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Smart meters: A users' view

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ABSTRACT

Smart meters are assumed to contribute to energy conservation by providing updated consumption data to energy utilities, but, given their pervasive presence in consumers' homes, they could also provide timely feedback to energy consumers/users. A precondition, however, is that smart meters are really usable to lay consumers. In the present study 40 participants were videorecorded while performing a set of reading tasks with the smart meter installed in their house, with or without the help of the users' manual; they were also asked to fill in a checklist to evaluate the meter after the task series. The results of the analysis suggest improvements in the terminology used, in the selection of information to provide, and in the navigability of the information system.

Keywords: *smart meter, usability, interface.*

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1. Introduction

The main distinction between a so-called "smart" meter and the older mechanical meter relies on a meaningful display to show not only the amount of energy used in the household, but also other historical data; and in the ability to communicate directly with the local energy utility for monitoring and billing purposes. In 2005, the Italian utility Enel was the first company in the world to massively implement the use of smart meters. In 20010 32 million smart meters were installed, and equipped with advanced features that ranged from reading usage information, detecting a service outage, changing the maximum amount of electricity that a customer can demand at any time, changing the billing plan remotely, changing the maximum amount of energy

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allowance, and turning the power off remotely. Eventually, it s foreseen that smart grids will use this information to estimate the energy demand more precisely, instead of generating more power a supplier than it is needed.

In addition to making remote control of the energy supply more efficient, information provided by a smart meter represents a direct feedback of the consumers' actions (Gölz, Götz, Deffner, 2009) which could be crucial to improve their energy conservation habits. According to a classic definition, Feedback Intervention (FI) consists of actions taken by an external agent to provide information regarding some aspects of performance (Kluger and DeNisi, 1996, p. 255). In the field of energy consumption, Darby (2006) distinguishes between three types of feedback: indirect, disaggregated and direct. Indirect feedback (e.g the kind of information shown on paper bills) needs to be processed before reaching the customers and only provides a general picture of the overall consumption; disaggregated feedback reports the consumption of individual appliances or categories of devices in a household; direct feedback is the one immediately provided by a meter or an associated monitor. Darby estimates that this feedback can lead to higher savings than interventions with indirect feedback, ranging from 5% to 15%. Feedback is most effective when it provides tailored and personalized information for a specific audience target (Jimison, Street & Gold, 1997; Fogg, 2003) and smart meters represent nowadays the only tailored and personalized source of feedback pervasively reaching the consumers.

The European Commission Energy Efficiency Action Plan (Energy Efficiency Action Plan, 2007) aims at reaching a 20% energy saving by 2020 and considers the residential sector along with the commercial building sector (tertiary) the one having the largest cost-effective saving potential. In the domain of gas consumption, a directive already exists according to which intelligent metering systems shall assist the active participation of consumers (Annex I(2), Directive 2009/73/FC). The progressive adoption of smart meters in the energy domain can be a further strategy to achieve energy conservation targets in the residential sector by improving the consumer's awareness. The issue, however, is whether the meter is ready to be exploited directly by the user.

The study illustrated in this paper addresses this issue by testing a common smart meter model from the users' point of view. The study relies on a series of readings of the meter information, required by the researcher to a sample of lay users in their own households. The users are also asked to select a series of attributes to evaluate the meter in a checklist, and to assign the responsibility for the failure that might have occurred in executing the tasks either to themselves or the meter. The paper presents the results, after describing the interface of the meter and the details of the testing procedure.

2. Smart meter interface

The smart meter considered in the study is the one adopted in Italy by the energy utility Enel, which already installed 32 millions at the time of the study (Figure 1).

