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# An analysis of smart metering information systems: A psychological model of self-regulated behavioural change

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ABSTRACT

Feedback is generally accepted as a suitable intervention technique to foster electricity saving in households. In this domain, smart meters are one promising way to deliver feedback in everyday settings. However, research has shown that feedback by itself is hardly sufficient. Hence, for a more effective design of smart meters, the opportunities which these offer to deliver feedback and to supplement this with other information should be considered. This article describes the specific characteristics of household electricity consumption that should be taken into account. Also, a comprehensive psychological model of self-regulated behaviour change that covers the complete process by which new types of behaviour are chosen and implemented is described in detail and different behavioural stages and components crucial for the design of information strategies are identified. A detailed overview is given of different existing applications and which stages of change these affect. However, as none of these existing smart meters features comprehensive and combined informational strategies that systematically cater to consumers in all stages of behavioural change, it is concluded that further efforts to optimise and evaluate smart meters should be undertaken. A smart meter information system which is designed according to these insights is outlined.



## 1. Introduction

Although an exact estimate of reduction potentials for electricity consumption in households is hardly possible due to substantial differences concerning the specific models of appliances in use and the way these are used, it is widely accepted that there is a relevant potential for saving electricity in households [1,2]. Against this background, the 2006 EU Directive (2006/32/EC) on end-use efficiency and energy services has set a reduction goal of at least 9% of the average consumption 2001–2005, to be realised until 2015 by each member state of the European Union [3]. The directive points out various strategies, how the member states are to achieve this goal. One of these strategies concerning households suggests the introduction of so called “smart meters”, i.e. digital meters that allow residents to access information about their recent actual energy usage. In 2012, Directive 012/27/EU repealed the 2006 Directive and expanded its requirements [4]. Now, billing must be based on actual consumption (information collected via smart meter feedback systems or in other ways) and must provide supplementary information on historical consumption, namely “cumulative data for at least the three previous years” and “detailed data according to the time of use for any day, week, month and year” (Article 10) and – where possible – “comparisons with an average normalised or benchmarked final customer in the same user category” (Annex VII). Beyond these requirements the format of the feedback and its informational context given by smart meters is not specified.

In recent years, smart meters have also been discussed in the context of load management, supply and demand balancing, peak reduction, load- and time-variable price signals, and prosumer management [5–9]. The focus of this paper, however, is on how a reduction of electricity consumption may be encouraged by smart meter information systems and the informational concepts associated with them.

Aiming at the reduction of electricity consumption, over the last years several smart meter information systems have been developed by various companies and research teams, ranking from simple digital meters that monitor and display electricity consumption (e.g. [10], see websites and website related materials) to enhanced smart meter information systems including home dis-

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plays, internet platforms, internet widgets or smart phone apps. These provide sophisticated interactive tools that combine differentiated feedback with additional information useful for decisions on electricity saving user behaviour and investments (e.g. [11]).

Fischer [12] points to some specific features of electricity consumption which explain why feedback measures are an important prerequisite to be able to control this type of consumption behaviour. The most important characteristic of electricity is that it is – in contrast to most other consumer goods – “abstract, invisible, and untouchable” ([12,p. 80]). For the consumer, thus far the only visible aspect of electricity consumption is billing which, however, informs the consumer often with a considerable delay and does not provide information on the consumption of individual devices and usage patterns[9]. That feedback can be a powerful intervention capable of motivating consumption reduction is commonly agreed upon [12–15]. Average savings range from 4% to 12 % [12,16]. The peak saving rates observed are larger than 20% [12].

However, there are studies where feedback does not show any effect at all [12,15,17,18]. This may be due to low baseline consumption of households and thus a bottom effect or a lack of motivation to save electricity or a lack of measures to induce such motivation [12,18]. The same general picture is obtained if real-time feedback only is focussed upon: real-time feedback results in significant consumption reduction in some studies ([16,19,20], but not in others [21–23]).

The difference in effectiveness between these studies seems to be accounted for, at least in part, by the type of the feedback. For instance, device-specific (via a central display or web-portal in the household or product-integrated) and room-specific feedback have been shown repeatedly to be more effective than feedback on total electricity consumption only [12,16]. Tailored feedback, which gives information about electricity savings referring to specific new behaviors, also seems to be powerful in inducing consumption reduction [24].

