A typology of flexible users in a smart grid project

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Abstract
Demand response and user flexibility are key issues in the development of smart grids. However, mainstream policies rely mostly on economic and technical instruments to make users more "flexible". In participating to a smart grid project in Belgium, we have explored how users might engage in other ways than dynamic tariff and direct load control. The Flexipac research aims at evaluating the potential of flexibility in storing electricity through the use of heat pumps and well-insulated buildings. We have been in charge of the ethnographic study, whose explicit objectives were, on one hand, to understand the practices related to the heat pump (and other appliances) and, on the other hand, to analyse users' flexibility. We have focussed our observations on what people do (and not on what they are supposed to do). We have investigated the following research questions: how do householders manage their comfort? How do they use and control their heating system? How do respondents manage their electricity consumption? Are they willing to delegate the management of their heating systems and appliances to external operators?

The analysis of the data of our sample results in four types of users: the Economist, the Technician, the Environmentalist and the Compromiser. In the paper we show how these types are related to the dimensions of economic calculation, environmental practices, technical competences, appropriation of the heat pump commands, control of energy consumption and thermal flexibility (as stated by respondents). We analyse these types from different points of views: electricity consumption, measured temperature, energy saving actions, notion of comfort, interest in the grid management, electrical and thermal flexibility. We conclude with a discussion of policy tools used for the development of smart grids, and we show that some segments of the population are not considered in current policies. Today, smart grid instruments are mainly based on information, prices and technology. Environment, participation, community are hardly explored in smart grid projects although they might rally important portions of the users.

Introduction: various representations of users
The electricity grid is probably the biggest machine ever built: at a national scale, it connects billions of appliances and other consumptive places to many sources of production. It is probably also the most complex technical system to be piloted since production and consumption must be balanced at all time. The increasing integration of renewable energy into the grid, mostly decentralised and intermittent, is transforming the topology and the use of the electricity supply network. As storage is still very expensive, the grid balance is achieved at lower cost in asking consumers to shift their electricity use. Industry has been associated to the grid balance for decades: big consumers can modulate their demand and can be interested in interruptible tariffs and dynamic pricing (Torriti et al. 2010). Indeed, electricity suppliers can offer cost-efficient prices to big consumers who are able to shift their load. Historically, the grid has been developed with an increase flexibility of the demand side. Today however, flexibility is searched beyond factories and tries to reach "intermediaries" consumers as retailers or offices (FERC 2012). The next step is to engage households and small businesses.

Experiments that aim at recruiting users in smart devices yield to varied results, however (Goulden et al. 2014). In-home displays are poorly appropriated (Hargreaves et al. 2013), and the results of pilot studies depend on the recruitment of good-willing participants (Klopfert & Wallenborn). Demand response schemes to shift consumption have produced better results, especially with critical peak pricing (Faruqui et al. 2010). More generally, smart grid projects seek to enrol users in order to modify electricity usage. The electricity grid must certainly co-evolve with the electricity uses, but the definition of uses has to be analysed. Engineers and designers have certain representations of an average user that orient their products and shape possible uses (Akrich 1992). Preconceptions of users and uses abound also among economists (Lutzenhiser and Hackett 1993) and socio-psychologists (Shove 2010). It is therefore important to question the way uses and users are defined.

In the current development of smart grid, users are often attributed a primary role in the management of the grid whilst requiring contradictory capabilities depending on the viewpoint (Verbong et al. 2013). For example, the term "active consumer" refers to a consumer eager to compare tariffs offered by providers (EC 2010). Other voices call for "meaningful citizen participation" (Mulugetta and Urban 2010) or for communities that build themselves around the energy issue (Seyfang et al. 2013). However, a dominant representation emerges from the analysis of energy policies and institutions, coined "Resource Man" by Strengers. This user of smart promises is "a data-driven, information-hungry, technology-savvy home energy manager, who is interested in and capable of making efficient and rational resource management decisions" (Strengers 2013). In mainstream smart grid developments, flexibility incentives are mainly based on prices. For example, Clastres (2011) advocates a purely economic approach that would foster competition and efficiency, and concludes that new forms of regulation are necessary to resolve uncertainties regarding the gains achieved, how these gains should be shared and how consumers would react. These uncertainties are not surprising when considering how the grid intertwines heterogeneous actors with sometimes divergent interests. The necessary transition to low carbon activities requires a full reorganisation of the relationships between the activities and the grid (considered as an assemblage of infrastructures, actors and institutions). We contend that the course towards 100 % renewable will span over a few generations and starts in questioning the way daily practices are shaped by the grid. The collective learning process will be laborious and complex and should explore new ways to align daily practices with the environment.

Resource Man prefigures most of the smart grid projects, which are generally piloted hand in hand by engineers and economists. These projects have some (often limited) success in decreasing or shifting electricity use. However, their greatest success is to shape the available technology and to define how markets should perform. Economic fictions, like self-interest and market competition, are performative through diverse self-fulfilling prophecies, inscriptions or socio-technical arrangements (Callon 2007). Some statements become real through the implementation of devices and institutions. The techno-economic development is certainly forceful, but it misses a wide range of possibilities. The opposition between promoters of centralised versus distributed systems polarise usually visions of smart grids. When the grid is reduced to technological innovations and is conceived as an expanding market, top-down visions points to big production units and interconnections between national grids. Alternatives are usually based on distributed generation and microgrids, and assume that users contribute to design the decentralised socio-technical arrangements which concern them (Wolsink 2012). When happening in low carbon communities, public participation to the building of the environment can challenge conventions and find new ways of acting together (Heiskanen et al. 2010). In this paper, we start with the assumption that final users are certainly involved in the grid functioning, although they are usually unaware of the technological and environmental resources required when they switch lights or push machine buttons on. Following Marres (2012), we suggest that the "material participation" of users lacks engagement because the energy issue is not a public one in the sense that it would concern users in their practices.

To investigate the issue of the place of the users in smart grids, two kinds of questions can be asked. First, how are users shaped by the current development of technologies and economic incentives? Is it possible to identify users who (actively or not) elude economic and technological instruments? This can be (partially) answered in following the realisation of a smart grid project research – and that is what we have done. Second, what could be the place of users in other grid configurations? This prospective question can only be examined with the active participation of users. For this reason, we have discussed different scenarios with participants in focus groups and interviews (see below).

