EXPERIENCES AND BEHAVIORS OF END-USERS IN A SMART GRID: THE INFLUENCE OF VALUES, ATTITUDES, TRUST, AND SEVERAL TYPES OF DEMAND SIDE MANAGEMENT

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ABSTRACT

In this research, the experiences and behaviors of end-users in a smart grid project are explored. In PowerMatching City, the leading Dutch smart grid project, 40 households were equipped with various decentralized energy sources (PV and microCHP), hybrid heat pumps, smart appliances, smart meters and an in-home display. Stabilization and optimization of the network was realized by trading energy on the market. To reduce peak loads on the smart grid, several types of demand side management were tested. Households received feedback on their energy use either based on costs, or on the percentage of consumed energy that had been produced locally. Furthermore, devices could be controlled automatically, smartly or manually to optimize the energy use of the households. Results from quantitative and qualitative research showed that: (1) feedback on costs reduction is valued most; (2) end-users preferred to consume self-produced energy (this may even be the case when, from a cost or sustainability perspective, it is not the most efficient strategy to follow); (3) automatic and smart control are most popular, but manually controlling appliances is more rewarding; (4) experiences and behaviors of end-users depended on trust between community members, and on trust in both technology (ICT infrastructure and connected appliances) and the participating parties.

INTRODUCTION

The transition of our energy system is characterized by more locally and sustainably generated energy. The growth of decentralized energy generation and the need for efficient energy use, be it to reduce greenhouse gas emissions or to prevent exceeding the limits of our current energy infrastructure, call for solutions that enable optimization of the energy value chain (e.g., Wissner, 2011). Smart grids may be part of the solution by offering technology for integration and intelligent control of multiple generators, consumers and 'prosumers' (who both produce and consume energy).

The main objective of the current research was to understand the experiences and behavior of end-users in a smart grid. In this research, we set out to explore whether smart grids can be attractive for end-users, and which kinds of demand side management may lead to active involvement in the smart grid operation.

PowerMatching City, a living lab demonstration of the future energy system in the northern part of the Netherlands, is a smart grid environment that consists of 40 households. The connected households are equipped with various decentralized energy sources (PV and micro CHP), hybrid heat pumps, smart appliances, smart meters and an in-home display. Based on present-day tariffs and information on the percentage of consumed energy that is produced locally, households were enabled to use their appliances at an optimal (cost efficient and /or sustainable) moment. Appliances were controlled either fully automatic (hybrid heat pump or micro-CHP), smart (washing machine), or manually (general appliances). How do end-users experience several types of control (automatic, smart, manually) and different forms of feedback (on costs versus sustainability)? Do end-users shift their energy consumption to off-peak hours? Which kind of feedback is effective and for whom?

Values, attitudes, intention and behavior

A growing body of evidence has pointed out that values, attitudes and behavioral intentions are important determinants of pro-environmental behavior (e.g., Ajzen, 1991; Schwartz, 1994; Stern, Dietz, Abel, Guagnano, & Kalof, 1999). Values can be described as relatively stable goals that serve as guiding principles (e.g., De Groot & Steg, 2009). Values are only indirectly related to (pro-environmental) behavior, for example through specific attitudes and intentions (Stern, 2000, Darnton, 2008).

In line with the research of De Groot and Steg (2008, 2009), we were interested in pro-environmental values (e.g. ‘saving the planet’), egoistic values (in this research economic or technical interest) and pro-social values (e.g. ‘doing it for others’ and ‘giving a good example to others’). We expected these values to influence the attitudes end-users have of the smart grid project as a whole, and of the energy services we provided (e.g. feedback on costs versus sustainability). Furthermore, we expected these attitudes to influence end-users’ intentions to actively engage with energy services. We expected these intentions, in turn, to influence behavior (e.g., shifting the timing of energy demand). For an overview of the theoretical model, see Figure 1.