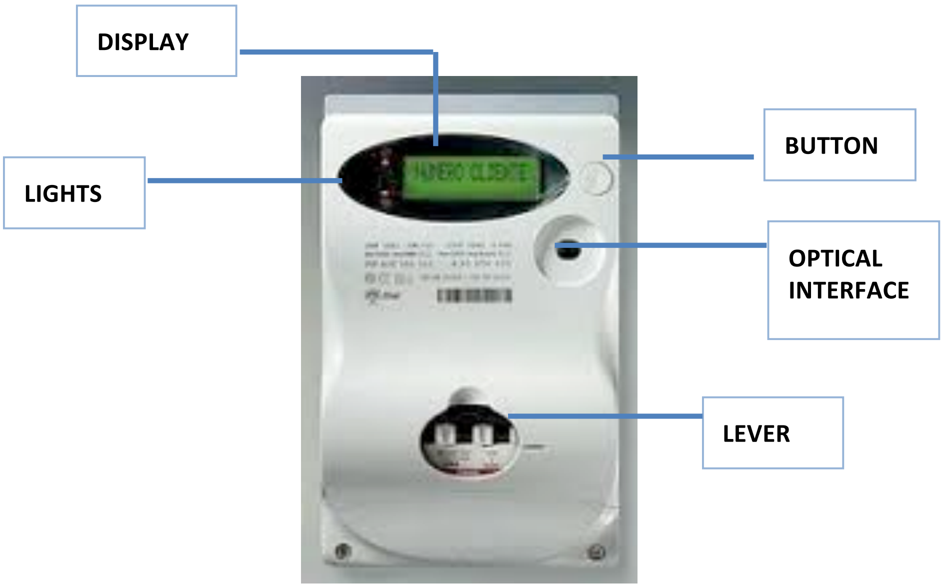

Figure 1. The smart meter model tested in the current study

A lever on the bottom part of the meter controls the house electricity supply. On the upper part of the meter are a display, two small lights and one button. The small lights flash at a higher rate if the house is consuming more than contractually allowed and at a remarkably lower rate if the house is consuming less; if both lights are flashing simultaneously, then no energy consumption for at least twenty minutes was registered. The information appearing on the display changes by pressing the white button on its right fro a certain number of times according to the desired information (Appendix 1)[1]. In addition, the corner of the display contains a symbol signaling the

[1] The Italian Authority for electric energy and gas asked to replace some of the information with more detailed one. Each A3 information was subdivided into A1, A2 and A3 (peak hours from 8 AM to 7 PM on weekdays; intermediate hours from 7 AM to 8 AM and from 7 PM to 11PM on weekdays and from 7am to 11 PM on Saturdays; off peak hours from 11PM to 7 AM during weekdays and Saturday, and all day

system state (i.e. “L1” if the meter works properly and “▽!” in the opposite circumstance). The meter also contains an optical reading interface, which is used by utility personnel only.

3. Method

The study consists of a series of reading tasks performed by the users at their own premises, followed by a checklist. The possibility to access the manual was granted to one half of the sample.

3.1 Participants and design

The sample was composed of 40 participants collected through a convenience recruitment procedure. They were asked to perform a series of tasks with the meter installed at their own house. To make sure that no linguistic bias prevented them from reading the information, they were all Italian native speakers. Also, to exclude people who had no direct involvement in the payment of their electricity bill and who, for this reason, could have poor knowledge of their smart meters, only people paying for the electricity consumed were included. Finally, experts in the domain of electricity (electricians, electronic engineers, etc.) were not included. Mean age was 47.2 (SD = 18.8).

The sampled was divided in three subsamples according to their age: 18 to 29 (12 people); 30 to 59 (18 people) and over 60 (10 people). One half of the sample was asked 10 minutes before the beginning of the task series to read the users’ manual accompanying the meter. Accessibility to the manual varied between subjects and task type varied within subjects.

3.2 Data collection procedure

Tasks

Each participant was asked to complete seven tasks, which are described in Table 1 below.

Task name	**Request**	**Button pressures needed**
Consumption	*Please, verify if your house is*	0 (The participant needs to visually check

during Sundays and National Holydays); similarly each P3 value was decomposed into P1, P2 and P3 with the same criteria as A3. As this innovation is progressively implemented, part of the meters still require 24 steps to read the full information cycle and part require 32 steps.

	currently consuming electricity	whether the lights on the left of the display are rapidly flashing or not.)
Failure	*Please, verify if there is currently a failure in the system*	0 (The participant needs to visually check the symbol at bottom left corner of the display).
Instant Power	*Please, tell me how much energy is currently being absorbed by your house*	4
Current Period	*Please, tell me how much energy was consumed by your house until the current billing period*	7 (or 9, in case of meters modified to meet the Authorities' requests described in Footnote 1)
Previous Period.	*Please, tell me how much energy was consumed by your house until the previous billing period*	10 (or 16 in case of meters modified to meet the Authorities' requests described in Footnote 1)
New bill period	*Please, tell me how much energy was consumed during the current billing period only*	10 (or 16 in case of meters modified to meet the Authorities' requests described in Footnote 1) In order to complete this task the participants have to press the button seven times to get the kW/h value related to the current billing period, then press the button three more times to get the value of the previous billing period and finally subtract the latter from the former.
Memorability.	The experimenter will choose a task in which the participant previously succeeded and ask the participant to teach how to perform that task.	NA

Table 1. List of tasks used in the test

Two cameras on tripods were used. Their exact position changed slightly to fit the configuration of participant's house. In all cases, one camera shot the meter from the user's perspective and the other shot the user while interacting with the meter. Adobe Premiere Pro 6 was then used to merge the videos from the two cameras into one so as to have a split screen with two synchronized views.

