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# Integrated Management of Residential Energy Resources

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**Abstract.** The increasing deployment of distributed generation systems based on renewables in the residential sector, the development of information and communication technologies and the expected evolution of traditional power systems towards smart grids are inducing changes in the passive role of end-users, namely with stimuli to change residential demand patterns. The residential user should be able to make decisions and efficiently manage his energy resources by taking advantages from his flexibility in load usage with the aim to minimize the electricity bill without depreciating the quality of energy services provided. The aim of this paper is characterizing electricity consumption in the residential sector and categorizing the different loads according to their typical usage, working cycles, technical constraints and possible degree of control. This categorization of end-use loads contributes to ascertain the availability of controllable loads to be managed as well as the different direct management actions that can be implemented. The ability to implement different management actions over diverse end-use load will increase the responsiveness of demand and potentially raises the willingness of end-users to accept such activities. The impacts on the aggregated national demand of large-scale dissemination of management systems that would help the end-user to make decisions regarding electricity consumption are predicted using a simulator that generates the aggregated residential sector electricity consumption under variable prices.

## 1 Introduction

Portugal has been doing important efforts to reduce the dependency on fossil fuels for electricity generation mainly through incentives to the deployment of generation systems based on renewable sources. Considering that among renewable generation, wind and solar have been steadily increasing, it is important to maximize their integration and be able to deal with their variability [1–3]. Automated demand response (ADR) could be a major help in dealing with this variability and thus contributing for the integration of renewables [1,3–6]. However, before establishing automated response actions, an adequate analysis of the disaggregated electricity consumption in the residential sector along with the typical patterns of load usage that can be somehow controlled is required [7]. Additionally, to assure the success of smart ADR actions to be implemented on manageable demand, technical constraints and consumer preferences that frame the way loads can be controlled must also be considered. These smart ADR actions will contribute not only to reduce consumer's electricity

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bills, but also to a more efficient operation of power systems [8], possibly increasing the supplier's profits from electricity selling and allowing higher penetration of renewables.

The aim of this paper is then to analyze the residential sector electricity consumption as a basis for categorizing loads, assessing potential manageable demand and identifying / extending potential demand management actions. Since, in this context, a part of demand will be treated as a manageable and responsive resource, impacts on the aggregated load diagram are expected. A simulator to assess the impact of actions on controllable demand for several households for a full day, according to the rate of penetration of energy management systems, has been developed. This simulator is able to generate the new aggregated residential sector electricity consumption under variable prices and according to different input variables. The actions considered are postponement/delay of working cycles (clothes dryer, clothes washer, dishwasher), re-set of temperature parameters and short time interruptions (air conditioning systems, electric water heaters and cold appliances).

## 2 Electricity consumption in Portugal

Electricity consumption in the residential sector in Portugal has increased and one of the reasons for this trend has been the increasing rate of ownership of electrical appliances associated with higher living standards [9,10]. The ownership of appliances such as microwaves, freezers, vacuum cleaners, clothes washing machines, clothes dryer, dishwashers, mobile phones, audio/video equipment and air conditioning systems have significantly increased between 1995 and 2005 (Figure 1).

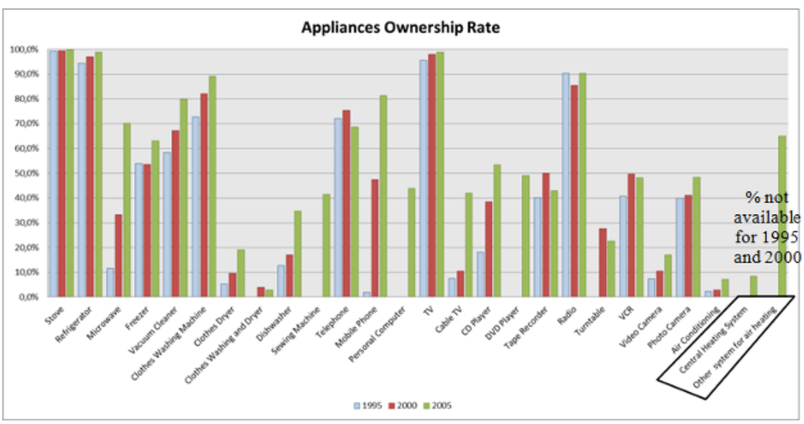


Fig. 1. Appliances ownership rate [11–13].

