

# Article

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Corso Magenta 63, Milan – Italy  
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# THE MITIGATION POTENTIAL OF CONSUMER ADOPTION OF SMART ENERGY BEHAVIOUR

By Elena Claire Ricci\*

*This article aims at analysing the potential of consumer empowerment and engagement in the electric power system, focusing on the case of Italy. Firstly, we build a System Dynamics model to evaluate the potential dynamics of consumer adoption of ‘Smart Energy Behaviours’, including within this term different levels and combinations of the following actions/behaviours: i) changes in the electricity consumption patterns; ii) effortless reduction of wasteful electricity consumption; iii) participation in Demand Response programmes; iv) residential electricity generation. Secondly, we evaluate the impacts of such adoption dynamics on the national electric power system in terms of electricity demand, system costs, and greenhouse gas emission reductions. Results indicate that consumer behavioural changes can induce important benefits to the system and participate to the reduction of the electric sector carbon footprint in an efficient way. Thus, innovative policies and initiatives that promote a more proactive end-user interaction and involvement in the consumption and production of electricity should be highly encouraged.*

**Keywords:** Smart-Grids, System Dynamics, Demand Response, Demand Management, Consumer Choices, Climate Policy

**JEL classification:** Q01, Q42, Q54

## 1. Introduction

Nowadays, national power networks are faced with various challenges: i) increasing demand and reliance on electricity implies the necessity to improve their efficiency, security and quality of service; ii) climate change issues bring about the need to manage an increased amount of renewable

energy sources; iii) current trends in society suggest to aim at a greater interactivity with consumers, that are becoming more proactive.

Though, even with these new pressures arising, current electric power systems have remained qualitatively very similar to how they were in the last century; although capacity and efficiency have been increased, the qualitative architecture of the network has not changed significantly, especially from the consumer side.

Recently, there is a lot of interest regarding Smart-Grids, i.e., the idea of introducing Information and Communication Technology (I&CT) features into the power network, so that it will be able to transmit and manage not only electricity but also information. Indeed, modern technology developments allow a greater interaction with clients exactly when current global environmental problems need the active participation of citizens in order to be tackled effectively (Chakravarty *et al.*, 2009). Smart-Grids and the innovation of the power network could represent the opportunity for the power system to align itself with trends currently seen in other sectors where consumers are increasingly empowered along the principles of the new knowledge-based society.

The aim of this analysis is to evaluate how a greater and active involvement of household end-users may contribute to reduce the electric sector carbon footprint. To do so, we identify and then model the adoption of smart behaviours by consumers, enabled by smart-grids in general and by the installation of smart-meters in particular. Then, we evaluate the resulting impacts in terms of electricity demand, system costs, and emission reductions.

## 2. Conceptual Framework

Advanced metering systems allow a bi-directional flow of electricity and a two-way flow of real-time information with multiple implications. End-users may introduce electricity into the system, becoming a more

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\***Elena Claire Ricci** is junior researcher at FEEM and a post-doc fellow at the department of Economics of Università degli Studi di Milano.

empowered subject, often referred to as “prosumer”. Utilities can gain more information on real-time loads and load patterns, and therefore improve the management of their activities. Consumers can access better information on their consumption that can be better tailored to their preferences. Finally, policies may include time-related tariffs that convey price signals to allow for product differentiation in electricity consumption, accounting for differences in time and season, production costs and impacts.

Up to now the electricity consumer has always had a passive role with very little choice. The demand for electricity, and energy in general, is not a demand *per se*, but a demand for the services that electricity can provide (lighting, refrigeration, food preparation, washing, entertainment, heating, cooling, etc.). Accordingly, end users had - or still have - no access to data concerning the costs of the energy services used. In addition, payment is often distant from consumption and aggregated, making it even more difficult to associate a price to the service. Darby (2006) shows the importance of feedback in making energy use more visible and quantifiable and, consequently, for triggering energy-use behavioural changes. The invisibility of energy resources makes consumers blind not only to their level of consumption, but also to the level of consumption of others and to the “appropriate” consumption level, that may serve as reference (Ehrhardt-Martinez *et al.*, 2010).

### 3 Methodology

#### 3.1 Modelling approach

The decisional process related to end-user energy management strategies, now enriched with the new additional options offered by smart grids, is extremely complex. An investigation methodology particularly appropriate is offered by System Dynamics (Forrester, 1961), born to analyse from a systemic point of view the behaviour of complex systems.

Indeed, the basic structure of our model

builds on Bass (1969) with features mutuuated from epidemiology models to describe the evolution of epidemics (Murray, 2002).