Figure 2. An example of the images collected by the two cameras.

Checklist

A checklist based on Microsoft's Desirability Toolkit was deployed to gather the users' evaluation of the meter after the task series (Benedek, Miner, 2002). To the original list of attributes, a set of attributes was added for this study, based on the attributes with which the meter is referred to in the 2006 manual and on the utility website[2] (domestic object, simple, familiar, efficient, safe, easy to use) as well as on the antonyms of these attributes (complex, unfamiliar, inefficient, dangerous, difficult to use). The resulting list was composed of 114 attributes, half of which were positive and half negative. In addition to the list, users were asked to complete a statement ("If I didn't manage to complete a task, it was:..") by attributing the responsibility for failures in completing a task to themselves or to the meter (1- only my fault; 2- mostly my fault; 3- partially my fault and the meter's; 4- mostly the meter's fault; 5- only the meter's fault).

3.3 Procedure

The procedure, which was refined after 27 pilot observations, started with the reading and signature of an informed consent. Then the participants moved to the room where the smart meter was located and started the task series. The instructions were given verbally, task by task. The tasks order was balanced across participants with a Latin square procedure in order to exclude learning effects. No pauses were planned between tasks. In case the participants asked for help, the researcher would remind them to only rely on their resources and judgment. At the end of the task series, the

[2] http://www.enel.it/it-IT/reti/enel_distribuzione/qualita/progetti_contatore_elettronico/contatore.aspx

participants were given the checklist, asked to read through it and invited to select as many attributes as they thought were adequate to qualify the meter. Later the participants were asked to restrict the choice to 5 attributes within those previously selected.

3.4 Data analysis

The video-recordings of the task execution were analyzed with the help of a video-coding software (The Observer by Noldus) in order to identify:

- task result, namely success, abandonment or failure;
- task length, minus repetitions or pauses;
- trade-off between the number of clicks made by the users and the minimum amount of clicks required for the completion of the task.

In addition, the following events were analyzed:

- misinterpretation of the functioning of the meter or of the information displayed;
- wish or intention to abandon the task before completion verbally expressed;
- request for repeating the instruction or receiving help in the execution of the task;
- adjustment of body position in order to reach the meter, e.g. crouching;
- adjustment of head position in order to read the display, as with light reflexes or darkness;
- pressure on the meter button ("clicks");
- inappropriate interaction, namely an operation on a part of the meter that is not appropriate to solve the specific task;
- non-verbal request for help, performed by stopping the task execution and turning the head towards the researcher.

Differences connected to user's age, gender, task order and access to manual were also considered and tested for significance.

Regarding the checklist, we counted the frequency of selection of each attribute. Regarding the final question about responsibility for failing in the tasks, the frequency with which the answer options were selected was considered.

4 Results

4.1 Effectiveness in monitoring household consumption

Effectiveness was the ability to successfully complete a task. It was decided by checking in the videos the answer verbally provide by participant as well as the information contextually displayed by the meter. Overall, 69% of the tasks were either abandoned or finished with the participant providing a wrong answer. The percentage in the different tasks is shown in Figure 2.

