roles in a system, that might affect their behaviour. The ontology also provides a fine-grained, detailed model of device resources (e.g. processing power, memory, operating system).

mIO! Ontology [45] is a modular ontology that is developed using NeOn methodology. NeOn methodology is an ontology development methodology mainly based on merging, re-engineering and re-using existing sources. mIO! re-uses several concepts from aforementioned context ontologies, additionally it also describes subdomains like network and interface as well as the context provenance.

PalSPOT is a human activity recognition ontology [46] is one of the most activity oriented ontologies. The granularity of activities is quite low, but it represents many different types of activities. Interval based time modelling allows us to model overlapping activities.

PiVOn [47] is a context ontology for pervasive systems that focuses on four main upper ontology concepts: user, environment, service and device. The ontology models a context with 5 Ws (What, Who, Where, When, Why) journalism principle. The design of this ontology considers each of the four concepts with these five questions. As a result, it offers four modular sub ontologies.

The user ontology focuses on what user wants to do and what she is doing. It models activities as a sequence of subtasks, therefore provides flexibility. It also models the current situation and role of a user in a context. Users can be associated with events and there is a messaging mechanism to remind event schedules to user.

The device ontology deals with devices and their various properties such as type, location, services they provide and so on.

The environment ontology describes spatial properties and colocation of entities (e.g. user, device) in the environment (near, inFrontOf etc.).

The service ontology is mostly focused on visualization of services that devices offer.

The survey [42] evaluates the aforementioned ontologies in the means of the subdomains (i.e. submodules, subontologies) they support. If an ontology specially supports a subdomain, it receives an extra point. Every subdomain has equal weight in the final score. According to the results of the survey, PiVOn performs the best for representing human activity. It supports almost every subdomain as the others and additionally has mechanism for social interaction and the most flexible task-activity model.

It should be noted that in ENTROPY, there is need to adopt a hybrid ontology that maps in an easy and verbose way how the human behaviour can lead to energy consumption reduction. The majority of ontologies available in the literature –like the aforementioned ones- represent in detail different energy metrics, devices, and building status in terms of energy consumption, however their interlinking with human behaviour aspects is often too poor and generic or adapted strictly on a very specific domain.

A representative example of a generic interlinking of energy efficiency metrics and demographic indicators is the SEMANCO ontology (see Fig. 2) that covers fully the demographic aspects of pilot participants (educational level, job etc.) but ignores totally psychographic indicators that ENTROPY aims to measure as well (e.g. personality types, curtailment behaviour etc.).

On the other hand, ontologies such as CONNON (see Fig. 3) and ThinkHome (see Fig. 4) seem to describe human behaviour at a person granularity but in terms of specific preferences related with the configuration of their home devices (e.g. fridge temperature).

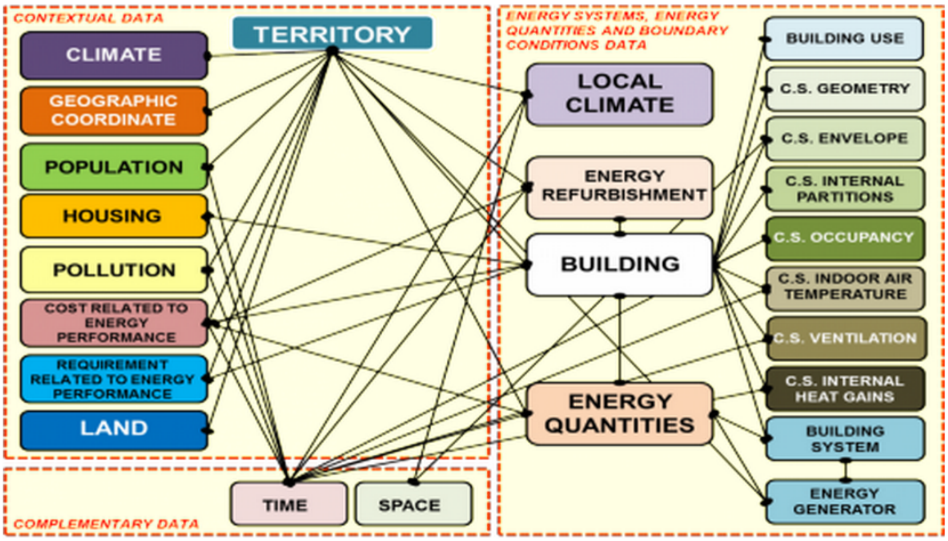

Figure 2: SENANCO ontology

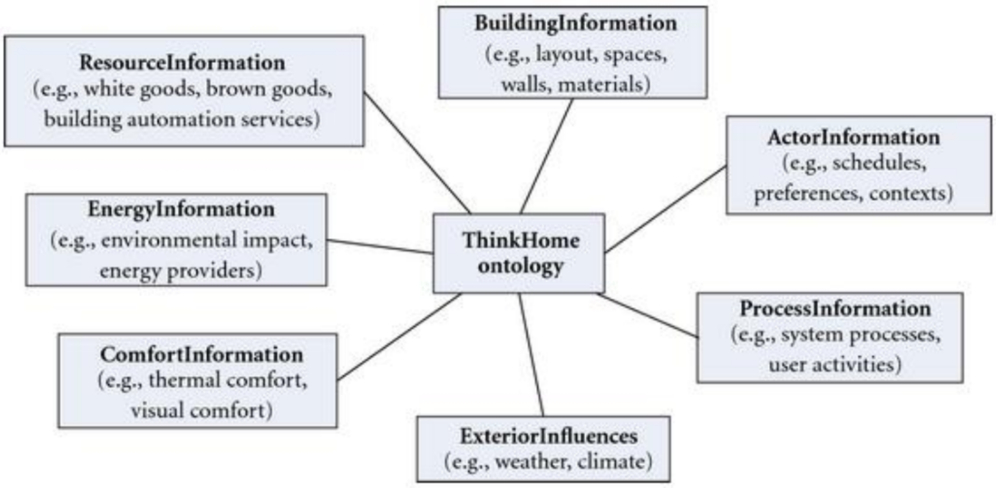

Figure 3: Thinkhome Ontology

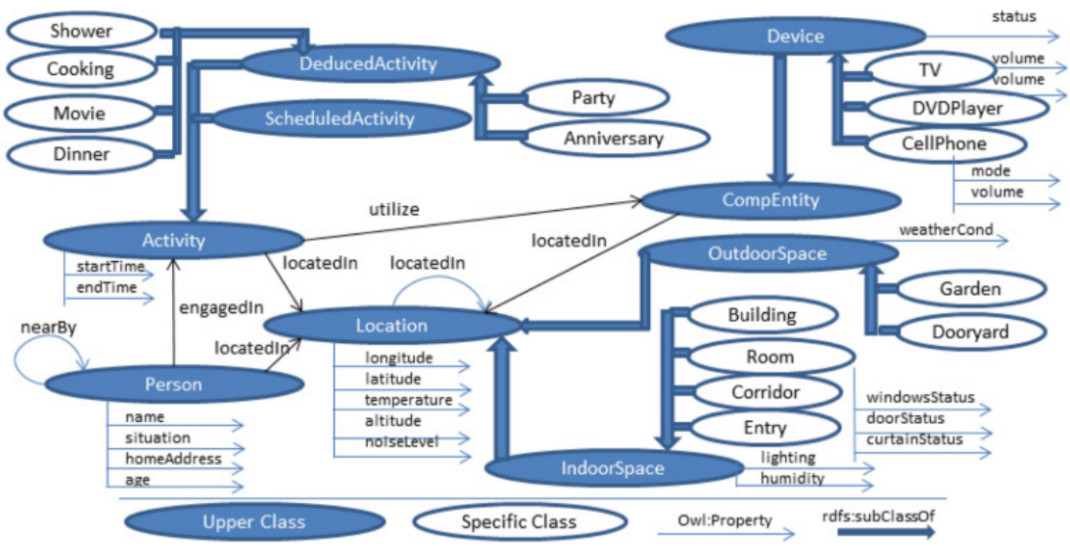

Figure 4: CONON Ontology

Taking into account the aforementioned information, in ENTROPY we are going probably to adopt an hierarchy of existing ontologies making the appropriate customizations and extensions (by creating inherited ontology classes) so as to reuse the maximum of existing knowledge from existing ontologies and at the same time be able to represent specific psychographic aspects of human behaviour that can lead to analytic results, discovery of human patterns and helpful suggestions to the end users.

Modelling Energy Efficient Buildings

Apart from the aforementioned modelling approaches of IoT infrastructures and data streams representation, there are also some efforts to implement semantic models for energy efficiency in smart homes and buildings.

One of such effort is ThinkHome ontology [48-50], as already mentioned, which is part of energy efficient smart home system. ThinkHome ontology is concerned with concepts related to thermal comfort, building information, information about users and their preferences, resource information (including white goods, brown goods and automation networks hosting lighting, shading as well as heating, ventilation and air conditioning devices), user behaviour (in terms habit profiles and predicted schedules), building processes, energy information (in terms of available energy providers and their trading conditions) and external weather; and it does not encode energy consumption related concepts at appliance level. The vision of ThinkHome, which is implemented in OWL, is to create a comprehensive knowledge base which includes all the different concepts needed to realize energy efficient, intelligent control mechanisms.

The Smart Appliances REFerence (SAREF) ontology[26] is a shared model of consensus that facilitates the matching of existing assets (standards/protocols/datamodels/etc.) in the smart appliances domain. The SAREF ontology provides building blocks that allow separation and recombination of different parts of the ontology depending on specific needs. The starting point of SAREF is the concept of device (e.g., a switch). Devices are tangible objects designed to accomplish a particular task in households, common public buildings or offices. In order to accomplish this task, the device performs one or more functions. For example, a washing machine is designed to wash (task) and to accomplish this task it performs the start and stop function. The SAREF ontology offers a list of basic functions that can be eventually combined in order to have more complex functions in a single device. For example, a switch offers an actuating function of type “switching on/off”. Each function has some associated commands, which can also be picked up as building blocks from a list. For example, the “switching on/off” is associated with the commands “switch on”, “switch off” and “toggle”. Depending on the function(s) it accomplishes, a device can be found in some corresponding states that are also listed as building blocks. When connected to a network, a device offers a service, which is a representation of a function to a network that makes the function discoverable, registerable and remotely controllable by other devices in the network. A service can represent one or more functions. A service is offered by a device that wants (a certain set of) its function(s) to be discoverable, registerable, remotely controllable by other devices in the network. A service must specify the device that is offering the service, the function(s) to be represented, and the (input and output) parameters necessary to operate the service. A device in the SAREF ontology is also characterized by an energy/power profile that can be used to optimize the energy efficiency in a home or office that are part of a building.

26 http://ontology.tno.nl/saref/

SESAME [51] uses an ontology-based modelling approach to describe an energy-aware home and the relationships between the objects and actors within the control scenario. SESAME is specified in OWL and N3 representations and provides a hierarchy of concepts of automation domain and the energy domain. SESAME ontology includes a number of concepts such as resident, location, appliance, sensors and tariff etc., and relationships between them. As a matter of fact, the main components of the SESAME ontology are Automation Ontology, Meter Data Ontology and Pricing Ontology. In particular, the SESAME Automation Ontology includes a number of general concepts such as Resident and Location, and concepts in the automation and in the energy domain, such as Device, and Configuration. The SESAME Meter Data Ontology is based on the DLMS standard model[27] for meter data modelling. The DLMS/COSEM specification defines a data model and communication protocols for data exchange with the metering equipment. With the set of interface classes (e.g., Register, Activity Calendar, Clock) and a set of instances of these classes, the meter acts as a server and publishes its data to the utilities, customers or providers which can access the meter data as clients. Finally, the SESAME Pricing Ontology captures the concept for making energy-aware decision and selecting the optimal tariff model for specified time and energy load. However, SESAME ontology does not provide appliances representation from perspective of energy consumption saving, rather it relies on overall energy consumption information and various tariff information provided by smart meter supplier.

SERUM-iB framework [53] uses ontologies to build the knowledge base. It contains concepts representing rooms, energy consuming appliances, building automation devices, environment parameters, events and their relations. It is represented in OWL (Web Ontology Language). In SERUM-iB framework, knowledge-driven analysis is adopted to find energy wasting conditions and to recognize energy usage anomalies in buildings. SERUM-iB framework uses it for identifying the operational state of an appliance, to identify appliance classes based on their energy consumption and to identify the user event or consumption behaviour based on the sensor data. Within the SERUM-iB framework, the three methods have been implemented to generate the ontology components: (1) manual ontology generation by an expert, (2) semi-automatic through interpretation of 2D-drawings, and (3) semi-automatic by data mining algorithms. For example, the ontological classes as well as their attributes and relations representing building automation devices, for instance sensor and energy meter, building environments such as door, window, room, are created manually by experts. Moreover, energy wasting situations are modelled by experts in the base ontology. These situations are described in a rule representing language called SWRL (Semantic Web Rule Language). SWRL is a language combined by OWL (Web Ontology Language) and RuleML (Rule Mark-up Language) that enables the integration of rules in OWL ontology. The ontology representing the building domain knowledge is enriched with ontological individuals from building specific information. The individuals are created by configuring the framework based on building specific information. They are also created automatically by interpreting the 2D construction drawing of the building layout depicting building structures, such as room, floor, door, windows and contained energy consuming appliances, as well as building automation devices, for instance temperature sensors and occupancy sensors. The semantic information of building environments such as rooms, lights, and appliances is obtained from geometric data through the interpretation of 2D-drawings.

27 www.dlms.com

The Energy Efficiency Ontology (EEOnt) [54] provides a foundation of a global and unified representation of buildings towards a fair comparison of their energy performance that is a new, crucial characteristic imposed by the current European legislation, which defines that buildings have to be certified with an energy efficiency index. EEOnt extends the applicability of other ontological models of buildings incorporating energy efficiency data and knowledge that can be calculated with high spatial and temporal resolution in what we call an Energy Efficiency Landscape (EELB). These EELB's provide significant information which allows a detailed diagnosis of the energy efficiency within the building. Consequently, EEOnt is capable of representing buildings and energy efficiency in a unified way. Furthermore, it supplies a tool for managing the energy efficiency in buildings and constructing national inventories. These two features link the global and particular needs of governments and users, thus becoming key to both improve the energy efficiency in buildings and to implement viable certification schemes.

The Adapt4EE shared semantic vocabulary and meta-data, called Common Information Model (CIM[28]), describes the information sources that are used by modules of both measurement and simulation frameworks of Adapt4EE. That means it does not contains the redundant copy of the data, it contains the description of the information sources from particular modules to be able to use them (the information sources) for the evaluation of the overall building performance based on occupancy. Thus it enables to integrate information about Buildings, Business processes as well as High-level events (e.g. Events about occupancy, devices and sensor measurements) in a measurement phase as well as results from agent simulation in form of Key Performance Indicators and templates in a simulation phase. Therefore, it can enable the user in the simulation process to interpret the results based on the dimensions under comparison (Time, Space, Process, Actor, Device, Energy).

