Preferences on Home Energy Management Systems - A Study of Potentials for the Use of End User Flexibilities

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ABSTRACT

Due to the increase of volatile renewable energy resources, additional flexibility in the electricity system is necessary to ensure a technically and economically efficient network operation. To tap flexibilities like private storages, participatory developed and user-friendly technical solutions are essential. In this work, the acceptance and the market potential of a home energy management system with focus on i) grid optimization, ii) self-consumption optimization, and iii) additional functions for increased comfort is presented. This is determined by means of a representative survey. The main results show that the perceived usefulness and accessibility are the most important influence factors affecting the end user's intention to use. Based on the given acceptance, the solution provides a market potential of one third of the users for an increased use of flexibilities in the investigated area.

KEYWORDS

User preferences, home energy management system, end user flexibility

INTRODUCTION

The energy system is subject to a sustained transformation due to the increase of volatile renewable energy resources. In order to continue a technically and economically efficient and secure network operation, additional flexibility in the electricity system will be necessary in the future [1]. Investments in photovoltaic (PV) systems and energy storage solutions are advantageous for both, energy providers and private end-users, as they all profit from increased flexibility in the energy system [2].

Furthermore, home energy management systems (HEMS) give users the opportunity to gain insight into their energy consumption behavior and receive recommendations to change their behavior in a sustainable way yielding savings for both energy and costs [3, 4]. Energy management and cost savings are significant acceptance drivers for residents to implement HEMS in their households. Although HEMS are already well accepted in general, users' skepticism occasionally occurs [5] particularly if their objectives and HEMS' feedback concerning their energy consumption behavior are in conflict (e.g. if a comfortable lifestyle needs to be changed) [6, 7]. To alleviate users' concerns, which lead them to ignore provided feedback, deriving benefits from HEMS can be supportive and increase acceptance, e.g. cost savings, environment protection, comfort, energy independence, possibility to control appliances in an innovative way as well as social aspects like being a role model, being part of a community, competition and fun [8]. However, monetary benefits are often more valued by consumers than contributing to a community [9]. Another important factor is innovativeness

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and the utility of HEMS, the latter being even more important than the ease of use when affecting the consumers' intention to use [10].
Besides device control and energy monitoring, one key feature of HEMS is the prediction of energy consumption patterns as well as energy generation opportunities [4]. Weather forecasts enable estimation of future energy generation, for example through PV or solar systems. Due to this indication, home energy usage can be scheduled automatically by the system. Alternatively, the provided information by HEMS empowers the users i) to contribute to grid optimization [7], and ii) to optimize their self-consumption [11].

Grid optimization

In respect to grid support, forecasts of energy consumption and generation that are developed by HEMS according to received household data provide direct benefits. The retrieved data from energy suppliers give HEMS the opportunity to reduce strain on the grid and therefore to better control whether and where investments in the grid are necessary, which subsequently optimizes the grid for consumers' usage [9]. Moreover, due to accurate predictions energy demand peaks and times of high renewable energy production can be identified and managed efficiently [7]. This gives energy suppliers the opportunity to structure their supply flexibly and according to demand [4]. Such an efficient management approach, in turn, avoids energy wastage. However, if users are encouraged to reschedule appliances from peak hours to regular hours due to grid optimization activities, they may feel restricted and perceive comfort decreases [7]. This could possibly be counteracted if the utility offers discounts for load shifting [12].

Self-consumption optimization

To optimize the users' energy consumption, HEMS recommend to shift their activities [5, 11]. Ideally, HEMS enable users to avoid energy wastage and monitor energy consumption, which is subject to the condition that consumers comprehend its content [7, 13]. HEMS either analyze the entire building, individual rooms or single appliances [7, 11]. Presentation of energy consumption data at appliance level increases consumers' comprehension and processing of the shown information as the disaggregated form helps consumers to relate the data to their personal activities. Furthermore, HEMS support consumers to identify and track devices that consume large amounts of electricity and thus create a cost saving potential by presenting consumption data at appliance level [4, 5]. A user-friendly interface that emphasizes specific data relevant for the respective user is crucial [4]. Another feature regarding self-consumption optimization that consumers expect from HEMS is to remotely switch on and off devices that are currently not in use [9]. This offers an additional comfort function to the self-consumption optimization component.