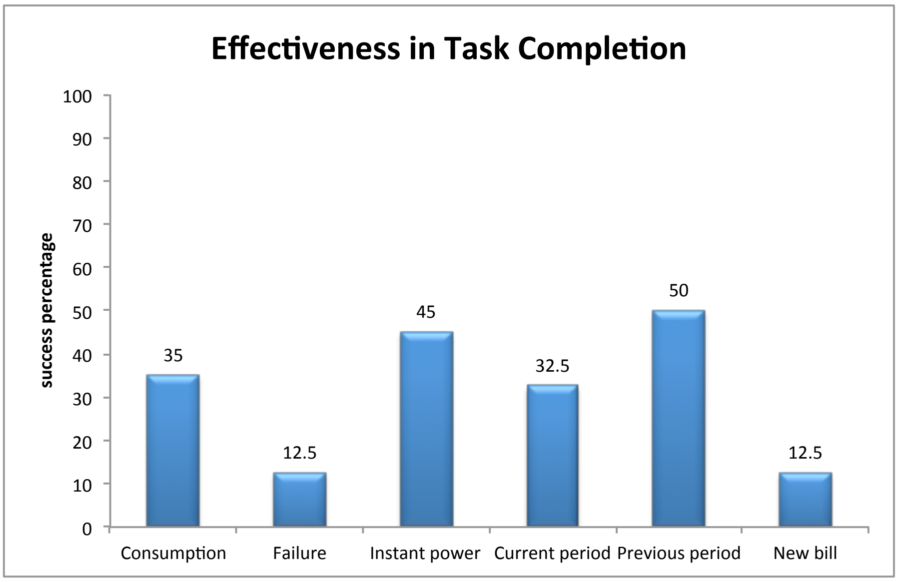

Figure 3. Percentage of participants who completed a task successfully

The figure shows that in the majority of the tasks, less than one half of the sample was able to get the right information. The lower effectiveness was reported in the tasks “Failure”, requiring to check if there was a failure in the electric system, and “New Bill”, requiring to calculate the total electricity consumption for the current billing period.

The participants’ age did not affect the success in completing the tasks. The access to the manual made a difference in two tasks, “Consumption” and “Failure”, where the performance in the two groups with and without manual differed significantly, with a higher performance in the former group (χ^2=9.294;$p<0.05$ and χ^2=11.693;$p<0.05$ respectively).

4.2 Efficiency

Efficiency consists of the amount of resources needed to successfully complete a task, in terms of time taken and of button pressures. The average time employed by the participants that completed the task successfully is shown in Figure 4. The task requiring longer to be completed was again the "New bill", which involved that the user obtained two different kinds of information from the meter and then subtracted one datum to the other. Age and the availability of the manual did not affect the time taken to complete the tasks.

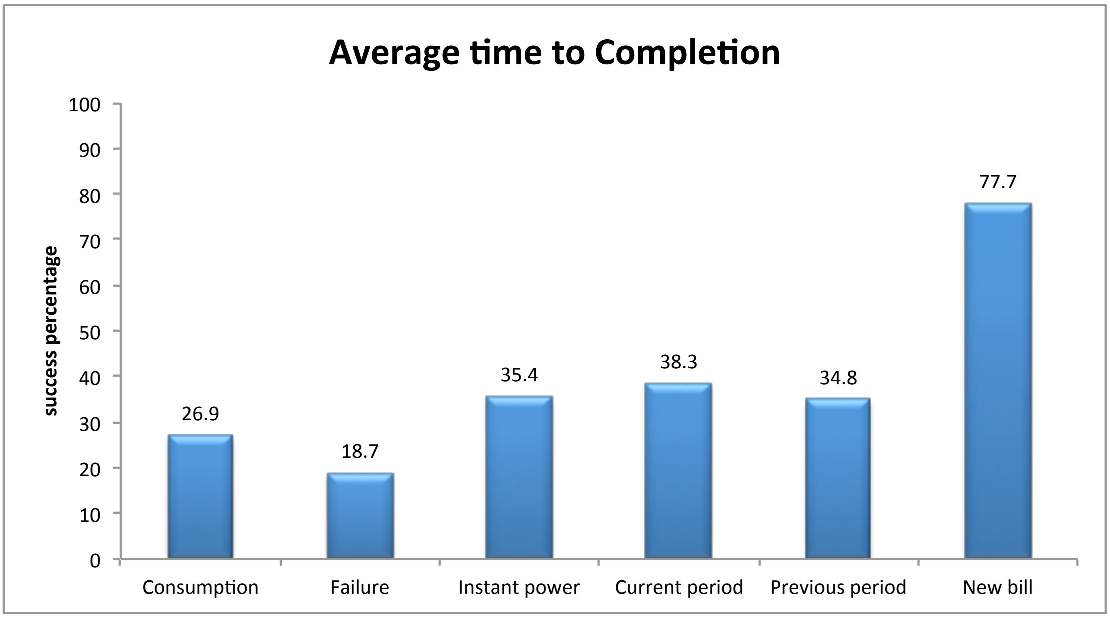

Figure 4. Average time in seconds used by participants to complete each of the 6 tasks

The other measure of efficiency was the number of exceeding click per task, which is shown in Figure 5 below.

