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Preferences for configurations of Positive Energy Districts – Insights from a discrete choice experiment on Swiss households

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ABSTRACT

By 2025, the EU aims to develop 100 Positive Energy Districts (PEDs) – communities that promote renewables for energy generation and an environment that enables sustainable lifestyles on the part of the resident. Despite rising interest in the topic, prospective residents' preferences for PED configurations have yet to be documented. This paper addresses this gap by implementing a discrete choice experiment (DCE) on Swiss residents to explore preferences for configurations of PEDs according to three attributes: ownership and expected citizen engagement, mobility options, and availability of shared spaces. We document that residents' preferences for PED configurations vary depending on respondents' car and home ownership, age, household size, and values. Findings suggest a variety of preferences for PEDs that policy-makers may want to consider when developing these communities. One key recommendation is that policymakers should pay attention to existing mobility patterns when designing mobility alternatives around PEDs. Helping citizens envision their energy system and recognize an alternative energy future may also be important to building familiarity and propensity for change.

1. Introduction

As part of the EU Green Deal, EU Member States have committed to reducing emissions by at least 55% by 2030, relative to 1990 levels (European Commission, 2020b). One of the supporting pillars in reaching this goal has been the Directive on common rules for the internal electricity market ((EU) 2019/944) which introduces rules that would enable citizens and energy communities to actively participate in the energy system (European Commission, 2020a). Further, the EU's 2019 'Clean energy for all Europeans package' has incorporated policies for "active consumer participation, individually or through citizen energy communities, in all markets, either by generating, consuming, sharing or selling electricity, or by providing flexibility services through demand-response and storage" (European Commission, 2020b). Energy communities, which can allow citizens to take an active part in the energy system, take on a variety of forms. While typically thought of as citizen-led efforts (Interreg Europe, 2018), energy communities can also be spearheaded by the private or public sector, or through public-private-people partnerships (PPP). For example, Positive Energy Districts (PEDs) are a concept that has been introduced by the EU to transition residential communities into neighborhoods relying on renewable energy technology to generate electricity and heat, while putting citizens at the core of the community and ensuring affordability in energy access to all. The implementation of these neighborhoods is envisioned to be a function of collaboration between the city, private sector, and public participation (European Commission, 2018). Overall, while a multitude of policies envision citizens participating actively in the energy system, even as energy producers and self-consumers (i.e., prosumers), it is imperative to first understand how citizens want these systems configured and to what extent they want to participate.

We explore this question by testing preferences for characteristics of Positive Energy Districts (PEDs) – residential communities that combine "built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emission and to create added value and incentives for the consumer" (European Commission, 2018, p. 6). PEDs and PED-like areas take on a variety of forms, whether the renewable energy technology is owned by the community or public and private sector (Derkenbaeva et al., 2020). This paper focuses on PEDs due to their salience to the EU's energy transition agenda – the EU aims to see the development of 100 PEDs by 2025 and current efforts to develop PEDs include a variety of EU Horizon 2020 projects (e.g., POCITYF, Atelier, Making City).

While a number of studies have examined factors influencing

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Abbreviations to be used:

PED	Positive Energy District
REC	renewable energy community
DCE	discrete choice experiment

adoption or acceptance of individual renewable energy technologies and related products/services, no study, to our knowledge, has explored what characteristics citizens might prefer in a holistic environment like an REC. For example, previous studies have explored and identified varying consumer segments, including likely adopters, of sustainability technologies in vehicle-to-grid charging (Khan and Bohnsack, 2020), electricity conservation programs (Hille et al., 2019), solar PV (Vasseur and Kemp, 2015; Petrovich et al., 2019; Heng et al., 2020), and green electricity (Tabi et al., 2014). In these studies, socio-demographic and psychographic characteristics have been utilized to understand drivers of preferences for green innovation or to explain pro-environmental behavior. Other studies have explored factors driving acceptance of community renewable energies and renewable energy infrastructure (Musall and Kuik, 2011; Batel et al., 2013; Bauwens and Devine-Wright, 2018). However, very few academic studies have investigated PEDs (examples include Lindholm et al., 2021; Olivadese et al., 2021) and, as far as we know, no study has explored preferences for different PED characteristics. Yet, this question is important as building energy communities that are appealing to people may help facilitate not only their overall deployment, but also citizen participation. This paper addresses this gap by documenting preferences of Swiss residents for different configurations of PEDs using elements found in current PEDs or PED-like communities.

In order to investigate differences in preferences for a variety of PED characteristics we designed a discrete choice experiment (DCE) wherein respondents were asked to repeatedly make choices about which one, among a number of profiles of PEDs, they would want to live in. DCEs are a useful way to explore preferences for PEDs as they allow respondents to compare profiles of PEDs as packages of characteristics rather than individual characteristics. This is fitting as PEDs are a setting made up of a variety of products and services: PEDs can be described not only by the way energy is generated and distributed, but also by extra attributes such as available sustainable mobility options or a built environment that encourages a community feeling. Existing district-level renewable energy projects – such as the Hunziker Areal in Zurich, Switzerland, and the Vauban in Freiburg, Germany – have shown that the appeal of living in holistic energy communities goes beyond reliance on renewable energy technology and includes benefits such as green mobility options and shared spaces that build a sense of community.

Indeed, DCEs are a common technique to gauge preference for new products. DCEs are often utilized to segment respondents based on stated preferences (Green and Krieger, 1991; Camilleri and Azzopardi, 2011) and are useful for understanding attitudes, personal norms, and values of users (Daae and Boks, 2015). Following previous work studying end-users in green innovation (Zimmerling et al., 2017; Khan and Bohnsack, 2020; Wever et al., 2008; Tolkamp et al., 2018; Hille et al., 2019), we argue that collaboration with end-users is critical in sustainability innovation (also termed "green innovation" or "eco-innovation"). The end-user can be integrated into a business model innovation at various points of the process (Wever et al., 2008; Cui and Wu, 2015; Tolkamp et al., 2018). Engaging users in the development of the value proposition – the product or service being offered – can lead to offerings tailored to consumer needs (Tolkamp et al., 2018) and user-centric design can lead to faster adoption of sustainable innovations (Daae and Boks, 2015).

The research questions we seek to answer are:

1. What attributes commonly described in PED-like communities are preferred by citizens?
2. How can we describe the segments of PED preferences (in terms of sociodemographic and psychographic variables)?

Findings from these research questions can inform the design of communities that meet and adapt to user needs and can help shape tailored communications to different segments. By collating information on preferences, socio-demographic and psychographic characteristics, developers of PEDs can take advantage of this forward-looking approach to create appealing value propositions for end-users (Khan and Bohnsack, 2020). Creating appealing and suitable value propositions means successfully matching what customers desire with the value offered while leveraging contextual information that motivates customers' desires. Psychographic characteristics, such as the values a person holds, can be useful in understanding what drives customers' preferences and is thus critical to designing attractive value propositions (Khan and Bohnsack, 2020; Rintamäki and Kirves, 2017). We follow Hille et al. (2019) in exploring consumers' values, understood as the general guiding principles of the respondents (Steg et al., 2014). Understanding peoples' values can indicate their tendency for pro-environmental behavior, as ecological consciousness is positively related to altruistic and biospheric values and negatively related to egoistic values (Steg and Nordlund, 2018). This can offer additional information in not only describing preferences, but also designing value propositions that leverage these values and appeal to future users.

We also map PED preference segments to different propensities for innovation adoption. Different users play different roles in helping innovation move from emerging to wider diffusion (Wilkinson et al., 2020; Geels, 2005). The different roles users play can be described by their speed in adopting innovations – innovators, early adopters, early majority adopters, late majority adopters, and laggards (Rogers, 2003). Early adopters can act as opinion leaders for the other adopter segments, thus leading to innovation diffusion (Rogers, 2003). Other research has criticized this notion, positing that early innovation adoption does not necessarily diffuse to other adopter segments due to fundamental differences between the user groups (Moore, 2014). Nevertheless, researchers have used Rogers' (2003) adoption segmentation in various ways. For example, Wilkinson et al. (2020) study the role of adopter groups in understanding their role in shaping the innovation process of peer-to-peer electricity markets. Nygrén et al. (2015) used a combination of interview and survey methods to investigate how different types of innovators and early adopters could enable the diffusion of sustainable small-scale energy solutions in Finland. Noppers et al. (2015) mapped how the different adopter segments evaluated electric cars according to their symbolic, instrumental, and environmental attributes. In our research, we map preferences for PEDs to adopter classes in order to understand whether certain adopter segments have specific PED preferences.

This study reports findings from our DCE conducted with 1486 Swiss respondents. PEDs in the DCE were described according to three attributes – ownership of the renewable energy technology and expected engagement from the user, mobility options available in the district, and any extra benefits like shared spaces available. These attributes closely follow characteristics of existing communities that reflect some of the values of PEDs (described in Section 2).

This study holds importance for policy-makers for several reasons. Exploring preferences for PEDs can inform the design of PED communities and help policy-makers target the priorities of potential residents, thus accelerating PED adoption. By identifying segments of preferences, it is possible to plan ahead to cover a wide range of preferences. Creating suitable PED configurations for individuals may increase the likelihood that they engage in their community.