Additional comfort functions

HEMS provide several comfort factors that increase user acceptance, e.g. thermal comfort (temperature), humidity and airflow, air quality (CO_2 concentration), or visual comfort (illumination) [5, 7], which is perceived differently depending on the age of the individual person. Due to a decreasing eyesight in advanced age, elderly tend to favor luminescent spaces [7]. In general, color changing lights can provide a pleasant atmosphere [5]. Additionally, automatic prediction of user parameters is a possibility to increase user comfort, especially for disabled persons, as it helps to operate with the system [7]. It enables relatives to remotely control appliances in their homes [9]. HEMS furthermore increase the comfort factor by scheduling certain devices, like a washing machine, in accordance with the need of users. In addition, the security factor is increased, e.g. by switching lights on and off automatically if residents are absent for a longer period [5]. As smart homes often require the usage of appliances from the same vendor, users may feel restricted by HEMS [7]. Therefore, compatibility is also a relevant comfort factor to consider when developing HEMS.

PROBLEM AND RESEARCH NEED

To sum it up, HEMS offer several benefits to the environment, to the grid, and to users. However, the intention to use HEMS and to adopt energy-saving behaviors not only depends on the technology itself, but also on the characteristics of the individual. The literature distinguishes between two ways of reducing energy consumption: i) energy conservation (users make changes in their behavior in order to save energy, e.g. in everyday life), and ii) energy efficiency (implementation of new, improved and more efficient technologies that save energy) [14]. Many social and psychological factors (e.g., attitude, values) determine whether people opt for one of the mentioned energy saving measures [15, 16]. In addition, the economic aspect (costs vs. benefits), income level and age group also need to be considered [17]. Therefore, flexibilities provided by PV, energy storages and HEMS may only lead to theoretical potentials for a real supply of flexibility to the electricity grid as private end-users often neglect or even ignore external recommendations of HEMS regarding beneficial behavior.

To convince users to implement HEMS and follow their recommendations, a participatory inclusion of end-users and user-friendly HEMS are essential to tap potential flexibilities beneficial for the electricity system [18, 19]. It is necessary to investigate the factors that are primarily responsible for driving user acceptance concerning the use of HEMS and how they link to the users' needs concerning self-consumption optimization and comfort with the grid's requirements and optimization. Furthermore, the factors negatively influencing the intention to use HEMS must be considered to develop appropriate strategies for motivating them to engage with it. To use such strategies in a targeted manner, potential user groups can be identified. Cut-off factors like individual motivation (e.g., economic benefit), social motivation (e.g., environmental responsibility) and personal characteristics (e.g., openness for innovations) can be used [10].

In this work, the intention to use a participatively developed HEMS with focus on i) *grid support optimization* by consumption in times of high renewable production, ii) *self-consumption optimization*, and iii) *additional functions for increased comfort* and its influencing acceptance and requirements factors are presented. Furthermore, the potential for a broad roll-out of the solution is exploited.

METHODS

The user acceptance of the HEMS is determined by means of an online survey in a three communities cluster sample of the Austrian district of Hartberg-Fürstenfeld, Styria, covering acceptance and motives to use the developed HEMS.

