Meet the Meter: Visualising SmartGrids using Self-Organising Electronic Institutions and Serious Games

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***Abstract*—Given that SmartGrids focus on the demand-side and are predicated on consumer participation, we propose an innovative user-infrastructure interface for SmartGrids, in which information visualisation for comparative feedback and new affordances for the Smart Meter are integrated within a virtual environment for a Serious Game. Moreover, in the context of a micro-Grid, we seek to encapsulate aspects of self-organisation and support the principles of enduring institutions through the same interface. We give an example to explain how some of the activities (rooms in the virtual environment) can be structured within the context of an electronic institution. In this way, we aim to use the SmartMeter to promote 'assistive awareness', not just for consumer participation, but also for other aspects of user engagement with critical infrastructure, for example as a citizen, as a stakeholder, and as a practitioner.**

***Keywords*-SmartGrids, Serious Games, Self-organisation, Institutions.**

I. Introduction

The electricity distribution and supply network has undergone significant changes to satisfy increased demands for efficiency, reliability and sustainability. The idea of SmartGrids is to use information and communication technology to underpin the network's infrastructure and performance, in particular targeting policy demands to address global warming and carbon dioxide emissions, consumer demands for low and competitive electricity prices, security and protection against malicious attacks, smoothing out peak demand, increased generation from renewable resources, more flexible storage options (in conjunction with the anticipated increase in electric vehicles), and consumer participation.

Given that SmartGrids focus on the demand-side and are predicated on consumer participation, we propose a user-infrastructure interface, in which information visualisation for comparative feedback [1] and new affordances for the Smart Meter are integrated within a virtual environment [2]. Moreover, in the context of self-determination, we seek to encapsulate aspects of self-organisation and support the principles of enduring institutions [3] through the same interface. The aim is to allow users to "Meet the Meter", providing 'assistive awareness' which offers the necessary experience and knowledge for long-term engagement with the new infrastructure and help them gain a better understanding, not just of prices, but of resource allocation, investment decisions, and sustainability.

Accordingly, this paper is structured as follows. We introduce SmartGrids and the issue of the user-infrastructure interface in Section II. In Section III, we review several mechanisms for user engagement with SmartGrids through information presentation and representation, including comparative feedback, Smart Meters, and Serious Games. Section IV, proposes a new user-infrastructure interface based on representing the SmartGrid as a self-organising Electronic Institution (EI [4]) embodied or contextualised within a Serious Game, which includes the representation of Smart Meters, novel information visualisation techniques, and the encapsulation of Ostrom's principles of enduring institutions. Section V presents an example to explain how some of the activities (rooms in the virtual environment) can be structured within the context of an EI. We conclude in Section VI with some remarks about privacy, generalisation to other infrastructure (water, agriculture, etc.) and how this approach of 'assistive awareness' can promote not just consumer participation, but also other crucial aspects of user engagement with critical infrastructure, for example as a citizen, as a stakeholder, and as a practitioner.

II. The User-Infrastructure Interface

The existing electricity grid in 2012 is both reliable and functional: it can normally meet normal demands for electricity even with short-term (minutes) and long-term (seasonal) variations. The primary challenge for the grid for energy generators and distributors is to be responsive to government policy and other national and international regulatory bodies. This includes meeting targets for CO_2 emissions, renewable energy sources, the low carbon economy, the electrification of transport and heating, and so on; and these targets have to be met within the limitations of current planning, operation and control practices.

However, the industry is exemplified by a willingness to innovate and there are unprecedented opportunities offered by using advanced communication and information technologies to massively improve asset utilisation and provide full choice to the consumer. This characterises the drive towards SmartGrids and the engagement with users. For example, the SmartGrid of Schönau in Germany offers a decentralised form of green-energy production, both in terms of increasing the efficiency of energy transmission and of empowering citizens to take charge of their energy consumption and production, and manage it through a citizen-owned social business.

The introduction of ICT to the grid alone is not a guaranteed panacea, as the optimisation of the system requires accommodation of, and adjustment to, the consumers' behaviour. Energy consumers need to learn how to interact with new technologies and to be aware of changing conditions over different timescales, e.g., energy 'spot price' depends on the total consumption of the energy at a given moment, but investment decisions (e.g. home insulation) require many years to see a return on the investment.