The place of the user has then been at the core of our research during our participation to the Flexipac project (2103–2015). This project has been funded by the Walloon Region (Southern and French part of Belgium) as part of the 20-20-20 target set by the European Union. It aims at evaluating the potential of flexibility of heat pump use, which usually occurs in well-insulated buildings. As the thermal inertia of these systems is large, it is possible to make pumps functioning when renewable production is high and/or electricity prices are low. It is even imaginable that grid actors (providers, distribution system operators or aggregators) take over heat pumps through some "demand load control" device. This project assumes that heat pump installations will increase and will provide an interesting inertial load for the grid management. The Flexipac multidisciplinary research team is compound of engineers, economists, thermodynamicists, climatologists, social scientists and designers; an electricity provider and a heat pump certification company are also part of the project. In order to collect consumption data, smart meters have been installed in 70 households and 15 small businesses which all use heat pump systems. Smart meters are used to collect data of the total energy consumption (heat pump consumption and the production of PV) at quarter-hourly intervals.

We have been in charge of the ethnographic study, whose explicit objectives were, on one hand, to understand the practices related to the heat pump (and other appliances) and, on the other hand, to analyse users' flexibility. Flexibility had not a clear meaning when we begun the research, and a task was to search for a meaningful definition for the interviewed users. We have framed our research questions to observe the relationships between technology, everyday life and the environment, notably in using the diverse dimensions of practices (Shove et al. 2012). We have been attentive to the place of objects in everyday life and to the process of appropriation or the creation of new uses. We have investigated how users are captured by technologies (Pantzar 1997), negotiate with them and eventually domesticate them (Certeau 2011, Denis 2009). We have thus explored how people interact with their appliances and which skills they develop. We have analysed how effort to execute some practices is perceived (Marres 2012). Information has been gathered about the ways users adapt their heating system in order to manage their comfort. Discussions about comfort raised spontaneously in various guises like heat perception, lighted spaces, air quality and floor heating. Effort was also an object of many conversations. We have examined to which extend people agree to delegate the control of their appliances to external operators. In particular, flexibility has been analysed in the perspective of the coevolution of the grid and its uses. A special attention has been given to the way practices combine and require electricity at certain hours and seasons, how practices vary from one household to the other and how respondents give meaning to their activities. Social and environmental issues of the electricity use have also been investigated. A blackout perspective in Belgium and the consequent largely publicised load shedding plan have been an interesting subject of discussion too.

Soon at the beginning of the project, we have noticed that engineers tend to see flexibility through remote control systems and are mainly interested in how to make them "acceptable" by users. On another hand, economists prefer to bet on the capacity of consumers to react to prices conceived as "clear signals". Obviously, field observations have shown a much more contrasted picture than these caricatures. To summarise our observations to our fellows, we have developed a typology of the respondents. Typologies cut the continuum of reality in a somehow arbitrarily way. They create overly simple and firm distinctions and they blank out singular relationships that are displayed in practices. However, typologies are convenient fictions that assist analysis and action in emphasising a limited set of relationships. The provided typology of heat pump users has both complicated the work of our research partners and allowed them to develop more accurate user models.

In the next section we describe the sample, its biases and our methodology that combines qualitative and quantitative data. In the following section, based on qualitative interviews, we explain how we have identified the 6 dimensions that were used to elaborate the users' typology. The combination of these dimensions results in four user types, which we describe. In section 3, we present the extension of this typology to the whole sample via an online questionnaire. In section 4, we draw some lessons from the second series of interviews, specifically designed to discuss flexibility scenarios. We show that potential development of flexibility is higher for certain types of users, and that current institutions and policies dismiss this potential. We conclude in discussing mainstream policy tools promoted for smart grid development, which miss out part of the users.

Methodology

SAMPLE DESCRIPTION AND BIASES

The recruitment process to smart grid pilots is rarely described, although it is suspect of strong biases towards already interested persons only. This information is nevertheless essential to apprehend the possible scope of the results. In the following section, we describe the sample and its identified biases. Those biases should be kept in mind if any generalisation from our results were drawn.

More than 500 households answered to an online recruitment questionnaire. We have eventually selected 85 participants, but only 66 can be fully analysed. In every participant's building, the project team installed smart meters that measure, every 15 minutes, heat pump consumption, total electricity consumption and, if relevant, photovoltaic production (41 % of users in our sample have photovoltaic panels combined with their installation). Participants have access to a website where they can see these data. Since recruited households have agreed to install a smart meter in their home, they have no reluctance to transmit their consumption data to observers. This was checked through discussions about data privacy. The performative effect of the recruitment actualise respondents who find an interest in the research project, like contributing to research, getting information about their consumption or receiving advices.

Participants belong mainly to the upper middle class, are owner of their home and live in detached houses with two main floors. Almost all enrolled houses have been recently built, and incorporate a relatively expensive heating technology (heat pump, underfloor heating, mechanical ventilation). 50 % have an air-to-water heat pump and 38 % a ground-to-water heat pump. As the flexible use of the heat pump depends on the thermal inertia of the whole building, including underfloor heating, participants have been also selected for the good insulation of their homes. In sum, participants are generally rich enough to afford a house in the countryside and make long-term investments.

MIXING DATA

Data have been collected through different means: interviews, focus groups, co-design sessions, online surveys, electricity consumption (and production) data and temperature. We present here the most relevant data for the construction of the user typology.

The qualitative collected data comes from two sessions of semi-structured interviews and two online surveys. 24 interviews were conducted twice with a one-year interval (in 2013 and 2014). It comprises photos, recordings, observations, map of the house and heating system plan. The semi-structured interviews lasted between 1h 30 minutes to 3 hours, conducted directly at respondents' homes, generally in presence of the husband and the wife. The first session focussed on practices at home and interviews concluded with a house tour, looking at the heat pump system and other relevant electrical devices. The second interview session was focussed on prospective scenarios of flexibility. Our objective was to build a typology that would be based on practices performed at home.