Participants and procedure

The sample consists of n = 93 potential users of HEMS, which leads to a sample error of 4.61%. Of those surveyed, the majority were male (63%) between the ages of 20 and 78 (M = 50.93, SD = 14.99). 31% of the respondents have a school-leaving certificate or a tertiary education as the highest completed education. 15% have completed intermediate vocational schools, less than a quarter (23%) has completed an apprenticeship. 65% live in single-family houses with floor spaces of 177.60 m^2 on average (SD = 52.26), 11% live in two-family houses or of larger size (M = 261.30, SD = 158.75). The remaining 23% of the participants live in flats (M = 78.00, SD = 10.98). Most frequently, the respondents' households consist of two persons (41%); households with four or more persons are also common (31%). 28% of the households with more than one person have children. 23% of those surveyed stated that they had already installed a PV system, typically with a rated output of 3 to 5 kWp (48%). Main participant sociodemographics are stated in Table 1.

Table 1. Participant sociodemographics

Sociodemographics	M	(SD)	%
Gender			
Female			35.90
Male			64.10
Age (years)	50.93	(14.99)	
Education			
Apprenticeship			23.10
Intermediate vocational school			15.30
School-leaving certificate			30.80
University degree			30.80
Housing and floor space (m^2)			
Flat	78.00	(10.98)	22.50
Single-family house	177.60	(52.26)	65.20
Tow-family house or larger	261.30	(158.75)	11.20
Other	90.00	-	1.10
Household size			
1 person			8.70
2 persons			40.90
3 persons			18.60
4 or more persons			30.80
Children living in household			
None			72.00
1 child			15.80
2 children			11.00
3 or more children			1.20

M = means, SD = standard deviations, n = 93

The questionnaire was sent by e-mail to the current 521 users of the local cluster utility with available e-mail addresses. In order to achieve a better response rate, the users could take part in a raffle for vouchers worth 50 EUR. During the first four days 62 customers were reached who opened the questionnaire. After five days a reminder e-mail was sent out. In the remaining ten days further 34 answers were collected. In the course of data cleansing, an obviously duplicate answer was removed, two further answers were excluded due to insufficient data quality. This results in a response rate of 17.85%.

Measures

To measure the relevant constructs, proven instruments such as the Environmental Attitudes Inventory (EAI) [20], the Technology Usage Inventory (TUI) [21] or the Technology Acceptance Model (TAM) [22] are adopted or slightly adapted with respect to the project context. Furthermore, scales from previous work are used [18]. Means, standard deviations and correlations are presented in Table 2.

Table 2. Descriptive statistics and correlations

		M	SD	2	3	4	5	6	7	8	9	10	11	12	13	14
1	COB	4.46	.42	$.25^{*}$	$.27^{*}$	-.01	-.09	-.20	.17	.17	.06	$.24^{+}$	.00	$.28^{*}$	$.26^{*}$	.17
2	TST	3.39	.72		$.41^{**}$	$.18^{+}$	$-.35^{**}$	$-.25^{+}$	$.33^{*}$	.18	.11	$.44^{**}$	$.32^{*}$	$.41^{**}$	$.39^{**}$	$.41^{**}$
3	CUR	3.69	.78			$.56^{**}$	-.12	-.17	.02	.19	.11	.20	-.10	-.01	$.37^{**}$	.18
4	INR	3.29	.77				$-.29^{**}$	$.35^{**}$	-.16	-.03	.04	-.04	-.23	-.06	.11	-.13
5	ANX	2.12	.66					.08	.06	$-.29^{*}$	.01	-.07	$.25^{+}$	.01	-.16	.05
6	SKE	2.39	.62						-.17	$-.47^{**}$	-.18	$-.29^{*}$	-.13	-.16	$-.31^{*}$	$-.37^{**}$
7	USF	3.12	.78							$.26^{*}$	$.28^{*}$	$.53^{**}$	$.65^{**}$	$.60^{**}$	$.48^{**}$	$.70^{**}$
8	USB	3.61	.53								$.54^{**}$	$.44^{**}$	.14	$.31^{*}$	$.42^{**}$	$.36^{**}$
9	ACC	3.25	.59									$.38^{**}$	$.25^{+}$	$.32^{*}$	$.38^{**}$	$.48^{**}$
10	SAV	3.99	.74										$.57^{**}$	$.79^{**}$	$.82^{**}$	$.52^{**}$
11	CMF	3.04	.92											$.68^{**}$	$.35^{**}$	$.52^{**}$
12	MON	3.49	.71												$.62^{**}$	$.52^{**}$
13	SUS	4.16	.65													$.49^{**}$
14	ITU	3.04	.90													