Taking into account the load profile of the residential sector disaggregated by end-uses [14], it is possible to identify the typical usage schedule of different appliances, as well as estimating their contribution to the total electricity consumption and electricity bill (Figure 2). Information such as the regular time of usage of end-use loads is very useful to extract habits and the potential of using certain appliances in other schedules.

Main loads such as fridges and freezers are responsible for a considerable consumption all day long that can be seen as part of the base consumption in the residential load diagram. Other loads such as electric water heating systems have a higher consumption in the morning, although the consumption during day time is still significant. Lighting and entertainment equipment have the peak of consumption between 7 pm – 0 am. Whereas dishwashers are mainly used after dinner, clothes washing machines preferred schedule is the after-lunch period. Clothes dryers are normally used after the working cycle of clothes washing machines is completed. An important part of the consumption is not disaggregated by end-use loads since it was not possible to get the data from DGGE [14] and therefore equipments like air conditioners and electric heaters are not identifiable on this load profile. Other appliances commonly used at the residential sector, such as microwaves, cooking stoves, hair dryers, and mobile phones chargers, although contributing for the aggregated consumption, are considered as uncontrollable loads.

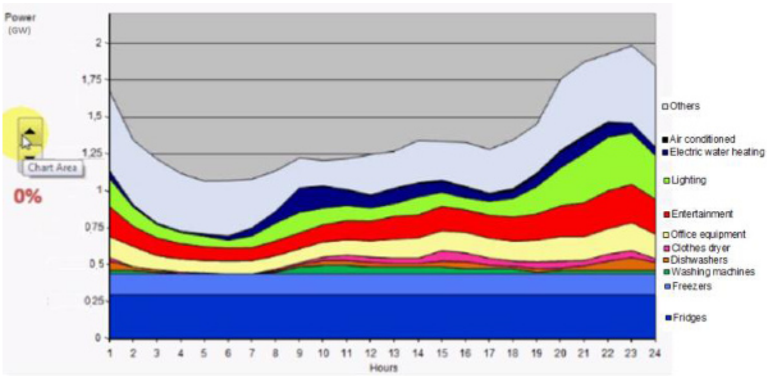


Fig. 2. Load profile of the residential sector.

The adoption of a dual-tariff system by some residential end-users in Portugal is a factor that induces changes in some habits and behaviors [15], mainly in the use of electric water heaters, dishwashers, clothes washing machines and clothes dryers. However, retail prices in the dual-tariff system do not completely reflect fluctuating wholesale prices at different periods of the day [16]. In a smart grid context and with the evolution of technology it is expected to have some of those price fluctuations passed to the end-user. Since the end-user does not have neither the knowledge nor the availability to respond to dynamic prices, the deployment of automated systems able to manage loads can be the answer to mimic end-users' decisions, taking into account preferences and respecting technical restrictions. Therefore, it is important to study the residential electricity consumption to clearly identify manageable demand in order to identify the most suitable demand response actions for each type of end-use load and to assess the impacts on the load diagram of the penetration of energy management systems (EMS).

## 3 Manageable demand and load categorization

Despite the diversity of appliances at the residential sector and the uncertainty associated with electricity consumption due to different end-users' habits and preferences, family composition and loads' usage [17], the existence of a common portfolio of appliances allows the identification of similarities to establish management strategies [18]. Therefore, considering consumption, technical characteristics and typical usage patterns of residential loads, it is possible to identify the manageable demand and to establish an appropriate load categorization.

Having in mind the main objective to decrease end-user's electricity bill without depreciating the quality of the energy service provided, and in the specific case of households with no generation units and energy storage systems, for a given end-use loads portfolio, the main reductions on costs lay on [3]:

- the postponement or the anticipation of working cycles;
- the re-set of temperature parameters;
- short period interruptions.