We have extended this typology throughout our whole sample. For this, we conducted an online survey, based on the identified dimensions. The questionnaire has been built (and tested) to address various practices of households covering the settings and representations of the heat pump, domestic investment practices, habits related to energy consumption, comfort temperatures, the use of the web interface giving access to consumption (and production) data, the use of various household appliances and environmental practices. Our objectives were to broaden the typology to the entire sample and validate the segmentation, but also to associate quantitative data to the different types (electricity consumption and temperature). Two thirds of the respondent received also a sensor measuring temperature and humidity every 30 minutes. Once the typology was made, we arrayed all the data in an excel table in order to analyse relevant relations.

Online survey biases are well known and the interpretation of their results should be cautiously done. They are respondent by individuals, erasing the subtleties of family dynamics. Furthermore, social scientists control the frame of enunciation, namely what are the possible answers while suggesting "good" answers in using some words. For example, we have observed that economic considerations are not present in the discourses of some interviewees. However, with closed questions, respondents are forced to think in ways that are unusual for them. In creating a limited number of possibilities, questionnaires perform the data and what is considered as real. In a closed questionnaire, answers are predetermined and practices are hardly comprehended. Constraints that shape practices are unknown, and what may appear as a choice (to use a bike or public transports to go to work, to have a food garden…) can result from available infrastructure, habits, familial traditions or from professional advices (e.g. architect, installer). An online questionnaire also captures social norms, i.e. what is expected to do or say. For example, it is now common to pay special attention to lights or labelling of appliances. In the case of "systematically turn off the lights", only 9 respondents declare not to do it, although we have interviewed people who do not do it but state the opposite in the questionnaire.

When analysing our data, we adopt the principle that our fieldwork prevails over the online questionnaire and helps us to interpret these data thanks to our discussions and meetings during interviews. Attributing a type to a respondent is sometimes easy, sometimes more difficult. We have sought to ensure consistency between the field observations (interviews) and answers to the questionnaire. The back and forth moves between the analytic reading table and the relation of known respondents to their answers has allowed us to grasp the distinction between types and to assign a type to each respondent. It is generally easier to say that a person is not one of the types than she belongs straightforwardly to a type.

Four types of users

When faced with the development of a complex sociotechnological system, multidisciplinary research is both a necessary and awkward task. Smart grid project requires the involvement of a multitude of actors that represent the different facets of the electricity grid. Each research partner has different problems to solve and takes specific perspectives to handle them. Common engineer's and economist's words like flexibility, comfort, acceptance, and appliance control have to be translated in our theoretical framework, whose repertoire comprehends also effort, resistance, appropriation, delegation and participation. The conditions of felicity of the project, however, lie in the ability of each partner to integrate others' data in one's task.

Our partners are not directly confronted to the "real" users. We view our role of social scientists in the project as to communicate the observations from the fieldwork and thus display the diversity of observed houses and practices. Engineers and economists employ average data to simulate user behaviour in their model. Through our work, they were forced to take into consideration the diversity of users and the variety of practices. 48 interviews represent a large amount of information and an impressive diversity of logics of action. To summarize this diversity, we have elaborated a typology of the respondents.

THE 6 DIMENSIONS OF THE TYPOLOGY

The semi-structured interviews were conducted to collect information on actions and constraints of the respondents, notably about their use of their heat pump and their electricity consumption. By inviting respondents to explain the reasons of their actions, we were able to apprehend the logics governing such actions. Through the analysis of the interviews, we have identified six dimensions of observed practices that can be related to forms of flexibility. Each respondent possesses all the dimensions, but to variable extents. We have arrayed each dimension according to an ordinal scale, linked to a degree of intensity in terms of effort. Each degree of the dimensions is illustrated by actions or practices observed during the interviews. It is then possible to place each household on the scale, giving it a "score" corresponding to the highest observed intensity. We present the 6 dimensions in detail for they constitute original ways of apprehending individuals through their actions (and not according to their stated attitudes).

The environmental dimension refers to practices that are known to be environmentally favourable. The dimension is ranked according to the intensity of efforts of the various actions, as shown on Figure 1. (1) Investment in a collective or citizen project (e.g. wind power community) ranks the higher on the scale of environmental practices. (2) On the level below, stand actions that demand daily and physical efforts (e.g. operating a food garden, cycling). (3) The next downward level relates to recurrent actions that could be associated to a special attention to entities outside the house (e.g. reducing meat consumption, composting, no dryer). (4) Investments in environmental technologies are the next lower intensity (e.g. rainwater tank, thermal solar panels, natural materials for insulating). (5) Persons are content with environmental education or a green electricity supplier. (6) Persons think they do enough for the environment in respecting current laws.

The dimension of economic calculation is inspired from the neoclassical economic model and applies to decisions made to acquire new equipment. Unlike environmental practices, economic calculation demands limited physical activity as it rests upon cognitive skills. The observed spontaneous practices of calculation indicate the intensity of this dimension, and goes as the following from the higher to the lower intensity. (1) The economical criterion predominates in the discourse, and comfort is presented as decisive and non-negotiable. (2) Economic efficiency dominates decisions, and includes the calculation of the return on investment. (3) Grants and subsidies are a decisive criterion to make a decision. (4) A financial plan is realised