Moreover, the ways in which users interact with the infrastructure is of critical importance. In another context, many large-scale irrigation projects tend to ignore this dynamic, presuming that users will somehow automatically adapt to more modern irrigation technologies. Frequently, this has not been the case, and in many instances has led to the demise of expensive water projects. For example, one study [5] focused on the infrastructure development and maintenance in correlation with the irrigation management system in Nepal. One of its findings was that new technology infrastructure could improve the performance of an irrigation system, but this enhancement depended on the institutions and their effectiveness for managing and maintaining the infrastructure. Both the institutions and social arrangements of the users together with the attributes of the infrastructure with which they interact have to be taken into account.

Therefore, the main problem is that, although SmartGrids focus on the demand-side and are predicated on consumer participation, the user-infrastructure interface is still largely neglected and the Smart Meter, through which information is supposed to be pushed, is perceived as the imposition of a centralised, controlling technology rather than welcomed as a generative, enabling technology (like the SmartPhone). To address this problem, in the next section we consider several attempts to address user participation or consumer engagement, including serious games, comparative feedback and Smart Meters. Subsequently, we consider the representation of institutions in this context.

III. User Participation

For an efficient and effective SmartGrid development and operation, users have a crucial role in their interaction with the network infrastructure. There are various ways for user engagement and participation. Serious games and Smart Meters provide interfaces for decision-making and displaying information respectively, while comparative feedback gives an overview of electricity consumption and helps consumers to observe changes to energy use or their behaviour.

A. Engaging Users through Serious Games

One way to design a SmartGrid interface that is engaging enough to hold users' attention for long-term decisions and actions for engaging users is to leverage the attractiveness of computer games. Serious games are digital games, simulations and virtual environments which purpose is not only to entertain and have fun, but also to assist learning and help users develop skills such as decision-making, long-term engagement and collaboration. They are experiential environments where features such as thought-provoking, informative or stimulating are as important, if not more so, than fun or entertainment [6].

Through serious games, users can have experiences that are not ordinarily possible due to constraints such as cost and time. Engaging and motivating people through games can help people to develop skills or abilities, for example training people on how to use the Smart Meters. Serious games can help in the design and implementation of smart metering interface that is engaging for long-term decisions and actions. Furthermore, changes in performance and behaviour can be achieved, whereas the user's skills and beliefs can be stimulated according to designer's predefined way.

Serious games are engaging as they enhance learning by teaching users a specific skill or by encouraging them to take part in real-life activities in which they were might not be interested before or they were lacking confidence in trying them [7]. By promoting active involvement and participation particularly in simulations, users' self-esteem is enhanced, they are getting prepared for the real world of work and their cooperative and competitive behaviour is encouraged when there is a strategic context. This is particularly important in the concept of SmartGrid, when we will start training the users for using the Smart Meters in their life.

Additionally, serious games are an effective way for motivating and engaging users through a training experience. Collaboration among players can be increased and the physical elements of the game can be a mean for promoting user engagement.

Therefore, there are two ways that serious games can be used to encourage consumer participation with a SmartGrid. One way is to use the game as serious (and normative) virtual worlds that allow direct consumer participation with the grid itself. The user can visualize in the virtual environment data coming from sensors in the real world (or simulated ones) and have some agent-based assistance about how to improve consumption. A second way is to use the game just for training purposes. It is an engaging experience for the user who participates playing and so better understands the institutions involved in the operation of the grid.

B. Users and Comparative Feedback

Comparative feedback can be used as a sufficient mean for engaging users with the Smart Meters and the Advanced Metering Infrastructure (AMI) in general. People's awareness can be increased by monitoring and controlling the electricity consumption on a daily basis. A desirable result would be a shifting in the peak demand in times with less need for energy use, or in the best case scenario a reduction in the electricity consumption will be observed [8].

For comparative feedback to be effective it should be based on actual energy consumption information, it should be provided on a frequent basis (daily basis is the ideal scenario) and in cooperation with an information service or assistance, it should provide details concerning how much energy each electrical appliance consumes and give advices on how to save energy. A display with a detailed pricing scheme will help consumers having a clear picture of how much they are charged for using specific electrical appliances in a particular time period [9]. Each household should receive feedback at a regular basis (at the end of every month), that compares past energy consumptions, which will help consumers identify their consumption patterns on a comparative basis and see if their behaviour has changed over a monthly period by receiving a daily feedback [10].