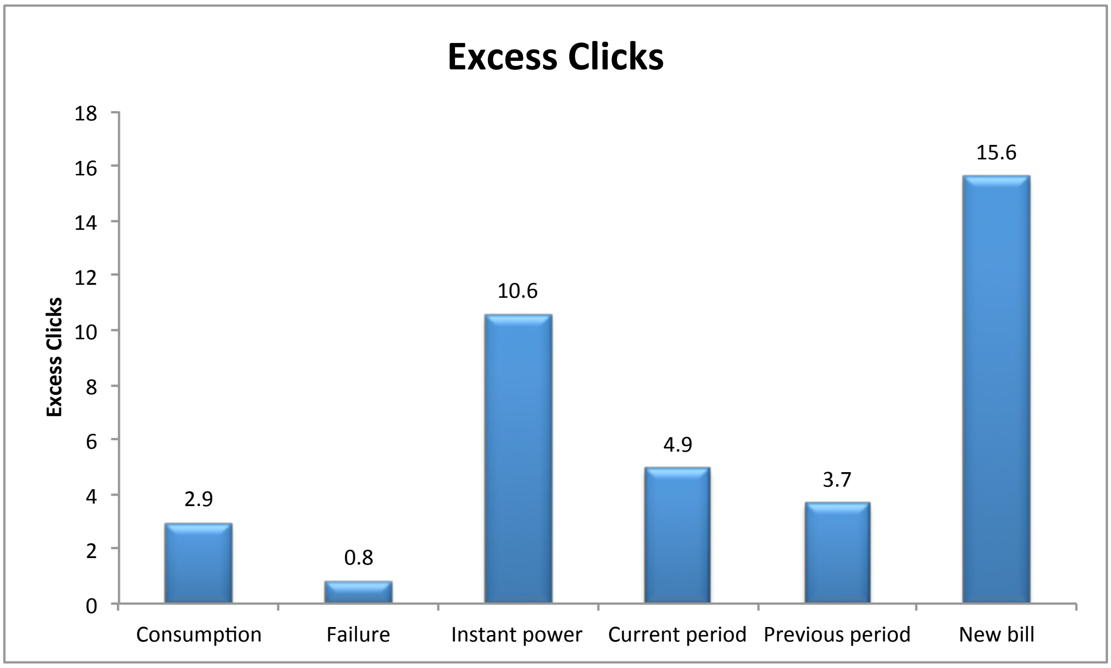

Figure 5. Number of clicks produced after reaching the correct information

The “Instantaneous power” and the “New bill” tasks seem critical; users did not seem to recognize the right info when they saw it, but kept on pressing the button. In case they realized that the right info had already been already displayed, they could not go back, but had to exhaust the full series of information and start over with a second round of clicks to see it again. Age does not affect this result, and the availability of the manual improved the result on the “Consumption” task only ($t=2.689$; $p<0.05$).

4.3 Comprehension of the information on the display

The cases in which users’ answers revealed an erroneous interpretation of the meter functioning and affordances were on average 1 per task (SD= 1.14) and took about 31.9% of the overall time spent on the task execution. Misinterpretations were only 0.16 in tasks completed with success and 1.75 in tasks that were failed or abandoned.

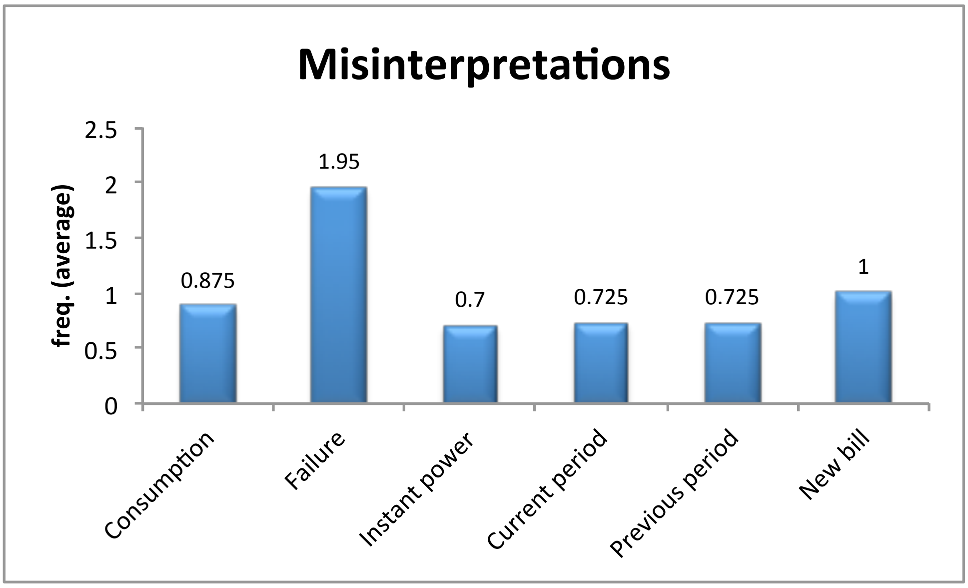

Figure 6. Average misinterpretation per user, revealed by the users' verbal answers, divided by task.

