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Julie Lassalle, Adélaïde Amelot

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APPROPRIATION OF TECHNOLOGIES FOR THE ENERGY TRANSITION: Determining factors

REPORT ADEME L7.1_14b (synthesis)

Julie Lassalle[1] & Adélaïde Amelot[1]

[1] Lab-STICC, Université Bretagne Sud

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Correspondence concerning this article should be addressed to Julie Lassalle, Université Bretagne Sud, Lab-STICC, 28 Rue de Saint-Maude, 56100 Lorient, France, Lorient, Bretagne, 56100. Email: Julie.lassalle@univ-ubs.fr

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BACKGROUND OF THE STUDY

CONTEXT AND OBJECTIVES

Today, the world faces unprecedented challenges to enable the sustainable development of our species and of our ecosystem more generally. Producing and managing energy resources is of the utmost importance as environmental, economic, and social issues are at stake. Policies of energy demand control are shifting towards increasing citizen accountability, and changing individual behaviors to exert greater control is viewed as one of the responses to the current challenges. The SOLENN project relates more specifically to the obstacles and the leverage points that impact people's energy – electricity more specifically - saving (ES). ES is a complex issue for people: it is not easy to establish the link between domestic uses of energy and their impact upon consumption because electricity is abstract, invisible, and impalpable (Fischer, 2008). Users do not consume it directly but indirectly, through domestic practices and using the electric appliances of the household; it is because people prepare meals that they use hotplates, the oven, the kitchen lights, etc. **It is thus possible to assume that immediate access to and the availability of information regarding the electricity consumption of a household,** unlike reading invoices that provide delayed and general information, **could make consumption visible and consequently bring about knowledge that, in the end, would induce greater control of electricity uses**. The planned rollout of "smart" distribution networks or smart grids is intended to achieve this purpose. The European directive on electricity (2009/72/CE) requires Member States to replace 80% of their electricity meters with so-called smart meters by 2020. The new technology that brings together information and communications technology (ICT) and smart meters (called Linky) provides users with the opportunity of optimizing the management of their electricity consumption since they can view their electricity consumption in near real time. Smart grid technologies thus engender new ES opportunities for users.

Usually, tools derive from people's needs to carry out an activity while fulfilling objectives of safety, performance, and autonomy. **In the case of the introduction of smart grids** as drivers of change of individual behaviors**, the tool proposed does not follow this natural path.** Driven by the needs of societies and institutions, this tool is pressed on people so they may seize it and use it for the purposes it was meant to meet. **The public authorities work from the assumption that the smart grid technology presented to people is appropriate,** i.e., used for the expected purposes, eventually leading to an increase of knowledge that is sufficient to induce controlled consumption practices. Hence, the type of uses and their impact upon ES practices are fully anticipated, determined in advance. Bobillier Chaumon (2016) reminds us that introducing a new technology is never neutral, but its consequences may not be determined a priori. Hence, the issue of people's appropriation of these consumption information retrieval portals is crucial and essential to understand their impact upon ES. As they constitute an available resource, does implementing

these portals create an enabling environment[1] that develop people Power to act[2] in increasing their knowledge, options for action, autonomy, etc. regarding ES practices. The longitudinal socio-ergonomic study conducted was intended to answer this question.

THE SOCIO-ERGONOMIC APPROACH: AN INTERDISCIPLINARY STUDY

The issue of appropriation is crucial to understand the obstacles and the leverage points that impact changing people's electricity consumption practices using smart grid technology. The psycho-ergonomic and sociology investigations conducted by the LAB-STICC (Université Bretagne Sud) in cooperation with the LUSSI Department of the Institut Mines-Télécom concerned the appropriation of the Internet smart grid portals developed and made available to volunteer households. The notion of appropriation relates to the actual use of the tool and to the meaning people derive from it. It is described as a complex process regarding the way individuals use and adopt tools and integrate these into their daily practices in the long term (Carroll, Howard, Peck & Murphy, 2003). Practices are thus progressively developed during the activity and for people's activity (Rabardel, 1995). To be understood, the use of a technological tool needs to be viewed within its actual environment, namely situated in people's actual activity reflecting their personal history and the organizational, social, and societal context (Proulx, 2005). Hence, appropriation results from dimensions that are both individual and social. In the context of energy management, the properties of the artefacts, individual motives, the social framework, or people's relation to the current issues of sustainable development are factors that may influence smart grid technology appropriation. In order to take these different dimensions into account, three coherent and complementary theories have been put forward: **(i)** the psycho-ergonomic theory of instrumental genesis (Rabardel,1995) to investigate the appropriation process as such (i.e., which uses, with which results); **(ii)** the sociological approach of uses (Proulx, 2005) to examine the influence of the social framework upon the development of use and its possible consequences on ES actions; and **(iii)** the theory of an actor-network (Callon, 1986) to examine the influence of the relations between individuals and the societal issues at stake regarding use. The socio-ergonomic investigation used this initial theoretical framework. However, a longitudinal investigation was used to enrich this framework to enhance its quality and ability to accurately account for what may help explain the appropriation of technologies. Hence, the psycho-cognitive theory of self-determination (Deci & Ryan, 2008) was also used.

The goal of the socio-ergonomic study was two-fold: **1)** to examine appropriation using the theory of instrumental genesis, namely considering both what people do on the portals (e.g., the functions used, the goals) and what the use of the portals actually brings them for ES practices (e.g., knowledge, actions); and **2)** to understand which conditions foster or hinder appropriation. For this second goal, the analysis focused on two issues:

[1] Environment that fosters learning and the development of opportunities for actions and options and that enables people to succeed and to develop (Sen, 1994, Falzon, 2005).

[2] Depends on the individual's external and internal conditions at a particular moment in time – state of the individual, artefact and resources available, etc. (see Rabardel, 2005a; 2005b for more detail on the conceptual framework of the Power to Act).

(i) the tool and its characteristics: from an analysis of the tool constraints upon the opportunities of use;

(ii) the idiosyncratic internal features : it concerns people's cognitive capacities to control the tools (i.e., knowledge and know-how regarding reading graphs and interpreting electricity data) ; conative capacities (i.e. motivations) ; external features concerning ES practices, monitoring consumption practices, the network of tools already in use to achieve ES (i.e. which tools, which goals) and the influence of the social and societal context (i.e., socialization process, family background, project background and domestic and technology context – built environment, equipment, technologies).

The analysis was thus broken down into three blocks:

- **Block 1:** analysis of the constraints brought by the portals upon use (influence of the usability level, technology maturity, rich and relevant functions upon use),

- **Block 2:** analysis of the idiosyncratic constraints (influence of the prerequisite internal resources - know-how, knowledge, motivation - and external resources - the tools used for monitoring, ES practices, social context)

- **Block 3:** analysis of use and instrumental genesis.

The detail of both the instrumental genesis theory and of the broader multi-disciplinary theorical framework is given and accessible in Lassalle and Amelot (2019) and in Lassalle, Amelot, Chauvin and Boutet (2016).

METHOD

STUDIED SMART-GRID PORTALS

For the SOLENN project, four Internet portals (or smart grid portals) were deployed to enable the participating households to view and monitor their electricity consumption in near real-time (i.e., the information is given every 10 minutes within a 24- or 48-hour delay). These portals were all specifically designed to display, at the very least, the consumption information provided by the *Linky* meters through a web interface. They differed, however, regarding delivering additional information concerning consumption or other matters (see Lassalle & Amelot, 2017 for more details regarding the characteristics of each portal):

- The SOLENN A portal: opportunity to view the overall electricity consumption of the household;

- The home automation portals (Dom. B and Dom. A): opportunity to view the household overall electricity consumption itemized by sector (e.g., appliances, domestic hot water, lighting);

- The SOLENN B portal: opportunity to view the household overall electricity consumption matched to weather information, to compare the consumption of the household with that of equivalent households, to receive general advice (eco-friendly actions), to take part in contests, to read the latest news regarding the issue, to view and participate in a forum, etc. The households using this portal also received support from the Local Energy Agency of Lorient, whether through group sessions or individual support.

SAMPLE

For this longitudinal study, the SOLENN project involved three campaigns. Each campaign involved (i) semi-structured interviews, conducted face-to-face in the home of the participants; (ii) observation of the activity of use of the smart grid portals, unrestricted by scenarios; and (iii) observation of the activity of use of the smart grid portals, restricted by defined scenarios to assess the usability of the portals. The same interview guide was used for all the panels. The goal of the observations of the activity of use was to assess the usability and perceived utility of each portal and the evolution of uses (see Lassalle, 2017; 2018 for more details). For each item of investigation, the protocols are outlined in Lassalle and Amelot (2017; 2018).

A total of four panels were monitored to investigate the ways people used, over time, the four smart grid portals of the SOLENN project: home automation portals Dom. A and Dom. B, general-purpose SOLENN A and SOLENN B. Table 1 shows the monitoring of the participants in each panel for each period of the socio-ergonomic study (Winter 1, 2, and 3).

Table 1: Participants in each panel for each campaign (Winter 1, 2, and 3).

	DOM. B	DOM. A	SOLENN B	SOLENN A	Total
Winter 1	9	10	0	11	30
Winter 2	7	8	9	8	32
Winter 3	0	5	4	6	15

A total of 77 interviews were conducted during the 3 study campaigns and collected from 36 households. The characteristics of the sample of the psycho-ergonomic study are presented in Table 2.

Table 2. Characteristics of the sample of the psycho-ergonomic study

	Socio-demographic indicators	Sample n=36 (%)
Sex	Male	61.1
	Female	38.9
Age (Year)	Under 25	8.3
	25–39	13.9
	40–54	13.9
	55–64	38.9
	65 and over	25.0
Level of education	No formal qualifications	-
	Professional upper secondary school (CAP, BEP)	24.2
	General upper secondary school (Baccalaureate)	9.1
	Higher education	66.7
Socio-professional category	Farmers	-
	Artisans, retailers or business managers	8.6
	White-collar workers and intellectuals	42.9
	Technicians, supervisors/line managers and middle management	14.3
	Clerical or non-executive employees	17.1
	Blue-collar workers	2.9
	No professional activity	11.4
Household size	One person	8.3
	Two people	5.6
	Three or more people	86.1

COLLECT AND RECORD OF THE DATA

Approximately 93 hours of interviews and 26 hours of video were collected, coded and analyzed. Two main types of data were collected, processed, and analyzed: speeches (from the semi-structured interviews and spontaneous verbalizations collected during the usage activity) and navigation data on the portals (the path usually taken, time to complete a scenario, number and type of difficulties observed, etc.). All interviews were recorded using dictaphones (Zoom H1). The participants and their use activity were also filmed throughout the use activity using the *Morae Recorder* software (v. 3.3.4). The coding of the use activities was carried out using the *Morae Manager* software (v.3.3.4). The coding and content analysis (verbalizations and interviews) was carried out using *Nvivo 11*. These tools allowed a detailed analysis of the activity of using the portals and the comments and discourse of the participants. The speeches and verbalizations collected during the use activity were entirely transcribed (Winter 2 and 3 and partial transcript of simultaneous verbalizations for Winter 1).