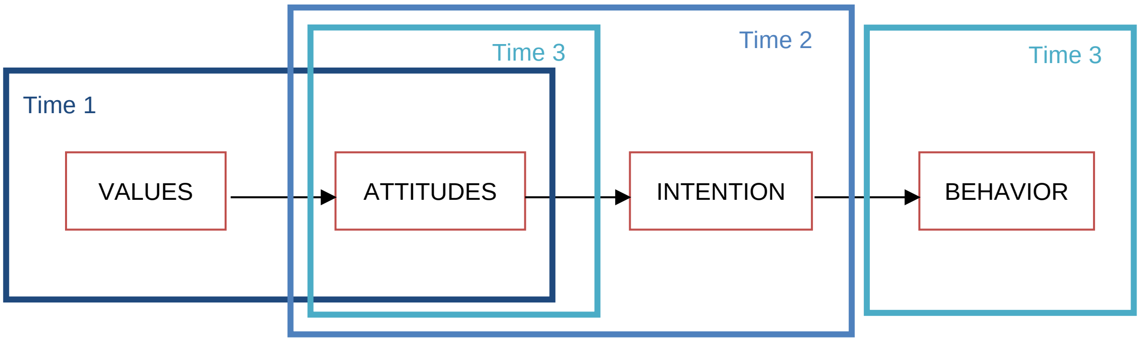

Figure 1. Theoretical model and timing of measurements

METHOD

40 households participated in the study. All households had a new, remotely controlled heating system (50% heat pump / 50% micro CHP). Of the households, 22 received a smart washing machine. Two energy services were developed in co-creation with the end-users.

Two energy services: feedback on costs versus sustainability

Households were randomly assigned to one of the two energy services. The first service was called ‘Together More Sustainable’ and it was developed to make optimal use of the energy that was locally generated (within the community). The second service was called ‘Smart Costs Savings’ and was developed to enable the households to consume energy when prices are low, and, if possible, sell self-generated and temporarily stored energy when prices are high. Households also received an energy monitor. The energy monitor end-users received, had one active profile, which depended on the energy service they received. The active profile displayed either the energy performance in euros, or the performance in percentage of the consumed energy that was generated locally. Participants could also access the other, non-active profile, which was in grey shades and offered insight in the other energy service (for example, energy consumption in Euro’s when the active profile offered insight in sustainability). End-users also received a forecast on which they could base their decision to consume energy immediately or delay consumption to a future moment (for an impression of the interface of the monitor, see Figure 2).

Figure 2. An impression of the Energy Monitor (courtesy of PowerMatching City consortium)

Three ways to control energy use

In each household, appliances could be controlled automatically (without interference of the end-user), smartly (programmed by the end-user), or manually to optimize energy use in line with one of the two energy services /goals (costs savings or sustainability). A 'PowerMatcher' was developed to monitor the demand for electricity in the smart grid. When the maximum capacity of smart-grid was reached, the PowerMatcher could set of a signal. Automatic and smart devices responded to this signal, for example by postponing their demand. For an impression of the infrastructure, see Figure 3.