The possibility to shift or interrupt loads and re-set temperature parameters strongly depends on the end-users' acceptance, habits, time of use flexibility and willingness to accept an EMS to control loads [3].

Focusing on the type of control that loads may suffer, four categories can be distinguished as presented in Table 1.

**Table 1.** Type of control and load categorization

| Type of Control | Description | Appliances |
|---|---|---|
| Uncontrollable loads | Loads that cannot be controlled since it may depreciate the quality of the energy service provided and cause discomfort to the end-user | Lighting, office and entertainment equipment, cooking appliances and others |
| Reparameterizable loads | Loads thermostatically controlled that can have thermostat parameters re-set without depreciation of the energy service provided | Cold appliances, air conditioning systems and electric water heaters |
| Interruptible loads | Loads that can be the target of short period interruptions without depreciation of the energy service provided | Cold appliances, air conditioning systems and electric water heaters |
| Shiftable loads | Loads that can have the working cycle delayed or anticipated while respecting end-users' preferences | Washing machines, clothes dryers, dishwashers and electric water heaters |

The potential of manageable demand can be identified in Figure 3 consisting of the sum of the loads that can be interrupted or have the thermostat parameters re-set plus loads that can be shifted.

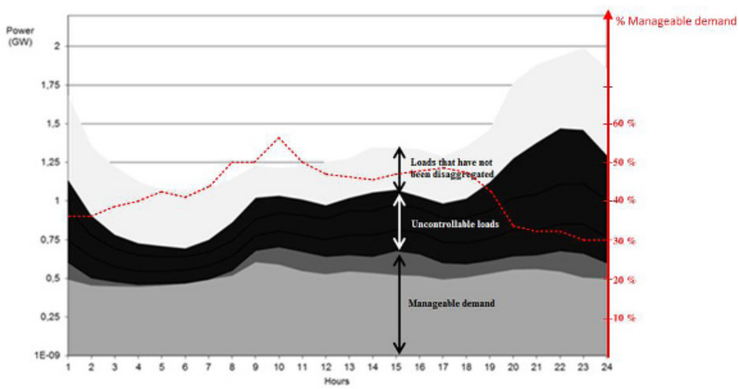


Fig. 3. Potential of manageable demand.

According to the categorization presented in Table 1 and the typical annual consumption of loads in Portugal [14], it is possible to develop a graph that shows the type of control that can be applied over the different end-use loads and their annual electricity consumption (Figure 4). However, despite the possibility of some loads being the target of the same type of control, the characteristics of the control actions (interruption duration, temperature parameters, time deferral, etc.) are not equal for every load. Therefore, each control strategy must be adequately tailored to each end-use load.

Automated control actions are already available at the residential sector, which are applied over air conditioning systems, electric heating systems and electric water heaters, that comprise setting thermostat parameters according to a locally or remotely programmed schedule and direct control [19]. On the other hand, short period interruptions of cold appliances may be useful not only to the residential end-user in certain situations (for example, avoiding power peaks) but also to the grid (helping to stabilize the electrical grid when electricity supply from renewable sources has high fluctuations) [3]. The goal is to increase the number of end-use loads that can be the target of management actions, thus increasing the responsiveness of demand and its benefits, and to extend the type of control applied over those loads, allowing non-disruptive control actions to be applied, thus contributing for improving the willingness of consumers to accept ADR. Different control actions can be applied over different end-use loads and some loads can be the target of different types of control.

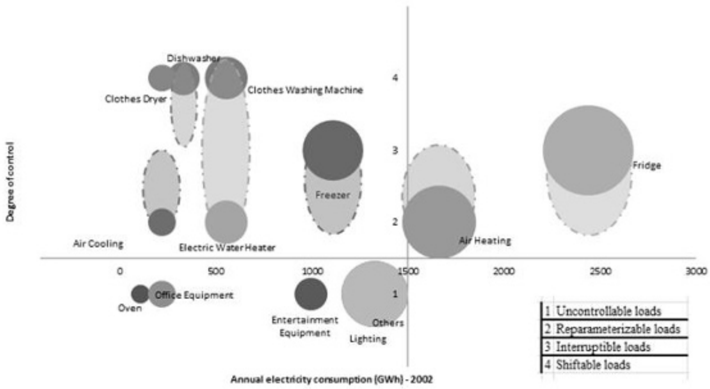


Fig. 4. Load categorization according to its degree of control and annual electricity consumption.