In the following sections we provide a background on PEDs (Section 2) and present the methodology of the DCE (Section 3). We then report results (Section 4) of the DCE in terms of preferences for PED configurations and characteristics of the segments, provide a discussion (Section 5) and conclude on important policy recommendations (Section 6).

2. Background on PEDs

While the majority of communities labeled PEDs across Europe are still in development stages (Gollner et al., 2020), it is clear that a number of different PED configurations are likely to arise. In a recent review, Lindholm et al. (2021) describe three types of PEDs based on boundaries and placement of renewable energy technologies: autonomous, dynamic, and virtual. An autonomous PED has clear geographical boundaries and energy demand is covered internally. Dynamic and virtual PEDs have less clear geographical boundaries. A dynamic PED might interact with other PEDs in the electricity grid (e.g., energy trading between district is an option) and heating network. A virtual PED may have renewable energy generation and storage systems outside of its boundaries.

Following Lindholm et al.'s (2021) discussion, this study explores the importance of boundaries and placement of renewable energy technology by varying ownership structures of renewable energy technology. Cooperative-owned PV allows cooperative members to take part in the energy transition without necessarily living in proximity to the technology. PV owned by a housing association may take a similar form, or the housing association may install it on the buildings roofs, thus moving the energy generation within the boundary of the community. The placement and boundary of renewable energy technologies may have consequences for how active a citizen can be in decision-making around energy generation and consumption – a notable issue if the EU's policies aim to foster active energy citizenship (see Bauwens and Devine-Wright (2018) for a discussion on a community as place vs. community of interest in driving attitudes toward renewable energy).

Attributes in this study resemble a PED or a PED-like community. In particular, we have collected information from three primary resources (see Appendix 1):

- Business Models for Prosumers in Europe (Hall et al., 2020)
- How Cities Can Back Renewable Energy Communities (Bolle, 2019)
- Value Generation by PEDs: Best Practices Case Book (Derkenbaeva et al., 2020)

The information gathered was distilled into three common elements that could describe profiles of PED-like communities:

Attribute 1. Ownership of PV solar panels and your involvement:

o Level 1: PV is owned privately[1] by respondent, the respondent is expected to buy and sell energy privately (full engagement)
o Level 2: A cooperative[2] owns the PV, the respondent may buy shares, receives dividends, and has voting power
o Level 3: Housing association owns the PV; the housing association reinvests part of the profits in the neighborhood and may ask for advice from residents
o Level 4: Utility company owns the PV and no extra involvement is expected from the respondent

Attribute 2. Availability of mobility options:

o Level 1: Great public transport; private vehicles are only permitted for shift workers and those with disabilities
o Level 2: Private cars allowed if they fulfil *low-carbon requirements* set by the district
o Level 3: Only shared fleet of electric vehicles (EV) allowed

Attribute 3. Available shared spaces in addition to those typically included (e.g. green spaces, bike racks, laundry room, storage):

o Level 1: None
o Level 2: Standard free communal spaces *and* for a small monthly fee, additional shared spaces such as work spaces, gym, toolshed, spaces for parties, and guest rooms will be available

Examples of PEDs and further information on derivation of attributes is provided in Appendix A1.

3. Method

3.1. Data

We implemented a DCE as part of the fifth wave of the Swiss Household Energy Demand Survey (SHEDS). The SHEDS is an online survey and was administered by Intervista AG who incentivized respondents to participate with bonus points for completing the survey. The sample is representative of the population in the German and French cantons of Switzerland with pre-defined quotas for age, biological sex, region, and housing status (mix of owners and tenants).[3] The survey was available in English, French and German. Participants were surveyed in May and June 2020, following the first wave of restrictions in Switzerland related to the COVID-19 pandemic. A sample of 1486 respondents successfully completed the DCE. Further details on sampling strategy and composition of SHEDS can be found in Weber et al. (2017).

3.2. Discrete choice experiment

Immediately before responding to our DCE, respondents were placed in a scenario wherein, in the year 2030, PEDs are being deployed nationwide to reduce carbon emissions and offer other benefits for residents. PED configurations would vary and residents would be asked to report the configuration they would most prefer to live in. Respondents were familiarized with potential PEDs through graphics that depict how it might look in a city setting, a suburban setting, and a rural setting. Respondents were told that any costs associated with the options are more or less the same – i.e. in terms of DCE design, price is not an attribute or, equivalently, price is kept fixed across PEDs.[4] Further details can be found in Appendix A2 that reports the full text and images presented to respondents.

Respondents were asked to choose between two options describing different PED configurations which result from the combinations of

[1] There was almost no difference in distribution of adopter types across the five segments, with all segments showing low percentages of innovators and high percentages of early majority adopters. No significant statistical differences were found in adopter segment membership among the five segments.

[2] Cooperative housing is quite popular in Switzerland and is a form of non-profit housing association (Balmer and Gerber, 2017).

[3] Quotas in SHEDS survey: Age: 18–34 = 30%, 35–54 = 40%, 55+ = 30%; Gender: males = 49%, females = 51%;• Region: French-speaking = 25%, German-speaking = 75%;• Living situation: tenants = 62.5%, owners = 37.5%.

[4] We are aware that it is common (and useful) to include a price attribute in order to infer willingness to pay for attribute levels. In this application, we have focused our attention on how preferences for non-monetary attributes vary when price is fixed –by assumption, indeed. Our motivation to keep price fixed is our interest in attributes that describe PEDs. We want to point out that keeping prices fixed is not an unrealistic assumption in itself. While price will vary depending on specific PED characteristics, it is also reasonable to think that several PED designs can be delivered at a given price. A strategy similar to ours has been implemented in previous DCEs. For instance, Garrod et al. (2012) explores heterogeneity in preferences for environmental benefits associated with ecosystem services by designing a discrete choice experiment that varies types of landscapes and does not include a price attribute.

attributes described in Section 2. Our DCE was generated using Ngene. As a full factorial design would have necessitated 276 choice tasks, we have followed a D-optimal design, and have implemented a DCE with a D-error of 0.094. The resulting design for our DCE was made up of six blocks with six choice sets in each block. Each choice set contained two options to choose from and no "none" option was included. The DCE design was uploaded in Stata and integrated into Qualtrics (the survey software) (Weber, 2019). Participants were randomly allocated to one of the six blocks.

A status quo option was not included which, consistent with the premise of our scenario, implies that preferences are stated under an "if all residential districts became PEDs" assumption.[5] Fig. 1 shows an example of a choice set.

The survey and language used in the choice sets for attribute levels was tested and refined with a sample of students and other researchers prior to full launch of the survey. Translations of the survey and choice experiment were confirmed by native speakers of the languages.

3.3. Segmentation and segment exploration

Through latent class analysis, we segmented respondents into groups based on their stated preference choices for different configurations of PEDs. This analysis was conducted using Sawtooth Software (2012)'s CBC/HB module which provides class membership information, part-worth utilities, and importance scores as an output. Part-worth utilities describe how much each level of an attribute contributes to the overall utility. Importance scores describe how much of an influence a particular attribute has on the choice (Orme, 2010). Together, these tools allow description of segments based on common stated preferences. Similar methods have been used by a number of authors exploring preferences for sustainable products and services (e.g. Hille et al., 2019; Petrovich et al., 2019; Tabi et al., 2014).

We confirmed the part-worth utilities and obtained more information on standard deviations by conducting secondary analysis with random parameters logit regressions in the Apollo package in R. This was done using both a maximum likelihood estimation and Bayesian estimation, both of which produced similar results (Huber and Train, 2001).

With the segment membership obtained through the latent class analysis, we conducted multinomial logit regressions with segment membership as the dependent variable to further describe the segments using a number of explanatory variables. Additionally, differences between segments were examined through the Tukey-Kramer means comparison test. The explanatory variables can be categorized as describing demographics and household characteristics, values and norms of the respondent, and adopter class of the respondent. Full information on variables and definitions can be found in Appendix A3.

Values and norms were included to explore their relationship to the respondents' choice of PED. Values and norms have previously been studied in relation to pro-environmental behavior (Stern, 2000; Steg and Nordlund, 2018). Information from SHEDS on respondents' values (egoistic, biospheric, hedonic, and altruistic) were included, as well information on intention to reduce carbon footprint in the next year, descriptive norms, and injunctive norms.[6]

Further, we included respondents' self-characterized adopter class to control for their proclivity to adopting new sustainability-related technologies and innovations (Rogers, 2003). For the identification question, respondents were asked about their willingness to adopt new smart-home technologies: products, gadgets, and apps that may help control different aspects of your home such as your room temperature, energy consumption, or water usage. Smart-home technologies were chosen as a proxy for technologies can support a change in lifestyle toward a more sustainable one and an early indicator for favorability toward PEDs.

4. Results

4.1. Segmentation

Solutions with two to seven segments were explored in the latent class analysis, and a five-segment classification was chosen. Table 1 reports measures of fit for the analysis, including the consistent Akaike information criterion (CAIC), Bayesian information criterion (BIC), and relative Chi-square values for each segmentation.[7] The five-segment solution yields the largest relative Chi-Square. While solutions with five and six segments are comparable in CAIC and BIC, the five-segment solution was chosen as it yields relatively large segment sizes that allow characterization analysis. Based on the five-segment solution, Segment 1 is the largest segment (N = 426) and Segment 3 is the smallest (N = 143) (see Table 3).