M = scale means, SD = standard deviations, correlations, $^{+}$ p <0.10, * p <0.05, ** p <0.01,
COB = personal conservation behavior, TST = trust in science and technology, CUR = curiosity, INR = interest, ANX = technology anxiety, SKE = skepticism, USF = usefulness, USB = usability, ACC = accessibility, SAV = savings, CMF = comfort increase, MON = monitoring, SUS = sustainability, ITU = intention to use.

Personal conservation behavior. Personal conservation behavior (COB) is measured with four items on a 1 = *strongly disagree* to 5 = *strongly agree* scale adopted from the EAI, e.g. “I always switch the light off when I don’t need it on any more” (α = .69).

Trust in science and technology. Trust in science and technology (TST) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adopted from the EAI. Three items were used to comprise the TST scale, e.g. “Modern science will be able to solve our environmental problems” (α = .69).

Curiosity. Curiosity (CUR) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TUI, e.g. “I am curious about the use of innovative energy and environmental solutions” (α = .89).

Interest. Interest (INR) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adopted from the TUI, e.g. “In the course of my life I have acquired a lot of technical knowledge” (α = .87).

Technology anxiety. Technology anxiety (ANX) is measured with four items on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TUI, e.g. “The idea of doing something wrong when using technical equipment scares me” (α = .72).

Skepticism. Skepticism (SKE) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TUI, e.g. “The HEMS solution will disrupt my daily routine” (α = .64).

Usefulness. Four items are used to measure the perceived usefulness (USF) on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TAM, e.g. “Using the HEMS solution would make many things more convenient” (α = .81).

Usability. The perceived ease of use, or simply usability (USB) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TAM, e.g. "Using the HEMS solution is easy to understand" (α = .76).
Accessibility. Accessibility (ACC) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TUI. Three items are used to comprise the ACC scale, e.g. "I think that the HEMS solution can be afforded by almost anyone" (α = .67).
Savings. The importance of cost savings (SAV) is measured using four items on a 1 = *not important at all* to 5 = *very important* scale taken from previous work, e.g. "To achieve rapid cost savings with the HEMS solution" (α = .82).
Comfort increase. The importance of comfort increase (CMF) is measured using five items on a 1 = *not important at all* to 5 = *very important* scale taken from previous work, e.g. "Shutter control" (α = .80).
Monitoring. The importance of monitoring (MON) is measured on a 1 = *not important at all* to 5 = *very important* scale. Seven items are used to comprise the scale taken from previous work, e.g. "To be constantly informed about my current energy consumption" (α = .84).
Sustainability. The importance of sustainability (SUS) is measured using six items on a 1 = *not important at all* to 5 = *very important* scale taken from previous work, e.g. "To support the use of renewable energy sources" (α = .88).
Intention to use. Intention to use (ITU) is measured on a 1 = *strongly disagree* to 5 = *strongly agree* scale adapted from the TAM. Three items are used to comprise the ITU scale, e.g. "I would purchase the HEMS solution" (α = .92).

Analysis

Data is analyzed with path analysis to detect influences on the intention to use the developed HEMS. It is assumed that attitudes (i.e., *personal conservation behaviour*, *trust in science and technology*, *curiosity*, *interest*, *technology anxiety*, *skepticism*) and demographic characteristics (i.e., *gender*, *age*, *education*, *floor space*) affect acceptance (i.e., *usefulness*, *usability*, *accessibility*) and requirements (i.e., *savings*, *comfort increase*, *monitoring*, *sustainability*), while the latter themselves affect *intention to use*. The hypothesized model is shown in Figure 1.