CODING OF THE QUALITATIVE DATA

The analysis of the statements collected involved the analysis of the joint thematic content (i.e., deductive and inductive) of all the verbatim statements made. Thematic coding was used: grids of categories were applied to the content (Zumbilh, 2004) using ex-ante categories arising from the literature and initial research hypotheses (see Lassalle & Amelot, 2015) and ex-post categories emerging from the discourse without predetermined assumptions. The thematic coding was thus initially both deductive, based upon categories arising from previous work, and inductive, to reflect the rich input of the interview data.
The ex-ante criteria involved the criteria of instrumental genesis *(Instrumentation* - identification of the schemes of use; *Instrumentalization* - identification of the catachresis; and *Instrumental mediations* - identification of the impact of the use of the technologies upon people's knowledge and practices regarding ES), the theory of uses and, to some extent, the examination of the socio-technical network. The coding grid used to investigate the appropriation and the conditions thereof referred to the psycho-ergonomic and sociological criteria found in the theoretical framework defined in Lassalle & Amelot, 2015. A separate coding grid based upon psycho-ergonomic criteria (Bastien & Scapin, 1995; Nemery & Brangier, 2014) was also used for the analysis of the perceived usability and utility of the smart grid portals (see Lassalle, 2017).
The ex-post criteria mainly involved people's motives for engaging in interactions with the technology.

RESULTS: BLOCK 1 (FOCUS ON THE TOOL) - THE ARTEFACTS CONSTRAINTS

The technologies presented to users are not neutral; they reflect both the designers' view of how the tools should be used and their representation of the end users (e.g., their goals of use, competence). Hence, the design decisions both open up a field of possibilities and create constraints on people's opportunities for action. Each tool brings a set of constraints that weigh more or less heavily upon activities. The initial forms and functions of artefacts prestructure action in relation to the way their designers have viewed and anticipated it. In other words, designers

create a universe of constraints and possibilities that people need to contend with when developing their activity (Rabardel, 1995).

Three types of interrelated constraints (see Trouche, 2003; 2005), all contributing to the pre-structuring of the user's action, have been selected and are detailed below.

INTERNAL CONSTRAINTS

Internal constraints involve all the minimal conditions that enable the technology (i.e., the Internet portals) to exist as intended, namely, to be an interface between the smart meters and the network users so that the latter may monitor their electricity consumption. So that the smart grid technologies may be sufficiently mature to fulfill their purpose, two main modes need to be met:

- **Portal access**

This mode refers to both portal visibility and the possibilities and ease of connecting to the portals. In the first case, the issue is to make the smart grid portals visible: people need to know they exist and can find them easily using search engines. In the second case, the issue is that people may connect easily to the portals. It is essential that this first level of interaction with the technology be optimal. The serious difficulties or even impossible access to the portals experienced in this project significantly reduced their usability and people's possibilities of use; consequently, the usefulness of the technology was nullified even before it was used. These difficulties thus constitute a major obstacle to technology use.

- **Portal efficacy**

The efficacy level of Web portals refers to their conformity with what they should do and be and with what is actually available and fully functioning. First, this issue involves the availability and display on the portal of the information concerning electricity consumption. One of the goals of the Brittany Electricity Pact is the increased control of electricity demand, in particular using ICT that offers households the opportunity of monitoring their electricity consumption. If this condition is not met (i.e., the information is not displayed), the existence of the Web portals is not justified from the users' perspective as they cannot use them even before discovering the opportunities afforded by the tool. Second, beyond the issues of access and availability of the main information, portals need to be entirely finalized before implementation. In particular, they need to show (i) a sufficient history of electricity consumption (at least 1 to 6 months, 1 year would be ideal) and a precise and explicit measure for the users; otherwise, **interpretation errors are significant and counter-productive**, and (ii) operational functionalities. Should this not be the case, users need to be warned of the situation. This is also true of potential malfunctions. Users who have abandoned interacting with the technology because of difficulties of use are not necessarily going to go back to it, even if the technology changes. Implementing beta versions (i.e., non-finalized digital tools) undermines appropriation and investigating it in similar projects.

Difficulties at the level of access and efficiency significantly restrict the use of these tools and become prohibitive as they represent a stopping point for users' willingness to interact with them.

In the SOLENN project, **examining the potential and actual impact of smart grid technologies was restricted as it was conducted with unfinished tools.**

COMMAND CONSTRAINTS

Command constraints correspond to the examination of the field of possibilities (i.e., the available commands) provided by the new tool to monitor electricity consumption. The level of functions varies from one portal to the next, but overall, the functions viewed as essential[3] are poorly integrated. Several participants saw the lack of explanations of eco-friendly actions and customized advice as a serious barrier to **going from knowledge to action; information on its own is not enough to drive this movement**. When the electricity data are read and understood, but people cannot translate them into actions, the data are irrelevant and useless from the ES perspective. In addition, **interpreting the consumption graphs provided by the tool is problematic when it is difficult to remember the context (e.g., weather conditions, domestic activities) relating to the consumption events shown on the graphs.** The decontextualization constraint is general and significantly restricts the opportunities of adequate information comprehension and appropriation of the technology. The lack of contextual information to read the electricity consumption information increases the users' cost because (i) it limits their understanding of the causes of the fluctuations observed, and (ii) it induces an increased personal effort for those who wish to overcome the negative effects of this decontextualization. Adding information such as the indoor temperature or weather data and giving users the opportunity of annotating the consumption graphs to match domestic activities (e.g., oven use, use time) and energy data appear to be essential to contextualize the data and enable their proper interpretation.
Conversely, some of the functions available on the portals were seen as irrelevant, in their current form, or even cause for demotivation or lack of credibility. In particular, these involved opportunities for interpersonal comparisons, taking part in contests, viewing a list of eco-friendly actions that is not regularly renewed, or having access to an inactive forum. Cost integration also brings mixed results; users' lack of involvement regarding some portal functions is dealt with in the next sections. The number of functions available is not enough, on its own, to predict or explain appropriation; the relevance of the functions is also a fundamental criterion.

ORGANIZATIONAL CONSTRAINTS

Organizational constraints refer to the ergonomic decisions made by the teams of designers who promote a certain type of portal use. The results and analyses of portal usability show clearly the characteristics of these constraints. Overall, the portals are found to be **rigid** (i.e., non-adaptive to the expertise level of users and non-customizable)**, difficult to manipulate, fallible, and barely intelligible.** The low usability level of the tools represents an obstacle to people's opportunities of use and appropriation of these tools.

[3]These functions are found in ADEME Deliverables L2.3_123, 31_4.1 and L2.3_4. These deliverables list the relevant functions to be implemented in the smart grid technologies to foster their acceptability. A sub-set of prioritized functions to be implemented has been identified. A grid of existing features has been established. The command constraints were investigated using a common comparative grid that provided a picture of the opportunities offered by each SOLENN portal.

- **Rigid portals**

The portals do not adapt to the expertise level of users, whether the latter are novices who do not possess enough knowledge to read and interpret the data or experts who would like to have renewed and/or technical information to continue learning and develop their electricity consumption control; their needs change, but the portals do not adapt accordingly. Furthermore, the portals are not customizable; the units and display formats of the data, the type of data shown, or the characteristics of the measurement cannot be modified by the users. This rigidity sometimes affects the relevance of the data shown. For instance, the decision to show the consumption of the induction plate, without giving the opportunity of modifying this function, was generally viewed as irrelevant. Users also deplored that the portals were not available in an application. This rigidity prevented users from adapting the tool to their needs or competence level. This lack of adaptability and flexibility significantly restricted the possibilities of use and consequently reduced the possibilities of appropriation.

- **Difficult or impossible manipulation**

The information relating to the daily consumption was difficult to find and to manipulate; most users found it difficult to find the daily power curve and to use the calendars to modify the display periods of electricity consumption. The opportunity of reading the daily power curve constitutes the primary function of these portals; it is the very reason why these Web interfaces were designed. Hence, the difficulties experienced or even the impossibility of accessing this information bring about a use failure: the usefulness of the technology is not perceived, and no positive effect of its implementation on the ES practices may be expected.

- **Barely intelligible information**

Consumption graphs are viewed as educational aids; they need to help users analyze the information on their own, thus developing their capacity to examine and modify their domestic practices in relation to their electricity use. People reading the graphs are thus learners; they are not empty vessels to be filled but learners who need to understand what they are doing. Yet, all those who used the portals and/or participated in usability tests met with difficulties to understand the information given. This was caused, on the one hand, by the decontextualization effect discussed above, and on the other hand, by the highly technical orientation of the digital tools. Reading the graphs, and in particular, interpreting the observable phenomena, requires knowledge in scientific (being used to reading graphs), technical (regarding electricity), and energy domains. Hence, reading and understanding the information require

- **competence in graph reading:** deciphering the axes, identifying the units, the captions, etc.;

- **competence in reading and interpreting the technical unit of kWh to situate the consumption figures:** the kWh unit was found "**unclear" by all the participants who had no link with the domain of electricity.** Hence, the electricity data displayed were abstract and of little use. Moreover, adding a comparison standard or the electricity cost was not always seen as relevant. In the first case, the comparison criteria, seen as too broad or too vague, made interpretation difficult. In the second case, the cost makes the

information more concrete and is deemed necessary, but adding it increases neither knowledge nor the implementation of control actions. Further investigation is needed to fully understand what this information brings to users who are unfamiliar with electricity data. Displaying this information is nevertheless essential to meet as widely as possible the needs of users of these portals targeting the general public;

- **knowledge, at least approximative, regarding the consumption of the household electrical appliances** (e.g., knowing the consumption of one's kettle to be able to identify it on a consumption curve). This comprehensive approach enables users to match an event seen on a graph with a domestic activity; otherwise, reading the daily power curve involves simply reading the key consumption moments (i.e., mostly preparing meals, leaving/returning home). The data show graphically information about everyday living; this information is perceived as trivial, and hence irrelevant;

- **a comprehensive view of the power-consuming appliances and their operation** (e.g., being aware of the permanent consumption of the Internet box or the night-time hot water tank activation). Without this comprehensive view, interpreting the consumption peaks, apart from the key consumption moments, is difficult or even compromised.

The technical nature of the information and of the portals is exacerbated by the decision to use an expert's vocabulary, little accessible to the majority of people, and unclear captions, or even lack thereof.

- **Fallible technology**

The severe malfunctions of the systems caused the lack or loss, whether occasional or recurrent, of electricity data. The loss of data was not signaled by error messages to inform the system users. Hence, portal users had no information enabling them to understand the origin and the nature of the data loss. The loss sometimes caused serious interpretation errors (e.g., self-comparison). The reliability of the smart grids as a whole is then called into question. Overall, the various malfunctions caused the loss of trust in the smart grids; both the smart grid technology and its content were perceived as fallible, and the credibility of the technology was undermined.