KnoholEM[29] is knowledge-based energy management for public buildings through holistic information modelling and 3D visualization, elaborating an intelligent energy management solution for energy efficient buildings and spaces of public use. The intelligence of the KnoholEM solution relies on an OWL represented knowledge base, comprising a generic ontology and building specific ontologies. The generic ontology represents a common information model for building energy management, and then it is populated and extended with building specific information resulting more building specific ontologies corresponding to the specific buildings. The KnoHolEM ontology main classes represent different objects involved in energy management in buildings. For example, the class BuildingElement models the building structures that are observed, examined and analysed in energy management activities. The class BuildingElement and its sub classes represent the fundamental of Building Information Model (BIM). The class BuildingControl indicates the entities related to building automation system elements in the building. It represents the sensors, actuators, controller, alarm, etc., which are elements of a building automation system. Finally, the class Actor that corresponds to either organizations or persons represents the human actors having bahaviour that can affect the states of BuildingElement.

The COINS Building Information Model specification[30] is formally recorded in the Web Ontology Language (OWL). The OWL files that specify the COINS kernel schema[31] and

28 http://www.adapt4ee.eu/adapt4ee/files/document/deliverables/Adapt4EE-Deliverable-D2.2.pdf
29 http://www.knoholem.eu
30 http://www.coinsweb.nl/wiki/index.php/COINS_Building_Information_System - COINS_BIM_specification
31 http://www.coinsweb.nl/c-bim.owl

two sub-schema's for the established reference frameworks (functional specification and quantity estimation) are part of this specification.

As ENTROPY focuses on micro-generation aspects, as well, the consortium will take into consideration OpenWatt[32], which creates an ideal scenario in renewable energy sector area that fully integrates heterogeneous data, introducing the paradigm Linked Open Data to represent the renewable energy data. It allows the improvement of data quality, usability, productivity and efficiency. The OpenWatt ontology is developed to guarantee the interoperability among data and applications, and is represented in RDF/XML format, importing other ontologies, such as SKOS, PROV and GeoNames. The main concepts represent the typology (consumption, potential, production) and category (biomass, solar, solid waste, etc.) of renewable energy, and also the measure. Measure describes data collection methods, such as estimation, census, metering, etc. The typology concepts are related to the concepts in location taxonomy (country, region, province, municipality, etc.).

2.3 Algorithm Design of Life-style Recommenders for Behavioral Change

This section puts forward an overview about existing algorithms that can be used in order to detect certain human behaviours. Next, existing solutions to modify the previously detected life-style behaviours, like recommendation systems or gamification techniques, are also described.

2.3.1 Analytics Methods for Behavioural Detection

Human behaviour detection is nowadays one of the foremost research topics in a varied range of domains like human-computer interaction, traffic management or automatic surveillance. Hence, the target behaviour to be recognized could be, for example, the current route covered by a driver or the motion activity (e.g. walking, sitting, running and the like) done by an employee within his office.

Furthermore, due to the endless improvement of infrastructure and mobile sensors, it is possible to distinguish among algorithms that focus on behavioural recognition on the basis of static sensors usually deployed as part of a larger infrastructure and other techniques that intends to detect human activities on the basis of sensors embedded in personal handheld and wearable devices.

Concerning the activity recognition by means of static sensors, image processing has played a key role [55]. In that sense, a palette of studies can be found that takes as input the image stream from camcorders so as to detect the behaviour of the recorded people.

Nonetheless, data sources for activity recognition are not limited to static sensors reporting measurements fixed to a particular location but moving ones capable to deliver measurements at different points within an area. This is mainly due to rapid development of wireless technology, mobile sensor networks and, above all, the advent of smartphones [56]. The sensor equipment of this type of contrivances (e.g. GPS, accelerometer and so forth) is capable to capture a large amount of information related to the phone’s holder and his/her surrounding environment.

32 http://ceur-ws.org/Vol-1133/paper-20.pdf

According to [213-3], it is possible to extract three types of properties from mobile sensors: 1) spatial-temporal properties (e.g., presence, count, location, track, identity); 2) behavioural properties (e.g., activity, group behaviour); and, 3) physiological properties (e.g., temperature, blood pressure, heart rate).

Regarding the behavioural properties, most of the efforts made in this line of research profit from the motion sensors of personal handheld and wearable devices (e.g. accelerometer or gyroscope) in order to automatically detect the motion-based activity of the device's holder at each moment [55]. In that sense, it is possible to distinguish between micro-activities and more complex ones. The formers have to do with very simple motion activities such as walking or running. The latter are related with longstanding behaviours like "working at the office" or "cooking". Broadly speaking, the second type of complex activities is usually detected on the basis of the more simple ones.

Furthermore, a second line of research for behaviour recognition makes use of the location sensors, mainly GPS, of personal mobile devices. In that sense, due to the inherent inaccuracy of this type of sensors, the target activities are more coarse-grained than the ones detected by using motion sensors, and they are generally limited to outdoor scenarios. As a result, most of the works in this area intends to perceived behaviours from the spatial-temporal trajectories generated by the GPS measurements. As a matter of fact, works like [57] detect illegal behaviours (like smuggling or illegal fishing) in the maritime environment on the basis of abnormal movements of vessels periodically reporting its current location. In urban context, other lines of research intend to compose personal or crowd-based mobility networks representing the movement-related behaviour of individuals within a particular area.

In addition, a novel course of action states the recognition of human activities by analysing the footprint of people in social network sites. From these soft sensors, an unprecedented amount of user-generated data on human movement and activity participation has become available. Unlike previous mobility datasets (e.g. GPS-based ones), these new ones not only include location or motion information (e.g. the spatial coordinates of a person at a particular moment) but also textual data attached to a particular spot which provides more semantic information.

In this scope, several solutions to give insight into these new social-media data have been proposed coming up with novel human-mobility models and patterns. More in detail, the work from [58] proposes a novel approach to semantically enrich spatial-temporal trajectories given data from different social media sites. This way, a more dynamic labelling is achieved. Moreover, the results in [59] describes a Bayesian network to predict movements and interest of people from their tweets. Finally, the work presented in [60] processes the spatial coordinates of geo-tagged tweets in order to compose the spatial-temporal trajectories of a set of Twitter users. Such trajectories are defined as simple Origin-Destination matrices and the labelling of each potential origin or destination is done by means of a third-party location service.

A third line of research makes up behavioural models on the basis of the transaction data generated by smart cards (e.g. transit or credit cards) citizens use during their daily routines. Since using these cards is part of the daily routine of most commuters, these mining techniques offer a non-intrusive solution for mobility-pattern extraction.

All in all, there exist many different alternatives to perceive the current behaviour of a set of individuals depending on the type of available datasources. However, in order to come up with more accurate and reliable activity recognition different static and mobile datasources should be aggregated and fused. Hence, during the last years, a host of studies have put forward novel approaches to generate probabilistic models for behaviour modelling that integrates data from several sources. In that sense, Bayesian networks [61], n-th-order Markov models [62] or hidden Markov models [63] have been some of the applied solutions.

2.3.1.1 Energy-related behaviour detection

In the energy field, energy-related behaviour detection has become a key expertise in energy management since the wide spread of Advanced Metering infrastructures (AMI) with a vast amount of data coming from Automatic Meter Reading (AMR) of the electric consumption in houses/buildings, enabling a fine grain monitoring; moving from a reading every two months to readings in a fine grain (hours). In addition, since the enablement of the technology the interest for enabling sub-metering in the houses / buildings with smart meters has also evolved during the last years making even more powerful and fine grain the available energy data.

The data collected is full of information that can be extracted using machine leaning algorithms giving raise many applications: data understanding (MEU[33]), human behaviour impact on energy consumption, data visualization [64], electric appliances detection and monitoring [65], energy consumption and production prediction [66], [67].

Despite the fact that the research energy-related behaviour detection and other types of behaviors has been carried out in a quite isolated way, its combination could bring suitable results. For instance, it might be interesting to study how the prediction of the future movement of a person in a building or a particular spatial area (e.g. university campus) can help to anticipate the energy consumption of such a building or area. This type of synergies will be considered in the ENTROPY project.

2.3.2 Recommendation Systems for Behavioural Change

As the societal demand for energy efficient solutions grows, the energy efficiency standards and regulations are driving the development on the electrical appliance market, including the application of smart data and semantic technologies [68]. It has been also demonstrated that energy efficiency measures can achieve approximately 50% savings from the baseline projected building energy use in 2030, and that the average cost of these savings is less than half the production cost of energy [69]. As the mass consumers' needs and actions are driven by available information, i.e., by their awareness of more efficient consumption (using less energy to provide the same service[34]), costs and potentials for savings, as well as by value-add offers, the regulators and markets react on that needs with respective measures and products. The labelling regulations are introduced as a means to enhance awareness, guide users in making energy efficiency enhancing decisions, and stimulate standard use[35] [70]. The regulations of EU-wide introduction of smart meters also aims at increasing energy consumption awareness.

[33] MEU project: http://www.hevs.ch/media/document/0/2013.08.26_meu_en.pdf

[34] What is energy efficiency?, http://eetd.lbl.gov/ee/ee-1.html, Lawrence Berkeley National Laboratory, last accessed June 2015

[35] EU, Energy Efficient Product Portal, http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products, Last accessed June 2015

The added value offers and services are rapidly appearing at the building automation and smart homes markets. The home automation data may bring energy efficiency at the new level: as products report their life cycles data, social trends can be recognized, prediction and planning improved and turned into services, and products can come closer to meeting consumers' and societal needs. A new breed of emerging home energy management systems increasingly utilize the IoT paradigms and infrastructures, and offer decision support to induce energy efficiency enhancing behaviour and actions, based on quantifiable facts, extracted from data collected from various meters, sensors, smart appliances, external systems and users.

The amount of data from IoT-enabled devices aiding in energy management promise to follow the exponential rate, and have a potential to fuel the energy efficiency data economy. Recommender systems are a well-established research topic with application mainly in movie recommendation, television, books, documents, e-learning, e-commerce, applications in markets and web search, among others [71]. These systems however are usually built with a specific short term, optimal outcome in mind, i.e. what specific product, action, or procedure yields the best immediate result. Human behaviour is usually treated only as an input vector to build the recommender systems, and to a lesser degree in predictive models. A work from Google [72] presents an approach for personalized news recommendation using a Bayesian framework based on the overall news trend and user's clicking behaviour. The approach uses collaborative and information filtering techniques to generate personalized news recommendations.

A complete survey of the field of recommender systems is beyond the scope of this report, since the field is well established and rather extensive. The narrower viewpoint of applying recommender systems to initiate change in human behaviour specifically in the energy domain however is still rather unexplored. Two examples from this specific area are discussed in the following.

A very recent paper [73] in the area of energy efficiency and smart homes provides a case study that combines unsupervised machine learning with smart home data in order to learn customer behaviour and optimize energy efficiency without sacrificing customer comfort. The historical training dataset (based on proprietary data provided by http://www.digitalstrom.com) this work is based on contains 33 homes with 3521 devices, which are related to 4,331,443 events and 6829 unique scenes. Standard pattern mining algorithms as well as a custom novel approach are used to find relevant patterns that act as the foundation of the recommender system. Unfortunately neither the dataset, nor the source code used in that project, are public. However the general outline of energy saving event types and their use in identifying relevant patterns in the input data are useful as inspiration for designing such a system.

A complete conceptual model for an intelligent system for energy conservation in domestic environments is shown in [74]. Here the recommendations are based on a threefold ontology describing appliances, society and energy usage recommendations. These ontologies are combined with a multi modal sensor network to identify abnormal (based on these ontologies) energy behaviour, e.g. a sensor of a washing machine might detect abnormal energy consumption which triggers a recommendation for the user. A feedback channel is used in order to evaluate the effectivity and acceptance of these proposed behavioural changes directly with the user. This allows the system to learn and fine tune its recommendations. The dataset and source code, to the best of our knowledge, is not accessible, however especially the idea of incorporating a feedback channel for recommendation evaluation, as well as the basic approach to modelling the different layers of the ontology (elaborated upon in [75]) can act as a baseline for designing the system.

Another important aspect of recommender systems that will be highly relevant to application domain is context-awareness. Human behaviour is subject to change according to user's context. One simple example can be the energy efficiency measures that should be taken in a cold day or a relatively warm day. Using static rule models for recommendation systems may lead to poor results in such cases. The work presented in [76] suggests an approach for recognizing significant changes in human behaviour based on "Multi-armed Bandit Problem". The approach creates recommendation vectors and aims to maximize the usefulness of recommendations according to feedback that is given by user on specific items. These interactions with user can help to detect changes of user's context. Sooner the changes are detected, faster the recommendations adapt to new context. This approach also presents several evaluations but there is no mention of any source code or documentation of prototype. We will explore further approaches for detecting context changes and investigate the possibilities of combining them with our rule based approach to achieve better context change detection to refine our recommendations.

2.3.3 Gamification techniques for Serious Games Development

As the term 'Gamification' is used to describe game design elements in non-game context, gamification is thus used for implementation and active use of computer game design concepts, game thinking, mechanics, analytics, procedures, services, products etc. to educate the user, and improve user skill, engagement and effectiveness.

The implementation and development of data obtained from sensors in the real world can be combined with the digital world, stimulating in this way collaboration and enforcing the achievement of sustainable results through the direct engagement of players (end users).

Game mechanics that are incorporated into a gamified software system or application may have a significant impact on type of player or user, who may or may not efficiently use those techniques and get maximum benefits from it [77]. This is referring to the suggested game mechanics that should be included within the serious games part of the ENTROPY project, regarding the end user.

Game mechanics that are incorporated into a gamified software system or application may have a significant impact on type of player or user, who may or may not efficiently use those techniques and get maximum benefits from it. In order to better understand the differences exhibited in the way the participating players engage with the game, Bartle [80] in his seminal work about player typology presented a typology of players stemming from Multi-User Dungeon Games in the 1960 (MUD). According to this typology, the players are classified in the following categories exhibiting different interaction behaviours:

- *Achievers*: Players driven by the in-game goals. They enjoy the process of achieving in the game, gathering points, completing missions and attaining goals
- *Explorers*: Players motivated by their need to understand the virtual world and the context of the game. They enjoy the process of understanding the game and experiencing it to its fullest regardless of achievements.
- *Socializers*: Players that utilize the game as a means to interact with other players.
- *Killers*: Players that engage in the game to interact with other players, but with the goal to be better than the others.

In all the aforementioned types of players, different mechanics and game elements will be used differently and, consequently, will produce different results. A compilation of relevant examples of game mechanics and techniques is available in the following Table based on the reference [78].