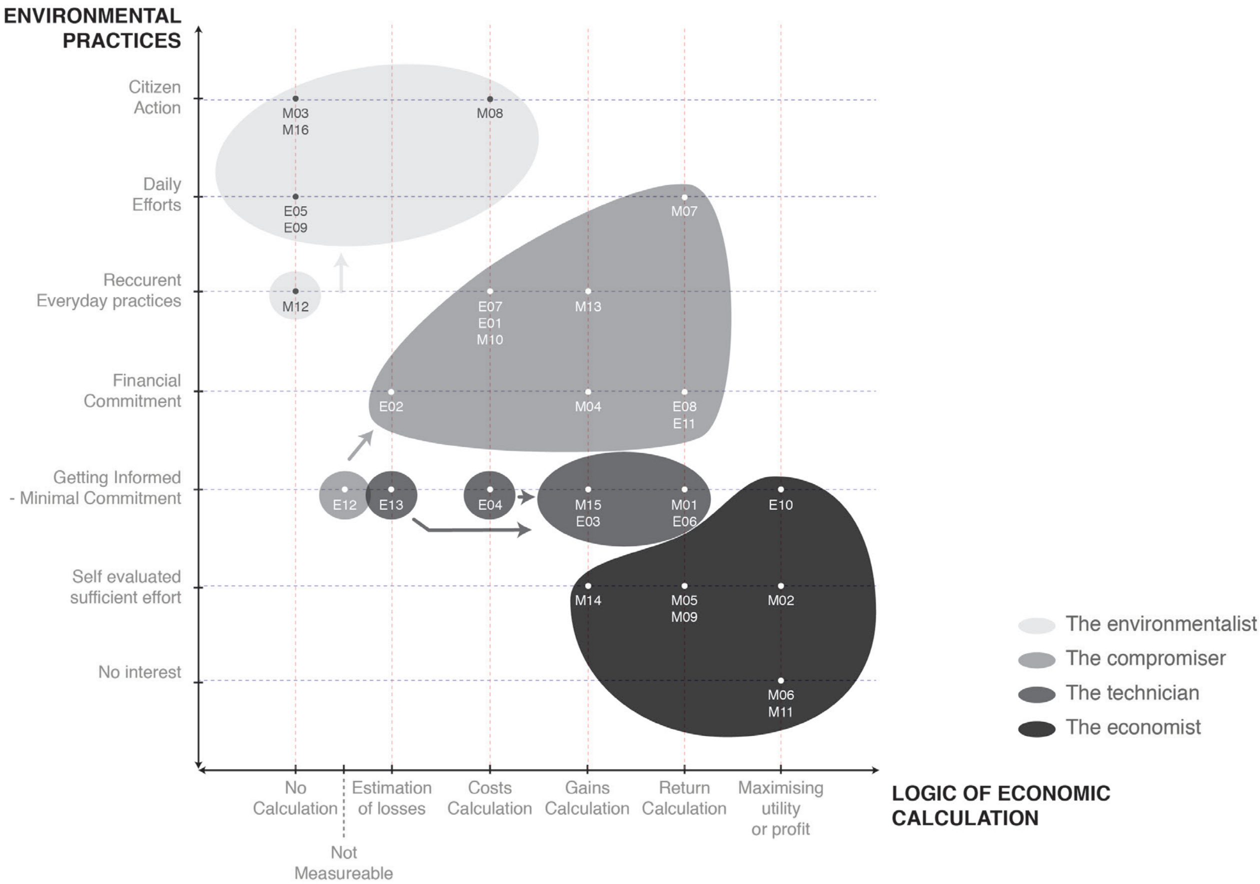

Figure 1. Environmental practices vs. economic calculation (M stands for households and E for enterprises).

in order to assess costs. (5) Energy costs or losses are estimated and actions against waste are taken if it is economically relevant and does not require too much effort. (6) Decisions are taken without performing economic calculation, in general because other "values" seem more important.

The technical dimension evaluates how some special skills are enacted. It is based on actual practices performed by the user and not on its technical background. We have assessed the interest of users in technologies and technical systems, including heating system, but also how they use their technical skills to tinker various devices. (1) The respondent takes part to the conception or installation of the heating system. He can adopt the viewpoint of a technological system and understand its inner functioning. (2) Experiments are conducted, and the technological system has been actively modified. (3) Data about consumption and other topics are collected and analysed. Small adaptations of the technological system are endeavoured. (4) Technology is superficially understood and energy units are mastered, but there is little interest in programming devices. (5) Lack of technological knowledge: machinery is perceived as complex. (6) Have no interest in the technology and seek only simplicity in usage.

The heat pump is a complex technical device, which remains difficult to grasp. Each user establishes a different relationship with his heat pump system. The **appropriation dimension** ranks the types of intervention on the heat pump settings according to their intensity and frequency. This dimension has been established to understand under which conditions respondents might be ready to delegate the functioning of their heating system. (1) The heat pump regulation depends on external temperature, and is changed with seasons through the adjustment of heating curves. (2) Room temperatures are differentiated through the regulation of hot water flows in the pipes. (3) The heat pump cycle is regulated and is stopped during the warm season. (4) Temperature is set lower during long absence. (5) Temperature is daily adjusted through a thermostat. (6) Temperature is reduced during the night or adapted to the family schedule. These settings have been realised by the installer and left untouched by the user. (7) No regulation is present.

An important part of the interviews was devoted to the management of electricity consumption in general (not only for heating). We have thus elaborated an **electricity consumption management dimension** based on the actions implemented by the users in their homes. (1) Actions that require a daily effort, such as switching off standby consumption each evening. The respondent is also ready to decrease temperature demand to 18 °C. (2) Actions that demand an occasional effort, e.g. the hourly programing of appliances and/or lighting are hourly, the measurement of electricity consumption with a manual meter, or to put on a sweater when feeling cold. (3) Daily actions that are not perceived as burdensome, e.g. switching off lights left on by other family members, using appliances at off-peak times, clothe washing at low temperature or hanging out one's washing. (4) Decisions with financial effort (and long return on investment), e.g. acquiring appliances or light bulbs with high energy efficiency label, reinforcing home insulation. (5) Energy management remains at a theoretical level. Information on electricity consumption is gathered and analysed, sometimes through social comparison, but do not result in actions beyond switching lights off. (6) Although displaying some interest in electricity management, no action is undertaken due to a lack of knowledge. (7) No interest in electricity management because comfort seeking is above all other consideration.

The thermal flexibility dimension is built according to users' indications. We have asked to households what were the limits of the acceptable temperature range (minimum and maximum) in their living room. These temperature statements allow us to evaluate approximately their thermal flexibility. Indeed, thermal flexibility is a crucial data because it is directly connected to the possibility of remotely controlling the heating system. It would be one of the parameters that an external operator should respect by all means. Therefore the intensity scale corresponds to the range of desirable temperature (e.g. 19 °C–22 °C).