4.2. Estimation of utility values and importance scores for each segment

The Sawtooth latent class analysis yielded part-worth utilities and importance scores. Part-worth utilities depict how much utility each attribute level contributes to the overall option utility i.e., how important each attribute level is within the segment. Importance scores (shown in Fig. 3) for attributes further depict which attributes are most important to a segment's choice. We use information from part-worth utilities and importance scores together to summarize preferences of each segment. Additionally, we have labeled each segment based on its preferences.

We confirmed these results using a random parameters logit regression for each segment.[8] Random parameters logit specifications were estimated using a maximum likelihood estimation and Bayesian estimation, using the Apollo package in R – both led to similar results (Hess and Palma, 2019; R Core Team, 2020). We report Bayesian estimations as they had a lower BIC, but results from both Bayesian and maximum likelihood estimations, as well as the standard deviations of random parameters from the maximum likelihood estimation, are reported in Appendix A4. Part-worth utilities are summarized in Table 2

[5] The decision to not include a status quo alternative implies that our DCE does not yield information on whether and to what extent respondents prefer their current housing configuration over a positive energy district configuration. While this information is relevant, our DCE is able to yield information of preferences as if every resident is expected to live in a type of PED –which would be in line with medium- and long-run EU's goals. Had our DCE included a status quo option, respondents may have engaged less in trading-off the attributes describing a PED.

[6] Individuals with strong altruistic values place more importance on ideas like equality and world peace. Those with strong biospheric values find respecting the earth and nature important. Those with strong hedonic values place higher importance on personal pleasure and enjoying life. Finally, those with high egoistic values find social power and influence highly important. Descriptive norms refer to how others behave, while injunctive norms refer to how others expect you to behave.

[7] For more information on measures of fit, see Weller et al. (2020).

[8] We use a random parameters logit specification as it allows for heterogeneous tastes within the population, relaxes the assumption of independence from irrelevant alternatives (IIA) assumption, and allows for persistence of factors that impact choice over time (Train, 2009).

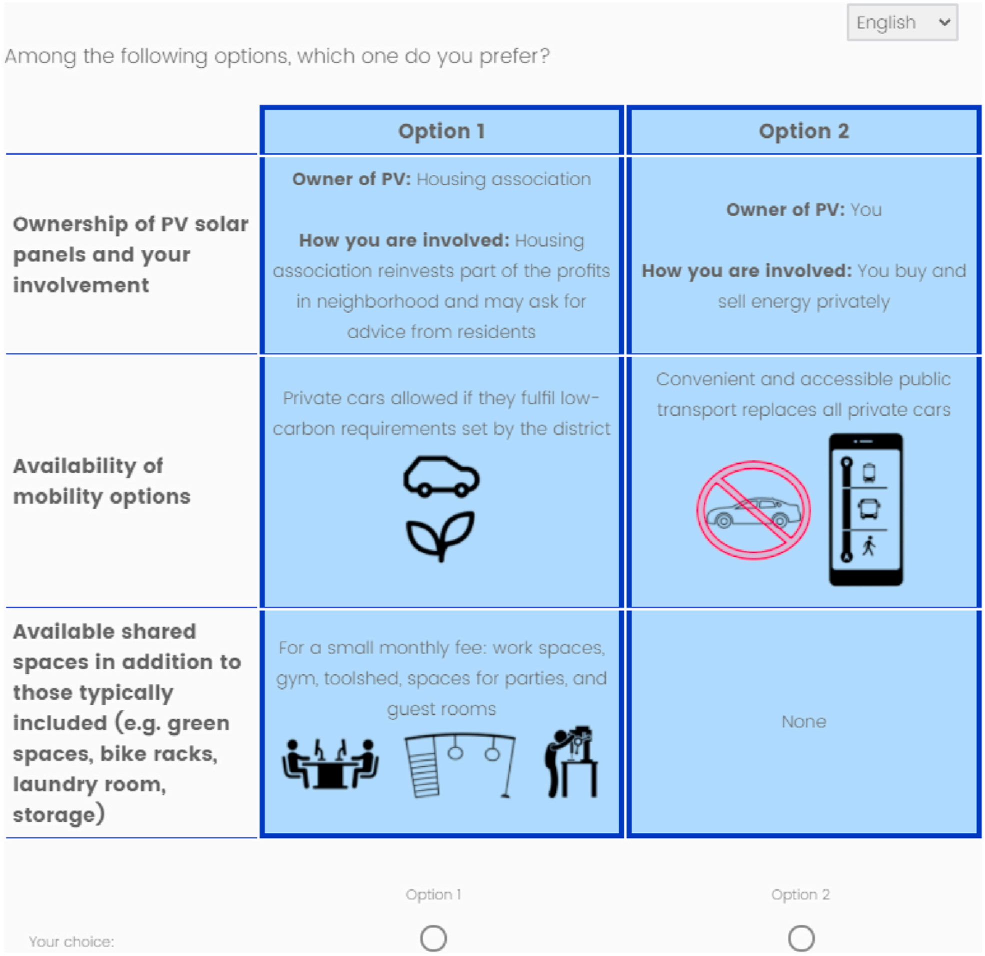

Fig. 1. Example of a choice set in the DCE.

Table 1
Summary of fit.

Number of segments	CAIC	BIC	Relative Chi-square
2	11,363	11,350	86.74
3	11,189	11,169	68.65
4	11,138	11,111	55.32
5	11,119	11,085	46.58
6	11,124	11,083	40.23
7	11,155	11,107	35.18

and depicted visually in Fig. 2.[9] Because attribute levels were coded using effects coding, we recovered part-worth utilities for the omitted levels (utility-owned PV, private cars with emissions restrictions, basic shared spaces) by calculating the negative sum of non-omitted levels by attribute (Hauber et al., 2016).

Importance scores in Fig. 3 show that characteristics of ownership and availability of mobility options were most important in determining choice of a PED. The attribute describing presence of shared spaces was less important in determining choice across segments. The part-worth utilities in Fig. 2 show that preferences for ownership of PV and engagement varied across the segments, with private ownership, cooperative ownership, and utility ownership creating the most distinction between segments. Although housing association was not the top choice or bottom choice for any segment, preferences for housing associations largely followed those of cooperatives i.e. both positive or both negative, with the exception of Segment 1. Shared EV was the least popular mobility preference and private cars with emissions restrictions were most popular among three of the segments. Preferences for shared spaces largely varied by segment as well.

For Segment 1, the biggest driving factor of choice was the mobility option present in the PED. The importance scores show that this was the most important attribute for Segment 1, and more important to this segment than all other segments. The part-worth utilities confirm this story: Segment 1 had the highest gain in utility from private cars with emissions restrictions (higher than any other part-worth utility presented). Among ownership options, Segment 1 preferred utility-owned PV over the other options. The presence of shared spaces was least important in Segment 1's choice of a PED. We label Segment 1 as *Car Defenders*.

The importance scores show that Segment 2's choice of PED is equally driven by ownership and mobility options present in the PED. This segment's preferences can be described as driven by a mix of communal and private preferences. The part-worth utilities indicate that Segment 2 prefers PV ownership by a cooperative, as well as private cars with emissions restrictions and extra shared spaces. We label Segment 2 as *Cooperative with car flexibility*.

The importance scores show that Segment 3's choice of PED is heavily driven by ownership of PV. This is also seen in the segment's high utility associated with private ownership of PV (the highest among all segments). Segment 3 has a high preference for private PV ownership and a moderate preference for private cars and basic shared spaces relative to other options. We label Segment 3 as *Private and autonomous*.

[9] Part-worth utilities in Fig. 2 have been re-centered for comparability across segments.

Table 2
Part-worth utilities by segment [aa] Note: Standard deviation of posterior after distributional transformation in parentheses, not included for levels omitted during effects coding. Shading reflects attribute level with highest utility (blue) and lowest utility (yellow) from each attribute. Preference for omitted level in effects-coding (utility-owned PV, private cars with emissions restrictions, basic shared spaces) recovered by calculation of negative sum of non-omitted levels by attribute (Hauber et al., 2016).

Attribute and levels	*Segment 1*	*Segment 2*	*Segment 3*	*Segment 4*	*Segment 5*
	N = 426	*N = 308*	*N = 143*	*N = 359*	*N = 250*
Ownership of PV solar panels and expected involvement of respondent					
Private ownership of PV; individual buys and sells energy privately	-1.01 (0.54)	0.45 (0.99)	5.66 (1.33)	0.27 (0.72)	-1.98 (0.90)
Cooperative-owned PV; individual buys shares in an energy cooperative, receive dividends, and have voting power	-0.35 (0.54)	2.14 (0.77)	-0.79 (1.03)	-0.80 (0.59)	1.98 (0.56)
Housing association; Housing association reinvests part of the profits in neighborhood and may ask for advice from residents	0.43 (0.49)	0.03 (1.27)	-1.49 (1.61)	-0.13 (0.49)	1.13 (0.68)
Utility-owned PV; No extra involvement	0.93	-2.64	-3.38	0.67	-1.13
Availability of mobility options					
Public transit only	-2.91 (0.52)	-2.41 (0.49)	-2.76 (1.35)	0.86 (0.42)	2.29 (0.63)
Private cars with emissions restrictions	3.18	2.34	2.35	-0.44	-1.92
Shared EV	-0.26 (0.65)	0.07 (0.52)	0.41 (2.04)	-0.43 (0.43)	-0.37 (0.82)
Availability of shared spaces in addition to those typically included					
No extra shared spaces	0.08	-1.24	2.10	-0.17	-1.41
Extra shared spaces for a small monthly fee	-0.08 (0.49)	1.24 (0.58)	-2.10 (0.38)	0.17 (0.05)	1.41 (0.60)

Similar to *Cooperative with car flexibility*, Segment 4's choice of PED is driven by ownership and mobility options. However, Segment 4 exhibits a strong negative preference for PV ownership by a cooperative, preferring utility ownership of PV, followed by privately-owned PV. When it comes to mobility, Segment 4's choice is positively driven by the option of public transit and negatively driven by private car ownership and the availability of a shared EV fleet. This segment also has a high preference for extra shared spaces. We label Segment 4 as *No cooperative PV, Public transit*.