Similarly, the users' actions revealed a problematic interpretation of the meters' affordances.

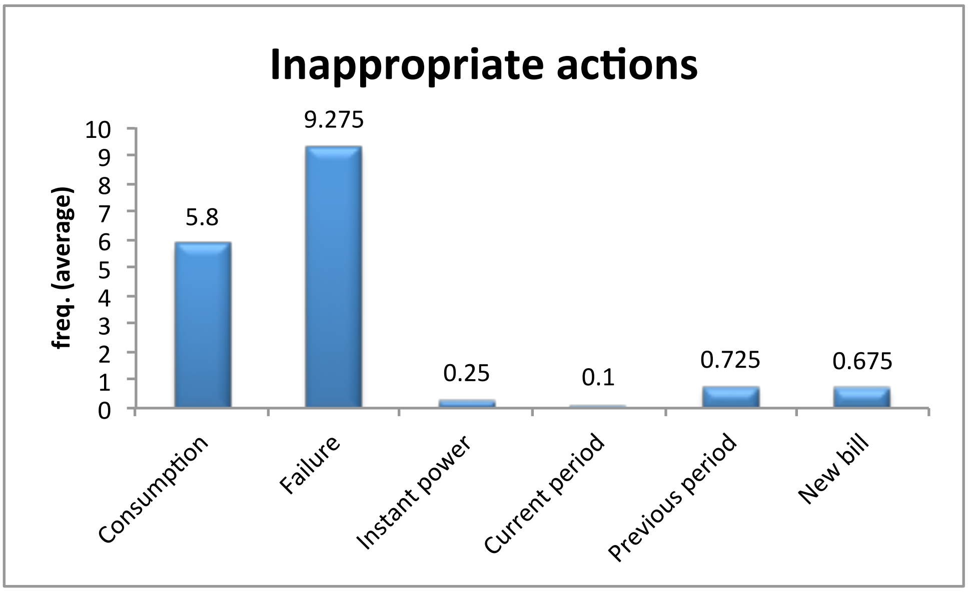

Figure 6. Average inappropriate actions per user revealed by the participants' actions, divided by task.

Taken together, figures 5 and 6 reveal that the first two tasks have a high number of problems in the usage of the meter: they required no special operation in order to get information because they just needed to interpret the default feedback provided by the meter (i.e. the lights or the symbols on the display corner respectively). In the consumption task, users had to define if the house was consuming electricity by referring to the lights on the side of the display. Here, the most common difficulty was to recognize the flickering lights as a cue: instead, users sought an answer on the display by clicking on its button and looking for the instantaneous power datum. Some users did not detect the lights flickering. Some did not even relay on the meter to answer, but on their knowledge that some appliances were currently working in the household. In the second task, users had to check the system status symbols always appearing on one corner of the display to define if the system was on. Instead, they relied on other cues, such as the mere fact that they could read the menu, the flickering lights or the power lever in up position.

The problems in the other tasks did not depend on the usage of a wrong part of the meter. These tasks required to provide a certain value of electricity consumed according to different criteria (instantaneous power, current billing period, previous billing period, new bill), and all users correctly referred to the display button to get the required information. However, they had difficulties in recognizing the right information when they found it and either reported a different datum or kept on looking of the correct datum, ending up in the excess number of clicks reported in section 4.2. For instance, when asked to provide the amount of instantaneous power consumed in the household, a recurrent mistake was to report the power absorbed in the current billing period. Or when asked for consumption on specific billing periods (previous, current, new bill), some participants asked to check their paper bills.

There is no significant difference between age groups, nor the groups with and without manual, except for the inappropriate actions in the “Consumption” task ($t=3.880$; $p<0.05$), which were higher in the group with manual ($M=10.2$ versus $M=0.8$).