A set of over 200 recommendations for development, broken down by portal, was provided in response to the ergonomic deficiencies observed. **Most of the observations made in the study and the recommendations deriving from them are in line with the recommendations found in the scientific literature regarding the technologies for sustainable development.**

The constraint analysis provides relevant insights regarding the reasons why 58% of the participants did not continue using the tool: the lack of visibility of the technologies, the frequent malfunctions, the considerable difficulty to locate the consumption information, the repeated and unannounced absence of data, the technical nature of the information, etc. made using the portals difficult or even impossible. Information that is difficult to understand places people in a no-win situation and prompts disengagement from using the tool, or even ES practices. Furthermore, if some or all of the information is not understood or appears unreliable, the information is not taken into account (Burgoon et al., 2000, cited in Nemery, 2012). Technical problems (e.g., absence or loss of data), difficulties of use, even small errors (e.g., spelling mistakes) have a very negative

impact on perceived credibility (Fogg et al., 2000). The resulting evaluation endures, just like the opinions people have of human agents (Fogg et al., 2000). Information that is viewed as credible and convincing is a prerequisite to acceptation of the system. Hence, it is necessary that the consumption information provided be clear and easily understood to be considered and to reduce people's fears regarding the smart grid type of technologies.

RESULTS: BLOCK 2 (FOCUS ON PEOPLE) - THE IDIOSYNCRATIC CONSTRAINTS

THE IMPORTANCE OF DIGITAL KNOW-HOW

The literature on the use of ICTs shows that inequalities in the use of technologies depend less on material access to technology than on people's actual or supposed technology skills, all things considered (Brotcorne & Valenduc, 2008). Hence, in this investigation of smart grid technology appropriation, it was appropriate to examine the participants' relations to ICTs. The analysis shows that the difficulties of using ICTs or the need to unwind after the day's work prevent or hinder the development of smart grid technology use. The lack of proficiency using digital tools, but even more so the feeling of incompetence or the lack of interest in technologies in the domestic sphere, are closely related to the non-use of the smart grid technology. The reverse, however, is not the case: it is not ICT-related digital skills that determine use, and other factors are involved.

THE IMPORTANCE OF KNOWLEDGE REGARDING ENERGY

In smart grid portals, the electric power graph represents the intermediary between people's domestic activity and their electricity consumption; it should show this link and foster people's autonomy towards more frugal consumption patterns. For the graph to make sense to people, they need to possess the necessary resources to read and interpret the information and use it. What is the meaning of the consumption evolutions? Do they represent considerable or normal consumption? Is it possible to change these evolutions?

The ability to read and manipulate graphs is a facilitator, but it is not enough on its own to fully understand the information. Processing and using the energy information requires basic knowledge of the energy domain. People who could not read and process graphs did not develop their use of the smart grid technology. Furthermore, lack of practical knowledge concerning ES implementation restricts the development of use and the possibilities of actions.

Know-how concerning reading graphs and knowledge in the energy domain that is both formal (power level of appliances, household energy-consuming devices, etc.) and practical (e.g., ES possible actions) are essential for appropriation of the technology. This observation is borne out by examination of the energy culture score: people who developed using the smart grid portals possess a significantly higher energy culture score than those who did not develop any use whether at the beginning or at the end of the project. These results show once more the high technical and expert characteristics of these tools and of the information provided. Prior knowledge in the domain of electricity consumption contributes to the construction of use.

People possessing enough know-how and knowledge to use the tools were also familiar with energy issues. They also all showed a high level of training and/or exercised or had exercised occupations involving frequent graph manipulation, sometimes in relation to the electricity domain. Hence, people's available knowledge and know-how can be transferred onto the use of smart grid portals

and reduce its use cost. Conversely, when competence is lacking or insufficient, people find it difficult to make sense of the data and use them. This technology is thus adapted to people with specific skills; otherwise, the learning cost is high and requires high levels of motivation.

THE IMPORTANCE OF INITIAL MOTIVATION

- ***A-motivation*: Generating interest and arousing people's curiosity are the first essential steps**

In the SOLENN project, the volunteer participating households engaged in the experiment with various motivations relating to electricity consumption. However, a small number of the households showed a-motivation regarding the project and the smart grid technology. Initially a-motivated profiles should not be minimized; a-motivated people regarding consumption monitoring or fearing the *Linky* meter could be largely under-represented in the sample. So that these technologies meet the challenges that drove their implementation, **a first step involves arousing potential users' interest and curiosity; should this not be the case, the technology is rendered invisible.**

- **The *contribution* type of motivation: Motivation that commits to the project but not to the interaction with the technology**

Motivations based on the desire to contribute refer to people's opportunity to contribute to their society or group through participating in the project. Project participation is then viewed as the opportunity of being heard, nurturing the social bond, or working for concerns that are important or hold personal relevance for people. This type of motivation responds to goals of meeting the obligations of the community to which people belong (e.g., solidarity), stimulating the feeling of belonging and self-worth (e.g., providing an example, being a pioneer), or even advocating (e.g., influencing public policies, conveying a political message). This type of motivation is extrinsic, i.e., it is not associated with people's powerful commitment to an activity. It commits people to the project but does not commit them to use and action. **Putting forward the notion of contribution or social distinction does not appear to be relevant to encouraging people's interest and commitment to interaction with the tools monitoring electricity consumption and the development of ES practices.**

- **The *management* type of motivation: Motivation that triggers the connection but does not explain appropriation**

The management type of motivation is the one people cite most often to justify participating in the SOLENN project (89% of participants) and relates essentially to a financial and budget-oriented interest. Almost all the people reporting this motivation used the Internet portals to monitor their electricity consumption; **this type of motivation thus seems to provide effective leverage for engagement in interacting with the technology.** However, if difficulties are met at the time of the first uses of the tool, and if these difficulties cannot be overcome and/or the utility of the tool is no longer perceived, the management type of motivation falls apart over time. It then becomes a-motivation towards the use of technology and may even lead to discrediting the smart grid. Furthermore, this type of motivation (i.e., avoiding overcharges, reducing the energy bills) is an

extrinsic motivation that does not lead to commitment. Less than one third of participants reporting this type of motivation eventually developed technology use generating ES actions. The management type of motivation was then always associated with intrinsic motivation. **The management type of motivation triggers the connection but does not explain appropriation.** Considering the results, **an argument focused on more effective management and financial benefits could draw people's attention to smart grid technologies.** Publicizing the issues of better managing one's household and one's budget using these technologies could then be used as leverage not to change people's practices but to make visible in people's environment those technologies that may assist them. However, **this argument will not be sufficient to sustain people's interest and lead them to changing their practices, which is what the technologies are intended to achieve.**

- **The *responsible citizenship* type of motivation: Motivation that is dependent on the management type of motivation**

Motivation based on the notion of responsible citizenship (e.g., avoiding wastage, preserving the environment, limiting nuclear production) is reported by 69% of the sample to justify their commitment to the SOLENN project and their electricity consumption monitoring. This type of motivation is autonomous in nature (i.e., it is a high level of motivation), but it remains extrinsic: it is not the activity in itself (i.e., consumption monitoring) that people are interested in; rather, it is the consequences this activity may bring. About one third of the people reporting this type of motivation developed smart grid technology use that then generated ES actions. Nevertheless, the initial motive of better management of the household expenses is always associated with it. Overall, when the responsible citizenship type of motivation is present, it is predominantly dependent on the management type of motivation; in other words, the financial motivation prevails. This result is congruent with the literature data showing that in the domain of energy consumption, environmental motivations are largely behind financial concerns (Sweeney, Kresling, Webb, Soutar & Mazzarol, 2013). The proximal dimension (i.e., intimate, concrete, and immediate) of the financial benefits in relation to the distal dimension (i.e., external, distant in time and space) of the environmental or citizen benefits could be a possible explanation. The link between practices and environmental impact appears to be less perceptible and more difficult to establish than that between practices and reducing the electricity bill. **Hence, arguments related to proximity and immediate and visible effects (e.g., financial benefits) could provide a relevant approach to make the new technologies visible and attractive, at the very least.**

- **The *collaborative* type of motivation: Motivation that uses the need to relate to others**

The collaborative type of motivation relates to the need to communicate to learn and grow. It involves the desire to contribute to innovation, the desire to share with other participants and/or project partners testimonies, tips, ES experiences of problems met when using the technologies, with a view to helping improve the use of the technology. The collaborative type of motivation relates to some extent to the notion of being part of forms of participatory democracy, whether technical or relating to the local environment. The main purpose is then to participate in constructing an innovation, whether technical or social, through the circulation of knowledge (Callon & Barthes, 2005). Portals designed to promote electricity consumption control, and more generally sustainable development, would do well **to enable users to communicate with a community of people who are involved in the energy transition challenge.** Relating to others

promotes learning through experience sharing and fosters intrinsic motivation whose positive impact upon commitment to activity has been shown in the theory of self-determination.

- **The *tech-savvy/epistemic* type of motivation: Driving both use and learning**

Overall, connecting to the portal involves the desire to satisfy people's natural curiosity to see the household electricity consumption; use is spontaneous, autonomous, and responds to an interest in data. If this curiosity is not satisfied, in particular because of the problems of usability of the portals, the interaction is quickly interrupted. Beyond this initial curiosity, some participants voiced their genuine liking for data and the opportunity of considering the data using dedicated technology and their prior strong interest in the opportunity of analyzing and better understanding the household electricity consumption. These participants all showed scientific sensitivity or even sophisticated knowledge in the domain of electricity. Most of them developed considerable use (i.e., frequent and sustained) of the smart grid technology and of ES knowledge and actions. This observation is congruent with theories of self-determination positing that intrinsic motivation fosters the development of activity and has a positive impact on people. It is the willingness to understand and learn about electricity data that drives the use of the technology. The intrinsic, tech-savvy/epistemic type of motivation constitutes the main leverage element of the development of smart grid technology use and of the individual power to act regarding electricity saving practice. **Technologies that aim to support people in an energy transition approach need to stimulate intrinsic motivation to maximize their chances of appropriation.**

THE IMPORTANCE OF PRIOR PRACTICES

- **The instrument systems for electricity consumption monitoring**

The participants demonstrating instrumental genesis were mainly those who, before the project, had developed an intensive system of instruments (i.e., several tools were used for monitoring, and monitoring was conducted regularly and frequently). Conversely, the participants demonstrating a weak system of instruments (i.e., using the electricity bill only, at the time of reception) did not develop the use of the smart grid technology. In the first case, interest was already present for the activity of monitoring, which characterizes intrinsic motivation for use. **Hence, the new tool gave participants the means of meeting a need and of developing an existing network of tools for their electricity consumption monitoring.** In the second case, prior monitoring practice was limited, or even non-existent, and remained so during project participation as the technological support provided failed to develop the activity. Overall, when the smart grid portal cannot be integrated into the usual monitoring practices or does not develop them, the portal is then viewed as irrelevant, and interaction is abandoned.
The existence of a prior system of instruments fosters smart grid technology appropriation. Inserting smart grid technology then provides new functions or brings together functions previously scattered within the existing system of instruments. The various functions arising from different artefacts that are used in the system of instruments indicate potential new avenues for designing a new artefact that could bring them all together (Bourmaud, 2006) as they may be viewed as essential functions for the development of ES practices. The functions used in the smart grid portals are examined in the analysis of instrumental genesis (Block 3). Moreover, when a system of instruments is developed through the introduction of technology, it is not necessarily destroyed in

case of use failure; its very availability or replacement by other monitoring tools actually empowers people. This final observation shows that introducing the tool fosters monitoring practices in some cases and develop the people power to act in this domain. It also indicates that monitoring tools that could provide greater usability than those offered in the SOLENN project are likely to engender greater pairing opportunities between people and tools, and their scope would then be much greater.