Finally, Segment 5 has a high positive preference for cooperative ownership of PV, public transit, and extra shared spaces. Segment 5's choice of PED is almost equally driven by all three attributes. This segment's preferences for cooperative ownership of PV, public transit, and extra shared spaces point to a preference for a communal feeling. We label Segment 5 as *Community-focused*.

In terms of expected involvement on the part of the respondent, the *Private and autonomous* segment is the only segment that prefers complete involvement in ownership of PV including buying and selling to the smart grid. Both the *Cooperative with car flexibility* and *Community-focused* segments exhibit preferences for cooperative-owned PV, as well as potential involvement in voting on cooperative projects and receiving dividends. *Car defenders* and *No cooperative PV, Public transit* prefer utility ownership of the PV and no extra expected involvement on their part. *Cooperative with car flexibility* and *No cooperative PV, Public transit* are inverse of one another. Due to the nature of the levels and the coupling of ownership with expected involvement, it is difficult to distinguish whether ownership type or the explicit description of involvement lead to the PED choice. In this study, we consider them together as a package.

Table 3 summarizes the main combinations of attributes favored by the segments. Ownership of PV and mobility options were included due to the importance they played in a respondent's choice of PED. Further, only the attribute levels with top part-worth utility for each segment are included.

Almost 60% of the sample (*Car defenders*, *Cooperative with car flexibility*, and *Private and autonomous*) would prefer private cars with emissions restrictions in their hypothetical PED, while the rest prefer public transit. With regard to ownership of PV, the most popular options were cooperative-owned PV, utility-owned PV, and privately-owned PV. Overall, about 53% of the sample prefers utility owned PV when both mobility options are combined.

4.3. Characterization of segments

Next, we explore the segments in terms of explanatory variables. In this way, we can begin to understand motivations behind preferences and create a more holistic picture of each segment. Appendix A5 contains a selection of summary statistics by segment. Table 4 shows the average marginal effect of each variable as a result of the multinomial logit regressions conducted for each segment, with segment membership

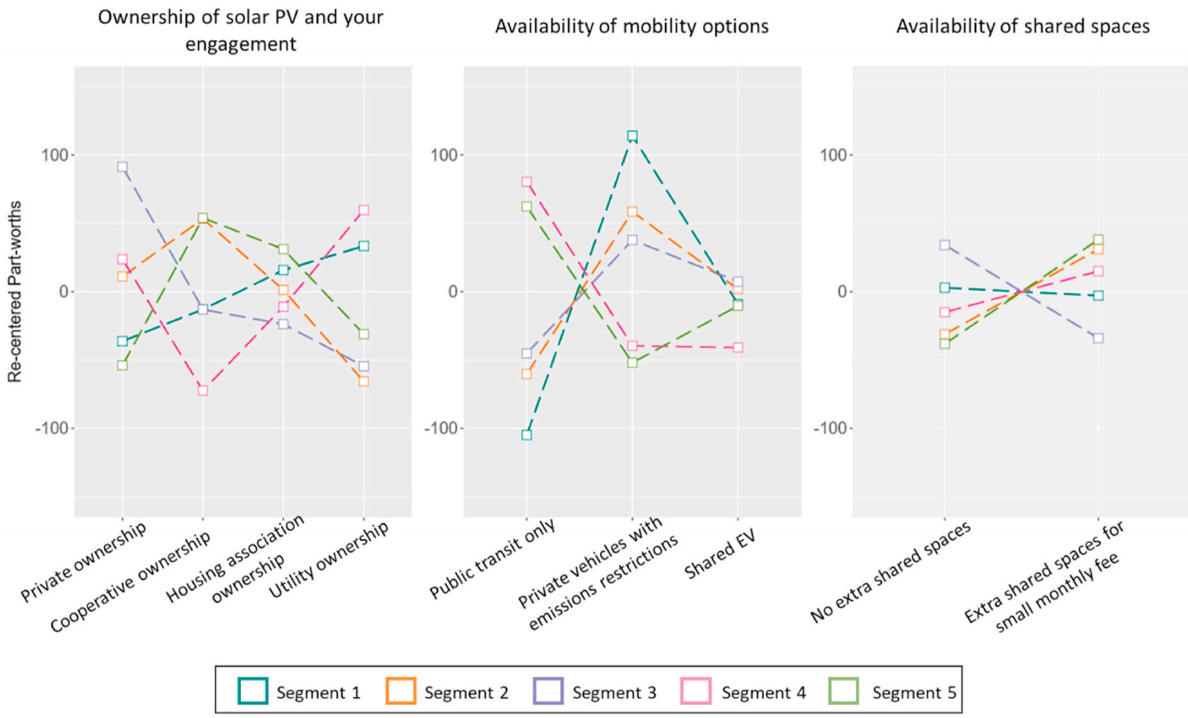

Fig. 2. Part-worth utilities resulting from random parameters logit, re-centered for comparability across segments[a.]
[a]Note: A positive part-worth utility indicates a positive gain from the attribute level in overall utility of an option. A negative part-worth utility indicates a negative gain from the attribute level in overall utility of an option.

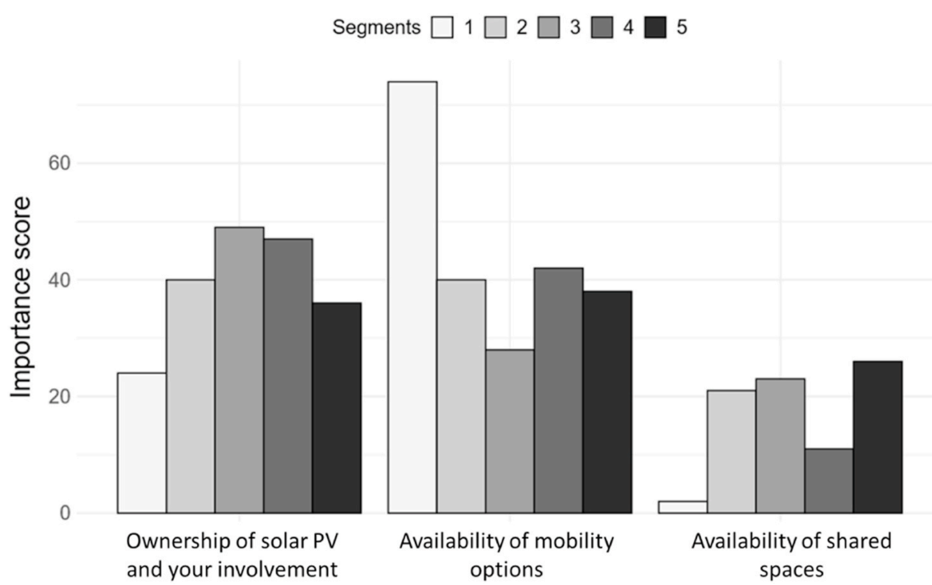

Fig. 3. Importance scores for attributes by segment[a]
[a]Note: Importance scores are calculated by taking the range of respondent utilities for a given attribute and dividing by the total range across attributes (McEwan, 2015; Sawtooth Software).

as the dependent variable. The average marginal effect denotes the average change in probability of belonging to a segment if the explanatory variable increased by 1 unit, keeping all other variables the same.

Results of the multinomial logit regression support choice of segment labels in section 4.2. Car ownership and living in the countryside were significant in increasing probability of being in the *Car defenders* segment. Biospheric values were found to be significant in decreasing probability of belonging to the *Car defenders* segment.

Being younger and car ownership increased probability of belonging in the *Cooperative with car flexibility segment*. Living in German-speaking Switzerland and having a household of 3 or more people were also significant in raising the probability of belonging to this segment. Respondents who were segmented into the Innovator, Late majority, or Laggard adopter classes also had a lower probability of belonging to this segment relative to the Early Majority.

Probability of belonging to the *Private and Autonomous* segment was positively impacted by house ownership. No other variables were found to be significant in predicting probability of membership in this

Table 3
Configurations of PED attributes contributing to segments' preferences.