In spotting respondents along the scales of the six dimensions, it is possible to represent them as a point in a 6-dimension space. The distances in this space are not "objective" but represent a relative order obtained in comparing respondents. The positions in the space refer to our whole sample of interviewees. In combining the dimensions two by two (i.e. in projecting the whole space on 2-dimensions frames), we have found that the crossing of the environmental and economic calculation dimensions provides us a relevant segmentation (Figure 1). Indeed, the tension between environmental practices and economic calculation logic appears at the heart of the flexibility potential. Although each respondent keeps its own singularity and are scattered within a continuum, we distinguish four types[1]:

- The Economist
- The Environmentalist
- The Compromiser
- The Technician.

Compromisers and Technicians are more or less on the same segment as regards as economic calculation, positioned between "estimated losses" and "return on investment calculation", although economic calculation is most dominant among Technicians. However, they are distinguished by their environmental commitment. Technicians have minimal environmental practices, mainly reduced to data collection or education, whilst Compromisers have more intensive environmental practices.

The frame that crosses environmental practices with electricity consumption management exhibits a clear correlation between these two dimensions. Indeed, the more users are sensitive to ecology, the more they make an effort every day to control their electricity consumption. Technicians and Compromisers both search for controlling their electricity consumption by developing different strategies. The two groups differ, however, in their environmental practices as we have seen in the former frame. Technicians tend to favour automatic systems (home automation, etc.), while the Compromisers achieve small everyday actions in order to save energy.

In the following sections, we summarise the characteristics of these four types as revealed by our analysis and justify hereby their denomination.

THE ECONOMISTS

The logic of economic calculation is predominant in the actions and discourses of Economists. Their main goal is to maintain the comfort of their family. However, their actions are also directed towards a search for profitability when they can compute it. In neo-classical language, their actions are determined by the maximisation of their utility under budget constraint. Economists believe that money drives the world and that their way of thinking is commonly shared.

> [C (PV owner):] The advantage of PV panels is financial. It is above all this. It is environmentally friendly in second place. I told you it's the dough that changes many people's behaviour. So this means that for me, bah, the advantage is a financial one, is the main criterion. If it would have cost me money without bringing more in, I would have never done it.

Although Economists try to maximize their utility and comfort, that does not entails an interest in the management of their energy consumption. The limitation of electricity use requires too much effort compared to resulted gains. They calculate that enacting strategies to limit their energy consumption would bring them at most a few dozens Euros by year. This line of thought is particularly strong among those who have installed photovoltaic panels and pay a reduced electricity bill thanks to feed-in tariff. Economists achieve few environmental practices and do not seek to control their electricity consumption. Environmental concerns are too expensive and they consider that the purchase of a heat pump displays their environmental responsibility enough.

Economists often have little skill or demonstrate a limited interest in programming their appliances. Their interest is limited to their data consumption or production. These data are only informative and are not used to develop new actions beyond the mere alignment of numbers. Delegation of choices and actions to technology appears then as an interesting option. They are pleased when the heat pump system is autonomous, "living its life and fulfil its duties." They have invested in an efficient and economical technology because they evaluate return on investments and subtract subsidies.

> [W:] And so [the heat pump] cost me €4,000 more than another system. But if I tell myself every passing year, it's €700 more [in comparison to acquaintances], bah it is amortised like that. And after a while, I will always win €700 more than the others but it will reduce the price I had set at the beginning. So I do my calculations, realising that it cost less than somebody else.

Investing in technology means that this technology can generate money when the initial amount has been returned. Meanwhile, Economists look for technology of which the use is simple. They use very few settings of the heat pump, which has been initially scheduled by the installer and left unchanged. They heat their homes often at constant temperature. Thermal flexibility of Economists is less important than the other types

1. To formalise the types, we have been inspired by Dong Energy (2012), Nielsen and Nørgård (2009), Beslay and Gournet (2010).

(from 0.5 to 1.5 °C). This resonates well with the image of individual seeking to maximise their comfort.

THE ENVIRONMENTALISTS

Environmentalists relate their actions to the conservation of the environment. Their discourse is clearly oriented towards ecological issues. Economic considerations are not spontaneously evoked and economic calculation is rare. Environmental values prevail over the economic calculation. For example, they will exhaust their budget to use natural materials or passive systems. Many Environmentalists are engaged in civic actions that requests time investment (e.g. wind power community). They think they are part of a general movement.

> [H:] I find that there is a general awareness of the fact that we had the industrial period, and that we have incredibly developed over everything. And only now one realizes that everything that has been created is very hazardous and that one must turn back.

The Environmentalists endeavour to actualise their awareness in their daily actions, in different practices like cooking, mobility or children education. They try to purchase sustainable or local products. They eat almost exclusively seasonal vegetables from local farmers or limit their meat consumption. They compost and usually grow vegetables. Environmentalists seek to manage their electricity consumption in performing daily actions. They pay then attention to the consumption of their various appliances and their energy labelling. They believe that energy is an important environmental issue and that everyone can contribute to mitigate it. They try to reduce their energy consumption without computing economic gains. Environmentalists have the greatest stated thermal flexibility (2–4 °C). They often declare accepting relatively low temperatures, down to 16 or 17 °C, and will not hesitate to put a sweater instead of increasing the heating temperature.

Energy management is perceived within a global environment. When they think to the environment, their argument starts with a global issue (generally climate change). They perceive their actions in relation to issues like climate change, biodiversity, overconsumption, forms of energy, all issues subsumed under the environment or the nature. They see their engagement as something that requires efforts imposed by the degradation of the environment.

> [Husband:] It seems that people are rather making effort, but it's not enough. […]

> [Wife:] When you look at Fukushima … This is catastrophic. But it is true that in other places, there are people who make efforts and that is what must be done. There are so huge disasters everywhere. That or oil leaks. In general, we can still say that the environment is deteriorating.

> [Husband:] Well, to be objective, there shall be a time when this will become too critical and everyone will have to make an effort.

Environmentalists have various technical skills. They generally understand their heating system and seek to appropriate it. The ecological aspect of the heat pump installation is very important. Using a heat pump and choosing a green electricity provider is a form of commitment.

> [J:] We wanted a clean energy. Well, it was not 100 % organic, or ecological. The principle is that we purchase 100 % green energy via Lampiris [Belgian supplier]. So, there you have to follow things through their logical conclusion. We heat with electricity via a heat pump, and if we do not always take green electricity … well we do not close the loop.