Darby's study proves that comparative feedback is more effective than direct feedback that comes straight from an energy meter display, as it gives an overview of the household's consumption over a period of time. Decrease in energy consumption can be from 0-10 percent [11]. Fischer's study shows that a 0-12 percent decrease is feasible through comparative feedback, which is also a way for triggering people's behaviour and habits over a long time [12]. From all the studies that have been done so far, an assumption can be made: comparative feedback changes consumers' behaviour towards electricity consumption.

A survey held on a neighbourhood in the city of Sydney, proved that users can monitor more efficiently the energy consumption over a long period of time, when they receive feedback in a regular basis. Comparative feedback helped them to apprehend better their behaviour's changes towards electricity consumption. The comparative feedback in this neighbourhood encouraged the social involvement and competition and increased awareness for energy consumption. According to the study, a feedback to be successful and effective has to fully to understand what motivates people to change their behaviour and develop endless actions for reducing electricity consumption [1].

C. Smart Meters

Recent research focuses on ways in which consumers can be involved in the electricity network infrastructure. Consumers know little about energy use. For example, they do not know which electrical appliances consume the most electricity or how much they are charged for using them in particular time periods [13]. The only connection among consumers and energy providers is the electricity bill, which includes in most of the cases only the data with the energy consumption and the amount of money to get paid. This lack of communication between these two parties results from the existing and poor metering system.

The first step of user involvement is through smart metering which above all provides a user interface for communication and interaction. Smart Metering is the installation of Smart Meters on buildings to control the energy consumption, process and transmit consumer's information to energy providers and provide with feedback the users [14]. Smart Meters are in general like the known meters that they are installed in our households for reading the energy consumption, but their advanced features make them more practical and helpful [15].

Data now follows energy flows and goes to and from end-users with benefits for both sides. Energy providers receive detailed information analysis, which helps them to better understand the users' habits by figuring out which electrical appliances are used the most, when and for how long. This data can be used for predicting customer's behaviour and reducing the peak in demand. Equally, users have a clear picture of real-time energy consumption through displays. They know exactly how much energy each electrical appliance consumes and this data evaluation can help them understand how to use electricity in a more efficient way. Through information history, users can check their energy demand, change their behaviour consequently and save energy [10]. The meters' reading can be done even remotely using a mobile application, avoiding in this way energy waste (for example the user can switch off the lights without having to be at home). The power consumption analysis from both parties helps maintaining the grid's efficiency [14].

Apart from real-time display of energy consumption, Smart Meters provide a real-time pricing service. Consumers can be aware how much electricity they consume but also how much they are charged for it. The different prices and the variation in tariffs promote the energy efficiency of the network, as when there is a peak in demand the electricity is more expensive, discouraging users from using their appliances.

Another possible service is to connect the Smart Meters with the electrical appliances and control them. The user can turn off the washing machine when there is a peak in demand, check if the lights are on by using remote control and turn them off for saving energy and money. In case there is a high peak in demand or a risk of blackout, Smart Meters can disconnect customers or send them messages or warnings in order them to switch off some devices. This may displease users, but the goal is to maintain grid's efficiency, reliability and security.

As mentioned previously, energy flows now in two directions (to and from end-users) and Smart Meters can help with the measurement of both flows. For example, households can have their virtual power plants (VPP) that demand energy from the network, but they also supply it with power when there is a need.

The cost of the Smart Meters depends on the services each of them provides. Some Smart Meters may only serve for measuring energy consumption, whereas other may be connected to electrical appliances, provide remote control or send messages or warnings to the users [16].

IV. Proposal: Serious Game Institutions

SmartGrids focus on the demand-side, placing particular emphasis on users and their engagement with the grid. The interface to this infrastructure must be taken into account, including the users' social arrangements, the affordances of devices such as the SmartMeter, and in particular their institutions. Therefore, we propose a new user-infrastructure interface for SmartGrids based on serious games, encapsulating in it Ostrom's principles for enduring institutions [3]. Table I shows the correlation between these principles and user participation in a serious game for a SmartGrid.