		Mobility options	
		Private cars with emissions restrictions	Public transit only
Ownership of PV and expected involvement	*Cooperative owned PV; dividends, voting power*	Segment 2 (*Cooperative with car flexibility*): 20.73% of sample	Segment 5 (Community-focused): 16.82% of sample
	Utility owned PV; no extra involvement by individual	Segment 1 (*Car defenders*): 28.67% of sample	Segment 4 (*No cooperative PV, Public transit*): 24.16% of sample
	Privately owned PV (by individual); individual buys and sells energy privately	Segment 3 (*Private and autonomous*): 9.62% of sample	–

segment. This preference for privately-owned PV by the *Private and autonomous* segment is consistent with the higher average house ownership in this segment (as seen in Appendices A5 and A6). Private ownership may give owners more control of PV placement, meaning they are able to envision such a scenario.

Higher age, home ownership, and lower income were significant in increasing probability of belonging to the *No cooperative PV, Public transit* segment. Car ownership had a negative impact on probability of belonging to this segment. Living in an accommodation with solar panels also had negative impact on probability of belonging to the *No Cooperative PV, Public transit* segment. Respondents who had identified as Innovators were significantly more likely to be in the *No cooperative, Public transit* segment relative to those in the Early Majority.

Probability of belonging to the *Community-focused* segment was positively impacted by higher income, higher intention to reduce one's carbon footprint, and higher altruistic values. Probability of belonging to the *Community-focused* segment was lowered with car ownership and house ownership.

The sharpest distinctions in segments can be seen through differences in age and car ownership. Age created distinctions between the *Cooperative with car flexibility* segment and the *No cooperative PV, public*

Table 4
Average marginal effects calculated from multinomial logit regression. An interaction term between age and income was included in the multinomial logit regression.

	(1) Car defenders	(2) Cooperative with car flexibility	(3) Private and autonomous	(4) Utility-owned PV, public transit	(5) Community-focused
Age	0.00118	−0.00369***	0.000759	0.00253**	−0.000778
	(1.31)	(-4.37)	(1.24)	(3.05)	(-1.08)
Sex	0.0229	−0.0120	−0.00705	0.0296	−0.0335
	(0.89)	(-0.52)	(-0.40)	(1.20)	(-1.64)
Income (log of income used)	0.0415	−0.00322	−0.0143	−0.0726**	0.0486*
	(1.37)	(-0.12)	(-0.70)	(-2.69)	(2.01)
Years of education	0.00724	0.00691	0.000724	−0.00636	−0.00851
	(1.13)	(1.16)	(0.17)	(-1.06)	(-1.61)
Car ownership	0.211***	0.0666*	0.0289	−0.0953**	−0.211***
	(7.65)	(2.50)	(1.14)	(-2.76)	(-6.54)
House ownership	−0.0555*	−0.0192	0.0734**	0.0745*	−0.0732**
	(-1.97)	(-0.72)	(3.20)	(2.41)	(-3.09)
Lives in countryside	0.0693*	−0.0133	−0.00493	−0.0211	−0.0300
	(2.10)	(-0.47)	(-0.21)	(-0.65)	(-1.00)
Accommodation is outfitted with solar panels for electricity or heat	0.00934	−0.00449	0.0292	−0.0590*	0.0250
	(0.29)	(-0.15)	(1.28)	(-2.05)	(0.87)
Households living in German-speaking Switzerland	−0.0484	0.0753**	0.00207	−0.0432	0.0143
	(-1.65)	(3.13)	(0.11)	(-1.50)	(0.61)
Household with three or more people	−0.0321	0.0906***	−0.00815	−0.0415	−0.00885
	(-1.19)	(3.42)	(-0.45)	(-1.58)	(-0.39)
Adopter classes (Early majority as base)					
Innovators	−0.0115	−0.0926**	0.0197	0.123**	−0.0389
	(-0.27)	(-2.60)	(0.68)	(2.64)	(-1.12)
Early adopters	−0.0313	−0.0486	0.0336	0.0535	−0.00709
	(-0.82)	(-1.37)	(1.24)	(1.36)	(-0.21)
Late majority	0.0167	−0.0579*	0.0432	0.0412	−0.0431
	(0.52)	(-1.99)	(1.85)	(1.38)	(-1.77)
Laggards	0.0332	−0.111***	0.0208	0.0401	0.0171
	(0.83)	(-3.35)	(0.75)	(1.10)	(0.51)
Intend to reduce carbon footprint	−0.0289*	0.00694	0.00924	−0.00828	0.0210*
	(-2.41)	(0.62)	(1.12)	(-0.74)	(2.14)
Values					
Hedonic values	0.0323	−0.0141	0.0139	−0.0200	−0.0121
	(1.81)	(-0.85)	(1.12)	(-1.19)	(-0.84)
Egoistic values	0.00136	0.00823	0.0136	0.0249	−0.0480***
	(0.08)	(0.52)	(1.15)	(1.51)	(-3.36)
Altruistic values	−0.00861	−0.00577	−0.0278	−0.0329	0.0751***
	(-0.38)	(-0.28)	(-1.86)	(-1.52)	(3.77)
Biospheric values	−0.0444*	0.0338	0.000347	0.0119	−0.00168
	(-2.12)	(1.70)	(0.02)	(0.58)	(-0.09)
Norms					
Descriptive norms	0.00300	0.00785	−0.00794	−0.000870	−0.00205
	(0.19)	(0.56)	(-0.75)	(-0.06)	(-0.17)
Injunctive norms	−0.0132	−0.00160	0.00318	0.00872	0.00292
	(-0.88)	(-0.12)	(0.30)	(0.62)	(0.25)
Observations	1338	1338	1338	1338	1338

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Pseudo R2 = 0.094, Log-Likelihood = −1888.35.

transit segment. An increase of 10 years in age increased probability of falling into the *No cooperative PV, Public transit* segment by 0.253 and decreased probability of falling into the *Cooperative with car flexibility* segment by 0.369.

Car ownership also created sharp distinctions between segments. As seen in Fig. 5, the *Car defenders* and *Community-focused* segments can be seen as opposite sides of the spectrum: car ownership increases probability of belonging to the *Car defenders* segment by 0.211 and decreases probability of belonging to the *Community-focused* segment by 0.211.

These results are consistent with those presented in the Tukey-Kramer comparisons[10] (see Appendix A6). Consistent with the preferences for PED characteristics and the multinomial logit, the Tukey-Kramer test indicated that the largest impacts (in magnitude) on probability of car ownership. The *Car defenders* segment, whose attribute importance scores depicted mobility as the strongest driver of utility, held a significantly larger average number of car owners compared to all other segments. The segments with strong preferences for public transit – *Community-focused* and *No Cooperative, Public transit* – had lower average car ownership. The *Cooperative with car flexibility* segment also had a significantly higher average number of household members with three or more people, indicating more need for transportation service.

The Tukey-Kramer results also depict differences in values and intention to reduce one's carbon footprint between the *Car defenders* segment and the *Community-focused* segment. Respondents who were likely to state their intention to reduce their carbon footprint and had higher biospheric values were less likely to fall into the *Car defenders* segment. *Car defenders'* preferences seemed to be less driven by environmental concerns. Conversely, the respondents that had high altruistic values, low egoistic values, and high intention to reduce their carbon footprint were more likely to belong to the *Community-focused* segment. The *Community-focused* segment may be more environmentally-conscious and community conscious, supporting the segment's preference for cooperative-owned PV, public transit in the community, and extra shared spaces. Table 5 summarizes the findings of our analyses.

5. Discussion

The aim of this research has been to characterize the preferences people may have for PEDs, with the goal of tailoring attractive value propositions to future residents. In the following, we respond to our initial research questions.

Research Question 1 (RQ1). What attributes commonly described in PED-like communities are preferred by citizens?

We have uncovered a diverse set of preferences. The largest segment was that of *Car defenders* who are very mobility-driven and prefer private cars with emissions restrictions in their future PED. The smallest segment was that of *Private and autonomous* respondents who preferred private PV ownership, private car ownership, and even showed a dislike for extra shared spaces in a future PED configuration. The *Community-focused* segment held respondents who seemed to be attracted to communal living – cooperative-owned PV, public transportation, and extra shared spaces. More environmentally-conscious respondents and those with higher altruistic values were also likely to fall into this segment. The last two segments, *Cooperative with car flexibility* and *No cooperative PV, Public transit*, differed on multiple levels: they not only exhibited different preferences for PV ownership and transportation options, but also age. Those in the *Cooperative with car flexibility* segment tended to be younger while those in the *No cooperative PV, Public transit* segment tended to be older.

In Fig. 6, we have created a visualization of the dominant preferences for aspects of PEDs to answer RQ 1. Mobility options are located at the beginning of the funnel in Fig. 6 due to their dividing nature and importance in PED choice. Overall, around 60% of respondents prefer private cars with restrictions on emissions in PEDs of the future. Preferences for ownership are more distributed: around 10% preferred private ownership of PV, 38% preferred cooperative ownership of PV, and 53% preferred utility-owned PV. These results support the development of diverse PED configurations as there was no one unifying set of preferences for all respondents. Tailoring PEDs and messaging efforts according to sociodemographic and psychographic characteristics will be important in reaching a variety of consumer segments.

RQ 2. How can we describe the segments of PED preferences?