In the context of ENTROPY project it is of particular interest to address different aspects of gamification techniques, for example:

- Incentive mechanisms – these can be different depending on players/stakeholders, from social and environmental responsibility, player status or to money savings/voucher schemes
- Feedback mechanisms – keep user informed about the progress in the game, his/her ranking, the effect of his actions etc.
- Behavioural mechanics – educate and motivate players; keep them interested and surprised; connect more players and community

Behavioural mechanics is a very important aspect of the game, and it will be based on the ENTROPY project research in the area of energy efficiency related behavioural change. Citizens' behavioural analysis will be used as a basis for providing suggestions for energy efficient lifestyles. Through different game levels we can support gradual behavioural changes of citizens and their engagement in every-day environmental friendly activities.

Table 1: Summary of game mechanics, types of players, and their possible benefits

Type, name of game mechanics	Details of game mechanics	Types of players	Possible benefits
Progression gamification mechanics			
Badges, trophies	An indicator of accomplishment or mastery of a skill; it is especially meaningful within a community or a group that understands its value. They serve as collectibles and the rate at which they can be obtained / exhibited can have an effect on the way the players aim to obtain them. Lastly badges can encapsulate user's interests, expertise and past interaction – achievements towards personal affirmation and group identification [81].	Achievers, explorers	Engagement, loyalty, influence, time spent, fun, User-Generated Content (UGC)
Points	Used to keep score and establish player's status. Players earn points through activities, sharing, contributing or by creating something useful to the community. There are different types of points like Experience points (XP) that can be obtained continuously, Redeemable points (RP) that are of the type of "earn and burn" and enable dual economy and external rewards, Karma points (KP) that are awarded from a player to another etc. *The point structure can be used to reflect the importance of each action and in Entropy can parallel the importance of the effect of users' actions that have an energy efficiency related real world effect.*	Achievers, explorers	Engagement, loyalty, influence, time spent, vitality, fun, UGC
Level or status within a professional community	Levels indicate long-term or sustained achievement; they are used to identify status within a community and to unlock new missions badges, activities and rewards. Level structure can play an important role in the resulting engagement of the players with the created gamified process as it will mediate the degree of difficulty of progression and achievements.	Achievers, explorers	Engagement, loyalty, time spent, influence, vitality, fun
Leadership board	Tools to monitor and display desired actions and current ranking of participants. The formation of the leader board can be in the form of: (a) an infinite leader board where all participants are visible, (b) a non-disincentive leader board where each player can see his/her relevant position in the centre and 1-3 users predating him/her and 1-3 following him/her. Lastly different types of contextual slice and dice allows users to create different leader boards (like social media circle, geographical closeness etc.)	Achievers, explorers	Engagement, loyalty, influence, time spent, UGC, vitality, fun

Feedback gamification mechanics			
Quests/ Challenges	Challenges usually imply a time limit or competition whereas quests are meant to be a journey of obstacles the user must overcome. Both can be used to ensure parallelism to the user goal at hand and constitute small steps that build up to the bigger goal of the gamification setup.	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC
Immediate feedback or response to actions	Encourage users to continue or adjust their activities with onscreen notifications, text messages or emails. Congratulate a user for reaching a goal, encourage the next step to a milestone or promote a new reward. Feedback is considered key to the gamification design as it enables direct interaction with the user upon actions	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC
Transparency	Show users exactly where they stand on the metrics that matter to you and to your audience. Individual and team profiles show progress in real-time and historically. Leader boards show who's just ahead and who's behind as well as overall ranking on any number of metrics. The degree of transparency enables users to get a sense of autonomy whilst not compromising their perceptions of fairness [82]	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC

Table 2: Summary of game mechanics, types of players, and their possible benefits (continued)

Type and name of game mechanics	**Details of game mechanics**	**Types of players**	**Possible benefits**
Feedback gamification mechanics			
Cascading information theory	Information should be released in the minimum possible snippets to gain the appropriate level of understanding.	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC
Appointment dynamics	At a predetermined times a user must return for a positive effect.	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC
Countdown	Users are only given a certain amount of time to do or to complete something	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC
Combos	Reward skill through doing a combination of things	Achievers, Explorers	Engagement, loyalty, revenue, influence, time spent, vitality, fun, UGC
Progression	Throughout the process success can be sequentially and granularly displayed and measured through the process of completing tasks. The application can be in the form of a progress bar within Quests, Challenges etc. or an overall goal progress Bar [83].	Achievers	Engagement, time spent
Behavioral gamification mechanics			
Goals (shorthand/ or long-term	Missions or challenges give players a purpose for interaction and educate players about what is valued and possible within the experience. All types of goals and the structure they are based on can have a different effect based on the predisposition of the participants towards attaining goals. Goal Contents Theory [84] enables us to (a) identify the perceptions of participants and (b) tailor our gamification goals to cater to the different types of participants.	Achievers, Explorers, Socializers	Engagement, loyalty, influence, time spent
Epic meaning	Users will be highly motivated if they believe they are working to achieve something great, something inspiring, something bigger than themselves.	Achievers, Explorers, Socializers	Engagement, loyalty, influence, time spent, fun, UGC
Discovery or exploration	Players love to discover and to be surprised	Explorers, Achievers	Engagement, loyalty, influence, time spent, fun
Community	Community gives meaning to goals, badges, competitions and other mechanics. Sharing participant achievements creates energy in the community making people aware of what others are doing. They learn about goals, badges and rewards that they may want to pursue.	Socializers, Achievers	Engagement, loyalty, revenue, vitality, UGC
Community collaboration	Connect users as a team to accomplish larger tasks, to drive competition and to encourage knowledge sharing. Show team members how they are contributing to the group's success. No one wants to let down their team. Further on the community in the gamification [85] enables the creation of peer intrinsic and peer extrinsic motivation to act as support of the motivation to participate and perform.	Achievers, Explorers, Socializers	Engagement, influence, time spent, vitality

There were number of projects which investigated public engagement and different perspectives on persuasion and behaviour change and consider how they may be used to inform the design of serious games and other digital media for sustainability. For example, within the context of Vancouver's Greenest City Conversations (GCC) Project: an interdisciplinary collaboration aimed at fostering and evaluating multiple channels for public engagement on sustainability policies, three perspectives were considered, the Information Deficit Model, Procedural Rhetoric, and Emergent Dialogue – an approach from Environmental Studies to public engagement that emphasizes bottom-up local solutions arrived at through participation in a dialogic process [79].

Therefore, not only different gamification techniques can be used within ENTROPY project, but it is very important to analyse this in context of behaviour change and take both into account when designing the serious game.

3. Market of Energy-aware and Energy-efficient Services and Applications

This section intends to provide an overview about actual solutions that are already deployed in the market that have certain similarities with ENTROPY. Unlike the previous sections, this one puts forward full-blown solutions already available for the general public.

3.1 Personalized Mobile and Social Applications

3.1.1 Social Applications

The advent of the MCS paradigm has eased the development of novel social applications in an unprecedented manner. In that sense, now it is possible to find in the market full-blown applications that profit from the MCS paradigm to offer their services by collecting of information that users explicitly or implicitly share by means its personal mobile contrivances so as to provide innovative services.

As far as the areas of usage of these applications are concerned, it is possible to distinguish two foremost domains, 1) the public transport in urban areas in order to help citizens in their daily trips and 2) environmental applications to involve users in ecologically-friendly activities. A brief overview of both domains is stated next.

3.1.1.1 Urban Transport Social Applications

The urban transport in our cities is a key aspect in the comfort of its inhabitants and an important source of energy consumption. Both public and private transports present different challenges that would improve citizen's daily life. Within the public transport, services such as route calculation or time arrivals applications are of great relevance. In the field of private transport the difficulty of finding free parking lots has become a routine frustration especially in downtown where the tendency is to pedestrianised the streets. For this reason, the cities and some projects are offering web/mobile applications to facilitate the finding parking to their residents.

The IoT paradigm is already present in some projects and cities in order to solve the described problems from different points of view. There are a lot of services that address urban transport issues. In the following lines we will describe some of these projects involving solutions for different aspects within the urban transport needs.

TMB Virtual-Mobile Urban transport information

The main objective of the TMB (Transports Metropolitans de Barcelona – Barcelona's Urban City Transport) Virtual application [86] for smartphones (iPhone and Android) is to help inhabitants moving by public transport in the city of Barcelona. Composed of several apps, this initiative offers different functionalities. One of them localizes the citizen's position and shows the nearest bus and metro stops over Google Maps. The user can select a stop and check information about the lines, the arrival time of the next bus and changes in the services. Also, the user can consult the line path and the timetables. The user can also plan routes from one specific location using public transport. The results offer also the total time needed adding the time the user would spend walking and the time using the public transport. Another interesting point of the application is the Augmented Reality function that shows the user a compass pointing at the path to arrive to the nearest bus/metro station.

Ring Ring, Bicing – Cycling

The city of Amsterdam offers to its inhabitants an application that rewards bike users for every kilometre they travel. This is possible with a smartphone application called Ring Ring [87] that automatically recognizes all the cycled kilometres (called Fkm) of the user. This application allows the citizen to redeem their Fkm at 100 per connected entrepreneurs in IJburg. Other interesting feature is that the joint Fkm to, from, and through IJburg go to neighbourhood initiatives, each Fkm equal to 0.10 €, and this is given to the finalisation of the art trail bike. Also, in order to motivate the users, each quarter is published a list of cyclists who are most/most often, the fastest or the longest route cycled to, from, or through IJburg.

Santander city offers to their inhabitants a functionality within the SmartSantander RA (Augmented Reality) [88] application. Users of the bike renting service in the city can consult the availability of bikes before they arrive to the bike station, or consult the number of the free lots available in the station before finishing the trip.

Barcelona offers to its citizen a similar application called Bicing [89], it is also oriented directly to those who use the renting bike service. With this application the users can consult their favourite stations, the availability of free bike lots in the stations and visualize a city map with the stations where they can hire and return the bikes after finishing the service.

3.1.1.2 Environmental Social Applications

One of the key challenges in cities today is sustainability, both economic and environmental. To achieve these purposes, not only technological innovation is required but involvement of their inhabitants. Although increasingly people are much more concerned about the environment it is important to offer real data on their hands. The IoT is a clear tool to set these problems closer to the citizens, making them conscious of the environmental data and the need for maintain or improve the environment in their city

The Green Home Watch (SMART-IP) – Eco crowd sourcing

The “Green Home Watch” [90] service tries to involve the user from their houses. This service provides a map-based crowd sourcing website that allows citizens to share their experiences of eco heating services and products – including both thermal insulation and new heating technologies. The UK government introduced a range of policy initiatives that encourage households to upgrade their properties to higher standards of thermal efficiency. There were significant barriers for this change to happen, and research shows that many households have had problems with their installations. In order to increase transparency and allow people to make more informed choices, the Green Home Watch was a collective resource that allows people to leave reviews and search other people’s experiences of specific installations of technologies.

WeatherSignal - Sensor Toolkit

WeatherSignal [91] is an android application that aggregate data sent from android phone sensors with the aim to create a live, accurate weather map in any given moment, anywhere in the world. With the consent of the user, the app submits the data from the sensors to a collaboratively updated weather map for the world to share. By using WeatherSignal people become part of this weather crowdsourcing project helping to record weather patterns on a more localised level.

WeatherSignal is capable of measuring temperature, humidity, pressure, light, magnetic flux, and acceleration. Temperature is measured using a novel algorithm that translates battery temperature into ambient temperature – which is the temperature in a room or surrounding an object (in this case the phone). Light is measured utilizing built-in light intensity meter, while humidity is captured via the hygrometer. Pressure is detected using the barometer, which is primarily designed to establish GPS location. Magnetic flux is measured through the magnetometer. An interesting feature of Weathersignal is the application of the Big Data paradigm. Doubts about the reliability of the data may arise. For example, when a smartphone calculates the temperature, it could offer strange values if it has been in our pocket or in a room. However, the Big Data paradigm allows combining all sensor reading

3.1.2 Personalized Applications

A different course of action of development for novel and innovative applications, it is possible to find in the market solutions that, in intuitive way, allow users to compose data, devices, and services to build simple, but personalized applications. Here, some remarkable examples of such solutions are briefly reviewed.

IFTTT (IF This Than That) [92] is a commercial service funded with more than 8M$ only in 2012 and based on a B2C service model. Initially conceived for social networks and online services, now enables physical mashups because it is able to connect a few physical objects like the USB blink (a USB micro lamp), the NetAtmo sensor suite and Belkin WeMo (a smart electrical plugs). IFTTT has a strong and appealing wizard to compose a trigger/action recipe, it seems aimed at the above-average web user and it results quite simple to use and activate. It does not enable any particular feature to discover devices and people in proximity and the mobile app replicates more or less the desktop features. It is not possible to share a device on IFTTT, but it is possible to share recipes. This last feature it is very interesting because opens to an even more simplified way to compose trigger and actions. Another feature is the number of channels actually available in the platform which now counts about 80 among online services, device types, and social networks. The system is provided as-a-service and the license model is EULA free of charge with data updates every 15 minutes. It does not provide any kind of API.

Paraimpu [93] is a tool running as-a-service born at CRS4 and recently spin-off as SME. It implements the concept of user-generated physical/virtual mashups. It provides a workspace where users can register devices (among devices, Arduino boards are supported) providing a basic level of device virtualization. Objects in the workspace are classified as data producers and data consumers and such roles can be played by devices or by social sites like Twitter and Facebook. A transformation engine allows composing producers to consumers. The logic of a composition is ruled by (match, replace) paradigm where every data coming from a source, if matches one expression, is adapted to be delivered to a consumer. Paraimpu allows objects in the workspace to be shared by a mechanism of bookmarks and policies. The workspace is aimed at end-user development and it targets above-average Internet users.

Xively [94] is a commercial (closed) service owned by LogMeIn company, formerly known as Pachube, first and Cosm, lately it is among the first IoT platform available online (if not the first). It is mainly focused to a B2B model. Xively cloud-based services allow deploying and managing batches of products in real time. The user workbench is oriented to skilled users: it provides a set of facilities to collect data from devices through a good set of API and wrapper libraries supporting programing languages and devices like Java, JavaScript, Arduino, Android, Objective-C, etc. Very interesting is the possibility to monitoring in real time data coming from devices through configurable graphs and charts. User workspace allows defining simple conditional triggers on connected devices data in order to automatically POST data to external services endpoints. Xively allows searching for devices already deployed in the Xively system, but not by proximity and it does not provide an advanced policy access: a device can be private or public. Not social features at all.

Node-RED [95] is a visual, workflow-oriented, browser-based tool for the Internet of Things. Written in node.js (JavaScript), it allows to wire together services/devices and to deploy them on the related server backend. Created by IBM, is released under Apache Licence 2.0. Node-RED provides a visual workspace through which it's possible to create a workflow between nodes; nodes are picked up from a palette, which categorizes them into: inputs (like MQTT, sockets, HTTP), outputs (like serial, TCP, Multicast); and functions (like http request, switch, range), social (for social networks communication) and storage (file, database). Node-RED comes with a predefined set of basic nodes, but community is developing a growing set of additional nodes, available to install and extend the platform. Users can also write new functions and nodes. While it's quite simple for a skilled user to create flows and services and deploy them in minutes, it doesn't seems so easy-to-use for the average Web user due to workflow paradigm, nodes configuration and deploying system. Node-RED is a general-purpose environment so it doesn't provide device discovering by proximity or other advanced functionalities but it is high-extendible and embeddable in other applications and could be a valid choice for an advanced user environment or for services developers. Also, it doesn't support device pairing between users using predefined nodes.