THE TECHNICIANS

Technicians define themselves as passionate about home technologies. Their main objective is to keep control on their devices. They aim at managing their energy consumption. They look for electricity losses and try to limit them. So, they develop efforts in order to get control over their appliances. Obviously, Technicians have technical skills that allow them to appropriate their heat pump. They often participate actively in the design of their technical system. The technology is designed to optimize the performance of the heating system. They adopt an empirical approach with their heat pump settings, seeking to refine its programming, through heating curves adjustments or hot water flow testing. Technicians do not rely only on the heat pump installer, but actively seek the information necessary for the appropriation of the heat pump.

> [R, in front of his heat pump:] At first it was hard to increase the temperature. Here we had set to 5 [load curve]. There were 5 positions to adjust. And I confess that since we are on this curve everything works fine. I haven't touched it anymore. Now I should return to the books if I had to change it.

Technicians have a rather average thermal flexibility, comprised between 1 and 2 °C. They optimize their system in order to create a stable comfort. Economic calculations are present in their actions but technology is evaluated through the possibility to understand and manage it. They generally believe that environmental measures are too expensive. They are sometimes interested to compare what others do and how they use their technology.

> [V, about a possible online forum:] Yes, to be able to know the settings, just seeing what others did for their insulation, trying to compare what is comparable. Their consumption, what type of pump they have, how they regulate their temperature, if like us they run it 24/24, if they cut it when they are not at home.

THE COMPROMISERS

Compromisers are more balanced between the dimensions we have identified. They appraise complex situations and often seek to accommodate financial effort with sustainable and environmental commitment in their daily life. They take the environment into account in their actions, but do not adopt measures that they would consider too "extreme". An environmental investment must remain cost-effective to be implemented. The Compromisers support environmental project as long as costs are competitive.

> [Husband:] Today we take steps that everyone does not take.

> [Wife:] Yes, but we talk here between a financial impact or a nature/environment impact.

> [Husband:] Both. Yes both anyway. We have always worked like that. You need a good balance between the two. For all

our investments. The pump again, if it was twice the price, if it was unaffordable, we would not have done it. It is necessary that soon or later we find our way in the feasibility of the project.

The Compromisers seek to modify their heating system and usually participate in the installation of their technical system. They often have technical skills that enable them to adopt a reflexive approach on their appliances. They state a thermal flexibility in the range of 1 to 3 °C. Above all, they want to be considered as responsible. They seek to master their consumption and avoid energy losses to reduce costs but also because it is a good thing to do. We have asked whether respondents would be ready to shift their consumption for environmental gains only, financial ones being not assured. Here is the typical Compromiser's answer:

[F:] If you are alone to do it uh … Well I do not know if it would really make an impact on ecology. So in this case, it is better to have a financial impact rather than environmental impact. Now, if everybody does it then yes, why not.

Quantitative correlations

While we were interviewing some respondents, data were being collected within a larger number of households. How could we relate and mix relevant data for the whole sample? In doing the online survey we had two objectives. First, we wished to expand the typology to the whole sample. Second, we aimed at crosscutting types with a set of indicators derived from measured consumption, production, temperature, and heated home surface. The correlations are presented hereunder with caution. Our methodology does not yield to evidence of causal relationships, but displays possible trends interpreted with fieldwork observations.

ATTRIBUTING TYPES TO ON-LINE RESPONDENTS

The analytical and comprehensive reading of our data about 66 respondents has resulted in the following distribution: 14 Environmentalists, 14 Economists, 19 Technicians and 19 Compromisers. As a way of memorizing these figures, we can retain that our sample is compound of 30 % of Technicians and Compromisers each and 20 % of Environmentalists and Economists each.

One of the questions of the survey was elaborated to catch the type of each respondent in demanding to choose one of the four self-descriptions. We observed however that these self-descriptions capture only partially the types we had attributed after the interviews. By confronting the types to the answers, we obtain Table 1.

The Table 1 attests a good correlation between types and self-description, but this criterion is not sufficient to attribute types. It has to be balanced with all criteria described above. It demonstrates that it is more difficult to assert oneself as environmentalist than any other type. Environmentalists are generally critical about the consumption society, but they don't want to be marginalised in reason of their positions. They prefer then to be regarded as more balanced. Compromisers are always environmentally aware, but are also caught between technical and economical interest.

OBSERVED CORRELATIONS

For each type, we have computed different quantitative indicators, based on electricity and temperature as measured in respondent's houses and on other collected data. We present here the most relevant results of the observed correlations. In Table 2, calculation comes from data collected through smart meters during one year, usually from November 2013 and October 2014. Averages are calculated on the totality of the sample.

We can observe that Environmentalists generally use 30 % less electricity than Economists, and 15 % less than average, whether for the heating pump consumption or the consumption without heating pump. Compromisers and Technicians are closed and around the average. The distribution of types among the sample seems to capture significant differences in terms of electricity consumption. How could we explain that?

The table 3 shows that the temperature setting in the living room is not a determinant parameter in managing consumption. Environmentalists declare a lower comfort temperature in the average, and seem to heat less. However differences between types are probably not statistically significant. Relatively high temperatures (around 21 °C) are probably due to the underfloor heating system present in all participants' homes. We have observed that heated floors raise people's standards of comfort.[2] Users are less favourable to temperature variations because the thermal system is highly inertial and slowly reactive to thermostats.

Differences in consumption are better explained by the surfaces that are heated in respective homes. Heated surfaces are of two kinds. They are heated either directly by water pipes coming from the heat pump and embedded in floors, or by air circulated through the mechanical ventilation system or open doors. Table 4 displays both kinds of surfaces and related efficiencies, i.e. the ratio of electricity used by the heat pump to surface. Environmentalists have lower heated surfaces, with a marked difference for the total heated surface. We have observed that Environmentalist do not usually heat bedrooms and the upper floor, as well as a large part of Compromisers. And this is confirmed by the obtained data. Economists have very big houses with an average heated surface of 377 square meters. However, their "castles" appear to be the most efficient if the whole heated surface is considered. This shows that energy efficiency indicators are not very relevant in this case to reveal actual consumption.