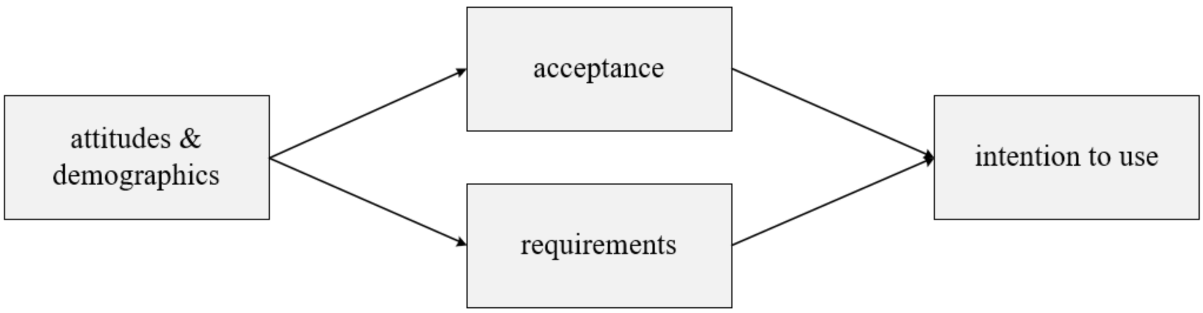


Figure 1. Hypothesized model

The path model consists of separate multiple linear regression models with standardized beta coefficients providing information about causal relationships. To explore the market potential in order to plan a broad roll-out, k-means cluster analysis is conducted.