- **The relationship to ES practices**

Given the central place occupied by electricity in people's daily domestic practices and the ambition of smart grid technologies to contribute to modifying these practices, it was necessary to examine the relationship of the participants to ES practices. The ES practice score arising from the quantitative analysis carried out by the management sciences team was used to characterize the level of practice of each of the households interviewed in the socio-ergonomic study. Beyond quantified practice, **the constraints and the value people derived from this practice** were also investigated with a view to better identifying its relationship to energy sobriety.
The management sciences investigations conducted for the SOLENN project (Innocent, 2017) formalized the sources of valorization and devaluation of the ES practice. This work was used to categorize the value people derived from ES practice in the sample of the socio-ergonomic studies. The four components of valorization identified by Innocent (2017) are as follows: environmental and citizen, household management, eudemonic (i.e., capacity exercising, knowledge development), and secondary benefits (e.g., a healthier and safer home). The three types of devaluation identified are as follows: experiential (e.g., cost of changing habits, time and organizational constraints), social (i.e., negative image identified/shown by practice), and lack of practical knowledge (i.e., lack of know-how, difficulties finding useful information for practices). The socio-ergonomic analysis also revealed two other constraints to ES practice: family organization and the feeling of powerlessness (i.e., the feeling of being powerless with regard to the constraints of the built environment, the technical and technological constraints of the objects, and contradictory instructions).
Overall, those participants who showed a low ES practice score, voiced their lack of knowledge concerning how to practice, and the lack of eudemonic value derived from this practice did not develop their smart grid portal use**. Overall, the non-use of smart grid portals is associated with the absence of value, in particular eudemonic, derived from ES practice**. Conversely, the use of smart grid portals is always associated with some form of valorization of the practice of electricity-related eco-friendly actions. In other words, **use and eudemonic value, and to a lesser extent, citizen and responsible value, are associated: when there is use, these values are also present.** Moreover, people who have developed use tend to report fewer experiential constraints or those linked to the lack of knowledge regarding this practice. Financial, family, or powerlessness-related constraints are not involved in the development of use. The link between ES and the development of smart grid technologies is related less to previously developed ES practice than to the values people derive from it, in particular the eudemonic value related to the satisfaction of increasing one's knowledge or better controlling one's energy expenses.

In a nutshell, the people who develop the use of the technology provided share a specific profile: they are interested in and competent to deal with energy issues, already engaged in monitoring practices using several tools regularly and frequently, and they already derive satisfaction and pleasure from exercising acts of control of their electricity consumption. In the sample, they are also older people and available because they are retired.

RESULTS: BLOCK 3 (FOCUS ON THE TOOLS USES) - THE INSTRUMENTAL GENESIS

A total of 78% of the people interviewed used the portal made available. This high rate shows genuine interest in smart grid technology and information regarding electricity consumption. However, the drop-out rate is also high: three quarters of the people who used the portal abandoned the interaction, including those who had developed some use of it. This is attributable to the constraints listed above: the technologies are generally difficult to use, and the information is difficult to understand and to use. In the end, 42% of the participants developed portal use, and only half implemented ES actions (i.e., 19% of the total sample).

USING THE TECHNOLOGY: HOW?

The longitudinal study revealed three main use schemes: viewing the home temperature, viewing the eco-friendly actions, when possible, and viewing the consumption data over long periods (i.e., the monthly and annual index) and/or short periods (the weekly and daily index or daily power).

1. Non-use and abandoning functions

Overall, the functions of interpersonal comparison, contests, alerts, and forum participation were not used for issues of usability and perceived usefulness. The opportunity of comparing their figures to some standard and of participating in contests are viewed as irrelevant or even demotivating functions by those households who had access to them (see Lassalle, 2017). Yet, the literature identifies comparison to a standard as a function that needs to be implemented in priority. The present analysis shows that the comparison criteria proposed were perceived as too vague to enable accurate comparison. A succinct comparison standard, comprehensive rather than detailed, could be sufficient and more relevant to enable people to situate their consumption level.

2. The functions used

Eco-friendly actions: Highly valued yet rapidly abandoned advice

The function "viewing eco-friendly actions" was used but rapidly abandoned, which shows both people's interest in practical advice to implement ES actions and the need to renew regularly the advice given to keep this function relevant in people's eyes. On the whole, the actions proposed were seen as too basic and too unvarying to initiate or continue developing ES practice. The smart grid technologies need to adapt to people's changing needs and competence to be relevant from the perspective of both the people using them and their impact on ES practice.

Viewing the temperature: Essential for effective smart grid portals

People with electric heating used the information regarding their indoor AND outdoor temperature to better understand the thermal and energy behavior of their household and then adapt their heating mode or appliances. When this information was missing, there were considerable difficulties of interpretation. The temperature information could be found using other tools (e.g., thermostat, Internet site) and incorporated into the smart grid technology to enable users to better understand

their consumption data. This incorporation represents an emerging function of use (catachresis), a possible avenue for smart grid portal evolution. This type of scheme and the strategies put in place to develop it and the impossibility of interpreting the data when the temperature information is unavailable show that the temperature information is essential and needs to be integrated into the Internet portals for increased control of the heating-related electricity consumption. This is one of the most electricity-consuming areas; hence, fostering accurate comprehension of consumption as it relates to use needs to be given priority in the smart grid technologies.

Comparing the household consumption over time (intrapersonal comparison)

Being able to view people's electricity consumption in near real-time and to compare it at different times (daily, monthly, annually) is the innovating feature of these portals. In particular, the hourly electricity consumption is a new piece of information for households. Permanent access to this new information is expected to give people more autonomy and to develop their power to act regarding their electricity consumption. However, this presupposes that both the information and the tool giving access to it are usable. It was shown above that the portals are not easy to access and use, the hourly electricity consumption is difficult to find and ignored (users do not know the opportunity exists), and the information is unintelligible (difficult to quantify, kWh unit not understood, difficult or impossible to explain fluctuations, decontextualization, etc.). These difficulties partly explain the limited impact of these technologies on ES; the use and learning cost is high and can be borne only by the most motivated users (i.e., intrinsically). Overall, the intrapersonal comparison according to consumption sector is relevant for all users who could access this function. However, the incomprehensibility of the measure (i.e., not knowing which consumption sector, or which electrical appliances) limits its use.

The intrapersonal comparison over long periods (several months or years) is carried out from time to time to assess the impact of actions on the long term: work, general energy impact of practice changes, situation changes. In this case, the portals' usability deficiencies (difficult use of calendars) and the impact of decontextualization also limit its use. Long periods make it difficult to remember the household activities, and the events observed are more difficult to process.

Consumption is viewed mostly for short periods (i.e., one day, or the current week or month). Short term viewing is useful to understand the energy impact of domestic practices and the use of electrical appliances and their operations. Viewing the graphs showing the daily power curve was usually carried out regularly, from daily to several times a month. When users' resources and knowledge were insufficient to read and interpret the low periods[4] seen on the hourly readings, four different strategies were used: (i) giving up the interaction; (ii) requesting expert help (ALOEN, the portals' design team, sellers of electrical appliances); (iii) carrying out a monographic investigation (i.e., matching graph-revealed events and domestic activities using a logbook); and (iv) carrying out an experimental investigation (i.e., plugging/unplugging the electrical appliances in the home, then checking the impact of these experimental manipulations on the consumption graphs; seeking information in real time induced using the *Linky* meter or the home automation system giving access to the data).

[4] Small local and/or repetitive events corresponding to the operations of electrical appliances, as opposed to the key consumption moments constituted by the salient events in the graphs provided (electricity consumption related to meal preparation, etc.).

Viewing the household electricity consumption over short periods, at regular and frequent intervals, and setting up specific strategies induced comprehension of the consumption data. Hence, understanding the information requires a high personal commitment level; its cost was accepted by people intrinsically motivated to monitor consumption and use the technology.

USING THE TECHNOLOGY: FOR WHICH GOALS?

1. Using to see and to become aware

Using the technology with the goal of seeing and becoming aware involved "seeing that / seeing how much" the household consumes. It was based mainly upon identifying the observable high periods on the graphs (the easily interpretable events such as mealtimes, etc.). This scheme was observed for all the users who developed the use of smart grid portals; it would thus appear that it is **a prerequisite for the development of more sophisticated uses.** The process involved people becoming aware of the impact of the household activities on the electricity bills and learning about the general pattern of consumption (i.e., the electricity consumption fluctuations in relation to use - heating, preparing meals, getting ready, etc. - or to specific situations - impact of the seasons, visits, etc. The smart grid technology shows the impact of some situations or appliances, particularly the most important ones (heating, hot water tank) upon the overall household electricity consumption. Hence, this use corresponds to people becoming aware of the information, its properties, and the impact of their actions. The electricity consumption information serves to reveal the organization of people's domestic life and homelife more generally. It is perceived as the **transcription of daily practices or isolated moments that cannot be avoided onto graphs. Consumption is seen as inevitable, hence uncontrollable.** Information that is viewed as obvious is neither stimulating nor interesting to people; knowledge stabilizes over time, and interaction with the portal is systematically abandoned when only this scheme is developed.
The first contact with information **makes visible the link between electricity consumption and the activities of the household members**. The smart grid technology reveals this link by **representing graphically what is not seen.** At this level, observations enable people to **become aware of their consumption shown in a concrete form**.

2. Using to analyze and diagnose

Using the technology with a view to analyze the consumption information and diagnosing the graphic events went beyond simply observing and helped answer a few specific questions. This use mainly involved identifying the low periods on the graphs and was driven by a real interest in data and the need to understand what the data show. The analytical approach shows why consumption takes its graphic form and involves deciphering the increases and the peaks shown. The data are examined, and the unrecognized events are specifically investigated (e.g., help from experts, monography, experiments) until they are identified. This phase of analyzing and diagnosing brought new technical knowledge (in particular concerning the heating and cooling electrical appliances) and specific understanding of the electricity consumption related to ancillary/subsidiary devices (tablets, lawn mowers, etc.). The minimal residual electricity consumption required for the household to function properly is identified and explained. The small "hidden" consumption items, unrelated to a specific habitual practice, are made visible. The electrical appliances running continuously (e.g., refrigerators, freezers, the Internet box) or

intermittently (e.g., heating devices) or from time to time (i.e., unrelated to regular life moments, such as hair dryers, vacuum cleaners) are identified. Using the smart grid technology may then help improve knowledge of a number of devices often ignored despite their consumption capacity (e.g., cooling devices). Users who developed this type of use learned the impact of both ancillary and episodic consumption practices and the operations of electrical appliances.