#### 3.2 Model Description

Our model focuses on the behaviour of small end-users of the electric power sector. This is an under-studied topic in the economic literature, and at the same time well represents the novelty associated to the introduction of smart-grids. We consider six different behaviours consumers can adopt once smart meters and tariff policies are in place: (i) shifting electricity consumption to less expensive (less polluting - congesting) hours, (ii) reducing consumption while maintaining similar comfort levels, (iii) adopting behaviour and home automation, (iv) enrolling in demand response programs, (v) improving energy efficiency, (vi) generating electricity autonomously. We will refer to these activities as ‘smart energy behaviours’.

These are depicted in the squared boxes of Figure 1 which are characterized by different levels of the six previously described activities.

In the model two motivational drivers induce a household to switch from one behaviour to the other: (i) cost savings and (ii) environmental and societal benefits. The main informational channels facilitating the change are: (i) information campaigns, (ii) demand-side-management policies, (iii) word of mouth, (iv) media coverage, and (v) advertising.

The flows between the different behaviours are described by a system of differential equations parameterized on the basis of pilot studies implemented to estimate the effects of behavioural changes that follow the installation of smart meters and/or the application of differentiated tariffs (Ehrhardt-Martinez *et al.*, 2010; Olmos *et al.*, 2010; eMeter, 2010). To characterize uncertainty in the adoption dynamics we run 2500 simulations, for each of which the values of the parameters are obtained by joint independent random sampling from

beta probability distributions centered on the values found in the literature.

We then apply our general model to the case of Italy, which is particularly interesting as the deployment of smart-meters covers the entire population.

### 3.3 Simulation results

The left panel of Figure 2 shows that by 2040 between 35% and 39% of total residential electricity could be shifted outside peak-hour consumption. The behavioural change starts from 2010 to grow at nearly one percentage point per year between 2015 and 2030. In absolute terms, this would imply shifting off peak a consumption of about 20,500 GWh/y by 2030. To give an order of magnitude, this corresponds to roughly one third of current Italian yearly electricity consumption by the residential sector. Shifting would allow to defer in time or even to avoid the development of generating capacity of around 8.4 GW in 2030. To understand the relevance of this figure consider that a medium size nuclear power plant has a capacity of around 1GW.

Electricity generation and transmission systems are sized according to the maximum peak load (plus a margin to account for forecasting errors or emergencies), as demand needs to be satisfied at all times. This means that part of the capacity installed is used only for a very limited amount of hours during the year. Therefore, a shift in consumption that smoothes load curves by delaying capacity expansion and better using the available capacity, may also give the possibility to lower overall plant and capital cost requirements. Cost savings are estimated to reach Euro 354 Million per year in 2030 (Table 1).

The environmental benefit associated to the behavioural changes allowed by shifting electricity consumption to off-peak hours is also relevant. In 2030 1.33 million tons of CO<sub>2</sub> can be saved. This, is about 14% of the yearly emission reduction target for the period 2008-2012 faced by the Italian electricity sector. Considering the marginal

abatement costs reported by the literature, this would also entail a total mitigation cost reduction of roughly Euro 26 million.

These benefits should be added to the Euro 500 million that electricity producers are saving each year because of remote operations on smart meters. Finally, aggregate savings for consumers can reach Euro 180 million in 2030.

Additional economic and environmental benefits can then be obtained from electricity consumption reduction promoted by smart metering. Recall that in our analysis this does not involve loss of comfort for household members: indeed, we refer to savings of wasteful power like vampire loads and/or to automated reduction of consumption. According to our analysis, the reduction in electricity consumption would range between 14% and 19% in 2040 (Figure 2 right panel) which would bring a peak load and capacity reduction smaller than in the case of shifting, but a threefold CO<sub>2</sub> and mitigation cost saving (Table 2). The Table also reports an estimate of the generating cost savings calculated on the basis of the average cost in 2011 (GME, 2011).

For households (Table 3), bill savings range between: 19-46 €/hh/y for a 5% reduction, 38-93 €/hh/y for a 10% reduction, and 76-185 €/hh/y for a 20% reduction. Therefore, consumption reduction has a much stronger economic saving potential for the consumer than shifting. Though, the latter remains effective in allowing economic, environmental and capacity savings for the system as a whole.

All in all, savings from a proactive engagement of the consumer are high, but also “cheap” as the costs are mostly efforts by the consumer.