Webinos [96, 97] is an Open Source platform that includes a set of software components for the IoT in the form of web runtime extensions. Webinos Architecture is centred on the concept of a "Personal Zone" as a mean to organise personal devices and services. Each device, whether it be a mobile, tablet, desktop, smart TV or in-car unit device, is extended to enable the device to be a part of the Personal Zone. Services are the Webinos way of exposing APIs. Webinos provides a personal zone hub dashboard where users can manage their account or service configuration, remove connected devices and connect to other personal zones. Also each connected device has access to a personal zone proxy "dashboard" where user can do a local discovery, edit PZP configuration and enrol, connect and share service between local/remote devices. There is also a set of links to get access to all the installed Webinos API TestPages.

Webinos architecture is extensible and exposes APIs for developers that can build their custom apps with a simple end-user environment. These Webinos apps can have a custom dashboard (https://developer.webinos.org/application-gateways) and can take advantage of the capabilities of the Webinos platform to virtualize real objects, such as sensors and actuators, as services. This means that every real object connected to a Webinos-enabled entity throws directly into the Webinos ecosystem its data stream. This Webinos application is able to interact with real objects using Webinos APIs within Webinos framework. These apps are integrated with the Webinos dashboard. It is a common interface for managing devices and services that belongs to the user's personal zone or to a friend's user.

Nimbits [98] is an Open Source Internet of Things platform running on a Distributed Cloud. It provides a collection of software components designed to log time series data from sensors. As that data is logged, events can be triggered. The Nimbits ecosystem consists on users around the world who have downloaded and installed an instance of Nimbits Server on their cloud. These instances around the world, all providing highly redundant and scalable data logging, are able to share data with each other, and can be made searchable so people can find data feeds and connect to them. The Nimbits Cloud platform is an installable server. It is a Process Data historian which means it's optimised to store data that comes in as time-s

3.2 Serious Games

Serious Games are currently used in various domains like emergency services training, military training, corporate education, health care as well as education at schools and universities around the world [99]. There is a growing body of research on the effectiveness of online games as learning tools. Several reviews of the literature have been conducted in recent years such as [100] concluding that that "there is a widespread consensus that games motivate players to spend time on a task within the game which is promoting particular issue or providing educational material".

Currently, there are very few serious games which deal with the problem of energy efficiency, such as: "2020 Energy", a serious game about energy efficiency, renewable energy and sustainable development, supported by Intelligent Energy Europe (European Commission) and Green My Place, a set of 8 mini-games developed by the 'SAVE ENERGY' project. These mini-games are web based, designed to promote certain aspects of the energy efficiency using predefined, static content, without the ability to interact with buildings and smart energy components or other players.

SIMULME, [101] developed by the Swiss National Science Foundation in the early 2000's is an Internet-based simulation game of the environmental and economic consequences of food consumption, to improve environmental knowledge, attitudes, and behaviours of individuals. The game was first applied with 215 pupils divided into 12 classes. Six classes were taught the consequences of food consumption using the learning game (experimental condition) and 6 using a standard lecture (control condition). Positive changes in environmental attitudes concerning nutrition behaviour were more marked in the experimental than in the control condition. An additional experiment tested the game's effects on subsequent buying behaviour. After playing the game (experimental) or not (control), participants entered the nutrition section of the online shop of the Swiss retailer Coop with the possibility of winning a purchase worth CHF 40. The consumption pattern of those who played SIMULME was ecologically more positive than that of the control participants. Aspects of game validity and game design are discussed with respect to the effectiveness of games for environmental education.

There are very few serious games which deal with energy efficiency in buildings (some are listed below).

The Green My Place serious game for the SAVE ENERGY project had an aim to foster behaviour transformation regarding energy efficiency. The project stakeholders were made to become more aware of the consequences of living in a world of ever more expensive energy and the potential impact (economic, environment and political) of current trends, while making them aware of the alternatives at hand [http://greenmyplace.net/].

A serious game about energy efficiency, renewable energy and sustainable development - the serious game 2020 Energy was designed within the framework of ENERGY-BITS a European cross-media awareness programme for teenagers (14-18 years old) financed by the Intelligent Energy Europe programme. The player's objective: to reduce the consumption of energy, increase energy efficiency and choose the best renewable energies. He finds help with 3 advisers: economical, environmental, social, but it is up to the player to take the good decisions to improve our collective future!

Another effort in the realm of energy efficiency can be found in Power House [102], an energy game that addresses home users as described by Byron Reeves et al. Through the interconnection of home smart meters of energy consumption to an online game, each participant's real world energy data are introduced in the online multiplayer game and in-game rewards invite users to complete energy-friendly real world challenges. Its main goal is to transform the energy consumption data into a "more palatable and relevant form of feedback"

The WP3 will provide gamification framework all required components for the design of gamified activities as well as serious learning games enabling and promoting citizen behaviour change towards energy efficient scenarios.

As one of gamified activities, the Treasure Hunt game concept can be made applicable to suit the needs of the ENTROPY project. The game exists in DNET portfolio, and can be customized specifically for the project. The basic idea behind the game (energy efficient hunt) is that the user is able to scan certain markers (in a building, or outside), and trigger augmented reality content, that can either be some useful information about the environment, or some live readings of specific parameters (CO2 levels...), also a series of markers can lead the user to a specific location in a building or a neighbourhood, that has an influence on the environment. The augmented reality content could also be triggered via GPS, for instance, when the user is near an environment sensitive location (or within 20-30m radius) he is notified of the parameters that are affecting energy efficiency of building.

The WP4 will provide the set of ENTROPY Personalized Mobile Applications and Serious Games that will be implemented and validated in the ENTROPY pilots. Therefore, it is very important to customize applications to suit the needs of the pilots and their stakeholders. The table below gives an overview of ENTROPY pilots:

Table 3: ENTROPY Pilots

User Community	Pilot Context – Types of Public-owned Buildings	Microgeneration Infrastructure	Leading Partner
Employees and visitors in the technology park, residents in the social housing infrastructure	Offices, Social Housing, Incubator, Canteen, Kindergarten, Auditorium, Meeting Rooms	Solar Panels	POLO
Students and employees in the University and the Incubators	Classrooms, University Buildings (e.g. Library), Incubator	Solar Panels	UMU
Students and employees in the University and the Incubators	Research institutes labs and offices, a restaurant, fitness room and multiple classrooms.	Microgrids based on solar energy	HESSO

The serious games will cover scenarios of everyday activities, and be able to build player profile and provide personalized experience which will be the main drive for behavioural change leading towards increased energy efficiency. The pilot's main stakeholder group are students and employees of the Technology Park and universities. In a sense this represents a good sample of users who are educated and technology aware, so in that sense they should be able to adopt and use gaming experience easier.

3.3 Smart Environment Projects

There are several projects in the scope of "smart environments" (e.g. city, university) funded by various organizations including the European Union, that have energy efficiency goals. The outcomes of these projects (ontologies, applications etc.) might be relevant to ENTROPY project.

3.3.1 OPTIMUS

OPTIMUS[36] [37] ("OPTIMising the energy USe in cities with smart decision support systems") is a European Union funded project that aims to develop a decision support system to optimize energy consumption of public buildings.

OPTIMUS utilizes an assessment framework called "Smart City Energy Assessment Framework" (SCEAF) which evaluates the energy consumption data of public buildings that is provided by authorities via a questionnaire.

SCEAF consists of three main aspects [103]

1. Political Field of Action: Evaluates the cities in the means of ambition of applying energy efficient policies and the level of adoption of EU directives
2. Energy Environmental Profile: Evaluates energy consumption and the level of renewable energy usage
3. Related Infrastructures – Energy & ICT : Utilization of ICT elements (e.g. sensors, smart meters) for energy efficiency

[36] http://de.slideshare.net/Gonsco/building-a-semanticbased-decision-support-system-to-optimize-the-energy-use-in-public-buildings-the-optimus-project
[37] http://www.optimus-smartcity.eu

3.3.2 Smart IHU

Smart IHU is an ambient intelligence application that is developed and applied in the International Hellenic University buildings in Greece. This system consolidates data collected from wireless sensors and some high level management applications into a middleware [104]. The middleware provides SWASDL annotated semantic web service endpoints. The annotations mostly contain terms from the project's context ontology [105].

The system is based on several rules defined by policy makers. A hybrid agent module [106] reacts according to existing facts and theories (e.g. sensor measurements) and these rules. This hybrid agent module uses a defeasible logic knowledge base. In case of an exceptional situation, the agent's reactions can be overridden by manual interference by an administrator using a manager application.

3.3.3 SEIS

Semantic Energy Information System[38] (SEIS) is a part of the RÈPENER project that aims to integrate energy related data at building level to guide people who are involved in the entire life cycle of a building, including its renovation and refurbishment, in order to support the decision making process concerning energy efficient buildings.

SEIS allows different parties to use the data that is collected and integrated, as well as allow them to import new data to this knowledge base.

SEIS uses the following data sources[39]:

- **ICAEN:** Energy certification of buildings and their simulated performance during several stages of the building life cycle, including design and refurbishment, collected by the Catalan Energy Institute (ICAEN), a public administration. Every energy certification contains the energy rating of the building, energy consumptions, types of the HVAC (heating, ventilation, and air conditioning) systems, and geometric characteristics such as the built surface or the compactness(a ratio between surface of a building and its volume).
- **LEAKO:** Building monitoring data provided by Leako, a company from the Basque Country dedicated to the installation, distribution and control of HVAC systems. The database contains energy consumption data (for example, thermal consumption for air and water heating, and water consumption) and indoor conditions (for example, air temperature) for several buildings.
- **Geographical Information National Institute (CNIG):** Geographical data collected by the Geographical Information National Institute (CNIG) public institute. It contains information about the Spanish territory including population, areas, elevation, or Universal Transverse Mercator (UTM) coordinate.
- **AEMET:** Climate data from the Spanish Meteorological Agency including 10 minute data from around 250 weather stations of the Aemet's National Surface Weather Stations Network.

[38] http://www.seis-system.org/
[39] http://www.seis-system.org/index.php/extras/datasources

3.3.4 SEMANCO Project

The goal of this project is creating an ontology based energy information system to enable stakeholders such as policy makers, engineers and citizens to make informed decisions on how to reduce CO_2 emissions in cities.

SEMANCO aims to integrate energy related data from open and proprietary data sources over a global energy ontology. They adapt building level ISO standard energy terminology to urban level.

They suggest a decentralized approach to map different data sources to, first, local ontologies; then to the global energy ontology. They have developed a set of ontology mapping tools to improve their global energy ontology with relational data from relevant energy related data sources.

There are also several tools for different stakeholders to interact with core of the project -Semantic Energy Information Framework (SEIF) - to analyse or to mine the integrated data. [107].

One important outcome of this project is the SEMANCO ontology[40], essentially the global energy ontology that is fed by the data from different use cases, ISO standards, sources related to urban planning, as well as geographical data in different scales and other external data that might affect energy consumption, such as climate data.

3.3.5 OpenFridge project

In relation to the energy saving for electrical appliances, OpenFridge platform[41] is an example for a system providing energy consumption transparency, complying with these trends and vision. It presents a simple and scalable Internet of Things data infrastructure suitable for building added value data-services for user communities based on the home appliance data, showcased in a pilot that focuses on utilizing the energy consumption data of the refrigerators [108]. The data management approach of the OpenFridge platform builds on the Semantic Web technology, which enables us to explore the potential of opening and linking appliances data, and of provisioning them to the end-users community as well as other interested stakeholders (energy agencies, appliance manufacturers, municipalities, etc.) under new data-service-based access mechanisms and usage models.

Linked open data sets resulting from the project are published:

1. Open Fridge vocabulary and ontology in the Linked Open Vocabulary (LOV) repository: http://lov.okfn.org/dataset/lov/vocabs/of , including more than a 1000 refrigerator model specifications in semantic format [109] and

2. A set of selected fridge measurements in the datahub under http://datahub.io/dataset/the-measurement-data-set-from-the-project-open-fridge.
Thus the produced ontologies and data are available for further reuse by other researchers and projects.

[40] http://www.semanco-project.eu/ontology.htm
[41] OpenFridge platform: http://www.openfridge.net

3.3.6 SESAME and SESAME-S projects

The SESAME project resulted in a technical solution that actively assists end-consumers to make well-informed decisions and control regarding their energy consumption [110]. The SESAME solution is a full-fledged prototype covering the whole energy value chain: a sensor and smart metering solution that can be installed in the house, equipped with the semantic software and user interfaces performing reasoning and control of the house on the basis on defined policies, sensor inputs and interactions – including energy monitoring, reporting and gaming [111-113]

While SESAME has developed the initial concept and demonstrated its technical feasibility as well as the customers' interest to acquire it as a commercial service, the focus of SESAME-S has been to extend the resulting system with an extended set of production quality attractive services, and to prepare its roll-out to the market. The extensions of the SESAME system include:

- Optimization of further resources consumption (such as water, heating) within the energy efficiency system, in addition to the implemented solution for the electricity: see in particular the SESAME-S ontology from the pilots published as open data:
- Installation of the SESAME system in trial real-life rooms for collection of real-life data, applying adjusted security and privacy solution, obtaining more advanced usability feedback [114].
- Definition of the privacy enabled publishing and commercialization principles of fine granular semantic linked data in the energy domain (i.e. using and publishing data in B2C scenarios and provisioning of data as a service both in B2B settings) [115]
- Design and development of energy efficiency services for mobile devices, thus extending the user interaction with the smart home from the developed desktop and touch screen facilities, relying both on internal energy consumption data as well as on external data to support energy efficiency [116];
- Bringing the usability for the energy efficiency data sales and user interfaces to production quality (tightly incorporating features that are important to market success, such as "coolness" factor of the services) [109].

3.3.7 Large Scale Energy Reductions through Sensors, Feedback and Information Technology

The works in [117] presents a human-cantered ICT project for energy efficiency. This project is one of the rare ones that put human behaviour into its core. This quite comprehensive project consolidates 20 smaller projects to create an engine, which consists of several software platforms, algorithms, behavioural interventions including serious games and data analytics.

The serious game part is particularly interesting, in fact it is still online[42] and the winner of this multiplayer game is entitled to acquire prizes sponsored by private corporations. The game even has a mode that users can play with actual data they collect from the smart meters at their residential buildings.

The final report of the project is quite extensive and can be found online[43].

[42] https://www.freeenergygame.com/portal/
[43] http://www.energy.ca.gov/2015publications/CEC-500-2015-056/CEC-500-2015-056.pdf

3.4 Analytics Reporting and Visualizations

Service Oriented Architecture that will be used for analytics reporting and visualizations (Intelen Middleware and APIs) is an architectural style with the goal of bringing together a worldwide network of collaborating services available on the Service Bus, supporting a cross-platform exchange, thus allowing all involved to communicate effectively. SOA takes existing software components on a network and permits those components to be published, or called upon by others.