However, this analytical approach is costly and requires the frequent use of the portal and/or setting up specific strategies when people's knowledge is no longer sufficient to understand the information provided. This scheme was developed by participants who showed intrinsic motivation for technology use and in most cases, prior knowledge regarding energy. This analysis/diagnosis scheme and the knowledge it develops were a prerequisite for actions.

The two schemes discussed so far seek increased understanding of consumption. The following ones relate to ES practice and seek actions or their validation.

3. Using to evaluate (confirming and strengthening)

The purpose of technology use is to be able to evaluate the positive effects (in kWh and/or euros) that were anticipated and that justified setting up ES actions (carrying out work, new equipment, actions to reduce consumption, etc.). **Observing a positive link between action and consumption bolsters users' choices and engenders feelings of satisfaction, control, and performance**. When the link is negative, the actions may be readjusted or abandoned.

4. Using to confront/accumulate information (enhancing reliability and enriching)

During the first uses, the information provided by the portal was confronted with information originating from other tools to check its reliability. Validation was a prerequisite to using the tool as learning may not occur if the information is deemed to be false or not credible. If dissonance is observed, the entire smart grid system may be disqualified. Conversely, when the information is viewed as reliable, intelligible, and precise, the tool may be seen as a potential tool for ES actions. Accumulation was also part of the purpose of this confrontation. Information items of different types (temperature, monthly averages of electricity consumption, consumption of water, gas, fuel, etc.) and from various tools are usually synthesized in a personal file. This function meets a managerial objective, already present before the implementation of the smart grid portals and ensures intensive monitoring practices. Using the tool enables people to develop existing habits and contributes to enriching and strengthening them.

5. Using to monitor a state (controlling and securing)

Portal access is viewed as a resource enabling people to control the stability of their electricity consumption patterns, which has been revealed through using the portal. Their goal is thus to detect anomalies and monitor the household activities (e.g., the activities of others or during absences). Monitoring is conducted to anticipate the electricity bills, prevent overcharging, or reduce the consumption level through detecting useless consumption and potential electricity leakage.
Another goal of using the tool was to control consumption after the purchase or the installation of

electrical appliances to check the accuracy of the predicted features. This goal also served to check the relevance of the subscribed power. Using the tool brings increased security and control of the household electrical appliances. Table 3 shows the schemes of use identified and developed within and for the smart grid technology and the modifications/adaptations (catachresis) people brought to the tool to adapt it to their needs.

Table 3. Synthesis of the instrumentation processes (schemes of use and instrumented activity) and instrumentalization processes (catachresis) operating in the instrumental genesis of the smart grid portals

Use schemes	*Catachresis*		*Instrumented action schemes*
Functions used	**Emerging functions**	**Resources used**	**Goals to reach**
Eco-friendly actions	T° (if absent)	T° sensor other	*knowledge*: Seeing - becoming aware (seeing that/seeing how much)
Indoor T°	Investigation by experimenting	Linky / home automation box	*knowledge*: Analyzing-diagnosing (understanding why)
Outdoor T°	Investigation by soliciting experts	Instructions, third parties	*Actions*: Evaluating (confirming/strengthening)
Intrapersonal comparison (sector, long/short periods)	Investigation through monographs	Logbook	*Actions*: Confronting/accumulating information (enhancing reliability/enriching monitoring) => synthesis of information (of various kinds – T°, consumption, activities, etc. - or of the same kind but issuing from different tools – bills, Web portals, etc.)
	Real time	Bills, consumption information for other services	*Actions*: Monitoring the state (controlling/securing) => monitoirng household activities (detecting anomalies) / controlling the truth of marketing speech
	Comparison with other consumption	Summary personal file (e.g. Excel table)	

USING THE TECHNOLOGY: WITH WHICH RESULTS?

1. Epistemic mediations: develop its knowledge

The main goal of the Internet smart grid portals is to be didactic tools for the development of knowledge and competence in the energy domain. This study shows that when the portals are appropriate, they do create knowledge, which involves mainly (i) the household appliances that use electricity - both those whose consumption was invisible and the most energy-intensive ones -; (ii) the usual or specific patterns of consumption arising from the lifestyle or special situations; and (iii) the technical operations of some electrical appliances (hot and cold in particular). Three levels of knowledge were identified:

- **Factual knowledge**, which concerns the visibility of the link between homelife and electricity consumption. When people use the tool purely for fact-finding, instrumental mediation is purely epistemic and involves this acquisition level only. Using the tool is then purely informative. **The changing consumption patterns observed are viewed as inherent in the homelife or changing times, and they are perceived as inevitable and non-modifiable.**

- **Technical/specific knowledge,** which concerns the visibility of the link between operations and use of the various household electrical appliances and electricity consumption. This sophisticated and specific knowledge was used to make decisions to adjust existing practices, guide work on the built environment, or select new equipment. It helped people better understand all the sources of household energy expenditure and view them as modifiable.

- **Contextual knowledge,** which concerns the visibility of the link between the network of energy supply and electricity consumption. This refers to improved understanding of the electricity path, no longer restricted to the home but contextualized to its entire path. Improved understanding of the whole electricity scene could have a long-term impact regarding the type of electricity production people wish to subscribe to.

Analyzing the scores of people's energy culture shows that they tend to remain the same over time, which could mean that the scores do not reflect the different types of knowledge that emerge and thus do not show the evolution of knowledge as it actually occurs. The score of energy culture established ahead of this study could be reworked, using these results, for future similar investigations. However, despite a high initial score, the score at the end of the project of participants having developed a use of the smart grid tends to have increased.

2. Interpersonal mediations: share its expertise

When technology use is developed, it is almost invariably accompanied by dissemination of the opportunities offered and the benefits to people through people's close circle. Depending upon the age and the ES context of the users, this dissemination spreads to parents, children, grand-children, or the close circle of spouse and friends. Three directions were observed:

- Downward direction (generational dissemination) from parents to children. Its aim is educational, through teaching the knowledge and competence acquired over portal use;

- Upward direction (retro-social dissemination) from children to parents. Its aim is informative as children make their parents aware of the smart grid technology and the practices of energy sobriety it generates;

- Horizontal direction (regulatory dissemination) towards significant peers. Its aim is to influence, persuade, and regulate. It is the most frequently observed type of dissemination and relates to the interactions between spouses, friends, or within the close circle (outside filiation) that are focused on smart grid technology use and its benefits. At this level, dissemination refers to the notion of sharing the experience of use and the expertise acquired concerning electricity consumption and more generally smart grid technology and the *Linky* meter. These interactions may be seen as promotional operations of the smart grid technologies, their opportunities, benefits, or even lack of danger. Dissemination then contributes to the social legitimation of technology. Furthermore, the social visibility of people's acquired competence or progress achieved is said to stimulate the feeling of competence that commits people to an activity sustainably. Smart grid technologies offering the opportunity of making visible the new acquired competence (e.g., participating in active and dynamic forums, accessing communities of practitioners) constitute a relevant avenue (i) to stimulate the feeling of individual competence regarding ES practices and induce a sustained commitment to ES practices; and (ii) to make possible the dissemination of this practice by significant peers in the community.
  Dissemination is also regulatory when it occurs inside the home. It is them specifically addressed to the spouses who are encouraged to modify their behaviors, although this encouragement is without any impact. In this study, the people who disseminate are not those who consume electricity through performing domestic tasks. This could be the reason why the ES actions developed concern mainly optimizing the material environment rather than changing the daily practices; men are mostly involved in the first domain and women in the second. Hence, even if technology use could become more gender balanced, it is likely that it would increase the load on women, particularly regarding the organization of their home life. This split tends to be strengthened by the technical nature of the smart grid portals. The scientific, mathematics, and technological domains inspire feelings of competence in men more than in women. The highly technical nature of the technologies proposed in the project would contribute to engendering feelings of competence concerning ES matters in men more than in women, thus reinforcing gender roles in this area too. **Technology use thus reflects the dynamics inherent in each family and strengthens gender stereotypes**. These issues bring about two kinds of recommendations: **(i) the need to design technologies that support autonomy and feelings of individual competence and seek to develop both knowledge and practice; (ii) the need to diversify the transition tools,** in particular by offering support other than just technological support so as to reach all the household members, who are all "electricity practitioners", rather than the consumption manager only.

3. Pragmatic mediations: act for energy saving

Portal use induced several instrumental mediations and first of all the opportunity of developing the practices of monitoring consumption. First, the near real-time information concerning electricity consumption is available in people's immediate environment, which changes their relationship to consumption monitoring, particularly if that information is perceived as accessible, objective, and reliable. The smart grid portal then increases people's power to act in ES domain by the very fact of its availability. Hence, publicizing the existence of smart grid Internet portals and the new opportunities they offer users is essential. Second, these opportunities have enabled the development of existing practices of monitoring (stimulation, enrichment, robustness). The portal increased users' power to act by giving them the opportunity of seeing and manipulating their consumption on their own. Furthermore, 19% of the sample set up ES actions as a result of portal use. Four kinds of actions were observed:

- Actions designed to optimize the timing of the organization of domestic practices: these were the main actions developed as a result of the use of the smart grid portals. These actions involved moving domestic practices from peak to off-peak hours (e.g., delaying the start of appliances, modifying some activities such as ironing or meal preparation);

- Actions designed to reduce electricity consumption (e.g., installing cut-off switches for the standby mode, unplugging devices when not in use, modifying the temperature settings of the refrigerator or heating devices). These actions derive from the specific knowledge acquired through use, in particular the observation of residual consumption;

- Actions designed to optimize the material environment (e.g., adding more energy efficient heating devices, changing light bulbs, using multi-plug sockets to monitor the standby mode). Users report feelings of competence and security when purchasing items;

- Actions designed to optimize the home temperature: smart grids represent a decision-making tool for immediate or future interventions on the built environment, purchasing new equipment, or optimizing the use of the heating modes. This mediation involves homes using electric heating. The acquired knowledge brings about improved understanding of the thermal behavior of the home and decision making and action concerning optimizing the material environment.

The ES actions implemented met mainly a management type of motivation (i.e., controlling the energy consumption to reduce the bills) and an environmental and responsible type of motivation to a lesser extent. The initial objectives of use were reached. However, the impact of use upon people far exceeds this benefit, as participants reported considerable satisfaction and feelings of competence related to the development of knowledge and ES actions. People's feeling of empowerment regarding ES possibilities and themselves increased.