## 4 Load diagram impact

The evolution in information and communication technologies (including monitoring systems and sensors), the distributed and local generation from renewables, the storage systems and demand side management [20] will change the until now passive role of residential demand [8]. That change will be also pushed by the expected progress of the traditional power systems towards a smarter grid, enabling end-users with the technological basis and the necessary input signals to adequately manage their residential resources, from typical loads to storage systems, including electric vehicles.

The changes in the way electricity is used will have impacts on the residential load diagram according to several aspects: the existence or not of EMS, the loads managed, the type of control applied over loads, the tariff system adopted, etc. The inputs acting as stimuli for ADR actions, the constraints and requirements, the information needed for performing smart end-use loads management and the outputs (control actions) of such EMS are shown in Figure 5. In order to analyze the impacts of an EMS with the features presented in Figure 5, a simulation test bed was developed. The first version considers only residential appliances, excluding at this stage local generation and storage systems.

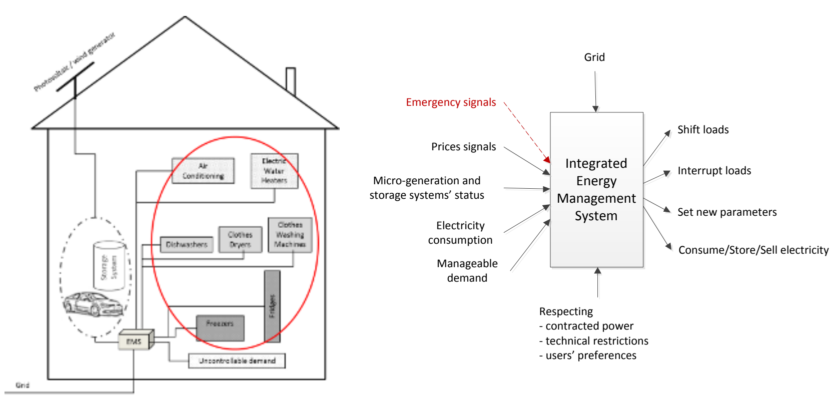


Fig. 5. Scheme of an Integrated Energy Management System.

This simulator is structured to automatically compute the aggregated residential load diagram based on information such as:

- number of dwellings;
- peak and off-peak hours;
- appliances ownership rates;
- average typical consumption profile of the appliances;
- penetration rate of the integrated EMS;
- willingness of the end-user to let the EMS automatically manage different appliances;
- type of control:
    - uncontrollable loads;
    - loads that can have the parameters re-set or be interrupted;
    - loads whose working cycle can be anticipated or deferred.

Also based on the information introduced and on the ADR actions implemented, the economic savings for the typical residential end-user are calculated. The actions considered are:

- changing the working cycles of dishwashers, washing machines and clothes dryers to off-peak hours;
- set new thermostat parameters on fridges, freezers, electric water heaters and air conditioning systems.

These actions do not assure that the amount of electricity consumed is reduced but that the end-user bill decreases when subject to electricity price-based incentives. Power demand is modelled over time and manageable demand is controlled with the aim to decrease peaks of consumption and reduce end-user's electricity bill.

According to the rate of penetration of the integrated EMS, represented by a percentage at the left side of the load diagram (Figure 6), different impacts on the load diagram are perceived. The basis scenario (Figure 2) is used to compute the daily residential load diagram based on the input information without the implementation of management actions (0% penetration rate of EMS). This scenario provides therefore a basis with which other scenarios may be compared.