The key advantage of a SOA approach is to offer modularity, isolation, flexibility, loose coupling, and interoperability, among a large-scale of heterogeneous networked devices.

The customers of a service do not need to be implemented in the same programming language or to run on the same platform as the service. The communication between software components that are written in different programming languages is possible with the use of protocols, formats and standards that have been developed for this particular purpose.

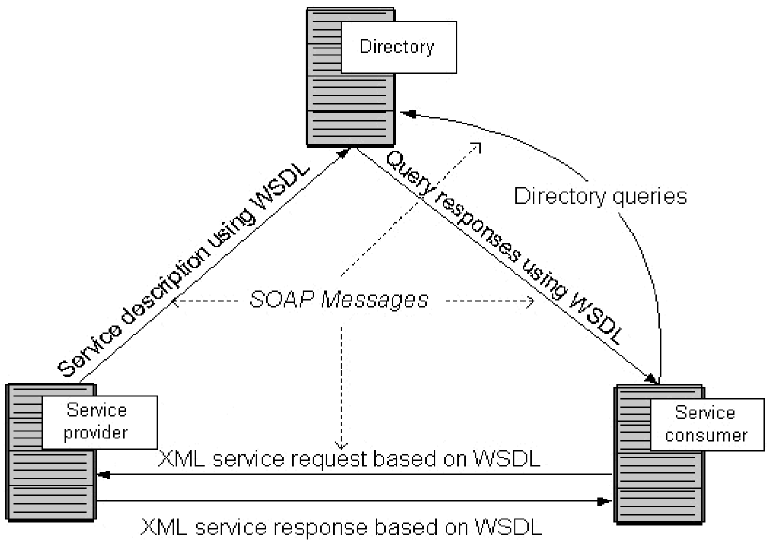

Figure 5: Soap Oriented Architecture for Intelen Middleware

The standards that have been used in the context of the SOA architecture are the following:

Extensible Markup Language (XML) describes a class of data objects called XML documents and partially describes the behaviour of computer programs which process them. Markup encodes a description of the document's storage layout and logical structure. Structured information contains both content (words, pictures, etc.) and some indication of what role that content plays.

JavaScript Object Notation (JSON) is a text notation that is based on a subset of the JavaScript Programming language. As XML, JSON is language-independent and platform-independent, and can be read and processed both by humans and by machines. JSON is considered to be much better suited for data interchange than XML, and is becoming increasingly common.

Representational State Transfer (REST) is an architectural style of distributed hypermedia systems, from which ROA emerged. Web services that follow this particular style are known as RESTful web services.

Middleware Web Services for Data Interoperability (APIs)

Web services constitute application programming interfaces (API) or Web APIs that are accessed via Hypertext Transfer Protocol (HTTP) and executed on a remote system hosting the requested services. Web services can implement a Service Oriented Architecture. Web services make functional building-blocks accessible over standard Internet protocols independent of platforms and programming languages.

Message Oriented Middleware (MOM): Widely used in distributed systems, Internet of Things and real time applications, the Message Oriented Middleware is a client-server architecture, structured as a set of components that interact through messages. The communication is usually asynchronous. Asynchronous communication enables a message sender to create a message, send it and terminate the communication, while the receiver may receive the message through a queue and process it at a later time. The sender and the receiver of a message do not need to interact with the queuing system at the same time. Some message queuing systems apply routing logic to messages, which will be explored in the ENTROPY. As with SOA, the different components that interact through the MOM architecture are considered to be loosely coupled. Each component does not need to have any knowledge of other component implementation details, except the format of the messages that they consume or produce.

Extensible Markup Language (XML) is a mark-up language that describes a class of data objects called XML documents and partially describes the behaviour of computer programs which process them. XML documents are made up of storage units called entities, which contain either parsed or unparsed data. Parsed data is made up of characters, some of which form character data, and some of which form markup. Markup encodes a description of the document's storage layout and logical structure. XML provides a mechanism to impose constraints on the storage layout and logical structure. .

Advanced Message Queuing Protocol (**AMQP**) is an open standard (ISO/IEC 19464:2014) application layer protocol for MOM which provides solutions for queuing, routing, reliability and security. AMQP was designed for interoperability between different vendors. It supports message exchanging though both point-to-point and publish-subscribe communication patterns. The main concept in AMQP is the link protocol. Components that interact through AMQP establish links and send messages over these links using the transfer frame. AMQP broker implementations include Apache ActiveMQ, Windows Azure Service Bus, Apache Qpid and RabbitMQ. The smallest packet size in AMQP is 60 bytes.

User Interface and Visualizations for Reporting

The user interface consists of an end-user web application and an administrative web application.

The end-user application aims to visualize electric energy and pricing analysis/behavioural information, along with presenting demand related data to the end user in order to motivate and influence his behaviour by using core concepts of persuasive technology and gamification principles.

The main functionalities of the end-user application are as follows:

1. The user is able to view an overview of his energy consumption for a selectable period of time.
2. The user is able to view a comparison chart, which compares each user with similar households and the efficient similar households. Efficient households in a cluster have been defined based on their energy consumption.
3. The user is able to view a list of upcoming demand response events that he can take.
4. The user is able to view an estimation of energy consumption savings related to demand response events and cost quantification in €.
5. The user is able to view billing info such as consumption per billing period, billing comparisons and relative statistics, based on smart meter readings.
6. The user is able to compete against other users in a game of winning points by engaging to demand events and committing to take energy saving related actions. In order to drive competitiveness the user is able to view his score and ranking against other users.
7. The user is able to view the environmental impact of his actions by means of energy consumption equivalents in trees based on carbon emissions, electric bulbs, working hours in a PC and electric car usage. These equivalents provide a quantification of energy usage and saving using metrics and concepts close to the user’s everyday life.
8. The user is able to view a description of the demand programs available.
9. The user is able to view a history of demand events he participated to.
10. The user is able to provide personal info and household metadata, such as household address, number of occupants and construction year through his profile page in the form of a questionnaire.
11. The platform is able to post messages on specific events on the user’s Facebook and twitter accounts. For example a message will be posted when the user commits to take some action.
12. The user is able to read energy saving tips related to demand response

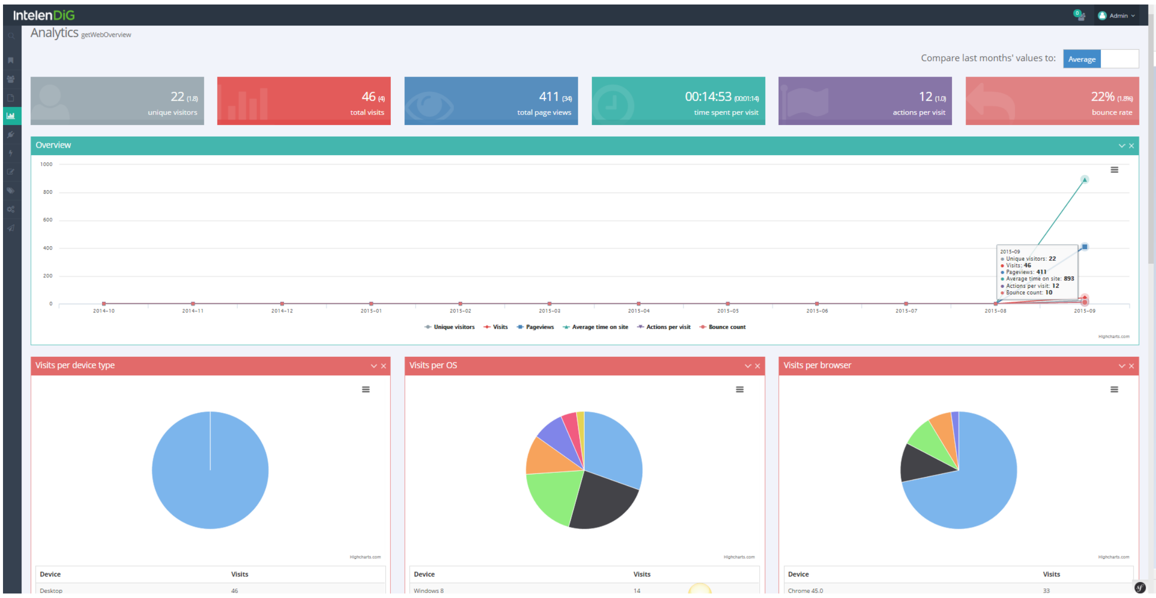

Figure 6: Analytics Visualization Dashboard regarding Energy and Behavioural interactions

Analytics is the discovery and communication of meaningful patterns in data. A general approved definition of analytics is finding the optimal path to a desired future. Especially valuable in areas rich with recorded information, analytics relies on the simultaneous application of statistics, computer programming and operations research to quantify performance. Analytics often favours data visualization to communicate insight.

Firms may commonly apply analytics to business data, to describe, predict, and improve business performance. Specifically, areas within analytics include predictive analytics, enterprise decision management, retail analytics, store assortment and stock-keeping unit optimization, marketing optimization and marketing mix modelling, web analytics, sales force sizing and optimization, price and promotion modelling, predictive science, credit risk analysis, and fraud analytics. Since analytics can require extensive computation (big data), the algorithms and software used for analytics harness the most current methods in computer science, statistics, and mathematics.

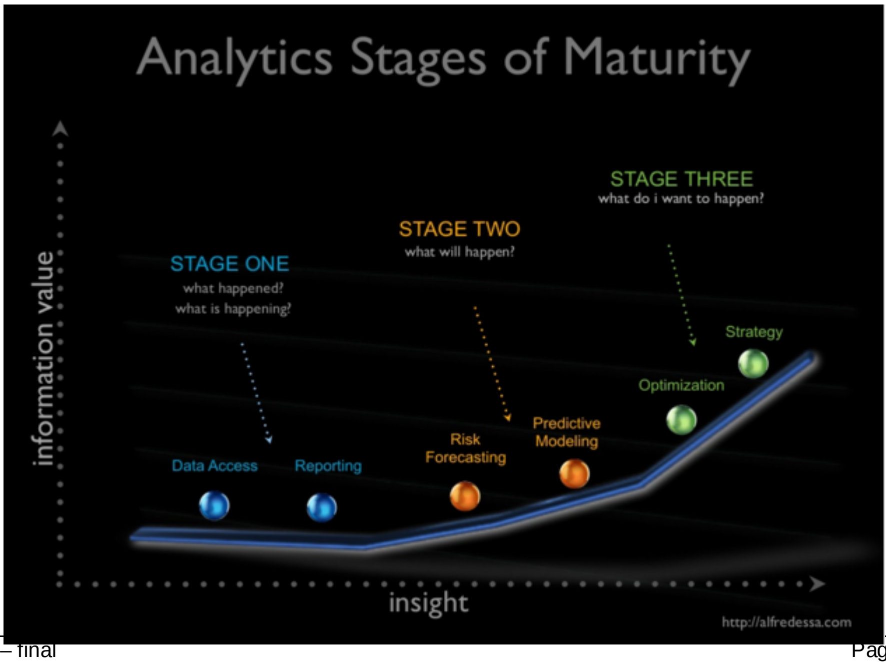

Figure 7: Analytics value

Types of Analytics

- Decisive analytics: supports human decisions with visual analytics the user models to reflect reasoning.
- Descriptive analytics: Gain insight from historical data with reporting, scorecards, clustering, etc.
- Predictive analytics (predictive modelling using statistical and machine learning techniques).
- Prescriptive analytics recommend decisions using optimization, simulation etc.

Basic domains within analytics

- Behavioural analytics
- Cohort Analysis
- Collections analytics
- Contextual data modelling - supports the human reasoning that occurs after viewing "executive dashboards" or any other visual analytics
- Cyber analytics
- Financial services analytics
- Fraud analytics
- Marketing analytics
- Pricing analytics
- Retail sales analytics
- Risk & Credit analytics
- Supply Chain analytics
- Talent analytics
- Telecommunications
- Transportation analytics

Examples

- Marketing Optimization

Marketing has evolved from a creative process into a highly data-driven process. Marketing organizations use analytics to determine the outcomes of campaigns or efforts and to guide decisions for investment and consumer targeting. Demographic studies, customer segmentation, conjoint analysis and other techniques allow marketers to use large amounts of consumer purchase, survey and panel data to understand and communicate marketing strategy.

- Portfolio analysis

A common application of business analytics is portfolio analysis. In this, a bank or lending agency has a collection of accounts of varying value and risk. The accounts may differ by the social status (wealthy, middle-class, poor, etc.) of the holder, the geographical location, its net value, and many other factors. The lender must balance the return on the loan with the risk of default for each loan. The question is then how to evaluate the portfolio as a whole.

- Risk analytics

Predictive models in the banking industry are developed to bring certainty across the risk scores for individual customers. Credit scores are built to predict individual's delinquency behavior and widely used to evaluate the credit worthiness of each applicant. Furthermore, risk analyses are carried out in the scientific world and the insurance industry.

- Digital analytics

Digital analytics is a set of business and technical activities that define, create, collect, verify or transform digital data into reporting, research, analyses, recommendations, optimizations, predictions, and automations.

- Security analytics

Software analytics is the process of collecting information about the way a piece of software is used and produced.

Most popular tools for data preparation, data analysis, reporting and visualization

- Python
- R
- SPSS
- SAS
- Spotfire
- Tableau

3.5 Large Scale Deployments of Energy-efficient solutions

Microgrids are emerging as an integral feature of the future power systems shaped by the various smart-grid initiatives. A microgrid is formed by integrating loads, distributed generators (DG) and energy storage devices. Microgrids can operate in parallel with the grid, as an autonomous power island or in transition between grid-connected mode and islanded mode of operation. A microgrid could be an attractive option to harness the benefits offered by distributed generation, eliminating the constraints on high penetration. Thus, substantial environmental benefits may be gained through the utilization of energy efficient generation resources and the integration of renewable energy resources. Moreover, microgrids could reduce the network losses, defer the high investment costs required for network upgrades and also reduce the central generation reserve requirements.

Distributed Generators: Generation technologies applicable for a microgrid may include emerging technologies (Combined heat and power (CHP), fuel cells, mini wind turbines, PV (Photovoltaique Pannels), micro-turbines, and some well-established generation technologies (single-phase and three-phase induction generators, synchronous generators driven by IC engines or small hydro). it is important to note that CHP (also known as cogeneration, which produce electricity and heat simultaneously) and wind power generation has shown considerable growth in technology and usage gaining strong points to be used in microgrids.