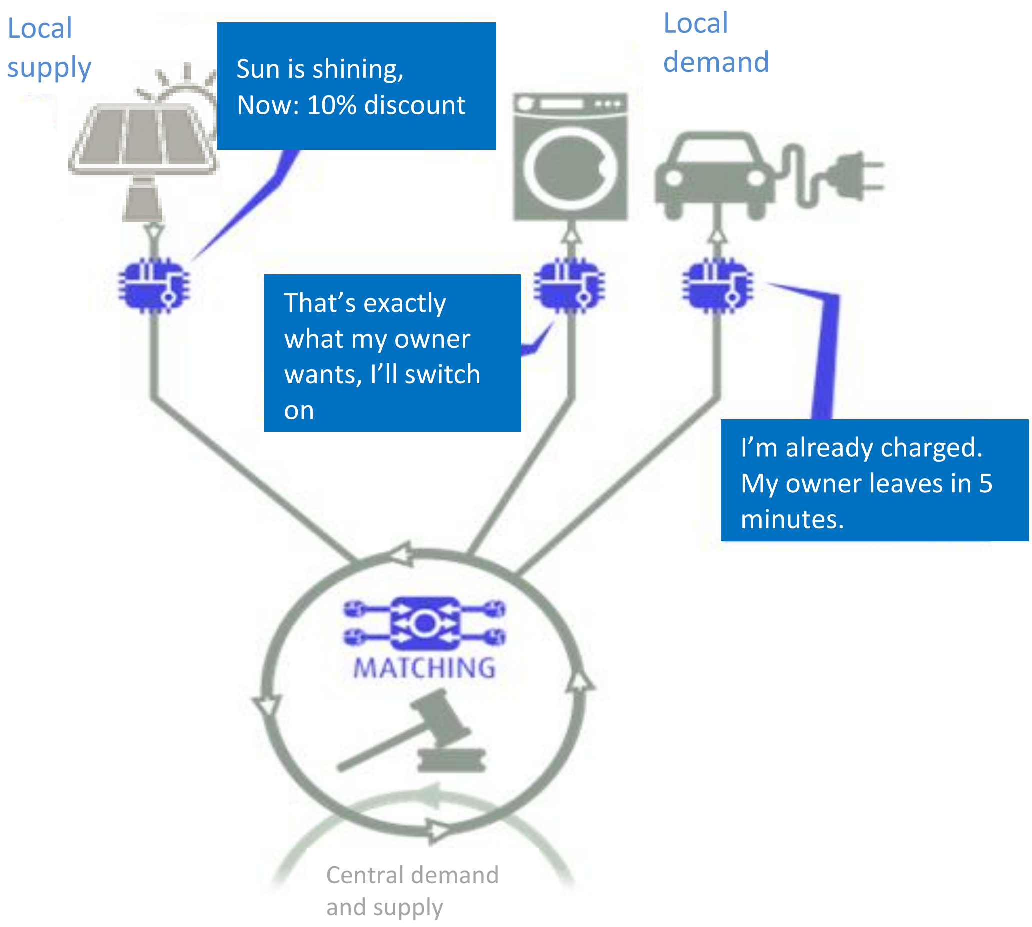

Figure 3. The PowerMatcher in the ICT infrastructure of PowerMatching City (courtesy of PowerMatching City consortium)

Procedure

Households participated in a series of tests. An initial test (Time 1) was conducted by means of a digital questionnaire. During the test phase (Time 2), households again responded to a digital questionnaire, after which about half of the households participated in a qualitative session (a focus group discussion to explore the results of the digital questionnaires in more depth). The concluding test (Time 3) consisted of a digital questionnaire and, again, a qualitative session which was attended by approximately half of the households. For a timeline of the research, see Figure 4.

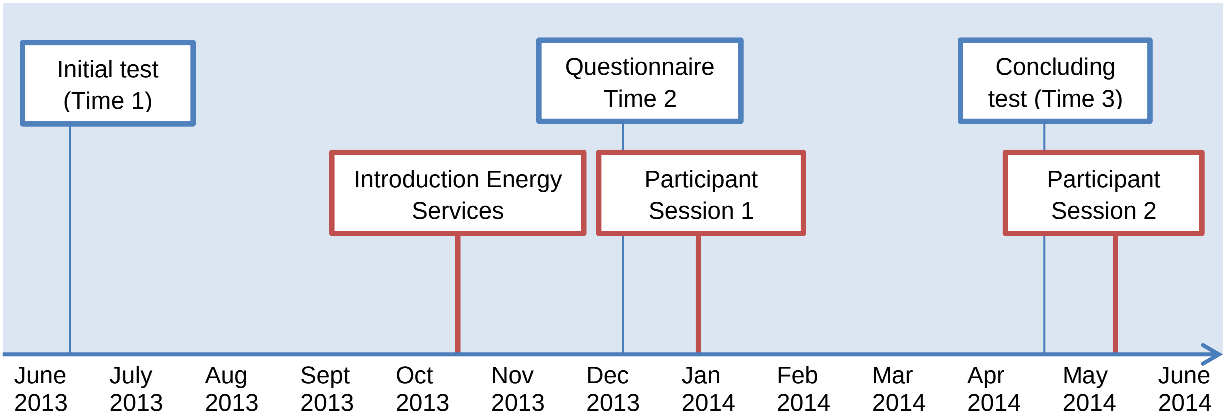

Figure 4. Timeline of the research

Measures of experiences and behavior

Values. Values were measured in an initial test, before the households were assigned to one of the energy services. Values were also measured in a control group that consisted of 255 Dutch respondents. This offered us the opportunity to investigate how representative end-users of PowerMatching City were compared to a wider group of Dutch households.

Values were measured in two ways: by means of a choice based conjoint analysis and by means of a direct, Likert scale measurement. Because both measurements rendered similar results, for the sake of space and clarity we chose to report the (simpler) Likert scales here. End-users were asked on six-point scales (1 = *not at all*, to 6 = *very much*) to indicate how much they valued: sustainability (saving the planet), cost savings (economic gain), technology, independence (autarky) and convenience.