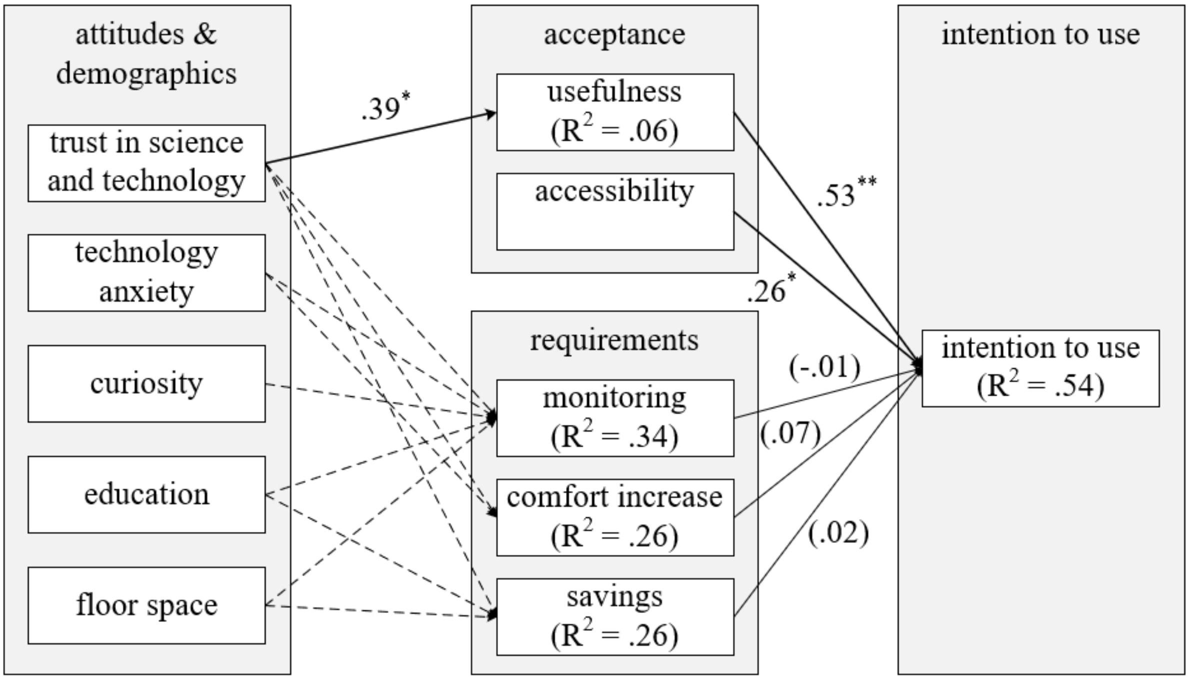
RESULTS

Table 2 indicates that the most important factor for using HEMS is the *sustainability* of the solution (M = 4.16, SD = .65). It's the contribution to environmental protection, the use of renewable energies, and their increase in efficiency considered rather important. Another determinant motive to use is economic benefit in terms of cost *savings* (M = 3.99, SD = .74). In addition, the possibility to *monitor* the own energy consumption, information from and interaction with HEMS are moderate to rather important criteria (M = 3.49, SD = .71). Moderate important motives are additional functions to *increase the comfort* (M = 3.04, SD = .92) like remote control regarding illumination and surveillance.

The acceptance for the participatively developed HEMS is slightly positive. The *usability* is considered comparatively best (M = 3.61, SD = .53), while *accessibility* (M = 3.25, SD = .59) and *usefulness* (M = 3.12, SD = .78) are considered rather moderate. The *intention to use* is also moderate on average, but the measures are slightly wider spread (M = 3.04, SD = .90).

Path analysis

The results of the path analysis show, on the one hand, joint effects of attitudes and demographics on requirements and effects of attitudes on acceptance. On the other hand, acceptance factors have joint impact on the intention to use the developed HEMS, while requirements have no impact (see Figure 2).



^{+}p <.10, $^{*}p$ <.05, $^{**}p$ <.01, dashed lines show further significant effects, beta values in brackets show nonsignificant effects

Figure 2. Path analysis illustrating direct effects

In terms of demographic characteristics, *gender* and *age* neither influence acceptance, nor requirements of HEMS. The user *education* level tends to influence the importance of cost *savings* (β = .22, p = .08) and shows a significant effect on *monitoring* (β = .26, p = .03). Furthermore, the results indicate significant influences of the users' floor space on both cost *savings* (β = .30, p = .03) and *monitoring* (β = .26, p = .04).

In terms of user attitudes, more effects on requirements are indicated than on acceptance. *Curiosity* influences the importance of *monitoring* (β = -.42, p = .02) negatively, *technology anxiety* shows significant effects on both the importance of *monitoring* (β = .27, p = .04) and *comfort increase* (β = .39, p <.01). The most influences are based on *trust in science and technology*. There are significant effects on the requirements *monitoring* (β = .47, p <.01), *comfort increase* (β = .52, p <.01), and *savings* (β = .34, p = .02). Furthermore, *trust in science*

and technology is the only influencing factor on acceptance, in particular on the *usefulness* of the developed HEMS (β = .39, p = .02).
Finally, effects on *intention to use* were tested considering the aforementioned dimensions of acceptance and requirements. The observed model has a moderate error since the variation of *intention to use* is explained to 54% by the scales *usefulness*, accessibility, *monitoring*, *comfort increase*, and *savings*. The results show that only the acceptance dimensions *usefulness* (β = .53, p <.01) and *accessibility* (β = .26, p = .02) have significant effects on the *intention to use*, while requirements have no significant effect on *intention to use* at all.

Cluster analysis

In addition, a k-means cluster analysis was carried out based on the dimensions of acceptance, requirements and intention to use the developed HEMS. Thereby, five segments were identified which are shown in Figure 2.