Respondents' stated preferences for PEDs configurations seem to be associated with current lifestyles. For example, mobility is connected to respondents' current mobility availability. Segments that contained respondents who were more likely to be car owners prefer PED options that allow for private car use, even with emissions restrictions, while the two segments that are less likely to contain car owners are more likely to prefer the PED option with public transportation. This finding points to the fact that current mobility practices guide future choice, even in hypothetical scenarios set in 2030. This is consistent with previous literature that points to the importance of routines and habits in determining transportation method (Schneider, 2013; Kurz et al., 2015; Lanzini and Khan, 2017).

In line with previous findings (Dargay, 2002; Nolan, 2010), location and household size play a factor in guiding mobility choice and will need to be considered in the design of mobility options in PEDs. Those living in the countryside were more likely to be *Car defenders*, indicating the need for private car use. Respondents in the *Cooperative with car flexibility* segment also exhibited larger households of three or more people, perhaps indicating the need for more flexible and/or private transportation options. Interestingly, shared EV was least preferred among the three options. In planning for future PEDs, it will be important to consider current mobility patterns, ways in which peoples' mobility patterns can be changed e.g., toward public transit (Beirão and Sarsfield Cabral, 2007) or shared and pooled vehicles (Stoiber et al., 2019), and how life events may shape these mobility patterns (Clark et al., 2016).

In terms of ownership of PV, the older segment, *No cooperative PV, Public transit* seemed to find cooperative owned PV less appealing and utility owned PV more appealing while the younger segment, *Cooperative with car flexibility*, found cooperative ownership more appealing. Drivers behind preference for ownership of PV may be tied to expected engagement. While no extra engagement on behalf of the respondent was expected in a scenario where PV is owned by a utility, cooperative ownership of PV offered the chance to act via voting rights and receive dividends from the organization.[11] Privately-owned PV and full engagement is also an attractive option for some, as shown by the *Private and autonomous* segment (see Ecker et al., 2017 for more on the value people place on energy autarky). Desire for participation and engagement may vary by age (as the younger segments preferred cooperative-owned PV), indicating that it is important to have a mix of residents from a variety of age groups if citizen participation is an objective in a PED.

It is worthwhile noting that the Swiss energy market may not be reflective of that of other countries in the EU; respondents' preferences for utilities and cooperatives may reflect their current energy supplier. Further, the Swiss energy landscape is comprised largely of utility companies (630 companies) (Axpo, 2021), although a large number of energy cooperatives (289) also exist (Rivas and Seidl, 2018). It is notable that 90% of electricity utilities are publicly-owned, either by cantons or municipalities (Axpo, 2021). Further, the electricity supply to homes in Switzerland is already largely based on renewables, although heating is still largely propelled by gas (Confederation Suisse, 2019). In

[10] The Tukey-Kramer test is used in place of the *t*-test in scenarios of multiple case comparisons by adjusting for error associated with multiple testing.

[11] Although it is also possible that desire for such opportunities in a cooperative may not be converted into actual consistent engagement (Yildiz et al., 2015).

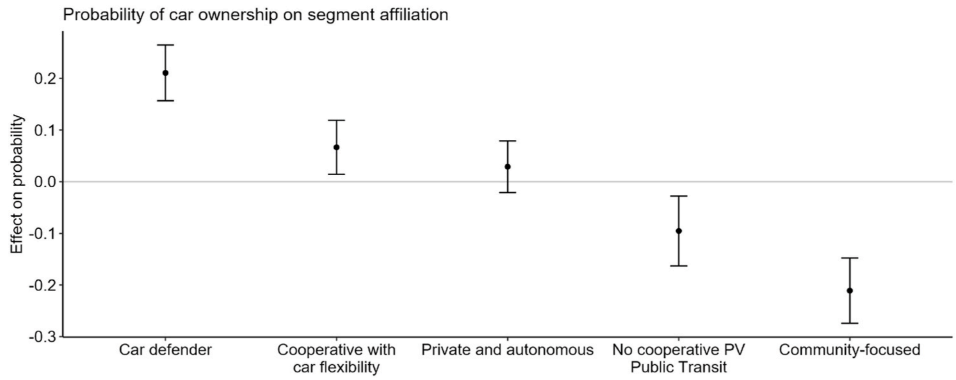

Fig. 5. Probability of car owners' membership across segments (based on average marginal effects from multinomial logit). A respondent's increase in probability of belonging to Car defenders given car ownership is highest, while belonging to the Community-focused segment sees the biggest drop in probability given car ownership.

Table 5
Summary of segments and their distinctive descriptors based on multinomial logit and Tukey-Kramer comparison test.

Segment 1: *Car defenders*	Segment 2: *Cooperative with car flexibility*	Segment 3: *Private and autonomous*	Segment 4: *No cooperative PV, Public transit*	Segment 5: *Community-focused*
Percent of sample				
29%	21%	10%	24%	17%
Preferences: This segment prefers …				
Utility owned PV, private car ownership; strongly mobility-driven	Cooperative ownership of PV, private car ownership	Private ownership of PV, private car ownership; strongly driven by ownership options	Strong negative preference for cooperative ownership, preference for utility ownership of PV, public transport	Cooperative ownership of PV, public transportation, extra shared spaces
Segment description				
• Likely to own a car • Higher income • Unlikely to be home owners • More likely to live in countryside • Less likely to have intention to reduce their carbon footprint • Lower levels of biospheric values	• Tend to be younger • Likely to be car owners • Likely to have a household of three or more people • Likely to live in German-speaking Switzerland	• Likely to be home owners • Higher average number of households equipped with solar panels relative to other segments	• Likely to be older • Likely to be lower income • Less likely to be car owners • Likely to be home owners	• More likely to have higher income • Less likely to be car owners • Less likely to be home owners • More likely to have intention to reduce their carbon footprint • Higher levels of altruistic values • Lower levels of egoistic values

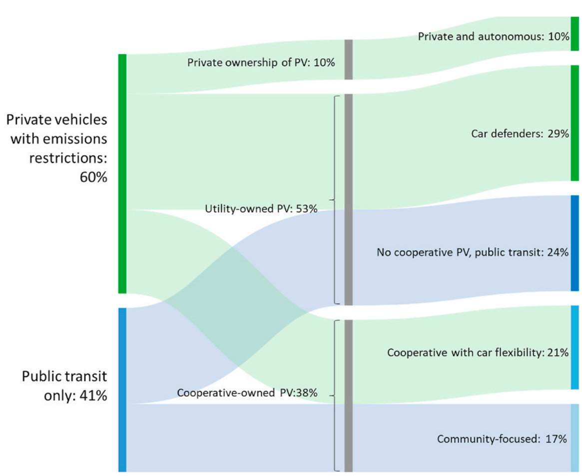

Fig. 6. Groupings of segments according to mobility and ownership preferences for PEDs (Note: percentages do not add up to 100 due to rounding).

Switzerland, tenants account for close to 60% of the population (Federal Statistical Office, 2019). Thus, private ownership of PV may not be a feasible option for all respondents. Due to this context-dependencies, the transferability of the results to PEDs in other countries probably need further investigation.

Exploring expectations for engagement in PEDs and desire for participation among future residents is important if active participation is expected in PEDs. However, given that the description of expected engagement and type of owner were combined in this study, it is uncertain what may actually have driven the choice – the nature of the ownership or the engagement potential. Future research could disentangle these factors to further understand what drives preference for ownership and engagement and whether the two are related.

Further, results indicate that private ownership of PV is less favored as an option relative to utility and cooperative ownership (only 10% of the sample). In creating opportunities, policy-makers should recognize the hesitations people may have around ownership of PV and heightened engagement with energy generation and trading. Barriers to adoption may include the high cost of purchasing such a system and the type of home the household occupies. This latter point is highly relevant for Switzerland where most households are in a tenant relationship and may not have the authority to install PV on their roofs. It is also telling that home owners were more likely to fall into the *Private and Autonomous* segment. Consistently, this segment had a higher number of homes equipped with solar panels compared to other segments – respondents in this segment are familiar with solar panel technology, with the corresponding capacity and control to install solar panels on their own property (see Vasseur and Kemp, 2015; Petrovich et al., 2019; Faiers et al., 2007; Hille et al., 2019; Baranzini et al., 2017; Balta-Ozkan et al., 2015; Dharshing, 2017; Briguglio and Formosa, 2017; Mattes, 2012 for motivations behind PV adoption).

Shared spaces play a smaller positive role or even a negative one in our respondents' preferences for PED configurations. The *Community-focused* segment reported shared spaces as important as mobility options and ownership options. On the other hand, the *Private and Autonomous* segment had a strong negative preference for shared spaces, consistent with the segment's tendency toward complete autonomy (e.g., privately owned PV, preference for private vehicles, no shared spaces). However, the role of shared spaces may increase in post-COVID-19 times as shared spaces may represent an alternative to work remotely, allowing for social gathering while keeping physical distance which ultimately would increase resilience of urban environments. As employers and employees around the world start conversations about whether and how remote work will be part of the new normal, it has become clear that employees find working from home advantageous but with some drawbacks. The conversation is evolving towards *hybrid working arrangements* that will allow remote work from a wide array of locations with flexibility on when and how frequently employees will be expected to commute to their employees' facilities (Beck and Hensher, 2021; Bojovic et al., 2020; Lara-Pulido and Martinez-Cruz, 2021; Microsoft Work Lab, 2021). Shared working spaces in PEDs can make the concept more holistic, meeting the needs of the energy transition and those of its residents, and aligning PEDs with the idea of developing self-sufficient neighborhoods or 15-min cities that has recently gained traction among policy makers and politicians in the EU (e.g., C40 Cities Climate Leadership Group (C40CCLG), 2020; Willsher, 2020). Thus, deepening the exploration into the preference for shared spaces –particularly, those equipped as offices— as part of residential configurations seems an area of research of relevance for the energy transition agenda.