The first scenario is the daily residential power demand with a penetration rate of 70% of integrated EMS. The second scenario is the daily residential power demand with the integrated EMS deployed all over the residential sector.

The adoption of the integrated EMS by residential end-users results in the decrease of consumption peaks and on a flattened residential load diagram (Figure 6) when compared to the basis scenario.

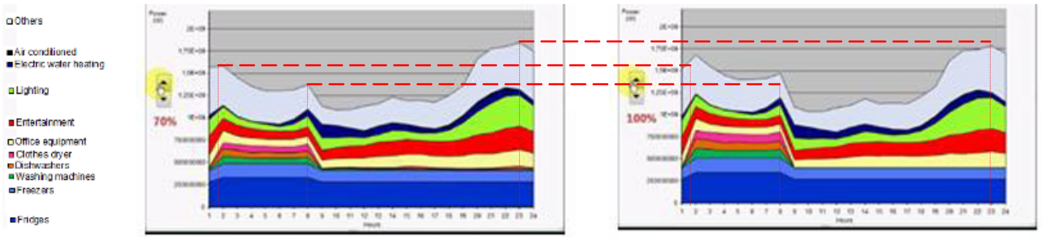


Fig. 6. Possible impacts on load diagram considering the penetration rate of EMS.

Although several studies considering direct and indirect feedback report savings in a range from 5-15% and 0-10% [21], this simulator points out about 5% of savings for the typical residential consumer in Portugal in this last scenario. Even though this saving percentage is low when compared to other studies, the fact that it does not depend on direct action of consumers is a major advantage. The savings originated by direct feedback with displays that show the instantaneous and accumulated electricity consumption depend on the consumer behavior and on the frequency that the consumers look at the displays, which is likely to decrease over time. The savings presented here only depend on the automated EMS and on the willingness of the consumer to let this hand-off system manage his appliances according to his preferences (Figure 7). This willingness may be different for distinct types of appliances, namely for the group composed by dishwashers, clothes washing machines and clothes dryers and for the group of thermostatically controlled loads composed by cold appliances, air conditioning systems and electric water heaters.

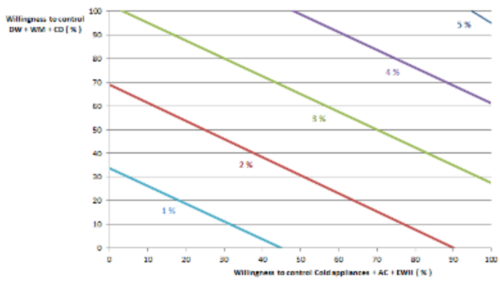


Fig. 7. Savings considering consumers' willingness to let the EMS control different types of appliances.

## 5 Conclusion

In a smart grid context with dynamic pricing, the successful deployment of integrated EMS with the aim to minimize residential end-users' electricity bill and maximize the use of electricity produced locally from renewables requires the study of loads consumption patterns, consumer preferences (convenience and availability), behaviors and habits [15].

Automated technology able to manage loads and other energy resources without the need of end-users direct intervention must include end-users' preferences since the reduction of users inconvenience will contribute to increase the acceptance of this type of automated EMS [3]. On the other hand, integrated EMS will be imperative to the traditional residential end-user who does have neither the time nor the knowledge to continuously monitor and make decisions to manage his resources almost in real time based on different input information, such as prices and comfort requirements.

The main objective of this paper was to characterize electricity consumption in the residential sector and categorize the different loads according to their typical usage, working cycles, technical constraints and possible degree of control so that this information could be adequately used when developing the proposed integrated EMS. Also the impacts on the residential load diagram of this type of system were presented. It has been shown that different penetration rates of the EMS and/or different percentage of end-users' willingness to let the EMS manage different loads would generate different savings and have different impacts on the residential load diagram. The scenarios analyzed in this paper show that savings can go up to 5 % and that it is possible to reduce peaks of electricity consumption in the residential load diagram and obtain a flatter valley due to the implementation of some ADR strategies.