4.4 Perceived simplicity

One measure of the perceived simplicity of the task is the occurrence of abandonments, help requests and requests to repeat the instructions; the former two events amounted to 0.95 per participant on average ($SD=1.44$), the third event was observed 0.22 times on average per participant. Requests for help regarded generically, what they should do (45%), if they should press the button (22%), if the answer was right (13%), what was the meaning of the displayed information (11%).

These questions confirm the results reported in sections 4.2 and 4.3, namely that participants had difficulties in comprehending the information and the affordance of the meter.

4.5 Accessibility

In order to check the occurrence of problems with the visibility of the display we checked whether participants adjusted the position of their body with respect to the meter or the position of their head while trying to read the meter (Figure 7). The first adjustment is due to the fact that meters are appended to walls sometimes at uncomfortable heights, so that the participants need to crouch or to reach up in order to see the display. In addition, adjustments of head position are due to light reflection on the screen of the display or darkness in the room whether the display is located.

Figure 7. A participant struggling to see what is written on the display

52% of the meters where positioned so a to force the participants to reach up or crouch in order to read them. Adjustments of the body position were performed during 33% of the time of the whole session, and adjustments of the head position were performed during 73.9% of the time.

4.6 Memorability

Memorability was measured as the amount of participants who were able to recount the way in which they solved one of the tasks in which they succeeded. In both conditions, with and without manual, only half of the sample managed to do so successfully, namely without any confusion or conceptual mistakes.

4.7 Evaluations

Users had to choose 5 attributes of the meter, out of a list 114 attributes where positive and negative ones were balanced. Regardless of the problems in the tasks, 62.5% of the chosen adjectives was positive; a higher amount of positive adjectives was selected by the group of users in the condition with manual compared to the users in the condition without manual (M=75 versus M=50, t=1.958, $p<0.05$).

Regarding the specific attributes chosen, Table 2 presents the attributes selected by more than 2 users.

		freq.
positive attributes	easy, easy to use	16
	accessible	11
	comprehensible	8
	innovative	7
	new	7
	avant-guard	5
	controllable	4
	clear	3
	credible	3
	safe	3
negative attributes	confounding	5
	ambiguous	7
	basic	4
	incomplete	4
	unfamiliar	4
	complex	3
	counterintuitive	3
	unsatisfying	3
	slow	3

Table 2. Attributes selected by more than two users, and frequency with which they were selected in the sample. Each user could select 5 attributes, either positive or negative.

At the top of the list are 'easy to use' (16 users), accessible (11 users) and comprehensible (8 users). It is curious that users evaluated the meter as easy regardless of the difficulties they just found in completing the tasks. This can be due to the simplicity of the interface per se, since it only had one button to press. Coherently, when asked to complete the statement "If I didn't manage to complete a task, it was:…" the majority of the answers selected involved the users' fault (Figure 8).

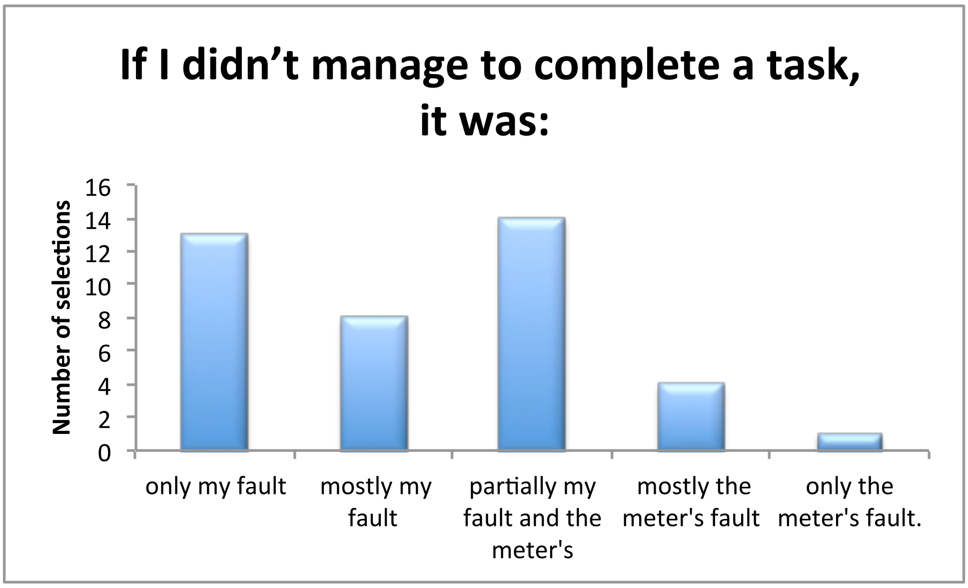

Figure 8. Participants' answers to the question asked at the end of the checklist.