Attitudes. Attitudes were measured three times; in the initial test, during the test phase (Time 2 in Figure 4), and in the concluding test. Attitudes towards the two energy services and towards specific components of the energy services (ways of demand side management: automatic, smart, manual control, and feedback on costs versus sustainability) were measured in the form of statements on six-point scales (1 = *totally disagree*, 6= *totally agree*). Global attitudes were assessed with five statements, for example: "I find this (e.g., 'energy service') attractive", "This appeals to me", and "I like this". Specific attitudes were assessed by five items, for example: "I'm positive about this component, because it enables me to save costs", "I find this component attractive, because it makes my energy consumption more sustainable", and "I find this component attractive, because it makes me more aware of my energy consumption".

Intention. Intentions were measured during the test phase. End users were asked whether they intended to make use of the energy services and, for example, to program their smart appliances, or to manually shift their energy consumption. Intentions were measured as statements and end-users could respond on six-point scales ranging from 1 *"totally disagree"* to 6 *"totally disagree*".

Behavior. Behavior was assessed during the test phase and in the concluding test. Behavior was measured by self-report, through the information we received from the smart appliances, and by measuring energy consumption patterns. The self-report measures consisted of questions about end-users' use of the smart appliances and about their use of regular appliances. For example, we were interested in the use of regular appliances and we asked end-users to indicate how often they shifted their use of different appliances (regular washing machine, dryer, dishwasher, oven, vacuum cleaner, et cetera). End-users could indicate their responses on six point scales ranging from 1 "*never*" to 6 "*always*".

RESULTS AND CONCLUSIONS

Values

Initial test. A comparison between households in the two PowerMatching City groups and randomly selected Dutch households, showed that end-users in PowerMatching City valued sustainability significantly more, and costs and convenience significantly less than the control group. There was also a significantly higher interest in technology in the PowerMatching City group. Households that would receive the 'Together More Sustainable' energy service significantly valued sustainability more than households that would receive the 'Smart Costs Savings' service. For an overview of the results, see Table 1.

Table 1. Values in the two PowerMatching City (PMC) groups and control group.

Values	PMC 'Smart Costs Savings'			PMC 'Together More Sustainable'			Control group		
	M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Sustainability	4.0[a]	1.64	31	4.6[b]	1.82	25	3.6[c]	1.75	255
Costs	3.8[a]	1.67	31	3.9[a]	1.34	25	4.7[b]	1.07	255
Technology	3.8[a]	0.89	31	3.8[a]	0.96	25	3.3[b]	1.11	255
Independence	3.2[a]	1.01	31	3.3[a]	1.12	25	3.3[a]	1.07	255
Convenience	2.8[a]	1.59	31	2.8[a]	1.59	25	2.9[a]	1.47	255

Note: Means that do not share superscripts differ at $p < .001$. Values were measured on a six-point scale (1 = not at all, 6 = very much).[1]

Attitudes

Feedback on costs versus feedback on carbon dioxide emissions. The six items (3 global items and 3 specific items) that comprise the attitude measures were highly related (Cronbach's alpha = .92 in the initial test, Cronbach's alpha = .92 at Time 2, Cronbach's alpha = .90 in the concluding test) and, therefore, we aggregated the scores of the six items. Results showed that the expectancies of the two services were significantly higher than the experiences with the services. There were no

[1] Dyadic data analysis (see Kenny, Kashy, & Cook, 2006) showed that the data of the partners within the household were not significantly more correlated than the data of the participants between households. Therefore, in the reported analyses we do not adjust for dependency of the data.

significant differences between the services. Furthermore, we noticed that individual scores were highly correlated between the times the tests were taken. For an overview of the test results, see Table 2.

Table 2. Attitudes towards the energy services.

	Initial test			Time 2			Concluding test		
Feedback	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Costs Savings	4.8[a]	.60	19	3.9[b]	1.00	16	4.2[b]	.79	19
Sustainability	4.7[a]	.83	17	3.9[b]	.82	15	3.9[b]	.98	13

Note: Means that do not share superscripts differ at p < .001. Opinions were measured on a 6-point scale (1 = totally disagree, 6= totally agree).

