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People or machines? Assessing the impacts of smart meters and load controllers in Italian office spaces

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ABSTRACT

Government initiatives in several developed and developing countries to roll-out smart meters call for research on the sustainability impacts of these devices. In principle smart meters bring about higher control over energy theft and lower consumption, but require a high level of engagement by end-users. An alternative consists of load controllers, which control the load according to pre-set parameters. To date, research has focused on the impacts of these two alternatives separately. This study compares the sustainability impacts of smart meters and load controllers in an occupied office building in Italy. The assessment is carried out on three different floors of the same building. Findings show that demand reductions associated with a smart meter device are 5.2% higher than demand reductions associated with the load controller.

Introduction

Recent government initiatives in several developed and developing countries to roll-out smart meters call for research on the sustainability impacts of these devices. Compared with old electromagnetic meters, smart meters improve access to electricity consumption information (Darby and McKenna, 2012). In principle, increased awareness regarding consumption should bring about conservation impacts and flatten peak demand. In North America and Europe providing feedback on electricity consumption through a smart meter device has been shown to reduce consumption by approximately 6–10% (Darby, 2008; Fischer, 2008). Meta-studies which include available data from other countries indicate that large-scale conservation effects from smart metering feedback are in the range of 3–5% (McKerracher and Torriti, 2013). Whilst most of the existing 100 pilot studies originate from developed countries (Torriti et al., 2010; VaasaETT, 2011), governments in developing countries are increasingly considering similar national roll-outs (Benzi et al., 2011; Depuru et al., 2011b; Ndinechi et al., 2011). Smart meters are also expected to bring about higher control over theft (Depuru et al., 2011a) and better integration with decentralised electricity storage (Römer et al., 2012). In other words, in developing economies smart meters – along with other Demand Side Management technologies – represent an opportunity for leap-frogging the demand side electricity industry where obsolete metering devices are in place or even absent (Doraswami, 1995). What is more, with the integration of renewable sources of energy, which are generally uncontrollable and intermittent, the automated solutions to Demand Side Management are increasingly appealing (Strbac, 2008) for both developed and developing countries. For clarification purposes, this paper adopts a broad definition of Demand Side Management, embracing both load management and energy saving measures (Greening, 2010). One problem with smart meters is that they require a very high level of engagement by end-users. End-users are expected to interact with these new devices and in some cases play an active role in changing their electricity consumption based on signals from the utility. This might be problematic when inertia characterises consumption patterns (Hargreaves et al., 2010). End-users, who normally bear the costs for smart metering deployment through higher bills, might think that smart meters could shortly be replaced with newer technologies and not invest time in understanding the functions of smart meters (Grünewald and Torriti, 2013).

An alternative to active monitoring of consumption via smart meters consists of load controllers, which control the load according to pre-set parameters, e.g. occupancy patterns, ambient temperature outputs, average seasonal external temperature, and comfort indexes. Load controllers vary in type, from Computer-Aided Home Energy Management (Williams et al., 2006) and Wireless Sensor Network applied to electrical power management (Molina-Garcia et al., 2007) to multi-level optimisation mechanisms for customer-side load management (Ha et al., 2007) and multi-agent home automation system for power management (Abras et al., 2008). To date, research has focused on the impacts of these two alternatives separately. Existing studies on load controllers show that, when combined with renewable sources of energy, they can bring about reductions in costs and carbon emissions despite increases in overall electricity consumption (Hong et al., 2012).

No studies have compared the outcomes of smart metering devices and load controllers. This paper aims to fill this gap by assessing the sustainability impacts of both smart meters and load controllers on electricity consumption over a two month period in an office space in Northern Italy. Findings on electricity consumption are comparable

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because other explanatory variables, including external temperature, building structure and occupancy are controlled as data are gathered from three different floors of the same building envelope.

After this introduction, the paper defines the main characteristics of the smart meters (Section 2, Smart meters in Italy) and load controller deployed in this study (Section 3, Load controller). It describes the configuration of the smart meter and the load controller taking into account the features of the building (Section 4, Configuration of smart meters and load controller). It presents findings on changes in electricity demand (Section 5, Variations in electricity demand). The conclusions discuss some of the research and policy implications of this study (Section 6, Conclusions).

Smart meters in Italy

Italy has one of the highest rates of penetration of smart meters in the world. In 2010 more than 90% of overall electricity consumers were provided with smart meters (Torriti, 2012a). By the year 2011, 37 million smart meters had been installed. Five issues make the Italian case study particularly relevant to not only developed, but also developing economies.