Energy storage: Energy storage devices are one of the main critical components to rely on for successful operation of a microgrid. The main function of the energy storage devices in a microgrid application is to be the care taker in balancing the power and energy demand with generation. Among the available energy storage technologies, batteries, fly-wheels and super-capacitors are more applicable for microgrid type of setup. In the use of a flywheel, it can be used as a central storage system for the whole microgrid. In the use of batteries, either storage can be mounted on the dc bus of each micro-source or can be used as a central storage system. Batteries provide extra function being able to reserve energy for future demand. Super capacitors would be an expensive choice compared to both batteries and fly-wheels. Another option is to have a large traditional generation having considerable in:

Load: A microgrid could serve variety of customers: residential, commercial and industrial. In general, commercial and industrial users are defined as critical/sensitive loads, which demand high degree of power quality and reliability.

The following table describes and compare the most relevant systems built all over the world willing to address the power measurement of consumption, local energy production and storage. Depending on the systems, measurements were available to analyse the energy flows, predict them and optimize them. The key variables taking into account are:

- DG : Distributed Generators
  - PV : Photovoltaique panel
  - Solar Thermal
  - Wind
  - Fuel Cells
  - Hybrid
  - Diesel, Steam, Gas
  - CHP : Combined heat and power
- Energy Storage
  - Source
    - Cen: Central
    - Int : Intermittent
    - Ind : Individual
  - Battery
  - Fly-Wheel
- Load
  - Type:
    - R: Residential
    - C: Consumer
    - I: Industrial
  - Static
  - Motor - Electronic
- Building Control
  - Central
  - Automatic
  - Agents-based (Distributed)
- Data monitoring
  - Internet of Things
  - Data Modelling
  - Open Solutions
  - Frequency Update

In addition to the reference pilots, the 3 pilots that will be deployed during the Entropy project are presented in green colour, these new features are mainly focused on the impact from human behaviour integration as part of the influences into the system performance.

- Human Behaviour Integration

- Human Dynamics
- Serious Games
- Challenges
- Communication Mechanisms

Detail			DGs							Energy storage			Load			Building Control			Data collection type				Human behavior integration					
Region	Energy control system	Radial Mesh	PV	Solar Thermal	Wind	Fuel cell	Hydro	Diesel Steam Gas	CHP	Central,Cen Individual,Ind Intermittent,Int (source)	Battery	Fly wheel	Residential,R Commercial,C Industry, I	Static	Motor/ Electronic	Central	Automatic	Agent bases	IoT Mobsing	Data modeling	Open solution	Update frequency	Human Dynamics	Serious Game	Challenges	Recommanda-tions Mechanisms	
North America	Boston, Canada	Radial	-	-	-	-	2	-	-	-	-	-	R	-	-		√										
	Santa Rita Jail, US	Radial	6	-	1	1	-	1	-	-	√	-	R	-	-		√										
	CERTS, US	Mesh	-	-	-	-	-	3	-	Ind	√	-	-	√	-		√										
	UW, US	Radial	1	-	-	-	-	1		-	-	-	-	√	-		√										
Asia	Aichi, Japan	Radial	3	-	-	7	-	-		Cen			I,C	-	-	√											
	Kyoto Eco-Energy, Japan	Mesh	2	-	1	1	-	1	-	Cen	-	-	R	-	-	√											
	Hachinohe, Japan	Radial	5	-	4	-	-	3	-	Cen	-	-	I,C	-	-	√											
	CRIEPI, Japan	Mesh	3	-	-	-	-	-	-	-	-	-	R	√	-	√											
	Sendai, Japan	Radial	1	-	-	1	-	2	-	Cen	-	-	R,C,I	-	-	√											
	HFUT, China	Mesh	2	-	2	1	1	1	-	Int(PV) Int(wind) Cen	-	-	-	√	√	√											
	IET, India	Radial		-	-	-	-	-	-	-	-	-	-	√	-			√									
Europe	Bronsbergen, Netherland	Mesh	108	-	-	-	-	-	-	Cen	√	-	R	-	-	√											
	Am Steinweg, German	Mesh	Sev-eral	-	-	-	-	-	1	Cen	√	-	R	-	-			√									
	DeMoTec, German	Mesh	1	-	1	-	-	1	-	Cen, Int (PV)	√	-	R,C	-	-	√											
	CESIRICERCA, Italy	Radial	8	1	1	-	-	1	2	Cen	√	√	-	√	-			√									
	Kythnos, Greece	Radial	7	-	-	-	-	1	-	Cen	√	-	R	-	-	√											
	NTUA, Greece	Radial	2	-	1	-	-	-	-	Cen	√	-	-	√	-	√		√									
	Uni. of Manchester, UK	Radial	-	-	-	-	-	-	-	-	-	√	R	√	-	√											
	NiceGrid, France	Mesh	200	-	-	-	-	-	-	Ind, Cen Int(PV)	√	-	R,C,I			√											
	Swiss2Grid	Mesh	20	-	-	-	-	-	-	Ind	√	-				√											

	UMU, Spain																						√	√	√	√	
	POLO, Italy																						√	√	√	√	
	HESSO, Switzerland	Radial	2	-	-	-	-	-	-	Int(PV)	√	-	I,C	√			√		IoT		Linked open data		√	√	√	√	

4. IMPACT OVER ENTROPY

This section explains how the different solutions described in section 2 will be applied and/or extended within ENTROPY..

4.1 Internet of Things Communications

4.1.1 IoT and Sensor Networking for Energy Monitoring

Bearing in mind the two visions of IoT described in section 2.1, the impact over ENTROPY will be the following.

Regarding the internet-based vision, the adaptation of several meters with low energy consumption protocols such as 6LoWPAN, described in section 2.1.1, will allow the energy-aware operation mode of the sensors deployment within ENTROPY project. In that sense, IoT technologies will be used for the end-to-end interconnection of networking devices, the support of advanced autonomic networking functionalities and the provision of advanced services in challenging (e.g. heterogeneous and/or resource constrained) environments.

Concerning the thing-based view of IoT, RFID and NFC technologies will be instrumental so as to detect the presence of people in different parts of a building. In that sense, activity recognition algorithms based on smart cards (see sec. 2.3) will be applied in order to infer the mobility of people within a building in order to further investigate how such movement behaviours affect the energy profile of a building.

4.1.2 Mobile Crowd Sensing Mechanisms for Energy-aware ecosystems

Mobile sensors can complement the information from static sensors deployed in an area of interest described in a previous section. In that sense, MCS will be used to collect several features and variables related to the users of a building.

This will be done by means of the two solutions related to explicit or implicit feedback collection. Regarding the former, the collection by means personalized mobile apps and social network sites is foreseen.

Concerning the implicit feedback gathering, the local processing of measurements of built-in sensors of a handheld device will be carried out so as to detect information of interest related to the user. In that sense, CEP has shown quite promising results to extract meaningful knowledge from distributed mobile sources. For example, it has been used to timely extract trips as origin-destination tuples from card records that only contain the origin of each trip. This destination recovery is done by means of the trip-chaining method [118]. Unlike previous proposals, the timely generation of the trips allows to use them to early detect potential card-usage fraud.

Next, a fuzzy clustering algorithm is applied to the detected trips to identify groups with similar features representing different profiles of usage of the public transport. Unlike other pattern mining approaches which only focus on extracting individual mobility patterns, this clustering step allows to extract more general profiles of the public transport which can be more useful for stakeholders.

All in all, a similar approach will be carried out in ENTROPY where a combination of CEP and fuzzy clustering or other machine learning algorithms will be studied to extract knowledge about energy-related activities within a building.

4.2 Data Modelling and Fusion for Energy-efficient Scenarios

4.2.1 Data aggregation and fusion techniques for mobile and static scenarios

In ENTROPY, an important line of research will be focused on the MCS mechanism to aggregate data from mobile and soft sensors of personal handheld devices and different types of smart cards.

For this type of data, a mobile CEP approach is devised to early recognize certain simple activities or behaviours related to a device's holder. In particular, it is intended to detect motion activities a person might perform within a building and its underlying goal. Next, how such activities and movements can help to improve the energy management of a building will be further investigated. As far as smart cards are concerned, ENTROPY project will specially consider information from transit cards in order to enrich the knowledge previously extracted from mobile and social network sensors.

Moreover, the Entropy project will not overlook one more important issue that has especially captured the attention of the research community after the increasing popularity and applicability of IoT and sensing technologies. It is the matter of the quality of the information collected from the various sensing devices used during the application of the Entropy services. We will examine, assess and improve the aggregated data to ensure that they are of high quality; taking in consideration that there is an extended stream of research that tries to enhance the technological performance of IoT and sensing technologies in order to eliminate missing or erroneous data.

Obviously, information quality (IQ) is important because it directly affects the effectiveness of the decisions made on this information. Better IQ of the developed Entropy services will lead to better, more accurate decisions concerning the energy use in the buildings, as well as the assessment of the citizens' engagement with the Entropy services.

Information quality is defined as "fitness-for-use" [119] or, more specifically, "fitness for intended use in operations, decision making and planning" [120] of information in a particular information system's context. It is widely agreed in the IQ field that information quality is a multi-dimensional concept [119, 121-122] . Among the main IQ attributes in the existing literature, *accuracy, timeliness and co*mpleteness are the most widely cited, well-documented dimensions.

- *Accuracy*: the extent to which data are correct, reliable and certified free of error [119].
- *Completeness*: a set of data is complete with respect to a given purpose if the set contains all the relevant data [123]. The completeness dimension can be viewed from at least three perspectives: schema completeness, column completeness and population completeness. At the most abstract level, schema completeness is the degree to which entities and attributes are not missing from the schema. At the data level, column completeness is a function of the missing values in a column of a table [124]. By population completeness, we mean the degree to which members of

the population that should be present are not present. For example, if a column should contain at least one occurrence of all 50 states, but the column contains only 43 states, then the population is incomplete.

- *Timeliness*: the extent to which the age of the data is appropriate for the task at hand [119]. It means that the recorded value is out-of-date.

The Entropy project will focus mostly on the accuracy of the aggregated data that will feed the developed Entropy platform.

4.2.2 Semantic Modelling of Human Energy-related Features

Regarding innovative IoT settings and data processing, in respect of energy efficiency, several developments were taking place in over to insert semantics in information systems. An approach to apply Semantic Web and Semantic Web Service technology to IoT and Smart Grid standards has been described by [125] and these developments are being followed on, particularly, in the area of smart homes [111]. Also, extensive architectures in this area [126], as well as well-developed real-life deployments have been executed [114, 127]. Further, many developments have been taking place to address processing of raw data coming out of IoT. This question has been addressed with frameworks addressing reasoning with incomplete and incorrect information such as in the context of the Web or smart cities' sensor data flows [128], as well as local efficient information processing mechanisms which e.g. incorporate step-wise processing and learning techniques [129].

Concerning software and services (including semantic) development, to facilitate data reuse, there have also been initiatives of generic data marketplace repositories appearing on the market, such as DataMarket[44], Factual[45], Infochimps[46]. The key specifics of the approach is that its design specifics are applicable to sensitive, often "closed" data (e.g., telecommunications, energy efficiency), and therefore have clear access, security and privacy measures, established data quality measures, and can be picked up by the communities concerned. Certain existing datamarkets already have the features of addressing specific communities (for example, Timetric, focusing on economic data) and ensuring the data quality standards (e.g. by relying on a limited number of verified data providers, like Windows Azure Marketplace Datamarket), however, they do not assume direct end user involvement. Even though certain commercial products, such as Google's PowerMeter (now discontinued), has employed energy data, the involvement of users and social aspects are still largely an aspect considered in theory only [130]. Regarding the essentials for the data-intensive platforms and services privacy and security mechanisms, the approach to achieving privacy protection is appropriate to implement through existing fine-grained access control mechanisms, such as the use of a high level access control specification language allowing the definition of a variety of access control user requirements. An applicable RDF access control approach [131] is designed to scale, as it orients itself at previous work on database systems, provides a formal semantics as in [132], and proposes an annotation-based enforcement mechanism. As a further evolution of such work, applicable to linked data, a new access mechanism is based on ORDL ontology is suggested by Steyskal and Polleres [133].

Several studies [134-136] show the importance of human behaviour for energy efficiency. There is no single pattern for modelling energy related human behaviour, but it can be modelled according to datasets and the goal of the modelling [137]. We will consider reusing existing human behaviour recognition ontologies, some of which have been reviewed in previous sections. Some generic concepts that are related to actions will be defined and then specialized according to possible user actions in pilots. Expressivity of OWL 2 allows us to extend the models with additional logical statements.

[44] https://datamarket.com/
[45] https://factual.com/
[46] http://www.infochimps.com/

In ENTROPY, existing technologies for data mapping to the designed semantic models are going to be exploited and namely techniques that support the RDFization of the available data, as well as techniques that support interlinking with available open data. Data collected through sensors, smartphones and crowdsensing mechanisms (e.g. from social media) is going to be mapped in the developed models in the project and made available for further processing to the various ENTROPY platform tools (e.g. analytics framework, recommendation engine, gamification framework). However, it should be noted that in some cases, usage of data in tabular format or processing of raw streams of data may be also supported.

4.3 Algorithm Design of Life-style Recommenders for Behavioral Change

4.3.1 Analytics Methods for Energy-related Behavioural Detection

To achieve energy efficiency in buildings, it is required to extract useful information about the context of buildings, which, after processing, allows recognition of behaviour patterns of aspects involved in energy consumption. Then, such patterns will be used to predict future consumptions of the buildings.

In this direction, localization of building occupants has been identified as a main problem which needed to be faced. To solve this, solutions based on (RFID) sensors [138-139] will be combined with human activity recognition based on motion sensors in an innovative manner.

Once solved the localization problem, we can split the overall problem of energy building management into four sub-problems related with: 1) the estimation of optimum comfort conditions in each location of the building 2) the estimation of energy consumption involved in such comfort conditions 3) optimization of the setting of those comfort devices and 4) forecasting of the energy consumption of the building in the long and the short term. This forth step represents a remarkable step forward with respect existing approaches for energy management of buildings.

Regarding the computational techniques for the estimation of energy consumption and comfort conditions, Neural Networks (NNs), Fuzzy Logic Systems (FLSs) and Genetic Algorithms (GAs) are the most commonly applied by researchers and developers [140-141]. Since a key issue in the design of this kind of intelligent system is that it must be understandable to the end users, and be able to show the reasons for the actions automatically proposed, fuzzy logic techniques are frequently applied. Fuzzy techniques offer a framework for representing imprecise and uncertain knowledge in a similar way to that in which people make their own decisions [142]. Thus, it is possible to identify anomalies and configuration errors of the system, and then users can understand the reasons for such suggested actions, using this as a learning tool. Then, a combination of techniques based on behavior-centered mechanisms and computational intelligence [140] can be implemented to solve the comfort and energy management of our target buildings.

Concerning the energy consumption forecasting, different types of regression trees and Markov models will be considered [143-144]. In addition to that, different types of outdoor and indoor data sources will be taken into account. In that sense, weather reports of the area enclosing the target buildings and the correlation between the energy consumption of a building and the predicted flow of people moving towards such a building will be also investigated.