Automatic, smart, and manual control. Again the six items were highly related (Cronbach's alpha for all measures >.86). The mean scores did not significantly differ between the two energy services. However, because smart washing machines were not installed when the measurements at Time 2 were completed, attitudes towards the smart appliances were not assessed. Similarly to the responses to the energy services, expectancies were significantly higher than experiences. For an overview of the results, see Table 3.

Table 3. Attitudes towards automatic, smart, and manual control.

	Initial test			Time 2			Concluding test		
Control	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Automatic	4.9	.98	36	3.9	1.26	31	3.8[a]	1.22	31
Smart	4.7	1.05	36	-	-	-	4.4[b]	1.10	31
Manual	4.2	1.12	36	3.5	1.03	31	3.5[a]	1.39	32

Note: Means that do not share superscripts differ at p <.01.

Results from participant session 1. After the initial test and the measurements at Time 2, we organized a participant session to share and discuss the results. Participants indicated that they doubted the functioning of the PowerMatcher program and the energy services. Indeed, the project team found some issues with the control mechanisms, which were solved after the participant session. Also, it was noted that feedback in euros was perceived to be more clear and simple than "feedback in leaves" which represented sustainability scores.

Results from participant session 2. After the concluding test we organized a second participant session. Participants indicated that shifting energy automatically with their heat pump or micro-CHP and smart with their smart washing machine was most attractive because it requires the least personal effort. However, participants again stated that they did not always understand the moments at which these appliances switched on. They indicated that their trust in the system was violated in the first part of the project, and that it is very hard to win it back once they started doubting the system. This was also the main reason participants preferred smart shifting above automatic shifting; because participants could always choose to manually operate the smart washing machine, they could always take back control into their own hands.

Participants also indicated that they had a strong preference to use energy from their own production first and foremost. Only if they had a surplus of energy, participants approved that the energy be supplied to the community.

Even though participants preferred automatic and smart control systems, they also stressed that shifting their demand manually had been most rewarding. To manually shift their demand, participants had to consult their energy monitor initially, but as time passed, they discovered patterns and did not always have to look at their energy monitor before altering their energy consumption.

Values and Attitudes

Only one of the values could be reliably related to the attitudes towards the energy services: We found a positive correlation between Independency and the attitude towards the energy services ($r = .60$, $p < .001$).[2]

Behavior

At the moment this paper was written, we were still analyzing the energy data and the data of the smart appliances. Initial results show that we were successful in shifting energy demand to off-peak periods, but further analyses are needed.
We noticed that end-users with a smart washing machine did not use the smart function most of the time: 88% from the times the washing machine was used, participants operated it manually. Participants indicated that they would manually shift the timing of the washing machine, dryer, and dishwasher most often ($M = 4.4$, $SD = 1.24$ for the washing machine; $M = 3.0$, SD = 1.88 for the dryer; $M = 3.9$, $SD = 1.80$ for the dishwasher, measured on a scale ranging from 1 = *never* to 6 = *always*). End-users stated that they would shift the timing of other appliances rarely or never.

Interestingly, we noticed that end-users who received the energy service ‘Smart Costs Savings’ tended to manually shift the timing of their appliances more often than end-users who received the energy service ‘Together More Sustainable’, for an example see Table 4. We also noticed that the former looked, on average, one to two times per day at their energy monitor, whereas the latter looked less than one time per day at their energy monitor.

Table 4. Manually shifting the timing of the dishwasher.

	Dishwasher		
Feedback	*M*	*SD*	*N*
Costs Savings	4.3[a]	1.59	33
Together More Sustainable	3.2[b]	1.93	20

Note: The dishwasher was shifted manually most often of all appliances. End-users indicated the frequency at which they shifted their appliances on a 6-point scale, ranging from 1 = never to 6 = always. Means differ at p < .05.

[2] After analyzing the first results, we included some extra measures in the questionnaire to explore the value ‘Independency’ (see Kasl, Sampson, & French, 1964 ;Weinstein, Przybylski, & Ryan, 2012). Analysis reveals that the value ‘Independence’ was related to the desire of autarky. We also found that independence was related to the desire to be less dependent on larger energy suppliers.

We could not yet establish a relationship between attitudes and behavior. Further analyses of the energy data are needed.

Participant sessions. Participants who received feedback on costs were more positive than participants who received feedback on sustainability and indicated to be more actively involved. Two thirds of the participants stated that they would choose for the ‘Smart Costs Savings’ energy service in future. This is a surprising result in light of the findings that the participants highly valued sustainability, especially the participants who received the energy service ‘Together More Sustainable’.