We conclude that Environmentalists and, to a lesser extent, Compromisers combine attention to their electricity consumption with smaller houses. They have lower electricity consumption because they have had the privilege to build (or sometimes renovate) their house, which constitutes a life project. In building their homes, they paid attention to strategies and technologies to limit their electricity consumption. They often acknowledge also that they are fortunate to live in green areas, with a nice garden, and are often a bit embarrassed to speak about their consequent mobility needs (usually two private cars and long journeys).

2. The increase of comfort standards has been observed also for air-to-air heat pump in Denmark: see Gram-Hanssen et al. (2012).

Table 1. Self-description repartition among types.

What is the description that matches you the best?	Environmental aspects are important and I try to take them into account in my daily actions.	In my decisions, I seek the best balance between environmental and economical aspects.	I seek to manage my energy consumption, to understand my devices and avoid any energy waste.	I seek primarily the profitability of my investments, while ensuring the comfort of my family.
Environmentalists	4	5	4	0
Compromisers	1	10	7	0
Technicians	0	2	11	5
Economists	0	2	2	10

Table 2. Electricity consumption vs. types.

	Total consumption (kWh)	Heating pump consumption (kWh)	Consumption without Heating pump (kWh)
Environmentalists	8,626	3,704	4,922
Compromisers	9,736	4,601	5,136
Technicians	10,252	4,942	5,310
Economists	11,913	5,422	6,491
Average	*10,111*	*4,683*	*5,428*

Table 3. Thermal flexibility and recorded temperature.

	Stated minimum comfort temperature (C°)	Stated maximum comfort temperature (C°)	Stated temperature (C°) in the living room in winter	Average T ° measured in January 2014 (C°)
Environmentalists	17–21	21–24	20,4	20,8
Compromisers	18–22	20–28 or more	20,6	21,6
Technicians	18–21	21–26	20,6	21,0
Economists	18–22	21–25	20,9	21,2

Table 4. Heated floor surfaces and related efficiency.

	Average heating underfloor surface (m^2)	Heat pump consumption/ heating floor surface (kWh/m^2)	Average surface of all heated rooms (m^2)	Heat pump consumption/ heating total heated floor surface (kWh/m^2)
Environmentalists	113	33	189	20
Compromisers	147	31	254	18
Technicians	138	37	315	16
Economists	147	37	377	14
Average	*137*	*34*	*248*	*23*

Flexibility in practice

During the second session of interviews, we have explored prospective scenarios of flexibility, drawn on literature and concrete examples. Users were invited to react and explain their viewpoints about possible contracts or interactions with grid operators. As we required from the ability to envisage their practices into fictional situations, this series of interviews was complex to interpret. Unlike the first series of interviews in which we focussed on domestic practices and their logic of action, here we had to project users in future situations while trying to make them think about the possible reconfigurations of their practices. It is therefore more difficult to analyse the results of the interviews in terms of real practices. We draw here the main lessons from the interviews and begin with "pure" economic tools.

We have presented a self-consumption scenario that incentivises consumption at the moment of production to respondents who own PV panels. Respondents usually consider the production/consumption balance on a yearly basis, and not as a instantaneous and ongoing process. They claim they are "energy autonomous" but use in reality almost twice more the grid than users without PV. Indeed, they bring electricity in the grid when they are not at home and they bring out electricity at night when their panels do not produce. The automy perception has been built through subsidaries ("green certificates") that use traditional meters whose measures are read once a year. However, among PV owners, many Environmentalists and some Compromisers endeavour to use their machines when the sun shines. They consider that this is just the reverse of peak and off-peak tariffs.

Time-of-use tariffs are already largely adopted by Belgian users through day and night/weekend prices – although those who have photovoltaic panels prefer a flat tariff as they have to balance their production and consumption on a yearly basis. We have explored the possibility to shift to a scheme of four prices, which reflect better the daily average price on the electricity market. All respondents rejected this proposition, as they think it would be too difficult to reconfigure their practices with the new tariff. Respondents usually think that they are already doing enough with the peak/off peak tariff. Discussions reveal that this well-adopted scheme fosters many households to shift their demand for some appliances (washing machine, dishwasher, hot water tank). Dynamic pricing (with a hourly tariff) is not more interesting for users – unless for some ones if they can embody this tariff in a programmable automaton. The big variability of the price is too complex to be managed: users are not willing to change their practices for a hypothetic gain.

We have explored a critical peak pricing scheme in which electricity prices can be very high during 2 to 4 hours and for a limited number of periods (maximum 15 by year). Users are informed 24 hours ahead on peak period and price. This scenario is not perceived as something affordable because users consider that they will always have to consume electricity at peak hours, and they are not sure that the sheer load shift of their heat pumps will be sufficient to compensate the price increase.

The perception of economic scenarios is clearly gender sensitive, as observed in interviews where the wife was present. The husband has the impression of having more flexibility while the wife has her time structured by fixed activities related to housework and children care tasks. We turn now to direct load control scenarios.

Heat pump is a heating system that requires little interaction and presents therefore interesting opportunities for delegating operations. We presented a scenario in which the electricity supplier remotely controls the heat pump. The remote control is performed in order to optimize the pump use, respecting temperatures that the user has previously indicated (minimum and maximum temperatures, variable with hours), and according to parameters such as electricity price, exposition of the building to the sun and local weather. If agreed, the supplier sets a fixed percentage discount on the standard rate that ranges between 5 and 10 % of the electrical part of the bill. Among our interviewees, Technicians and Compromisers are the most interested in this kind of load control. Environmentalists fear that provider interests will prevail over their own. They perceive the loss of control as an intrusion of an external actor in their domestic sphere. Economists need to see the resulting financial gain and esteem it is limited. They would prefer a local automaton they can supervise. In general, programmable automatons that communicate with the grid are more credited than a direct load control. Technicians and Compromisers are more interested in the remote piloting because they think that experts will perform it. They trust technology, and they perceive the electricity supplier as more technologically competent than themselves. The issue of delegation is therefore narrowly linked to the issue of trust to grid actors. When suppliers are considered as experts, control delegation is possible. But when suppliers are perceived as primarily safeguarding their particular interests, users are reluctant to delegate their heat pump management.