Future work should include energy storage systems, namely plug-in electric vehicles, along with ADR. The inclusion of these systems will allow reshaping electricity consumption profiles such that they can be supplied by a higher share of renewables and according to price or system condition signals.

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## References


1. P.S. Moura, A.T. de Almeida, The role of demand-side management in the grid integration of wind power, Applied Energy. 87 (2010) 2581-2588.
2. Plano Nacional de Acção Para as Energias Renováveis ao Abrigo da Directiva 2009/28/CE, (2010) 144.
3. N.G. Dlamini, F. Cromieres, Implementing peak load reduction algorithms for household electrical appliances, Energy Policy. (2012) 1-11.
4. M. Kushler, E. Vine, D. York, Using energy efficiency to help address electric systems reliability: an initial examination of 2001 experience, Energy. 28 (2003) 303-317.
5. S. Gottwalt, W. Ketter, C. Block, J. Collins, C. Weinhardt, Demand side management—A simulation of household behavior under variable prices, Energy Policy. (2011) 1-12.
6. G. Strbac, Demand side management: Benefits and challenges☆, Energy Policy. 36 (2008) 4419-4426.
7. A. Rosin, H. Hoimoja, T. Moller, M. Lehtla, Residential electricity consumption and loads pattern analysis, in: Proceedings of the 2010 Electric Power Quality and Supply Reliability Conference, IEEE, Kuressaare, 2010: pp. 111-116.
8. A. Molderink, V. Bakker, M.G.C. Bosman, J.L. Hurink, G.J.M. Smit, Management and Control of Domestic Smart Grid Technology, IEEE Transactions on Smart Grid. 1 (2010) 109-119.
9. International Energy Agency, Energy Policies of IEA Countries: Portugal 2004 Review, Paris, 2004.
10. M. Shahbaz, C.F. Tang, M. Shahbaz Shabbir, Electricity consumption and economic growth nexus in Portugal using cointegration and causality approaches, Energy Policy. 39 (2011) 3529-3536.
11. Direcção de Serviços de Macroeconomia e Planeamento, *Portugal em números - Situação Socioeconómica*. Lisboa, 2002.INE, I.P., Inquérito às Despesas das Famílias 2005-2006, (2008).
12. "PORDATA: Base de Dados Portugal Contemporâneo." [Online]. Available: http://www.pordata.pt/. [Accessed: 02-Nov-2011].
13. DGGE /IP-3E, "Eficiência energética em equipamentos e sistemas eléctricos no sector residencial," 2004. [Online]. Available: www.p3e-portugal.com. [Accessed: 24-Feb-2011].
14. A. Rosin, H. Hoimoja, T. Moller, M. Lehtla, Residential electricity consumption and loads pattern analysis, in: Proceedings of the 2010 Electric Power Quality and Supply Reliability Conference, IEEE, 2010: pp. 111-116.
15. A.-H. Mohsenian-Rad, A. Leon-Garcia, Optimal Residential Load Control With Price Prediction in Real-Time Electricity Pricing Environments, IEEE Transactions on Smart Grid. 1 (2010) 120-133.
16. E. Carpaneto, G. Chicco, Probabilistic characterisation of the aggregated residential load patterns, IET Generation, Transmission & Distribution. 2 (2008) 373.
17. R.J. Meyers, E.D. Williams, H.S. Matthews, Scoping the potential of monitoring and control technologies to reduce energy use in homes, Energy and Buildings. 42 (2010) 563-569.
18. C. Roe, S. Meliopoulos, R. Entriken, S. Chhaya, Simulated demand response of a residential energy management system, in: IEEE 2011 EnergyTech, IEEE, 2011: pp. 1-6.
19. A. Molderink, V. Bakker, M.G.C. Bosman, J.L. Hurink, G.J.M. Smit, A three-step methodology to improve domestic energy efficiency, in: 2010 Innovative Smart Grid Technologies (ISGT), IEEE, 2010: pp. 1-8.
20. S. Darby, The effectiveness of feedback on energy consumption, A Review for DEFRA of the Literature on Metering, Billing and Direct Displays. (2006).