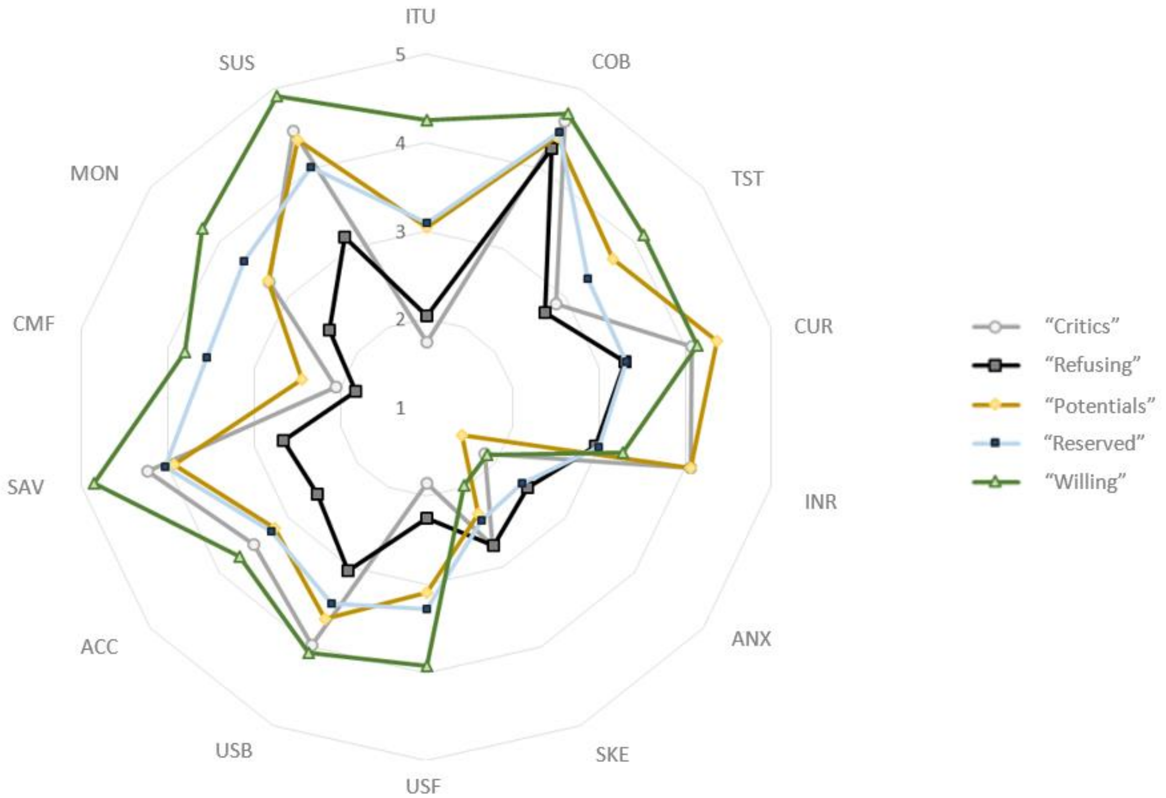


Figure 2. K-means cluster analysis illustrating user segmentation

<u>*Segment "Willing" (17%).*</u> The prototype "Willing" is 44.86 years old (SD = 16.65), gender is distributed balanced. Compared to users of other segments they are more than twice as likely to have completed general or vocational school with or without a school-leaving certificate. Their housing situation is about 50% more often that of multi-family houses with households of four or more persons. Typical usable floor space of their homes amounts 158.28 m² on average (SD = 78.15).
Participants are most likely to use HEMS (M = 4.26, SD = .41). Their most relevant motives are sustainability (M = 4.91, SD = .20) and cost savings (M = 4.86, SD = .27). They evaluate HEMS as more useful (M = 3.93, SD = .59), more user-friendly (M = 4.08, SD = .51) and more accessible (M = 3.70, SD = .51) compared to the other segments. While interest in new technologies is only moderately pronounced (M = 3.28, SD = .92), there is a rather high level

of trust in science and technology in this segment (M = 4.14, SD = .62). Furthermore, users in this segment seek possibilities for monitoring energy consumption (M = 4.24, SD = .47) and for increasing comfort in their home (M = 3.80, SD = .62) through HEMS.