Figures 3 and 4 compare the costs of installing the smart meters with the cumulative system and consumer bill savings, respectively. Note that these evaluations are only indicative as they extend current values in the future, and they take into account only a sub-set of benefits induced by smart meters. For example,

outage reduction strongly reduces system costs, though we do not currently have this data for Italy; in the US, outages shrink by 24.5% the revenues of the electric power sector (ISGI, 2010). All this said, costs are outweighed by power system savings in just three years, and by consumer bill savings in 11 years.

#### **4 Discussion**

These results show that the smart energy use “epidemic” has a high spreading potential, i.e., the consumer can be successfully involved in an improved management of the power system, using appropriate signals (Information, Communication and Knowledge). This can generate important and beneficial effects for the environment, for national governments engaged in mitigation policies, for the consumers and for the producers in the short and medium term.

It can also push in the direction of electric self-sufficiency. This not intended in a pauperistic way, but following the idea of taking advantage of local opportunities to reduce environmental impacts and increase economic opportunities within communities connected with the global system integration of “local energy ecosystems”.

Naturally the risk exists of contrast between small smart and active prosumers and large utilities that may aim at defending their market positions. But we have just shown how these two realities can synergically interact.

To govern and maximize the advantages offered by this transition, it is crucial that both governments and firms play an active and coordinated role. Policies can be targeted to both consumers - e.g. with awareness campaigns - and utilities - e.g. by implementing best practices or price schemes like it has happened in Italy with the tariff differentiation - to foster the diffusion of smart energy behaviours. Electricity providers, on their turn can decide to implement what is strictly necessary to comply with the regulation, or to design proactive initiatives and take advantage of

the new opportunities of interaction with the end-user.