4.3.2 Recommendation Systems for Energy-efficient Lifestyles

In interaction with the users, in the evaluations, we followed an established "Living Labs" approach [145], where the users have been employing our services and their interfaces to co-create smart data and interact with it. The Living Lab methodology is rooted in the social shaping of the technology paradigm [146], where technology is not seen as a force external to the society which is impacting it, but rather, as the outcome of a process of socialization where its meaning and impact is constructed through people's everyday use of it. A Living Lab, therefore, offers an experimental setting where various users or stakeholder groups participate in co-creative practices, inserting innovation in daily situations in order to get an idea of the possible, societal impact of innovation [147-148]. It yields insight into *performance expectancy* (e.g., perceived usefulness, relative advantage…); *effort expectancy* (e.g., ease of use, complexity…); *social influence (*e.g., social norms, image…), and, *facilitating conditions* (e.g., compatibility…). With this approach in mind, the work here seeks to test new ways of obtaining, handling, improving and disclosing data between different participatory service infrastructure stakeholders in a Living Lab setting, using the real world as a lab. We have been having previous project in the area of smart homes, where we were engaging real users in energy efficiency saving processes in buildings [149-150], and in this work, we continue to apply best practices of such user involvement. It is also generally known that the linked data can be successfully acquired from the users in real-life settings e.g. employing games [151]. With our work here we expand the types of the scenarios where users contribute and interact with linked (open) data.

Making recommendations to intervene in users' energy consumption practices can be challenging for many reasons. Developing an effective recommender system supplied by an accurate behavioural and infrastructural model is crucial to provide sensible recommendations. As discussed in the previous sections, recommendation systems domain is quite extensive, but the instances that actually aim to change human behaviour are limited. Our approach is focused on a rule based engine that uses linked data provided by internal and external sources and works on a context-aware model that feeds the gamification process via semantically annotated (see Hydra[47]) lightweight web services. In this sense, recommendation engine is almost invisible to the end user but since it drives the serious games, it has a significant impact. Using ontologies for modelling the sensor and human behaviour data provides an implicit support for creating rules for the recommendation system. In order to improve modelling, hybrid stochastic approaches will also be considered. We will also consider context changes to make better recommendations. As a start, the detection of changes can be achieved by sensing the changes in the observable context elements, then this detection also can be elaborated according to users' feedback to prior recommendations. Since recommendations interact with users through serious games, a feedback mechanism can provide necessary data back to recommendation engine.

4.3.3 Analytics Reporting and Visualizations of Behavioral and Energy-related Information

In this behavioural analytics and visualization section, we will focus on how users behave in the ENTROPY platform and why their doing so. Hence, in order to provide

[47] http://www.hydra-cg.com/

those analytics and in turn thoroughly explore them to gain behavioural insights and knowledge, four key data sources are needed.

To shape any user's behaviour in any app his demographic and behavioural data is required. However, ENTROPY will take its analysis one step further, and among the previous ones, it merges psychographic and energy data too. Basic queries to be answered are "Do users follow a particular pattern in the app", "Why they are doing so", "What interaction they usually do", "How savings are determined by their actions" and "What is the impact of their behavior on energy consumption". In other words, data tells us not only what is happening, but also how and why it is happening.

Before we dig into the types of users' data needed and how these data can be collected, we should first define what the main frame of our analysis is based on. We seek to operationalize, constructs like attitude and behaviour alteration, influence in social media communities and knowledge dispersion through the ENTROPY players. Also, ENTROPY will have the power to predict or even determine future trends (since obtains the knowledge of how these trends have been emerged), break users down into similar groups to gain a more focused understanding of their behaviour and even recommend additional services that users are likely to buy based on their previous behavioural patterns on the app.

With regard to data types, some information concerning the player is objective and the platform can collect it through user's interaction with the applications or through user's interaction with social media. The other type is the self-reported data that the player must himself undertake action and respond, so as to feed the platform. This phenomenon usually is referred as crowdsourcing. Crowdsourcing or "crowdfeeding" is not just the user pushes data into the platform. It is something more than that. It is about the users respond on something that triggers them on a specific topic; their real-time opinions about a notion or an event. It is extremely important for ENTROPY to collect these type of data, because it can provide more meaningful information to users and the feeling of a ENTROPY community behind the app. Summarizing, each type of data enlightens different aspect of his persona, all very important for calculating ENTROPY metrics.

Demographics

First and foremost, we will collect users' demographics. Specifically, we aggregate users' gender, geographic location, age etc., in order to paint a picture of who ENTROPY's players are. Connecting with social platforms like facebook and twitter, ENTROPY is able to collect all these historical data, analyse them and provide a more customized learning offering.

Behavioural data

According to "The State of Always-On Marketing Study"[48], 76% of marketers have failed to use behavioural data in segmentation analysis and targeting execution. This derives from the fact that it is just not good enough to only invest in the technology or data analytics skills. You need your digital marketing ecosystem working together. In order to achieve this, ENTROPY not only will take into account demographic data. Is will also

[48] http://www.razorfish.com/binaries/content/assets/news/2014/press-releases/031914_razorfishalwaysonmarketingstudy.pdf

trace all users' activities inside the app/web such as the page views and the clicks they do, the tips and quizzes they read and the feed (i.e. faults) they push back in the platform. Thus, this kind of data is both objective (user's log) and self-reported (ex. faults' registration), and effectively supports the categorization of the players into the following types:

Psychographic data

As previously mentioned, it is essential to have an advanced analysis on behavioral data, in order to cluster the users. But to be accurate and precise and deliver a service as customized as possible, it's highly important to search for information about the users beyond the obvious sources. To provide a more predictable response from consumers, ENTROPY will employ psychographic data and marketing. In other words, demographics explain "who" your user is, while psychographics explain "why" he did what he did. Again, social media connection to ENTROPY is a key player in order to identify user's preferences and shape his persona. Basic questions to be answered through social media analysis are: "What's their lifestyle like? What are their daily habits or hobbies? What kind of values and opinions do they have? How satisfied is he from his everyday environment?" Moreover, to figure out more about the causality behind users' actions, ENTROPY will take into account all the data the application accumulates from crowdsourcing. As it is discussed earlier, this is a very important indicator about users' attitude in any notion.

Energy Data

With the use of smart meters, all the related to energy consumption behavior can be tracked and then studied. Every single interaction that users have with the apps is recorded and so as our collection of objective data and our knowledge on potentially energy efficiency practices, is constantly increasing.

To sum up, ENTROPY will track day-to-day actions to calculate metrics that afterwards will be correlated to demographics, behavioural, psychographic and energy data, in order to enhance the analysis and the users' behaviour understanding. By doing so, ENTROPY will be able to ensure customized insights, valuable reports and useful proposals to the companies and organizations.

The architectural style for the analytics, embeds the design choices made to characterise the ENTROPY architecture. The major factors affecting the design decisions are the following:

- Requirements of low latency, real-time (down to seconds) data acquisition from ENTROPY sensor grid
- Sensor and data communication limitations that impose diversity in reading intervals.
- The variety of measured data from various sensors.
- The distributed nature of sensor data gathering
- The requirement for a scalable solution able to manage millions of data sources.
- International and EU standards and guidelines.
- Current technological trends regarding data storage, software architecture and data analysis.

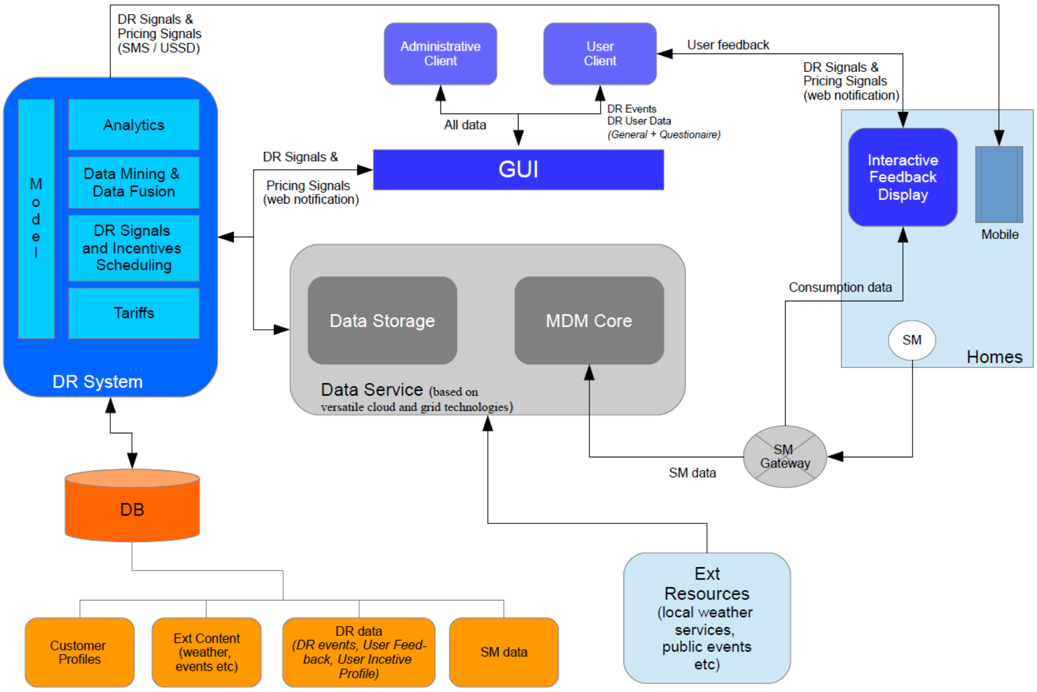

Figure 8: Overall architecture of Intelen Demand-response/Behavioural based Analytics middleware (Analytics and Visualization)

Behavioural Information Models

Behavioural-based learning adopts the idea that the instruction is centralized around individualization. Understand each individual characteristics and personality, it provides an effective way of learning. During the following paragraphs, it will be discussed about the three key factors which contribute in the success of this system's model and at the same time constitute critical challenges for vendor designers.

Task-based Behavioural Learning

One of the most important features of this model is the user's ability to learn while playing a game, solving a problem or sharing information and experiences. These can all be considered as relevant and authentic task. Task-based learning approach (TBL) is a different way to teach an abstract learning object. It can help the student by placing him in a situation like in the real world; a situation where practice and action are essential in order to execute a specific task. Users are much more wide and varied expose to the reality by fixing and acting on real situations and thus develop environmental awareness. Moreover, Behavioral-based Learning Platforms achieve their purpose of increasing learner's activity by making the usage a necessity. This is achieved by making the nature of the interface enjoyable and motivating. Besides, it is important to emphasize that this kind of learning objectives, like driving environmental awareness, are difficult to be taught by simply choosing what is to be learned. They have not elements simply slot into place in a predictable order. For this reason TBL is usually the only way to achieve results.

User's Motivation

One of the main objectives of Behavioural-based Learning Systems is not only to change people's behaviour but also alter his attitude about the learning object. The platform should provide the appropriate tools and methods in order to change user's attitude about the learning object and user's behaviour on daily routine. To do so, there has to be applied motivation and persuasion methods. The fields of psychology and marketing have developed theories and perspectives on how to influence and motivate people, but all approaches have limitations. There is a lack of a single set of principles fully explains what motivates people, what causes them to adopt certain attitudes, and what leads them to perform certain behaviours.

This is because human psychology is complex, and persuasion is a large domain. Without a universal theory of persuasion, we must draw from a set of theories and models that describe influence, motivation, or behaviour change in specific situations and for specific types of people. This limitation creates an additional challenge for designers of persuasive technology products such as Behavioural based Learning Systems. In the next part it will be presented and analysed a real case of a Behavioural-based Learning System that deploys specific methods to meet these requirements.

Architecture on Behavioural Analytic

The engagement Intelen ecosystem is consisted of three layers, each one of them with a discrete role and a set of assigned functionalities: the AMR layers, the Data Modeling Layer and the Analytics Layers.

The AMR Layer is responsible for the deployment of the network communications infrastructure and the interconnection of the smart meters with the cloud data aggregation components. The networking infrastructure consists of a set of wireless and wired sensor nodes deployed in various areas and being able to monitor energy consumption and production parameters, as well as other environmental-oriented metrics (e.g. CO_2 emissions, air pollution). Data aggregation is realized based on a set of heterogeneous data sources, including the sensor nodes (e.g. smart meters in the buildings/flats/home appliances, smart meters in microgeneration infrastructure, environmental sensors.

The Data Modeling Layer (Meter Data Management, MDM) is responsible the data visual representation based on the description of appropriate business models and the data fusion of energy, sensors and mobile app data, according to the business needs of the application scenario/pilot. The representation of the energy and behavioral data is realised based on the input from sensors and from the gamification mobile app.

The Analytics Layer describing is responsible for the design and deployment of a set of algorithms and mechanisms for the provision of recommendations (recommender engines) to citizens for adopting energy efficient and the support of lifestyles, the realisation of advanced behavioural analysis over the collected data as well as the deployment of a gamification framework to be used towards the development of games (offered though the mobile app or web). Recommendations are provided based on analysis and reasoning over the collected data (energy and behavioural), upon being mapped to the above-mentioned engagement models and is some cases interlinked to other available datasets. The deployed recommenders focus on the generation of suggestions for energy efficient ways of living and managing the buildings' infrastructure.

For the analytics extraction part, a wide range of algorithms is supported including algorithms for classification of available data, energy consumption patterns recognition, forecasting and trends reporting algorithms with regards to energy consumption and the associated costs as well as to the use and analysis of the user's behavioural collected data from the mobile app.

Behavioural Analytics Visualization

Behavioural metrics are measured and identified on the digital provision channel (mobile app or tablets) and are being analysed in real time, using the behavioural models described above

Below some visuals on the behavioural metrics can be seen, where various KPIs are analysed and visualised such as Awareness, Commitment, Engagement, Knowledge and Effectiveness during a specific behavioural game

Figure 9: Behavioural metrics visualization per user

The overall engagement and point system of the user can be mapped and tracked in real-time, as the behavioural metrics are measured and visualised on specific dashboards/user/behavioural game.