4. Reflexive mediations: develop one's power to act

Developing knowledge in the domain of ES and setting up control actions increase people's autonomy and competence and generate feelings of pleasure, entertainment, and satisfaction. Understanding the electricity data and confrontations with other information, accumulating

information to enhance reliability, enrich the system of instruments, and develop consumption monitoring practices, evaluating the ES actions implemented, or monitoring the home consumption status: all these outcomes of use brought security, reliability, comfort, or feelings of increased certainty when selecting ES actions. **Using the portal brought people the feeling of having a greater capacity of action on their environment and controlling their own practices.**

The feelings of self-efficacy and competence are fostered, and people experience knowing how to perform the tasks and feeling they can do it successfully; hence, people's motivation to learn and persevere is increased. Conversely, when using the tool brings failure because of usability problems (difficult connections, difficulties understanding the information, etc.), people's self-image is degraded, and they avoid the situation and abandon the interaction. Furthermore, using the technology reinforces the gap between the initial levels of ES knowledge, instead of eliminating it. When participants' knowledge is initially moderate or high, knowledge is developed through use. However, this does not happen when knowledge is poor at the beginning of the project; people find it difficult to read and interpret the electricity data. The lack of knowledge is made even more salient through using the technology: the environment does not facilitate ES; at best, "nothing happens", and at worst, the technology is discredited, and people turn away from ES. **People who were not really interested at the beginning are even more uninterested after using the smart grid technology, and those initially interested become even more so.** Using the technology may even induce an experience of incompetence and arouses or fosters this feeling. **People who are learning rarely engage in an activity they believe they cannot successfully complete, and therefore they lose interest in situations they feel they will not manage successfully** (see Bandura, 1997, cited in Galand & Vanlede, 2004). In contrast, enhancing feelings of competence brings a positive impact in terms of commitment, performance, and learning trajectory. When using the smart grid portals brings about this experience of control, people report feelings of competence and increased self-efficacy. They then take pleasure in understanding and learning, and they make a long-term commitment to the technology and ES through implementing actions; they seek contact with the technology. For this process to take place, however, it is necessary to enable people to use their knowledge by offering them moderately challenging tasks, relatively easy to execute in a short period of time (i.e., immediate goals). Learners' involvement in determining these immediate goals increases their motivation to reach them (Schunk, 1985, cited in Galand & Vanlede, 2004). In general, pairing the experiences with self-evaluations or information feedback (i.e., feedback on the status of people's individual performance) fosters the feelings of self-efficacy, performance, and increases people’s interest in a given activity domain. Comments on possible improvements or encouraging messages foster interest and performance more effectively than scores or congratulations. **Hence, active experiences of control have a greater impact when they target goals of comprehension or competence acquisition rather than performance goals** (e.g., threshold/reducing consumption). Analyzing and diagnosing consumption information generated interest, pleasure, entertainment, and satisfaction, despite the cost involved in understanding the information (e.g., requesting expert help, logbook, experimentations). On the contrary, it would appear that this personal engagement (time, resources used, energy spent) is the source of commitment to use and to ES, as it represents an exciting challenge for people, leads to success, and fosters feelings of self-efficacy.

All these observations show the need to enable people to determine their own challenge level through involvement in formulating the ES goals to be reached.

A second source of fostering feelings of self-efficacy involves comparing people's performance with that of others. Comparing the household electricity consumption with that of peers is based upon this notion. However, when people feel less competent than others, performance is lower,

they do not persevere and lose interest in the activity. This is what happened in the SOLENN project: participating households whose performance was compared negatively viewed the opportunity of comparing it with that of others as demobilizing (see Lassalle, 2017). **When comprehension and competence are brought to light rather than comparison with third parties, people who feel less competent persevere and reach performance levels that are the same as those of others who feel competent.** Comparison needs to be a means of self-evaluation rather than a goal to be reached; otherwise, it has a negative impact on people who feel less competent.

Acquiring new skills regarding electricity issues also prompted some participants to question consumption practices other than those solely related to electricity (e.g., water or food consumption or mobility). **People saw their consumption practices as interrelated rather than in isolation.** In view of these results, it would appear to be necessary to propose technology that offers different entry points to reach energy reflexivity.[5] This would involve fostering people's inner motivation resources by identifying and soliciting their interests, preferences, and needs (see Sarrazin, Pelletier, Deci & Ryan, 2011) so as to enable them to transition from the activity domain that suits them best at the beginning. **Rather than offering a tool that distinguishes and segments, a tool that groups consumption activities together could reach more citizens, maximize their chances of appropriation, and help them participate in the development of an enabling environment for ES in particular and transition in general.** A co-design approach appears to be particularly relevant; it would involve offering open options and enabling people to influence the decisions taken by selecting topic areas that reflect their values, interests, and current concerns. Feelings of autonomy would thus be high (Reeve, Nix & Hamm, 2003). This approach would enable the technologies to support intrinsic motivation on the one hand by offering diverse practice domains as the chances of arousing interest would be greater, and a snowball effect on the other hand, as questioning the practices in one activity domain may induce people to question practices in other domains (energy, mobility, food, etc.).
Table 4 shows the instrumental mediations identified: epistemic (developing knowledge), interpersonal (disseminating information to people's close circle), pragmatic (ES actions), and reflexive (self-development). These mediations would be developed through the use of smart grid portals.

[5] Brisepierre (2011) defines energy reflexivity as people's capacity to question their own energy consumption practices and to modify these.

Table 4. Synthesis of the instrumental mediations observed: epistemic (developing knowledge), interpersonal (disseminating information to people's close circle), pragmatic (ES actions), and reflexive (self-development)

Instrumental mediations

Epistemic	Interpersonal	Pragmatic	Reflexive
Factual knowledge	Generational dissemination (downward)	Actions for time optimization of domestic practices	Experience of control
Technical/specific knowledge	Retro-social dissemination (upward)	Actions to reduce electricity consumption	Feeling of self-efficacy and competence
Contextual knowledge	Regulatory dissemination (horizontal)	Actions to optimize the material environment	Feeling of autonomy
		Actions to optimize the home temperature	Wider/general reflexivity (considering practices other than energy consumption alone - mobility, food -)

Developing empowerment

GENERIC RESULTS (BLOCKS 1-2-3)

APPROPRIATION PROFILES

The longitudinal analysis results established a typology of several modes of appropriation. Three profiles were identified and are presented in the following paragraphs. Figure 1 shows a synthesis of the findings; it can be found in the video of the socio-ergonomic results of the SOLENN project available with this deliverable.

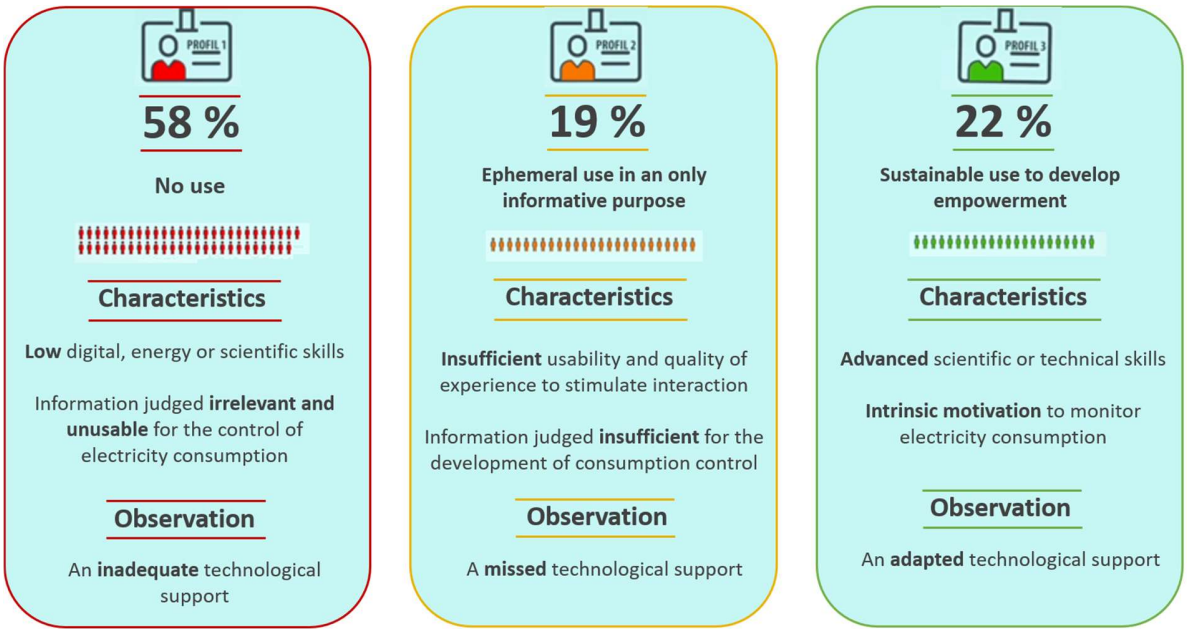

Figure 1. Synthesis of the profiles of appropriation of the smart grid technologies revealed by the longitudinal socio-ergonomic investigation.

1. Appropriation profile n° 1: Non-use or non-appropriation

This profile accounts for 58% of the participants to the socio-ergonomic investigation and is characterized by the non-use of the technology, which is not appropriate. Either there is no use as a result of a-motivation for the tool, the monitoring activity and/or ES, or use is prevented by the lack of maturity and usability of the tools, which prevents users from (i) understanding how to use them; (ii) understanding why the electricity consumption is presented the way it is in the graphs (what does the peak shown mean? what does 1 kWh mean? etc.); and (iii) understanding how to control their electricity consumption better (what to do to avoid peaks? etc.). Participants in this profile are those who report no knowledge of energy or practical issues, which limits their ability to understand and act upon their electricity consumption. In other words, the portal does not help this profile develop the necessary knowledge and competence to motivate actions. Conversely, its use leads to a situation of failure, or even an experience of incompetence, which creates or fosters

the feeling of incompetence that leads to disengagement from activities. The technologies thus exclude those people who have little or no prior knowledge regarding the issue, as they are aimed at and assist the "knowers". As they do not consider the users' experience level, opportunities of appropriation are greatly limited, and so is the impact of these technologies. Consequently, the final perceived functional value of the tool by people in this profile is non-existent; the technology cannot constitute a relevant resource for the development of energy sobriety practices. Pairing technology and people is not possible because the portals restrict too strongly people's opportunities of use. This does not mean that the technologies are useless, but rather that they are unusable in their current form and the functions they offer. **In the SOLENN project, investigating the issue of appropriation was severely limited by the lack of maturity of the technologies. This user profile shows the need to design tools for appropriation.**

2. Appropriation profile n° 2: Use for information purposes

This profile accounts for 19% of the participants and is characterized by use for information purposes. It corresponds to the development of "knowing that", which leads to the materialization of consumption, and of "knowing how much", which leads to quantification. The portal enables people to see, to visualize, to realize, and to match domestic practices with electricity consumption. The technology makes visible the energy expenditure related to the homelife (e.g., meals, number of household members), the seasons, or the use of electrical appliances, but it does not bring the resources needed to support the modification of domestic practices. The portals are used passively, in an exploratory approach; use does not relate to answering specific ES-related questions (e.g., how can I optimize the heating management?). The knowledge acquired is factual, and electricity consumption is seen as trivial, reflecting the life of the household, and unavoidable; hence, it is viewed as impossible to modify. The final perceived functional value of the tool is informative, in the sense that it enables users to see the fluctuations of electricity consumption of their home, but it is non-existent regarding controlling this electricity consumption. The technology does not support any active control experience because it does not provide access to practical knowledge (i.e., what to do). People belonging to this profile have prior knowledge of energy issues and intrinsic motivation for use (i.e., curiosity for the data/technology). However, this prior interest is not stimulated by use; instead, interacting with the technology is systematically abandoned. These observations show the need to design technologies that foster the acquisition of "knowing that/knowing how much", which is the prerequisite to actions. They also show the importance of maintaining people's interest for consumption monitoring and ES practices with usable, adaptive tools that support autonomy and feelings of competence. The absence of sustainability and/or development of use reveals **the inability of the SOLENN project technological offer to meet the expectations and needs of users. Pairing technology and people is missing;** the information is available, but inadequate on its own to be exploited and to initiate a reflexive approach.