Adopter classes were generally unclear predictors of segment affiliation and may play little role in understanding how adoption of an innovation like a PED can spread. The complexity of a PED and the number of features that describe such a community may contribute to this. The adopter segmentation based on proclivity to adopt smart-home technologies may also not be completely representative of the complexity of PEDs.

6. Conclusion and policy recommendations

The results of our study hold several implications for future development of PEDs. Given the heterogeneity of stated preferences, PED development will require careful examination of potential residents based on their sociodemographic and psychographic characteristics. At the same time, the achievability of implementing certain PED configurations needs to be assessed further. For example, can a PED for the *Community-focused* segment be developed in a rural area that may necessitate private car use? Also, can members of the *Private and autonomous* segment achieve full ownership of PV in a non-detached house? These questions are particularly relevant under the likely scenario that more people may decide to permanently live farther from urban centers as remote working becomes part of the new normal. These questions have implications for transportation and land use policy research agendas as their answers require examining how the existing built environment entrenches mobility patterns and guides capacity to install renewable energy technologies (Beck and Hensher, 2021).

It is significant that respondents' preferences depict mobility as a key determining element in PED choice. This means that mobility related preferences need to be taken as a main design factor, but not necessarily in only switching to e-mobility as smart city concepts set out to do (e.g., Paalosmaa and Shafie-khah, 2021; Cassinadri et al., 2019). Policymakers should carefully weigh options of the design and operation of PEDs in terms of mobility choices, i.e., bans of private cars in the PED, easy access to alternative transport modes, car sharing and distribution of space to different modes of mobility and recreation. While not explicitly tested in this study, possibilities of active modes of transport and public transit can complement e-mobility trends and allow policy-makers to reach a wider demographic (Liao and Correia, 2020), though development is dependent on local goals of the area (Akhatova et al., 2020). It is also important that policymakers tailor options to preferences (taking into account diversity), while also providing structure (e.g., mobility solutions beyond private cars) in order to break path dependencies and existing routines. This can be done by creating an environment that facilitates change to more sustainable modes of transport and taking time to understand the factors that drive current car ownership.

The finding that respondents choose PEDs that reflect their current mobility options may also indicate that respondents have difficulties in envisioning a future that differs from their current way of living, even in a scenario set in the future. Stated preferences may not be telling of what respondents want, but rather that they are unable to envision a different future. Policymakers should consider "visioning" exercises to explain that futures with alternative mobility and alternative energy ownership (such as privately owned PV) are possible. Building energy and environmental awareness and consciousness of our energy future may necessitate a more engaging and participatory approach to introducing citizens to their built and unseen environment (see Walking with Energy: Ambrose, 2020). Policies that support private PV ownership could also help people see it as a practical possibility.

Framing appealing value propositions to future residents of PEDs will require an understanding of both values and needs. Certain segments, like the *Community-focused* segment, may be more responsive to messages that recall the community's social justice focus or environmentally-beneficial features. This segment's respondents recall residents of car-free cooperative housing studied by Baehler and Rérat (2020), whose motivations were largely driven by their values. Other segments, like the *Car defenders*, may find such messages less appealing as they scored significantly lower on altruistic values, biospheric values, and intention to reduce their carbon footprint. Overall, the tailoring of value propositions of PEDs will need to rely not only on respondents' values but also other elements such as car and home ownership, household size, and age.

The diversity of preferences seen in the results of the DCE indicate a number of pathways for PED and REC development. Overall, policymakers may find it beneficial to make citizens aware of new possibilities that the future energy system can enable. Helping citizens understand that they can engage in a decentralized energy system e.g., as prosumers and showing them *how* will be important to fostering the engagement the EU aims for in developing PEDs.

CRediT authorship contribution statement

Darja Mihailova: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Iljana Schubert:** Supervision, Funding acquisition, Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Adan L. Martinez-Cruz:** Methodology, Formal analysis, Writing – review & editing. **Adam X. Hearn:** Conceptualization, Methodology, Writing – review & editing. **Annika Sohre:** Supervision, Funding acquisition, Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A1

Table 1
Examples of PED-like renewable energy projects in Europe described by three common attributes. Examples taken from Hall et al. (2020), Bolle (2019), and Derkenbaeva et al. (2020).

Example of PED-like renewable energy projects and RECs	Ownership of renewable energy technology	Mobility options available	Communal spaces
Hunziker Areal, Switzerland	Cooperative	Cars allowed in case of physical limitation or job-related necessity; shared fleet of bicycles, e-bicycles, and an electric car is provided	Work/tool room, gym for community use, parks and playgrounds
Vauban District, Germany	Cooperative	Car-free	Parks and playgrounds
IssyGrid, France	Municipality-private company partnership	Cars allowed; additional emphasis on car-pooling, experimentation with autonomous vehicles	Parks
German Mieterstrom model, Germany	Landlord or delegated energy services company	Any (not a physical community with boundary)	Not in scope (not a physical community with boundary)
Ecopower, Belgium	Cooperative	Any (not a physical community with boundary)	Not in scope (not a physical community with boundary)
Quartierstrom, Switzerland	Private	Any	Not in scope (focus on P2P trading)

More information on PED and PED-like communities described in table:

Hunziker Areal, Vauban District, and IssyGrid are examples of "contained" districts, operating with boundaries. These districts exemplify the goals of PEDs to varying extents by integrating renewables into the grid and fostering a human-centric focus. Hunziker and Vauban emphasize a community focus through a participative cooperative structure, a built environment that is pedestrian-friendly, and extra communal spaces like a tool room, gym, and many parks and playgrounds (Derkenbaeva et al., 2020).

The German Meiterstrom model is not a PED, but is an example of achieving the integration of renewables into the grid in a multi-family home. PV-plants are placed on multi-occupancy buildings and the landlord sells this energy to residents based on their metered usage. Tenants are able to fill any gaps in demand with a retail supplier of electricity (Hall et al., 2020). While not a PED, this model could be adapted to multi-family homes in a given district.

Ecopower is a cooperative based in Flanders, Belgium that seeks to provide citizens with an opportunity to invest in renewable energy by holding shares in renewable energy technology installations. Further, each shareholder is able to vote in the general meeting and receives a dividend if profit allows it. Those with solar power installations are also able to feed their electricity into the grid and receive payment (Bolle, 2019). While a regional cooperative like Ecopower does not explicitly meet the goals of PEDs due to its expansive boundaries, it nevertheless supports the energy transition and allows citizens to participate. Further, partnerships between cooperatives and municipalities can narrow the geographical scale while following a similar model.

Finally, the Quartierstrom pilot study is an example of a peer-to-peer (P2P) energy trading scheme that took place in Wallendstadt, Switzerland. Thirty-seven households connected to the microgrid were able to buy and sell solar power locally. Although this particular pilot ended in July 2020, many other initiatives that test P2P trading or enabling technology exist (Quartierstrom). For example, POCITYF, an EU Horizon 2020 project focused on developing PEDs, is integrating P2P trading into its Lighthouse city of Évora, Portugal (Oliviadese et al., 2021). The city of Groningen in the Netherlands has plans to engage households in P2P energy trading with the help of technological expertise from Spectral (Spectral). Finally, companies like Lumenaza and sonnenCommunity in Germany offer technology that enables a household to engage in P2P energy trading (IRENA, 2020). These initiatives indicate that P2P energy trading may have a place in PEDs of the future, transforming citizens into prosumers.

Appendix A2. Description of PED scenario prior to choice experiment

We are now going to ask you to imagine that you are in a hypothetical situation which is likely to happen in the future. Place yourself in the scenario to make decisions based on the information provided. It is 2030 and your neighborhood has begun its transition into a Positive Energy District (PED), as required by the Swiss Energy Transition Policy. This means your neighborhood will eventually produce more energy (through renewable resources) than is being consumed (thus becoming net energy positive). Each district will also ensure that each resident is able to track their energy consumed through tools like smart meters. Below are examples of what your neighborhood might look like in different settings:

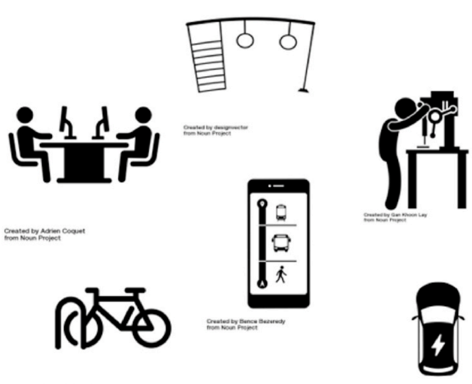
An apartment building might have solar panels on the roof.

A detached family home might have solar panels on the roof or somewhere close to the home.

The government envisions that each district will also offer other benefits such as:

- Communal spaces
- Environmentally friendly mobility options
- Social housing
- Citizens' abilities to play a greater role in their own energy management

However, the government is still exploring the demand for such aspects.