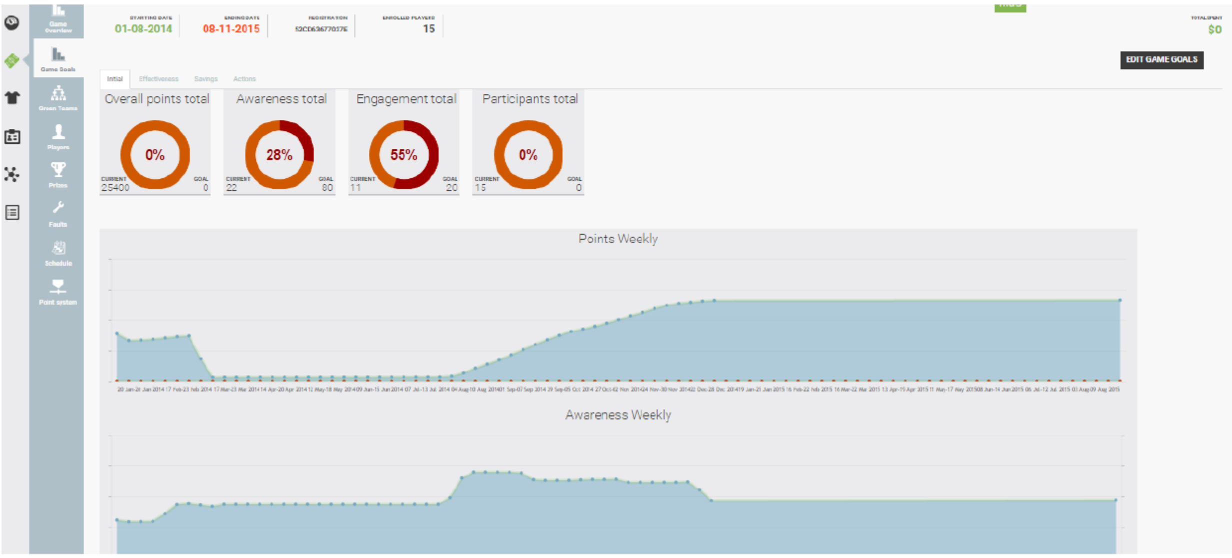

Figure 10: User human engagement metric dynamics over time

Energy Analytics Visualization (Clustering)

Clustering and classification of electricity consumption data has emerged as a recent research topic. Traditional data mining and machine learning methods are used extensively in the problem domain together with particular modifications and hybridization.

Electricity consumption data of numerous customers that are collected at hourly intervals by AMR devices over long periods are stored in centralized databases of electricity distribution companies. These vast amounts of data can be used to generate crucial information that provides the basis for developing business strategies and planning electricity usage through processing with suitable analytics techniques

Clustering power series from a single AMR can provide typical daily chronological load curves on the electrical use of the customer. The importance of the timestamp of the power series emerges as the most important feature.

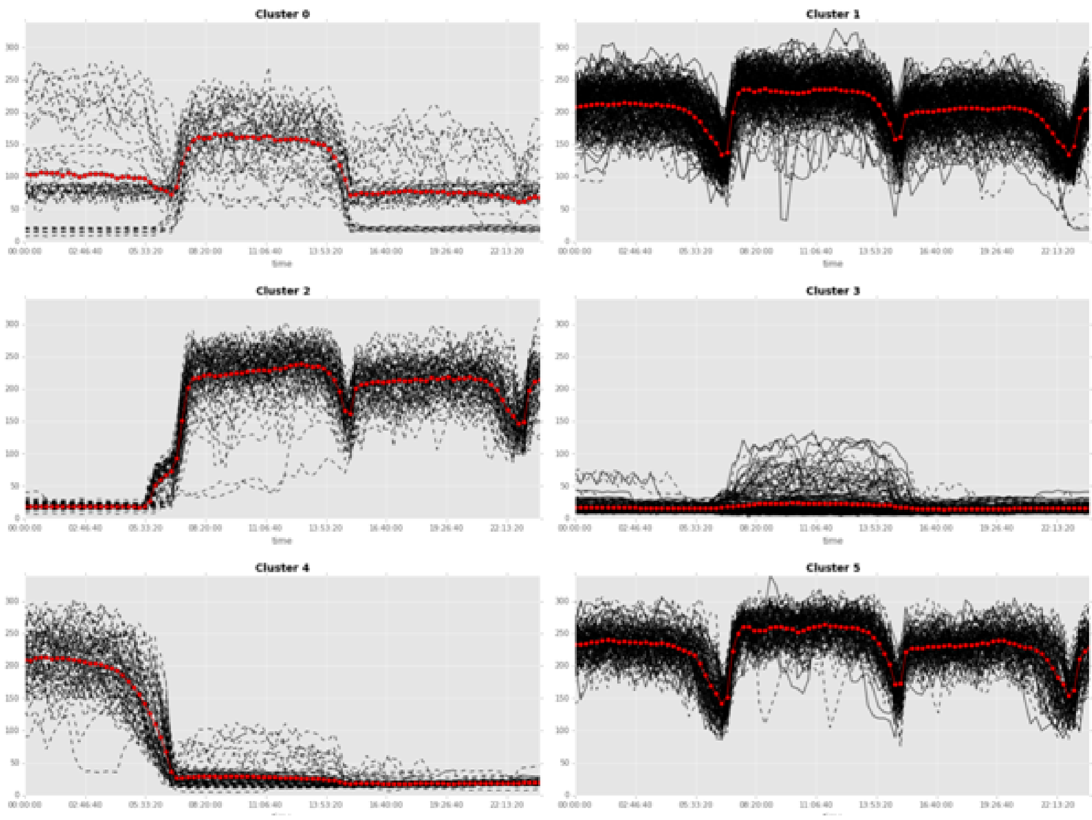

Figure 11: Clustering of hundreds of electric loads over a specific period of time (K-means)

Clustering and classifying electricity customers based on real power consumption measurements has been particularly important in the last decade following the liberalization of the electricity markets in numerous countries. Economic processes have been impelling distributors and retailers to participate in the market. From this situation, customers could be benefited by selecting the optimal price for the service they need. Therefore, the correct knowledge of customer classes must be identified in order to achieve intuitive analytics. Customer classes can also participate in the development of business strategies. The business owner can deduce the most profitable groups via continuously monitoring his clients. The identified classes could constitute a very important aspect in forecasting revenues and in evaluating quality of the provided services.

Electrical energy cannot be stored for re-use. Therefore, forecasting future electricity consumptions based on previous real consumption measurements regarding each customer class is of the utmost importance. Formed customer classes should be compact and well-separated from each other and be as robust as possible against the presence of noise so as to develop applications upon them. In order to stimulate consumption or disposal of then-current electrical energy, appropriate strategies could be established based on characteristics of each customer class. These characteristics are useful in planning dedicated tariff structures and future investments, as well. In short, discovered customer classes are of significant informative value for characterizing and manipulating the whole electricity market.

The collection of data is achieved by employing AMR systems that record consumption and status data from electric metering devices and transfer the data to central databases in predefined intervals. By examining the data acquired for a relatively long period, e.g. yearly, representative load diagrams can be computed. In our study, we examine data coming from single AMRs in order to extract high intuition and information for them.

The process involves a two-step processing of data; firstly, we cluster daily electricity load diagrams and then we classify the recently-formed labelled data for generalization purposes. Our analysis combines supervised and unsupervised learning methods, similarly to. The components that are included in the customer management task are visualized in Fig. 12.

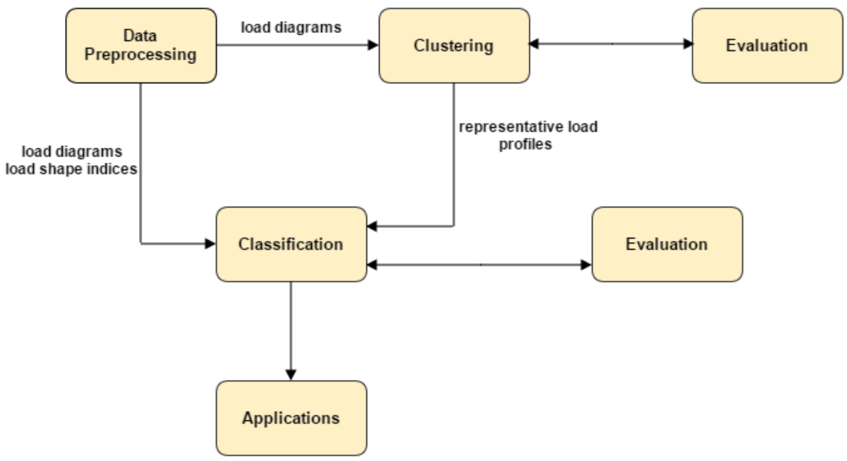

Figure 12: A modular representation of components of customer management

4.3.4 Gamification techniques for Energy-related Serious Games Development

Games and gamification can be used to motivate and support citizens' behaviour in energy use, but this is not without its potential downfalls. Since most games rely on some method of internal or external reward, associating rewards with activity is not to be taken lightly. One false move and you risk serious negative impact, rather than a positive one [152]. As research has shown, the use of external rewards such as points and badges, which are the staple of bad-gamification, can have a negative impact on the overall outcomes in the long term. Alfie Kohn's Punished by Rewards details how the use of points, stars and otherwise so called game mechanics championed by examples of gamification have a serious long term consequences in reducing the joy of doing the activity for the sake of it.

Therefore it is very important to closely examine different stakeholders and find out what motivates and drives them to change their behaviour.

How can we use gamification or games for energy efficiency depends on the behaviours being tackled, the mode and context. If the gamification mechanism does not include 'utility', 'collective action' or 'social norms' – and instead includes words like 'competition', 'engagement' and 'reward' without a sound behavioural science ground it may negatively affect the game influence. Some practical ways to engage users are given below [153]:

- Use the highest level of metering you can afford – likely to provide more information to users on the impact of their actions, and is perhaps more clearly and fairly attributable to the relevant individual or group
- Make feedback visible for all monitored units – this creates awareness of others engaging and to influence social norming
- Use emoticons – or other techniques in addition to energy readings, to reinforce behavioural changes as positive or negative
- Use financial incentives, such as rebates or discounts where possible – evidence suggests those with lower income are more likely to respond to financial or cost incentives
- Competitions and rivalry are good motivators – prizes are an added incentive
- Take time to understand why your target audience behave as they do – this is necessary to exploring ways to get them to behave differently (you may wish to checkout Intervention Mapping techniques see : http://en.wikipedia.org/wiki/Intervention_mapping
- Educate the target audience in power management functionality
- Make sustainable behaviour fun – consider using games and other fun activities
- Use social media – take advantage of existing virtual communities and create new ones for your target market
- Involve celebrities as role models – organise social champions to promote engagement

- o Organise campaigns that cover the entire year, not just a one shot.
- o Consider synergies with events and social activities relevant to the target audience
- o Monitor building occupant behaviour where applicable to inform building management systems settings

Reference [234-2] highlights the following factors that will also influence how the serious game is accepted:

- o Positive emotions (experiencing joy, pleasure, fun, safety, etc.).
- o Engagement (being constantly involved in activities).
- o Relationships (enjoyable/supportive interactions).
- o Meaning (creating a purposeful narrative).
- o Accomplishment (achieving goals, following core values, etc.).

Additionally, the serious game placed on corporate web site promotes:

- o Better dissemination and promotion of web-published information.
- o Better retention and efficient memorization factors.
- o High customization of information.
- o Better interactivity and maximum implication.
- o Attractive and non-intrusive advertising.
- o Better “word of mouth” virality.

All the aforementioned, alongside with the operationalization of the gamification mechanics, can be structured under different theories that support motivation and optimization of the end goals and result of the gamification as a utility to support and enable behaviour change. Considered theories to be introduced in ENTROPY and guide the motivational design include:

- Cognitive Evaluation Theory – Self Determination Theory [154]: In this theory the principal motivation systems that guide motivation are intrinsic motivation and extrinsic motivation. *Intrinsic motiva*tors include achievement, competence and responsibility and stem from actual performance of the task or work to be done. *Extrinsic motiva*tors include outcome, feedback, conditions of participation and work and stem from the environment or control of others. Although both are powerful motivators, each person regarding his/her predispositions can be motivated in a different degree. Intrinsically motivated individuals perform for their own achievement and satisfaction, whereas extrinsically motivated individuals perform driven by the context and environmental pressures
- Reinforcement Theory of Motivation [155-157]: Here, the principal grounding stems from the positioning that individual’s behaviour is a function of its

consequences. The theory focuses on what happens to the individuals based on the outcome of their actions and the effect it has. The different states of reinforcement include: *Positive reinforcement*: provide positive responses when an individual exhibits positive and required behaviour. *Negative reinforcement*: rewarding the individual by removing undesirable consequences. Punishment: Removing positive consequences to lower the probability of repeating undesirable behaviour and Extinction: Absence of reinforcement. The present theory requires careful application and poses considerations for application of incentive mechanisms in a gamified setting.

- Equity Theory [158]: The present theory suggests that that the perceptions of individuals pertaining to the rewards of given actions plays an important role in their attitude towards any given goal. In general, it postulates that individual's motivation to act resides in their perceptions of relative effort required by their known other participants. A person will compare the ratio of reward to the effort with the comparable ration of reward to effort that he/she thinks others are getting. In Entropy as there is knowledge of participation of others in the gamified system Equity Theory can be used to drive the ratio of Effort given to complete a goal in parallel to the reward for doing so.

- Theory of Planned Behaviour / Theory of Reasoned Action [159-163]: These theories suggest that individual's behaviour is determined by the intentions to perform the behaviour and intention is in turn a function of attitude toward the behaviours and subjective norms. The main determinants are (a) attitude towards behaviour, (b) Subjective norm and (c) perceived behavioural control. The change from TPB to TRA was conducted by the identification that behaviour appeared not to be absolutely voluntarily and under control (hence the addition of behavioural control).

All the above will be considered when designing serious game which will aim to change people behaviours and motivate them using different mechanism to get more involved towards living in energy efficient buildings.

5. CONCLUSIONS

In this document a detailed overview of the foremost technologies, paradigms and frameworks within the different domains enclosed in the ENTROPY project has been stated. In addition to that, the current needs in each domain that should be solved in order to come up with the project final objectives.

Regarding the data management scope, the different vision of the IoT domain along with representative usages of the Mobile Crowd Sensing (MCS) paradigm have been put forward. In that sense, many different end-user solutions already profit from such paradigms in domains like public transport or healthcare.

However, a complete integration of infrastructure, mobile and "human" sensors in order to extract meaningful knowledge is still a pending issue. In that sense, ENTROPY will make use of trendy technologies such as Complex Event Processing (CEP) and semantic modelling in order to undertake the aggregation and fusion of such varied type of data. In addition to that, the modelling

Another important course of action related with ENTROPY has to do with the human-behaviour recognition. In this scope, most of the efforts focus on detecting human activities with different levels of details. In that sense, the data processing from the location and motion sensors of personal handheld is a well-established trend. In that sense, ENTROPY intends to extend current solutions in order to perceive energy-related behaviours. This will be carried out by also considering other types of sensors like smart meters and how the movement of individual or group of users affects the consumption profile of a building.

As far as the recommendation systems are concerned, in this document we have tried to give an overview of the current state of the recommender systems in human behaviour and energy efficiency domain and some of their possibly relevant aspects to the ENTROPY project. Although recommendation systems field is a well-established area, we found that guiding human behaviour with the use of ontologies and recommender systems, i.e. recommending actions and guidelines on a more holistic and abstract scale to drive lasting behavioural change, is relatively understudied field that allows for further exploration.

As for serious games, we can support gradual behavioural changes of citizens and their engagement in every-day environmental friendly activities through different game levels. Consequently, a varied range of gamification techniques can be used within ENTROPY project, but it is very important to analyse this in context of behaviour change and take both into account when designing the serious game.

Finally, the different technologies to visualize and formally analyse all the generated knowledge from the aforementioned techniques have been also described in the context of the project.

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