Interestingly enough, participants perceived their return of the energy service, either the contribution to more sustainable local energy or lower costs, from the three methods of control (automatical, smart, manual) as rather equal, whereas the return of automatically shifting the heat pump or micro-CHP is significantly higher than smart shifting or manually shifting several appliances. During the participant session, participants revealed that they still did not have a clear understanding of how much energy appliances use.

SUMMARY AND DISCUSSION

To summarize, the results of the current research on experiences and behaviors of end-users in a smart grid show that end-users preferred feedback on costs to feedback on sustainability. End-users who received feedback on costs were more actively involved than end-users who received feedback on sustainability. This is an interesting result in light of the findings that end-users, compared with regular households, valued sustainability to a higher extent than costs. As a possible explanation, end-users indicated that feedback in euros was more tangible than feedback in percentage of energy consumption produced locally.

Also, end-users preferred to use their own produced energy. This finding is interesting, because it may not always be the most efficient strategy, either from a cost perspective or from a sustainability perspective. From a cost perspective, at times it may be better to deliver energy, for example when energy prices are relatively high. Similarly, it is not always the most sustainable strategy, for example when delivering energy to the community can better balance demand and supply within the community.

The latter case, delivering energy to the community so that the community as a whole operates more sustainably, requires that people have sustainability motives that are not only applied to their own energy consumption, but to the energy consumption of the whole community. This may expose a complex problem, because participants already expressed their doubts as to whether the other community members also live in a sustainable way. In the words of one of the end-users: “What if my neighbor decides to use my sustainably generated energy for his Jacuzzi?” This ‘Together More Sustainable’ perspective requires an orientation that transcends the individual, egotistic perspective and, what is more, also seems to require trust between the community members. It is questionable whether these conditions are always present within communities.

The results reported herein show that automatic and smart demand side management is most popular, but manually shifting energy demand is more rewarding. The main reason for the preference of automatic and smart control is that these kinds of control cost end-users the least effort. The most important boundary condition for end-users concerning remotely controlled automatic appliances is that they have to trust the technology (ICT infrastructure and connected appliances) and the third parties involved. Once this trust has been violated, it is very hard to win it back. The current research involves a complex system in which demand and supply has to be matched in a smart grid. In a system like this one, complex decisions are made which are not always in the direct interest of one specific end-user. This end-user, on seeing the results of the decisions on the display, has to trust that the system was well developed and will benefit the community as a whole. Similarly, end-users have to trust all parties involved. Especially in the case of for-profit organizations, such as energy suppliers, this may be difficult. We experienced that people were on guard and were quick to ask questions such as “Why is this company involved?”, and “How much profit do you make in this situation?”.

One important limitation of the described research was its sample size: The small sample size reduced the power of the current quantitative analyses and may have obscured relations in the data. Because we chose for a combination of quantitative and qualitative research, interesting findings nevertheless could be reported. In future research, larger sample sizes are needed to determine whether the results reported herein can be replicated and consolidated.

We would also encourage further research on trust of end-users in smart grids and in the other members (companies, community members) involved in the smart grid. We believe that active involvement of end-users, and therefore the success of a smart grid, requires trust both in the system and between the parties involved. We encourage more research on community processes as well. We noticed in the current research that end-users were focused primarily on themselves and not so much on the community. For example, they preferred to use their own produced energy instead of offering it to the community. Nevertheless, they stated that they value the community and could see that a community may render more optimal results. Whether a pro-social / community feeling can be established, and under which conditions, may be addressed in future research.

In conclusion, the current research offers insight into the experiences and behaviors of end-users in a smart grid project. Even though the sample size was relatively small, due to the use of different methodologies, interesting findings have been observed. Trust in technology, participating parties, and even trust between community members was a theme that repeatedly resurfaced. Also, more egotistic motives seemed to predominate: End-users preferred an energy service based on costs. Furthermore, when they received an energy service based on sustainability (which was actually consistent with their values), end-users preferred to use their own energy first and foremost, instead of sharing it with the community. Future research may explore whether pro-social motives can be induced and under which conditions, in order to pave the path towards truly sustainable communities. We hope that our research may inspire others to take up these issues and explore them in future in more depth.

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