Segment "Reserved" (39%). The prototype "Reserved" is more likely to be characterized by female users (61% more often) aged 47.94 on average (SD = 13.58) who tend to have completed an apprenticeship (48% more often). Persons in this segment are more likely to live in larger houses, as the typical floor space of their homes amounts 158.55 m² (SD = 88.81).

"Reserved" users have comparatively high requirements towards the HEMS solution, as the motives of comfort increase (M = 3.55, SD = .44) and monitoring (M = 3.65, SD = .38) are more important in for users of this segment compared to other users. Their attitudes are more defensive in terms of curiosity (M = 3.31, SD = .69), interest (M = 3.00, SD = .52), and trust in new technologies (M = 2.39, SD = .57). This results in a positive evaluation, but only a moderately pronounced actual intention of use the HEMS solution (M = 3.09, SD = .54). With 39% share it is the largest target group and therefore relevant for HEMS providers.

Segment "Potentials" (18%). Typical "Potentials" are 54.29 years old (SD = 11.15) and equally distributed on gender. They are more than three times more likely to have completed tertiary education than users in other segments. They are a more than 1.5 times more likely to live in large flats with typical floor space of 166.26 m² on average (SD = 79.34).

Persons in this segment are generally open to new technological developments, as curiosity (M = 4.37, SD = .47) and interest (M = 4.06, SD = .47) are comparatively high, and technology anxiety (M = 2.12, SD = .66) is rather low. However, the "Potentials" have only limited confidence in the developed HEMS, particularly with regard to usefulness (M = 3.66, SD = .48). Above all, little value is placed on additional functions that are intended to contribute to increased comfort (M = 2.45, SD = .76). The intention to use is moderate (M = 3.04, SD = .68).

Segment "Refusing" (18%). The "Refusing" user is typically male (1.4 times more frequent) with an average age of 55.43 (SD = 13.30) who tend to have completed an apprenticeship (1.9 times more frequent). Persons in this segment are 1.2 times more likely to live in larger houses than single-person households with floor spaces of 134.87 m² on average (SD = 56.75). The intention to use the HEMS solution is rather low (M = 2.03, SD = .36).

Segment "Critics" (8%). The prototype "Critics" is comparatively young at 38.81 years of age on average (SD = 14.01). There is a slight preponderance of male users within this group (58% more frequent). They are almost twice as likely to have completed tertiary education compared to users of other segments and live predominantly in apartments or multi-family houses (1.2 times more likely). The intention to use is rather low in this segment (M = 1.73, SD = .65).

CONCLUSION

The respondents are generally rather to very environmentally conscious, but only moderately interested in technological developments. However, curiosity and openness towards new technologies are present on several occasions. They are generally quite open to the developed HEMS solution, although acceptance is moderate in general. The most important motives of the users are sustainability and the potential monetary benefits of the HEMS. Moderate to rather important factors for the use of the HEMS solution are possibilities to monitor one's own energy consumption and to increase the comfort of the home through additional functions.

The main results show that usefulness and accessibility are the most important influencing factors that affect the end user's intention to use the HEMS solution. The perceived usefulness depends heavily on trust in science and technology.

A further market segmentation indicates that about 17% of the end users show a high acceptance and intention to use the developed HEMS. This target group could be reached by highlighting the monetary advantages of the HEMS solution and the ongoing savings potential. Since this

user group puts just as much emphasis on sustainability, both monetary and idealistic motives are addressed, which are often seen as rather contrary. An additional target group of 18% of end-users could be reached by specific marketing campaigns, especially as they are very open to new technological and sustainable developments.
Based on the given acceptance of the developed HEMS, a component for a successful energy transition is provided, since the solution unleashes further potential for an increased use of flexibilities.

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