3. Appropriation profile n° 3: Self-determined use

This profile accounts for 22% of the participants and corresponds to people whose use of the smart grid technology has induced the development of knowledge, a reflexive approach to energy use or even other practices, and actions for energy saving. These participants are all characterized by an initial intrinsic motivation for electricity consumption monitoring and largely by high prior knowledge of the domain and intensive monitoring practices. The tool meets their existing need

for more sophisticated electricity consumption monitoring and/or genuine liking for the topic area and the technology. The tool is used to analyze the household electricity consumption; technical/specific knowledge is developed and generates greater understanding of the operations of electrical appliances. The tool is used to diagnose, monitor the state of consumption and avoid electricity leakage, understand the technical features of some electrical appliances, evaluate the energy impact of the control actions implemented, or optimize the household electricity consumption monitoring. Hence, the portal is a **support tool for decision making,** mainly to guide the intervention decisions regarding the built environment and the purchase of equipment or to implement consumption-reducing actions. Use brings about strong feelings of satisfaction, in particular because it fosters the development of autonomy and feelings of self-efficacy that initiate activity and stabilize behaviors over time. The tool fosters and increases the initial intrinsic motivation and people power to act in the energy domain. Moreover, the interest initially associated with energy consumption extends to other domains, and the tool initiates a more general transition. These are also people who disseminate their ability to access these technologies and promote the benefits derived from them. This dissemination aims to persuade people in their close circle or to regulate ES practices within their household. Hence, use enables these participants to meet their basic psychological needs of competence, autonomy, and affiliation, as identified by self-determination theories; over time, use becomes self-determined. The final perceived functional value of the tool is many faceted; it is epistemic, pragmatic, management related, reflexive, developmental, and social. Pairing technology and people is successful: the information is available, viewed as relevant and exploitable.

APPROPRIATION AXIS

The three-blocks analysis (1, 2 and 3) reveals a final set of appropriation axis, these one are shown in Figure 2.

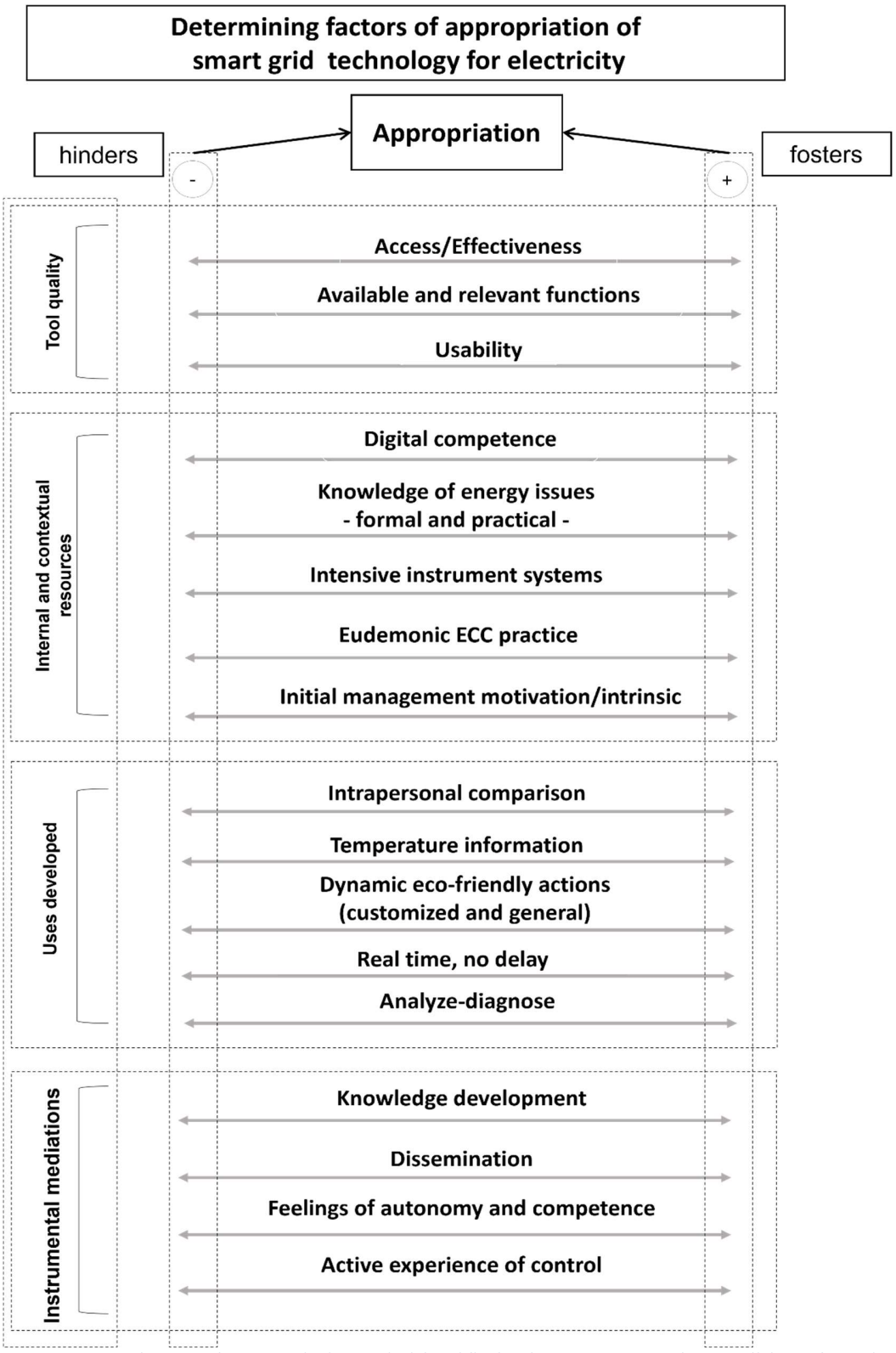

Figure 1. The set of appropriation axis identified. These represent the conditions fostering or hindering instrumental genesis (i.e., the appropriation process) depending upon the position of the cursors at the positive or negative end.

APPROPRIATION "MODEL": TOWARDS A SELF-DETERMINED LOOP OF USE

The socio-ergonomic study has shown that it is intrinsic motivation that drives use, i.e., use is autonomous, spontaneous, and performed out of interest or curiosity for the technology and the consumption information. For use to become sustainable and have a positive impact upon the ES household practices, it needs to foster and encourage the initial motivation by supporting autonomy and feelings of competence and affiliation. Motivation then supports use over time and the development of instrumental mediations; otherwise, use ceases. In other words, **people's intrinsic motivation** (curiosity, interest, desire) **induces knowledge development** (desire to learn and understand) **and control actions** (people's desire to develop and exercise their capacity, to diagnose, explore, face adapted challenges**); in turn, intrinsic motivation is fostered by technology use and the derived mediations.** Hence, this cycle creates a self-determined loop for use (Figure 3). **Intrinsic motivation constitutes the main leverage point for appropriation of the smart grid technologies and their positive influence on ES practices.** Technologies aiming to support people in their energy transition approach need to be designed in such a way as to promote the self-determination of use.

The instrumental approach and the theory of self-determination are very close: the instrumental mediations (epistemic, pragmatic, reflexive, and interpersonal) detailed in the former and the satisfaction of basic psychological needs (competence, autonomy, and affiliation) shown in the latter overlap. Both advocate a developmental approach of people and tasks and call for the development of enabling environments targeting people's autonomy and power to act improvement to make progress possible. Technologies aiming to support people in their energy transition approach need to be designed in such a way as to promote the **self-determination of use.** The main results of this analysis are shown in Figure 3.