First, the improvement of quality of supply is the main reason why smart meters were installed in Italy in the first place. The minimisation of electricity theft from the distribution network, elimination of meter reading costs, and faster detection of power outages have also been looked at as reasons why the Italian energy regulator intervened in the smart metering planning (Faruqui et al., 2010; Lo Schiavo et al., 2011). Second, much emphasis was placed on the potential integration of smart meters with an Italian smart grid, where renewable sources of energy, particularly from solar photovoltaic and wind, could be connected to the grid. Third, regarding functions, it should be noted that for most meters installed before 2007, the main difference, compared with the old Ferrari electromagnetic meters, was the digital screen which replaced the wheel component. After 2007, some new meters were integrated with additional functions, such as current consumption of electricity, daily consumption and monthly consumption (Di Castelnuovo and Fumagalli, 2013). Fourth, the limited functions and problematic locations within the building envelope of the new meters imply that in most cases 'digital meters' might be a more appropriate definition than 'smart meters' (Torriti, 2012b; Torriti, 2013). The location of the meters within buildings represents an obstacle towards full real-time monitoring of consumers' loads. In essence, the place where the smart meters were installed was invariably the same as where the old meters used to be. For building blocks, which host 65% of Italian residential consumers, the meter location is in a communal area, typically either the basement or the loft. For detached and semi-detached houses, the meters vary in location. The most typical examples consist of shelter in the garden, meter box built in the fence or external wall, garage, detached storage room, hallway and entry corridor. The common factor is the distance from areas where residents tend to spend the majority of their active occupancy time, i.e. living room, kitchen and bedrooms. Fifth, electricity bills are high, representing 60% of bills for an average Italian consumer (CRU, 2010). This is considered a high indicator of fuel poverty with links to the developing world (Kemmler and Spreng, 2007). The high levels of active occupancy of residential users compared with other European countries from Harmonised European Time Use surveys (Torriti, 2012a), the ageing population and the recent introduction of non-voluntary Time-of-Use tariffs are all significant factors in relation to the monitoring and use of smart meters in this country.

Unlike what happened in Sweden (Nguni, 2006), little research has emerged from this pioneer experience on smart meters. One explanation could be that the abovementioned issues of functions and location prevent researchers from gathering relevant information about residential electricity demand in the built environment. One way of eluding this problem is by focussing on non-residential buildings. In Italy 98% of businesses are small and medium enterprises (Zecchini and Ventura, 2009). These have a lower energy consumption compared with larger businesses, but also a higher share of the overall building population and higher overall electricity consumption. An office space of a medium sized business (about 40 employees) is fairly representative of the average Italian day-time weekday consumption. Assuming that a person works 9 h and sleeps 8 h per day, the sample covers her/his electricity consumption for about 27% of the overall time in a week and 56% of active (i.e. non-sleeping) time during weekdays.

Load controller

The load controller enables floor level balancing of electricity demand and supply. It collects a number of demand inputs from the electricity services and appliances in the office space. It then classifies the demand inputs into groups according to their priority level. The low priority group consists of highly controllable demand inputs. The medium priority group entails medium controllability of demand inputs, whereas the high priority group is made of inputs which have low controllability. The prioritisation of groups determines the overall level of demand for the office space floor. When the total electricity demand is greater than the available total electricity supply, the load controller will take into account priority groups based on demand inputs. The demand control will occur from the high priority group to the low priority group based on the decreasing order of controllability of demand inputs.

Once demand inputs have been controlled for the high controllability group, the load controller takes stock of all the demand inputs, even those from medium priority and high priority groups to measure the size of the new total demand and assess this with the size of the available supply. When the total demand of all groups exceeds the total supply, the load controller will change priority by moving to the next group and repeat the operation. When the total demand level is lower than the supply level, the load controller will stop implementing control actions and move to the next control step. When total demand is less than total supply, a load recovery component is initiated which is designated to recover the demand high priority group (Hong et al., 2012). The load controller will measure the new total demand against the total supply based on the total demand including the demand associated with the recovery. If the total supply still exceeds the new total demand, the load controller moves to the next priority group. This operation is repeated until the total supply is lower than the total demand.

Configuration of smart meters and load controller

In this study, the location of the smart meter is within a common open-space office area. The recently converted office building offered the opportunity to have the smart meter device in a much more visible space than it normally occurs for e.g. residential users. Whilst access to the smart meter is possible for all office occupants, a sustainability warden was named for a period covering the two months of this study. His role was to monitor real-time consumption and interact with colleagues regarding their use of appliances and lighting.

Each floor of the office building is formed as a rectangular zone containing four external wall surfaces, a flat ceiling and floor, two doors,

Table 1
Building characteristics.

Wall/window	Surface (m^2)	Direction	U ($W/m^2.K$)
External wall	176	North	0.311
External wall	92	East	0.311
External wall	176	South	0.311
External wall	92	West	0.311
Window	7.5	North	1.014
Window	2.5	East	1.014
Window	7.5	South	1.014
Window	2.5	West	1.014