Table I: Ostrom's Principles encapsulated by a Serious Game

Serious Game	
Ostrom's Principles	*User Participation*
Clearly defined boundaries	Game access
Congruence between appropriation/provision rules and context	Locations supporting comparative feedback for different 'roles'
Collective choice arrangements	Deliberative Assembly location
Monitoring	Smart Meters
Graduated Sanctions	Sanctions and Incentives
Conflict resolution	Court Room location

We encapsulate Principle 1, clearly defined boundaries, by having access to the Serious Game (or not). Therefore the online world represents the institution, and playing a character in the game implies membership of the institution, and vice versa. The institution is responsible for representing the interests of a collective forming a (micro) SmartGrid.

The affordances for the Smart Meters concern the locations (different rooms for the pricing or consumption scheme) and the capabilities allocated by the environment. The representation of the Smart Meters as agents enables them to act in an autonomous and un-predefined way, making the interaction with the environment easier and in a non-predictable way. These Smart Meter agents can learn from their experiences and previous actions and relationships can be created between them and the users [17].

With information visualisation for comparative feedback, users gain significant understanding by simply looking at features and images which trigger their memory. Data in any form can be visualised and conceived [18]: our intention is to use the SmartMeter to provide 'assistive awareness' of the different forms of information available and visualised according to the specific role the user is occupying. For example, in the 'prosumer' role, the user make choices about prices, which energy provider to get their electricity from, selling surplus (locally-generated) energy back to the grid, and so on. This is a personal choice about utility. In the 'citizen' role, the user may be concerned with collective utility and the impact of his/her consumption profile on global warming, have an interest in setting and meeting policy targets, and so on. In a 'practitioner' role, the user might be concerned with coordinated activity for providing storage and planning local (micro-Grid) developments.

Different locations would provide visualisation of different sorts of data for different purposes, enabling users to configure the rules of their institution to the perceived environment (Principle 2). This configuration would be implemented by having some specialised decision-making forum for collective choice, i.e. a deliberative assembly of some kind (Principle 3).

This data would be streamed by some sort of monitoring agency, this would in fact be the role of the SmartMeters (Principle 4) Note the SmartMeter is not just limited to be being a passive device: it can even be a non-player character or avatar in its own right (hence our expression: "meet the meter"). Ostrom's Principle 5 concerned graduated sanctions for 'inappropriate' behaviour. In this setting, we prefer to generalise this notion and refer instead to *graduated incentives*. By this we mean the virtual environment rewards both successful game play and sanctions inappropriate behaviour, both in the physical and virtual worlds.

Finally, where disputes occur in the operation of the SmartGrid, these can be resolved in another specialised location, such as a 'Court Room'. Additionally, Ostrom defined two other principles: no interference from external authorities, and systems of systems. The former can be encapsulated by ensuring that each instance of the Serious Game cannot be controlled from the outside; and the latter by allowing communication between game worlds and possible 'meta-games'.

V. A Working Example

The integration of the SmartMeters, information visualisation and Ostroms principles into a virtual environment for Serious Games will create a new user-infrastructure interface which enables long-term user engagement within SmartGrids. Therefore, we propose a novel user-infrastructure interface which aims to extend a communication bridge between the user (i.e. the consumer) and the computer (i.e. SmartGrid). Our concerns focus on the use of advanced technologies to build this bridge. We advocate that Virtual Institutions (VI [19]) can help with this, as they are 3D normative environments which allow direct human participation in an Electronic Institution (an organisation centred multi-agent system) [20], by means of a 3D Virtual World (VW) interface. VIs have been successfully used in a variety of e-applications, such as e-learning [21] and e-government [2].

Figure 1: Virtual World populated by 3D virtual characters performing collective arrangements (human-human and human-agent interactions)

The latter work implements a water market as a VI where participants can be both human and software agents. Whilst the EI models the market (e.g., defining roles and interaction protocols), the VW offers a 3D advanced interface which facilitates direct human inclusion within the system. We use VIXEE [22] as the VI infrastructure, a robust *Virtual Institution eXEcution Environment* that provides interesting features, such as multi-verse communication and dynamic manipulation of the VW content.