5. Conclusions

The results of the present study show that users provide positive evaluations of the smart meters they have in their house and tend to consider them as simple; as a consequence, they hold themselves responsible for any failure in extracting useful information from them. However, the analysis of the performance during task execution suggests that such failure and difficulties are embedded in the design of the smart meter interface. To lay customers, it proves rich of misleading affordances, namely of cues that direct the users' towards actions that are inappropriate to reach the goal. In addition, the information is provided through confusing and ambiguous language or cryptic symbols, difficult to comprehend even by users who have access to the manual.

The more direct cues, namely the ones that are available without any need to operate on the meter, are generally not understood; this is the case for the flashing lights on the left side of the display, and for the symbols on the corner of the display. The information that is accessible only by pressing the meter button, on the other hand, has three downfalls: there is no way to access the desired information directly without also being exposed to a long set of undesired information; there is no way to go back in case too many clicks are executed; the language with which the information is provided is too technical and confusing to the user. These defeats impact both effectiveness and efficiency so that even if the user is prepared to go through the long series of button clicks to access the desired information it is likely that this information is not understood or recognized because of the way in which it presented. And even when participants reported the right information, in one half of the cases they could not remember how they managed to do it.

Therefore, in order to improve the usability of the meter and encourage its usage as a means to increase awareness and have direct feedback on energy consumption in the house, it would be recommendable to take into account:

- the familiarity of the terminology to the user; lay consumers are not expected to know symbols (such as "▽!" top signal that the meter is working properly), codes (such as "t2" for the price rate type) or jargon (such as "instantaneous power")
- the adequacy of the information to the users' needs; for instance, users need to get two values and do a subtraction in order to know the consumption in the current billing period.
- the availability of a back button, since running through 24 clicks in order to see the last information, and having to go though the full series of clicks in order to see it again if by mistake one presses the button once more is not a usable design.
- the perceptual visibility of the information on the display; this can be improved by avoiding that the meter is positioned in an inaccessible point on the wall, and by increasing the lightening of the display or using a back lightened display;
- the reduction of superfluous information, since a small display forces to several steps in order to get a long or complex information. A case in point is the sentence "*For information about the contract and notifications of failures please call (a telephone number)* " is divided into 6 chunks, each one requiring a click in order to progress to the next chunk. In case the meters model can still be chosen and is not already installed at the consumers' households, then models with larger displays should be preferred.

6. Acknowledgments

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8. Appendix

Information appearing after clicking the smart meter button.

1	click	Numero Cliente	*Customer Number*
2	clicks	321 932 025	
3	clicks	Tar in atto [*codice*]	*Active price rate [code, e.g. T2]*
4	clicks	Pot. Istant=000,1	*Instantaneous power= … (i.e. the energy absorbed by the household at the of the reading)*
5	clicks	Lettura Potenza	*Power Reading*
6	clicks	Periodo Attuale	*Current period*
7	clicks	A3 lettur= 000126	*A3 reading= … (i.e. energy consumption in kW/h till the moment of reading)*
8	clicks	P3 Pot. Max=000,7	*P3 maximum power= … (i.e. maximum amount of energy absorbed in the current period)*
9	clicks	Periodo Preceden	*Previous period*
10	clicks	A3 lettur= 000101	*A3 reading= … (i.e. energy consumption in kW/h till the end of the previous billing period)*
11	clicks	P3 Pot. Max=000,9	P3 Maximum Power= … (i.e. maximum amount of energy absorbed in the previous billing period)
12	clicks	Data 07/11/09	*Date*
13	clicks	Ora 09:26:44	*Hour*
14	clicks	Per Informazioni	*For information*
15	clicks	sul Contratto	*about the contract*
16	clicks	e Segnalazione	*and notifications*
17	clicks	Guasti	*of failures*
18	clicks	Telefoni	*please call*
19	clicks	n. 800-900800	*(a telephone number)*
20	clicks	Contratto inAtto.	*Active contract*
21	clicks	[code and description]	*[code, e.g. D2 - household usage]*
22	clicks	Di Residenza	*for residents*
23	clicks	[vuoto]	*[blank]*
24	clicks	[vuoto].	*[blank]*