Another scenario was based on load shedding of the heat pump and/or other appliances during consumption peaks. A device placed on the electrical panel communicates with the grid and can shut down some fuses via a remote signal for a limited period. In this scenario, financial benefits are not guaranteed, while solidarity and environmental aspects are emphasised. This scenario is the most popular from respondents' perspective because of its simplicity and its environmental commitment. They consider that brief load shedding cannot jeopardise their comfort. By contrast to the former propositions, no effort is here required. Unsurprisingly, Environmentalists emphasise the environmental and collective dimensions of this scenario. Other respondents highlight that grid solidarity engages them to act: their uses are connected to others' uses. This scenario refers to a kind of "material participation" (Marres 2012). Environmental and collective solidarities are realised through a material device that simultaneously ties a multitude of users. The possibility of environmental or collective gains seems to be sufficient to enrol most of the respondents.

This scenario echoed the possibility of blackout in Belgium, which was much publicly discussed in the weeks preceding the interviews. A national load shedding plan has been launched and most of people know whether they might be affected. Respondents were then already receptive to the grid balance issue. The former load shedding scenario presents a similar call to citizenship and collective action. The majority of users are then open to flexibility if it can help to avoid load shedding that appears unfair because it will affect some (rural) territories and not other (urban) territories. The possibility of such an event creates a public (Marres 2012) and gives new meanings to energy and electricity (Strengers 2013). Users realise how much a wide range of activities depends on electricity provision. The event makes the grid existing and reveals the possibility of large flexibility for limited periods envisaged as disruptions (Wallenborn forthcoming).

We have also explored the interest towards microgrids and energy communities. Without surprise, Environmentalists are enthusiastic about the active participation in the local management of the grid, for example through the organisation of local energy councils where decisions and investment would be democratically taken. Compromisers are ready to engage in grid management if they feel that other users are involved too and that they are not the only ones to make efforts. Their engagement is conditioned by a collective impulse that would prove that everybody is concerned.

Conclusion: Alternative development paths for the grid

Demand response and user flexibility are key issues in the development of smart grids. The integration of renewable and intermittent sources into the grid requires that users begin to learn to consume electricity when it is abundant and restrict their consumption when wind and sun are absent. The long-term societal objective can only be 100 % renewable, and as long as electricity storage is much more expansive than direct consumption it is critical to engage demand side in the active management of the grid. The reorganisation of the grid implies the reconfiguration of practices, which cannot be reached without redefining at the same time the meanings of comfort and control. However, the current development of smart grid focuses on a combination of economical and technological interests that limit the potential participation of users to the grid balance.

We have developed a typology that characterises four ways of dealing with heat pumps and electricity at home. This typology was first aimed at our project partners, but we think that they reveal interesting features about the logics of actions and what can be expected from users in term of flexibility and smart grid development. In our typology, Resource Man (Strengers 2013) has been divided in two figures, the Economist and the Technician. In completing the picture with environmental considerations, however, we have found two other types, the Environmentalist and the Compromisers – who are better allies to the grid evolution than Economists and Technicians. We could have segmented our sample in other ways, with other questions of investigation. Nevertheless, we think that in focussing on what people do, and how they perform some practices, we have captured some coherent bits of how households interact with their heating system, appliances and the environment. The typology of our sample has achieved to catch material effects of how people give different meanings to electricity production and consumption, as the crossing with quantitative data has demonstrated. Of course, our sample is strongly biased and it is not possible to generalise the proportions of the four types to the whole Belgian population (and beyond). We think nevertheless that our study shows that another grid is possible with the active participation of some users.

Incumbent energy grid actors conceive "the user" (singular) as someone who will make decisions based on price and maximum delegation to the technology. Technological and economic viewpoints combine together. The technological viewpoint assumes that flexibility should be handled via remote piloting tools that will reinforce technology in homes and the decrease of user's direct control. Technician and Compromiser types might be interested in these tools, provided that grid operators demonstrate their skills to manage properly the heat pump. The economic viewpoint fosters individualist tools for the development of the grid. Mainstream smart grid policies mainly focus on the Economist type and, to a lesser extend, to the Technician one. We have however observed in our study that Economists are ready to make efforts for financial gain only, and that this gain is considered too low compared to the expected efforts. And other types are not more interested in economic tools, even though discussions about tariffs oblige respondent to frame their answers in economic terms. We have seen also that all interviewees are open to respond to exceptional events, namely when the functioning of the grid is threatened. It reveals that other grid developments are possible or even desirable for some parts of the population. In the mainstream development of smart grids, environment is not considered as something that concerns users.

Flexibility cannot be universally defined because it depends on how users configure their practices and on the way they relate to technology. Flexibility is relative to the way users interact with technology, which means that other technologies and infrastructure might lead to different kinds of flexibility. Flexibility is a matter of priority. Users prioritize certain actions with various criteria that might be price signal, comfort, ease of use, availability, environment, community, etc. Therefore, enhancing other incentives or other criteria than those currently used might yield to higher flexibility among Environmentalists and Compromisers. Flexibility mechanisms are based on response to signals. Signals are not inevitably economic, nor are they necessarily mediated through information and communication technologies. PV users can adapt their consumption just in relying on weather forecast. However, signals need to be meaningful and to create links between specific entities and activities. We confirm Strengers' (2013) observation that alert signals can mobilise a large public. Some parts of the population seem open to deepen their flexibility in giving new meanings to the grid. The reason for such a commitment must be stronger than just a financial incentive. In this perspective, flexibility may be more important than development based on individuals because it would reach other existing dimensions of the grid.

Environmentalists have a broader view on the grid and the place they occupy in it. They are more aware of the resources needed to bring services to homes. They are however rather critical with the idea that private interests might take over their daily lives. They do not trust providers (and distribution system operators to a lesser extend) and are reluctant to give away the control of their appliances. They are clearly favourable to local energy communities in which citizens could collectively choose how to develop the grid to meet local demand. The people who are the most committed to a flexible network are also those interested in other incentives than economic ones. The potential of flexibility would be enlarged if environmental and collective concerns were included in policy tools, as the possibility of a blackout has demonstrated. "One-shot" flexibility mechanisms could be considered in order to relieve the grid in case of overload. These exceptional events can be seen as critical experiments for exploring a higher level of flexibility.

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