A 3D VW provides all the necessary means for human inclusion in the system (in our case, a SmartGrid). A human gets immersed in the environment by controlling her/his avatar (embodied character) in the VW. Such a VW enhances the visualisation of information about the system and its facilities, e.g., data coming from sensors in the real world (or simulated ones). Moreover, participants interact in a seamless and intuitive way with other participants (e.g., to perform collective arrangements) and with the environment (e.g., virtual Smart Meters) by using multi-modal communication channels (e.g, voice chat, text chat, information panels, touching objects and doing gestures). Figure 1 shows how humans and agents interact inside a room of a VI.

A VI structures agent interactions by defining the following components: an *ontology*, which specifies domain concepts; a number of *roles* participants can adopt; several dialogic *activities*, which group the interactions of participants; well-defined *protocols* followed by such *activities*; and a *performative structure* that defines the legal movements of *roles* among (possibly parallel) *activities*.

It is then possible to structure the interactions of participants playing our serious game as a VI. Six different activities can be enabled: the i) *SmartGrid Presentation* activity provides novel participants with the necessary background about the SmartGrid; the ii) *Private Information* and the iii) *Public Information* activities provide comparative feedback about the SmartGrid usage (e.g., individual monthly electricity consumption and group consumption histograms); the iv) *Simulation* activity models the actual environment (e.g., a house with electrical appliances that can be switched on and off) including the virtual Smart Meters, so that the user can learn how to use the SmartGrid facilities; in the v) *Assembly* activity, discussing and voting protocols can be implemented in order to collectively establish arrangements between participants within the SmartGrid (e.g, allocation methods/prices and a neighbourhood community/family consumption behaviours); finally, necessary conflict resolution mechanisms can be implemented in the vi) *Conflict Resolution* activity (e.g., penalties for contract violations).

Furthermore, Almajano et al. proposed an *Assistance Infrastructure* [23]. It is composed by two layers: i) the organisational layer structures agent's interactions in the system as well as manages historical information about the organisation and its execution state; and ii) the assistance layer is populated by a set of *Personal Assistants* (PA) which provides general *Assistance Services* to participants within the organisation. One PA directly and solely helps to one participant within the system to fulfil its goals and, if they are aligned with system's goals, the overall system's performance is improved. Finally, we also propose to further improve our serious game by providing assistance services to the user by the so-called *Personal Assistants*, i.e., software agents that belong to our infrastructure. These services include: refined information about the system, which can be included in the information activities or even before, when the agent enters the system for the first time; or decision support, which can be useful in the simulation activity in order to help users to make an efficient use of the resources.

In addition to the attractiveness of 3D graphical environments, there are other ways to enhance users' engagement in our serious game. Users can experience the game as a direct competition (e.g. users have to solve a particular challenge, in order to obtain some awards or prizes), or as an indirect competition by means of ranking lists, which could be public at different community levels (e.g. family or neighbourhood). Users can compare their ranks against others in order to motivate them and, at the same time, to improve "social commitment". We can also include a "mystery factor" in our serious game. For example, a virtual scenario that simulates a system failure can get player to determine what's happening, and how it can be solved?

VI. Conclusion

The main contribution of this paper is to propose a user-infrastructure interface for SmartGrids, in which information visualisation for comparative feedback, Smart Meters and user participation are integrated in a virtual environment. Using a SmartMeter to provide 'assistive awareness' in a serious game enables long-term user engagement and offers participants a deeper insight into decision-making, resource allocation and sustainability in their different roles, not just 'prosumer', but as citizen, stakeholder and practitioner.

There are some restrictions concerning the user participation inside the network. The majority of end-users are not aware of grid management and as energy generators, they should provide details about electricity production and demand. For an effective grid operation, a high percentage of user participation is needed, whereas the decision-making should be immediate and accurate. Consumers are not always willing to spend money on services or resources that they do not really want or need, and by making them active participants, they have to invest money on amenities with long-term benefits [16]. Users should fully understand their role inside the grid and their future gains and benefits.

As players in the serious games are humans, the collection of data needs to mindful of limits which have to be set from policy makers. Users should be aware of who is accessing their information and how it is used. Personal details should be used only for purposes that are identified and specified from regulations and they should be protected against loss, alteration or unauthorised use. Policies are also needed to ensure that users have the right to ask for their data to be deleted from the database any time they want to. As participants' information can expose their habits, access and control over this information should be limited. Some users might also not be willing to sacrifice their privacy for any personal benefit [15].

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