Figures

Figure 1. Stock and Flow Diagram

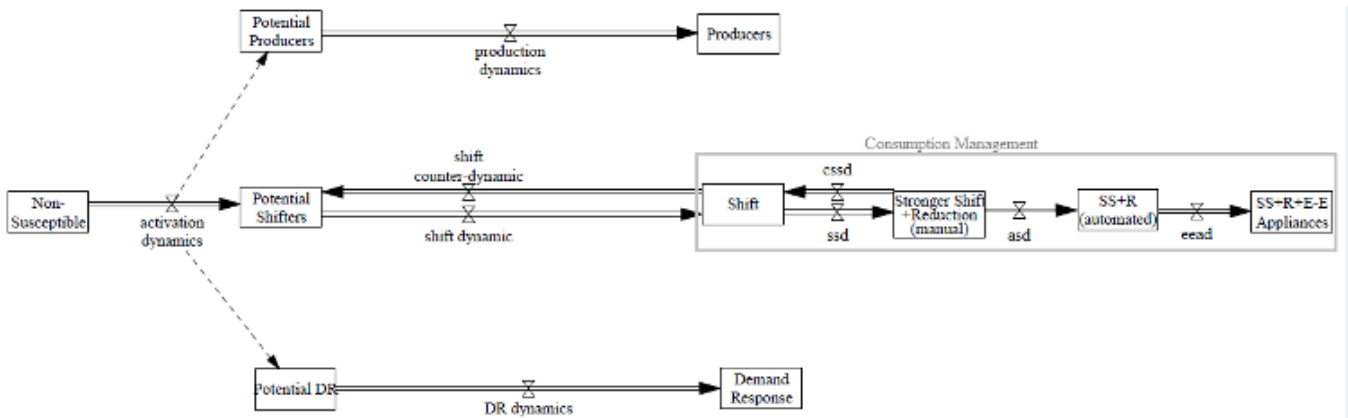


Figure 2. Total percentage of household electricity shifted and reduced

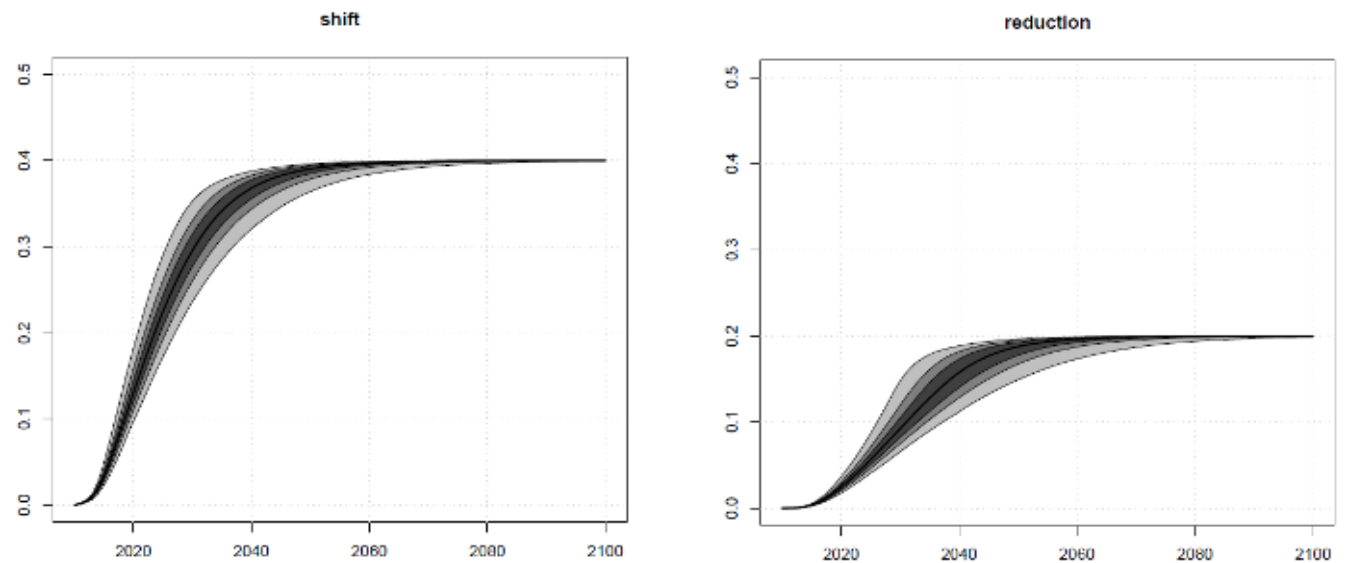


Figure 3. Advanced-Metering-Infrastructure costs and power system cost-savings

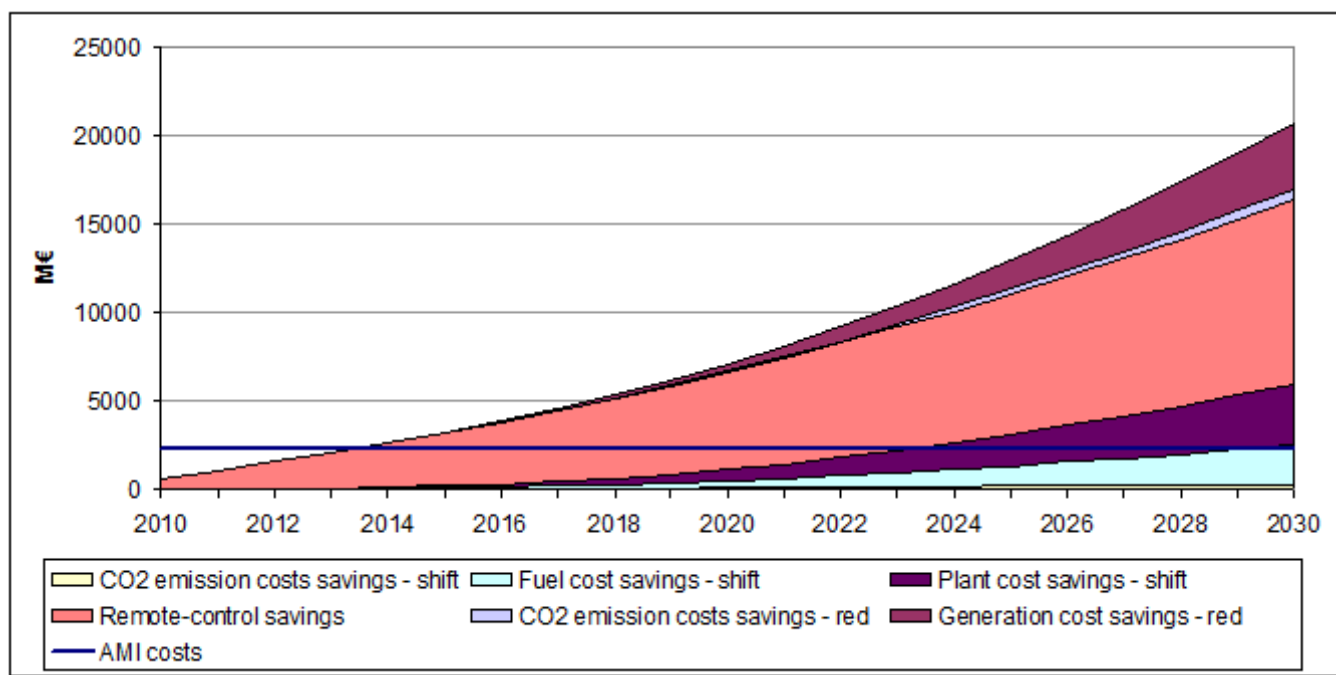
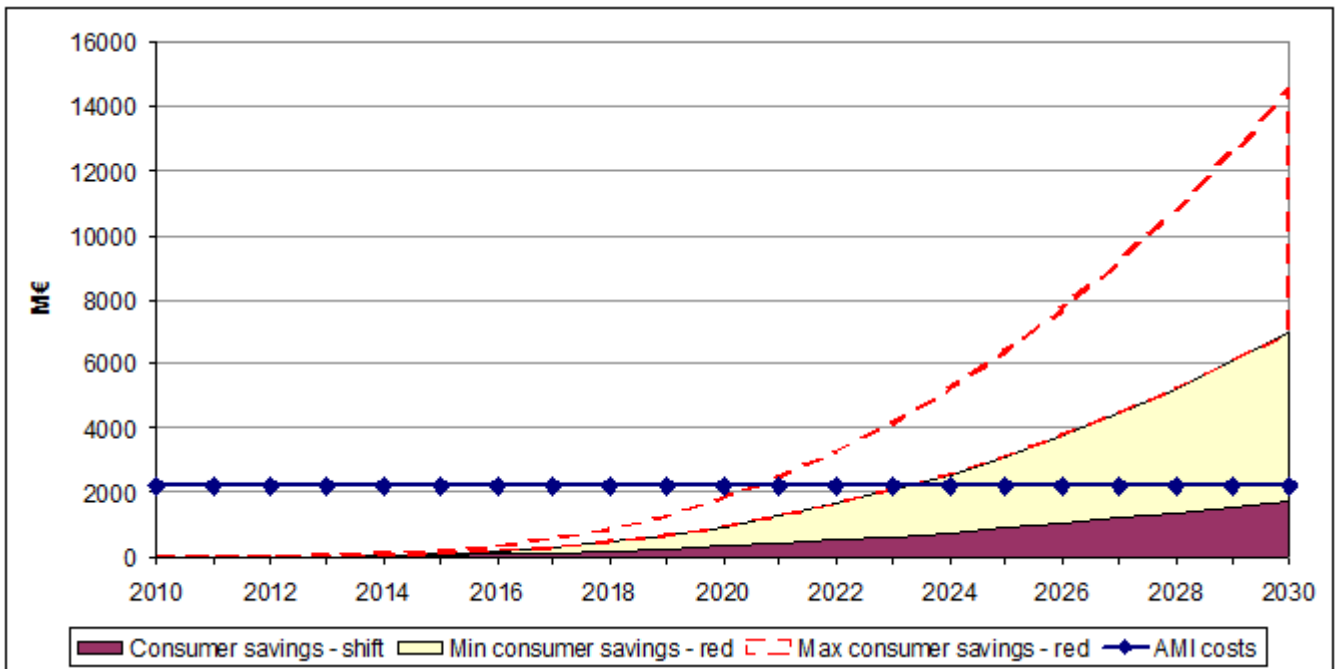


Figure 4. Advanced-Metering-Infrastructure costs and aggregate consumer bill savings





**Table 1. Avoided CO2 emissions and costs by shifts in consumption**

	2015	2020	2025	2030
CO <sub>2</sub> emission reduction (Mton CO <sub>2</sub> /y)	0.15	0.58	1.01	1.33
CO <sub>2</sub> emission costs reduction (M€/y)	2.95	11.69	20.19	26.60
Fuel costs (M€/y)	26.22	103.92	179.50	236.44
Plant costs (M€/y)	39.34	155.88	269.24	354.67

**Table 2. Peak load reduction potentials by reduction in consumption, maintaining constant comfort levels**

	2015	2020	2025	2030
Peak load reduction (GWh/y)	250	1700	3906	6391
Peak capacity reduction (GW)	0.03	0.23	0.52	0.86
CO <sub>2</sub> emissions reduction (Mton CO <sub>2</sub> /y)	0.14	0.98	2.25	3.68
CO <sub>2</sub> emission cost reduction (M€/y)	2.88	19.58	44.99	73.62
Generation cost reduction (M€/y)	19.65	133.64	307.05	502.40

**Table 3. Aggregate households bill savings by reduction in consumption with the 2010-2012 tariff scheme**

	2015	2020	2025	2030
Min aggregate savings (M€/y)	27.6	187.2	430.1	703.8
Max aggregate savings (M€/y)	67.2	456.2	1,048.3	1,715.4

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