Temporal factors are also important. Direct feedback ((near) real-time feedback often presented on in-home displays or web-portals) induces higher savings than indirect (delayed) feedback [16,25]. However, daily or weekly feedback is not much worse than real-time feedback and better than enhanced billings [16]. A combination of device-specific and real-time feedback appears to be the most effective variant [16]. Findings concerning breakdown and directness suggest that feedback is more effective to the extent that the connection between behaviour and its consequences are salient to the user.

Socially comparative feedback represents another interesting case. It provides people with feedback about their own consumption, compared with the consumption of others. It has an effect on consumption, but the effect size is relatively small and differs between subgroups with high and low baseline consumption [26]. The overall small effect size of socially comparative feedback may be accounted for by the observation that, on the one hand, it induces a substantial reduction of consumption if a comparison group is consuming less [14,26] and, on the other hand, induces a so-called “boomerang effect” if the comparison group’s consumption is higher [27]. However, the “boomerang effect” may be inhibited by the invocation of injunctive norms (as introduced by Cialdini et al. [28]) approving low consumption for people whose consumption is already low [14,27,29].

It should be noted that methodological problems (small sample sizes, non-representative samples, limited comparability of studies, confounding of feedback with other intervention techniques or confounding different types of feedback) and research gaps prevent reaching more than preliminary conclusions concerning the effectiveness of different types of feedback. Further research is needed [12,15,16,30].

The way feedback is combined with other measures seems to have a strong impact on an intervention’s effectiveness [12,15]. Feedback is significant to the extent that an agent is motivated and has set himself or herself a goal [18] and knows about effective specific procedures of goal attainment [12]. Therefore, feedback should be combined with other motivational intervention techniques like goal setting/commitment and action-relevant information. This combination of measures proved more effective than each measure on its one [15,18,30,31]. With reference to computerized interfaces (in-home displays, web-portals, apps) both Erhardt-Martinez et al. [16] and Fischer [12] emphasize that the most effective designs incorporate multiple feedback and analysis options, including historical comparisons, as well as motivational techniques and electricity saving-related information.

All these findings point to the necessity to more thoroughly understand the situation of consumers in their households and their needs in the process of electricity saving. We claim that the existing smart meter information systems on the market do not satisfactorily exhaust the possibilities inherent in these systems to optimally support customers and to tap the reduction potential in household electricity consumption. We assume that smart meter information systems which offer only feedback should be accompanied by additional informational offers to maximise the effects. We further assume that the design of an optimal smart meter information system should be guided by a thorough understanding of the decisional processes and the learning tasks which are part of an enduring electricity saving strategy in households.

In this paper, we offer a psychological model of behaviour change to analyse in detail this task of saving electricity and point to appropriate measures to support actors in their endeavour to reduce electricity consumption. In this context we also highlight specific aspects of electricity consumption which have not yet been integrated in the model and the challenges which the adaptation of the model to this behavioural domain poses. As the model has successfully been applied in several studies concerning mobility behaviour [32–34], an adaptation seem most promising, even though no comprehensive evaluation of such an adaptation can be presented yet. Subsequently, we use the model to exemplarily analyse several existing smart meter information systems and present an approach how such systems could be optimised according to the model. The detailed analysis of existing systems requires the in-depth knowledge of which information in particular is available to the consumer under which circumstances. Therefore, within the scope of this article, we largely focus on systems implemented in Germany, where user-level access to smart meter information systems could be obtained. However, most findings highlighted here should be applicable to other countries where smart meter information systems are implemented.

## 2. The nature of electricity consumption

In Germany, more than 50% of residents report to have the goal of saving electricity [35]. However, at the same time electricity consumption in German households has not significantly changed over the last years [36]. One possible explanation for this discrepancy is that people indeed want to save electricity but do not know how to achieve their goals and how to put their intentions into action. This seems plausible, because an important feature of household electricity consumption is that it is caused by a variety of behaviours. These do not only have different relevance for the total electricity consumption but are also carried out with varying frequency, ranging from every day behaviour (habitual use of appliances) to behaviour that is only carried out once within a decade or even lifetime (purchase of new appliances). The saving potentials of single behaviours can differ enormously. They vary