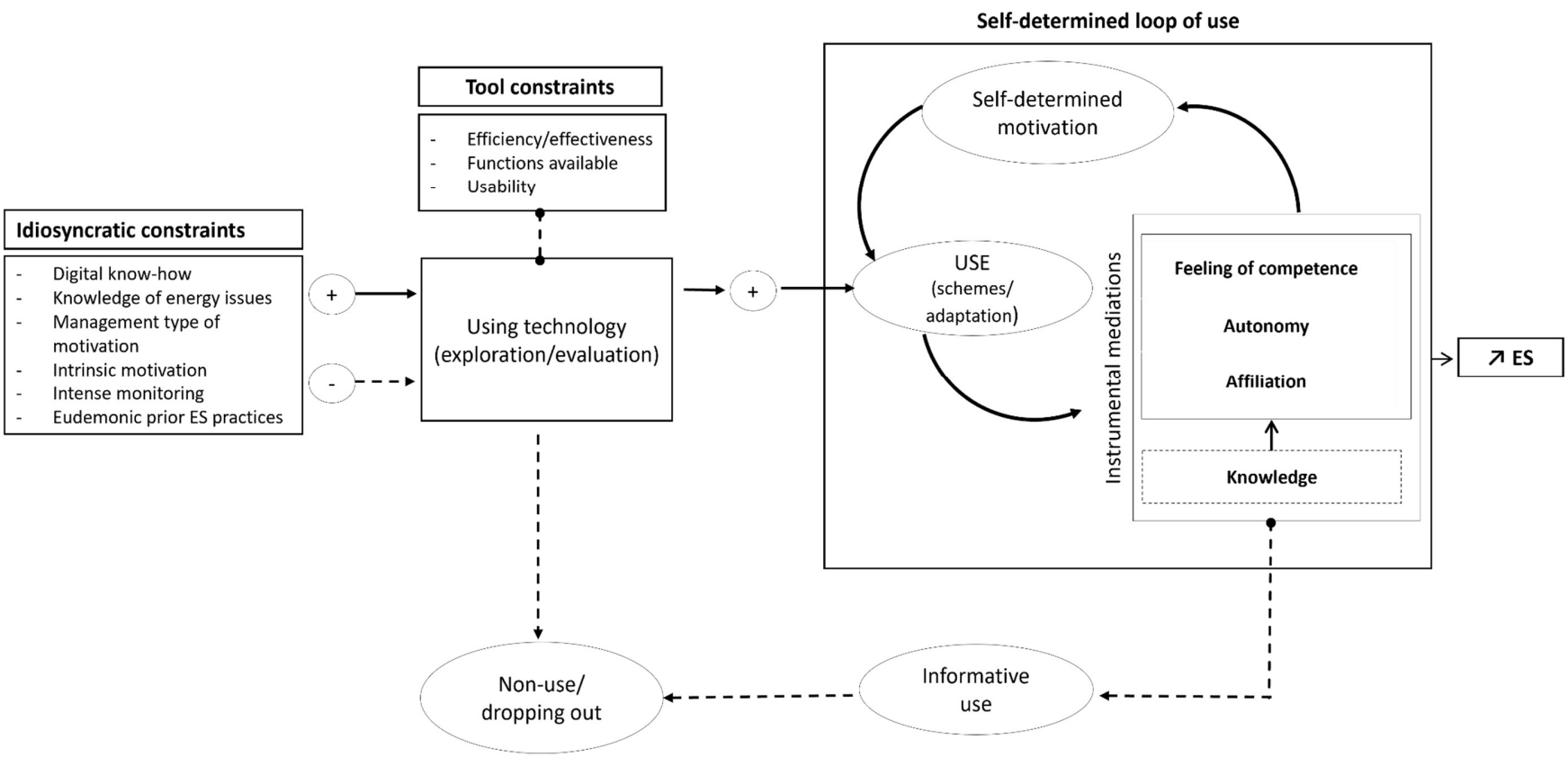

Figure 2. Synthesis of the main outcomes of the longitudinal socio-ergonomic investigation: Toward a design promoting the self-determination of use.

CONCLUSION

This socio-ergonomic investigation has considered how the technologies supporting the electricity transition were appropriated, i.e., the way in which they are used, for which goals, and with which results. The study first focused upon the conditions fostering appropriation. The longitudinal analysis results established a typology of several modes of appropriation. Each appropriation profile was defined in relation to the artefact-based and idiosyncratic constraints, both internal (i.e., cognitive and conative characteristics) and external (i.e., systems of instruments and existing practices, social context), and the type of interaction with technology, namely the schemes of use and instrumental mediations developed.

The study shows that the essential starting point is to design portals with enhanced usability, that are flexible, adaptable, and easy to use. Initially, considering and integrating end users from the start of the design process is necessary to obtain technologies adapted to their needs and to avoid the pitfalls of the exclusive vision of the design teams that, as the results of the study show, may be very far from those of the people who will use the tool. On a broader level, technology designed to support autonomy, competence, and affiliation is bound to promote the chances for long-lasting motivation towards commitment to a transition approach. Introducing open options and explanations support autonomy, and introducing adapted tasks, advice on means of making progress, guidance, encouragement, and positive information feedback supports competence. Sharing personal concerns and acquired competence supports affiliation and the sense of belonging to a community. It is necessary to **design for appropriation using people's internal motivation resources by involving them in the design process**; hence, it is internal rather than external leverage points that need to be activated. An approach based on **co-designing the technology** for transition elicits people's interests, needs, and preferences; **design also needs to continue over time** (Béguin & Rabardel, 2000) using instrumental genesis to maintain a coherent link between people's changing needs and the instrument characteristics. These features could maximize the enabling potential of the technologies and their chances of appropriation. **Tool design** needs to target **people's development and the self-determination of use and actions**. A change in the design of tools for sustainable development needs to be made away from techno-centered design, conveying only the vision of the design teams focused on access to information, to design for users' appropriation and self-determination. A change in the design of tools for sustainable development needs to be made away from techno-centered design, conveying only the vision of the design teams focused on access to information, to design for users' appropriation and self-determination This posture focused on the people and family’s power to act development to enable them to progress regarding ES. An approach based on co-design and continued use-based design could reach this goal.

Today, the world faces unprecedented challenges to enable the sustainable development of our species and of our ecosystem more generally. Policies of energy demand control oriented toward changing individual behaviors need to support self-determined motivation, regardless of the kind of support provided.

RECOMMENDATIONS

The following list synthesizes the outcome-based recommendations made throughout the document. The main goal is not to recommend design strategies that would target behaviors; instead, what is needed is design for and through use and for the self-determination of actions and activity. This study brings out a set of recommendations for the design of transition technologies. The following recommendations concern the essential aspects emerging from the longitudinal socio-ergonomic study:

- **The absolute need to design tools that are sufficiently mature and usable to be accessible and to avoid placing people in a no-win situation**. Otherwise, feelings of incompetence may arise, the initial lack of interest may be reinforced, or the initial interest be curbed. In addition to the recommendations found throughout this document, a substantial set of recommendations is presented in Lassalle (2017; 2018). The main ones regarding this issue are the following:

  (1) **Making visible the smart grid Internet portals** through awakening people's curiosity and interest in their use. **Focusing on the immediate, visible, and people-oriented benefits** such as optimizing the household management (reduced bills, enhanced heating comfort, enhanced security with more efficient devices, etc.) could successfully draw attention to the existence of these tools. The main goal is to make people want to manipulate them;

  (2) **Offering tools that are easy to access and to use** (see the Lassalle, 2017; 2018), **entirely operational, flexible, and adaptive** in terms of people's competence levels and needs. The main goal is to make the tool manipulable.

- **The need to design tools that support people's autonomy and feelings of competence through**

  (3) **The opportunity of living active experiences of control**. The main goal is to make people win in a particular activity, namely electricity consumption control, and enable them to feel successful in this activity. For people with little initial competence concerning energy issues and ES practices, the goal is to make visible potential improvements through offering strategies to be developed (designed to improve understanding of the information, as people can then adapt the actions to implement considering their own situation) and success feedback as evidence that the strategies have been used correctly. **The main goal is to create experiences of successful practices** to develop people's feelings of competence and self-efficacy in this domain. The technologies need to aim to develop knowledge and practice rather than knowledge alone;

(4) **The proposition of clear goals, relatively easy to achieve, and short term** to guide learning. These goals need to help people understand their consumption, in particular the link between electricity consumption, domestic practices, and the impact of the operations of the household electrical appliances, and enhance their competence through practice rather than performance objectives to be reached (reducing, thresholds, etc.);

(5) **The involvement of users in constructing the goals to be reached and the self-evaluation process.** This feature, too, indicates the importance of the co-design of technologies for the transition with those people who will use the technologies;

(6) **The users' focus on progress made and ways of increasing their control;** however, it is necessary to avoid aptitude evaluation in a competitive context or one of individual comparison;

(7) **The proposition of specific comments on the strengths and weaknesses of the "performance" and avenues for improvement;** scores or general comments are to be avoided. The main goal is to help people improve;

(8) **The proposition of several entry points to transition, other than ES alone.** These entry points may be identified by involving people in their definition with respect to their interests, preferences, and needs. A snowball effect could then help them reach the energy transition;

(9) **The diversification of tools for the transition** through offering kinds of support (e.g., human) other than technology alone, particularly to involve all the household members instead of the consumption manager alone;

(10) **A design focused on comprehension and competence acquisition** rather than access to information and performance to be reached (e.g., threshold/reduction of consumption);

- **The need to design tools that support the affiliation need through**

(11) **Increasing the social visibility of acquired competence and progress made** through, for instance, access to a community of practitioners, participation in active and dynamic forums or citizen groups;

- **The need to design tools that support use through**

(12) considering people's actual activities. Design needs to be empirical; in other words, it is based upon use to serve use and the development of people and their activities. It is necessary to use instrumental genesis and the existing schemes (i.e., routines of use) and the adaptations people bring to the tool as they use it (catachresis) to design the technology instruments. Examining these in the smart grid portals of the SOLENN project prompted the reconfiguration of the hierarchy of functions to be implemented; this hierarchy was identified beforehand in the acceptability part of the study (see Section 2.2.2). The following configuration is proposed (Figure 4)

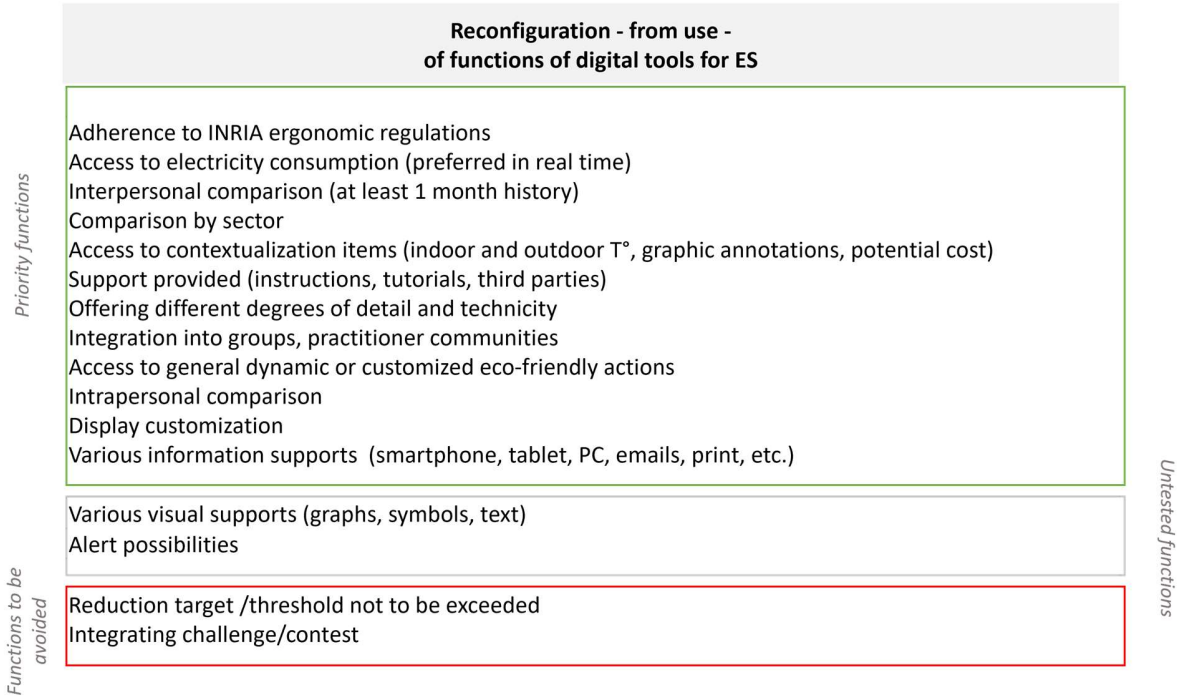

Figure 4. Configuration, identified through use, of the relevant functions to be implemented to foster the appropriation of digital tools for ES.

Hence, it is necessary to design tools for the energy transition that support instrumental genesis and self-determination of behaviors by stimulating the feelings of competence (desire to learn and act), autonomy (arousing curiosity and interest), and relationships with others (establishing links with learners in the domain of energy transition), and by enabling people to succeed and progress in this domain.

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