Each Positive Energy District will be organized differently and some people have even moved into a district model that they prefer. On the next pages you will see several choices showing how such a Positive Energy District might look like. Given the government's emphasis on energy affordability, the costs associated with each option are more or less the same and should not impact your preference. Please choose the Positive Energy District model you would be **most prefer to live in.**

Appendix A3. Definitions of explanatory variables

Variables		Questions/items
Demographic variables	Age Gender Income Years of education Car ownership House ownership Lives in countryside Accommodation with solar panels Households in German-speaking area Household with three or more people	Age (years) (information collected from Intervista) Gender: Male = 1, Female = 0 (information collected from Intervista) Income: Midpoint of the range chosen by respondent (3000 or less; 3000–4499; 4500–5999; 6000–8999; 9000–12,000; 12,000 or more; I prefer not to say; I do not know) (information collected from Intervista) Number of years of education (information collected from Intervista) Car ownership: Own at least 1 car = 1, Do not own a car = 0 House ownership: Own a house = 1, Other = 0 (information collected from Intervista) Lives in countryside = 1 (information collected from Intervista) Accommodation equipped with PV, either solar panels for electricity or to produce hot water = 1, None = 0 Households living in German-speaking: Households living in regions including Alpen and Voralpen, Westmittelland, Ostmittelland = 1 (information collected from Intervista) Household with three or more people: Households with three or more people = 1
Values	Hedonic values: concerning personal pleasure, enjoying life and self-indulgence. Egoistic values: concerning social power, wealth, authority, influence and ambition. Altruistic values: concerning equality, world peace, social justice and helpfulness (towards other people) Biospheric values: concerning respecting earth (and other species), nature, protecting the natural environment and preventing pollution.	Please rate how important each value is for you as a guiding principle in your life. Hedonic values (mean of 3 items): Psy4_4: Pleasure: joy, gratification of desires; Psy4_10: Enjoying life: enjoying food, sex, leisure, etc Psy4_15: Self-indulgence: doing pleasant things. Egoistic values (mean of 5 items): Psy4_3: Social power: control over others, dominance Psy4_7: Wealth: material possessions, money Psy4_8: Authority: the right to lead or command Psy4_12: Influential: having an impact on people and events Psy4_16: Ambition: hard-working, aspiring Altruistic values (mean of 4 items): Psy4_1: Equality: equal opportunity for all Psy4_6: A world at peace: free of war and conflict; Psy4_9: Social justice: correcting injustice, care for the weak Psy4_13: Helpfulness: working for the welfare of others Biospheric values (mean of 4 items): Psy4_2: Respecting earth: harmony with other species Psy4_5: Unity with nature: fitting into nature Psy4_11: Protecting the environment: preserving nature Psy4_14: Preventing pollution: protecting natural resources Scale: 1 (not important) – 5 (extremely important)
Intentions	Intention to reduce car carbon footprint in the next 12 months	1 item: In the next 12 months, are you planning on reducing your … Psy8_4: carbon footprint? Scale: 1 (very unlikely) – 5 (very likely)
Descriptive norms	Assessment of others' environmentally friendly behavior	1 item: Psy5a_2: I believe that most of my acquaintances behave in an environmentally friendly manner whenever it is possible. Scale: 1 (totally agree) to 5 (totally disagree)
Injunctive norms	Perception of others' expectations for self to act in an environmentally friendly way	Mean of 2 items: Psy5a_1: The members in my household expect that I behave in an environmentally friendly manner. Psy5a_3: Most of my acquaintances expect that I behave in an environmentally friendly manner. Scale: 1 (totally agree) to 5 (totally disagree)
Adopter segments	Classification of likelihood to adopt innovation according to Rogers (1983)	Multiple choice question: Ped_adopter: Which of the following describes you best? For your information: Smart-home technology products refer to products, gadgets, and apps that may help you control different aspects of your home such as your room temperature, energy consumption, or water usage. (1) Innovator: I am the type of person who closely follows new technological developments and who dares taking risks by being the first to purchase innovative smart-home technology products (2) Early adopter: I am the type of person who envisions potential advantages in innovative smart-home technology products and who is one of the first to make use of these advantages and to profit from those (3) Early majority: I am the type of person who is interested in innovative smart-home technology products but at the same time is pragmatic. First I would like to take time and be persuaded by the advantages that an innovative smart-home technology product possesses. My decisions are (mainly) based on recommendations of existing users (4) Late majority: I am the type of person who is not thrilled by innovative smart-home technology products, but who rather appreciates security. It is safe to purchase an innovative smart-home technology product when it has been on the market for some while and offers obvious advantages

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Variables	Questions/items
	(5) Laggards: I am the type of person who is traditional and has little affinity with innovative smart-home technology products. I do not like changes in life and I purchase innovative smart-home technology products only when the existing methods I use do not work anymore

Appendix A4. Estimation of part-worth utilities for segments – results for Bayesian estimation and maximum likelihood estimation of random parameters logit – and standard deviation of parameters from maximum likelihood estimation. Results are to be interpreted relative to the base option (used as omitted levels in model): Ownership of PV by utility, private cars with emission restrictions, basic shared spaces

Attribute and levels	Random parameters logit, Bayesian estimation, standard deviation of posterior after distributional transformation in parentheses					Random parameters logit, maximum likelihood estimation, standard error in parentheses				
	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Ownership of solar PV and your involvement										
Private ownership	−1.01	0.45	5.66	0.27	−1.98	−0.87	0.24	3.45	0.21	−1.75
	(0.54)	(0.99)	(1.33)	(0.72)	(0.90)	(0.12)	(0.12)	(0.38)	(0.07)	(0.18)
Cooperative ownership	−0.35	2.14	−0.79	−0.80	1.98	−0.35	1.60	−0.26	−0.65	1.86
	(0.54)	(0.77)	(1.03)	(0.59)	(0.56)	(0.10)	(0.14)	(0.17)	(0.07)	(0.19)
Housing association	0.43	0.03	−1.49	−0.13	1.13	0.40	0.16	−0.95	−0.11	0.93
	(0.49)	(1.27)	(1.61)	(0.49)	(0.68)	(0.08)	(0.09)	(0.17)	(0.05)	(0.12)
Availability of mobility options										
Public transit only	−2.91	−2.41	−2.76	0.86	2.29	−2.52	−1.88	−1.62	0.70	2.02
	(0.52)	(0.49)	(1.35)	(0.42)	(0.63)	(0.16)	(0.12)	(0.19)	(0.05)	(0.17)
Shared EV	−0.26	0.07	0.41	−0.43	−0.37	−0.28	0.07	0.08	−0.35	−0.30
	(0.65)	(0.52)	(2.04)	(0.43)	(0.82)	(0.09)	(0.07)	(0.13)	(0.05)	(0.11)
Availability of shared spaces										
Extra shared spaces	−0.08	1.24	−2.10	0.17	1.41	−0.07	0.89	−1.30	0.15	1.15
	(0.49)	(0.51)	(0.58)	(0.38)	(0.60)	(0.06)	(0.09)	(0.14)	(0.04)	(0.13)
BIC	1604.75	817.08	369.78	2359.23	781.68	1935.69	1091.16	592.50	2685.75	1056.86

Attribute and levels	Standard deviation parameters from random parameters logit, maximum likelihood estimation				
	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Ownership of solar PV and your involvement					
Private ownership	0.004	0.009	0.011	0.008	0.580[a]
Cooperative ownership	0.001	0.00	0.267	0.0009	0.001
Housing association	0.164	0.008	0.003	0.0007	0.009
Availability of mobility options					
Public transit only	0.008	0.002	0.002	0.004	0.024
Shared EV	0.662[a]	0.004	0.015	0.006	0868[a]
Availability of shared spaces					
Extra shared spaces	0.167	0.0003	0.227	0.002	0.289

Note: A number of models with different distributions for random parameters were run. However, a normal distribution of random parameters with Bayesian estimation produced the best fit based on BIC.
Note: Standard deviations of the random parameters show significance for Segments 1 and Segment 5 indicating heterogeneity in respondents' preferences for these levels.
[a] = T-ratio greater than 1.96.

Appendix A5. A selection of summary statistics by segment; mean with standard deviation presented in parentheses

Variable	Segment				
	Segment 1: *Car defenders*	Segment 2: *Cooperative with car flexibility*	Segment 3: *Private and autonomous*	Segment 4: *No cooperative PV, Public transit*	Segment 5: *Community-focused*
N	426	308	143	359	250
Age	49.1	45.1	50.1	51.96	47.8
	(14.9)	(15.3)	(15.45)	(16.03)	(15.5)
Sex	0.49	0.45	0.41	0.48	0.46
	(0.50)	(0.50)	(0.49)	(0.50)	(0.50)
Income	8723.03[a]	8708.4[b]	8647.72[c]	7603.04[d]	8134.04[e]
	(3226.9)	(3141.8)	(3306.97)	(3248.5)	(3179.3)
Years of education	14.07	14.20[f]	14.16	13.83	14.02[g]
	(2.00)	(1.96)	(1.98)	(2.04)	(1.95)
Car ownership	0.88	0.81	0.87	0.67	0.48
	(0.31)	(0.39)	(0.34)	(0.47)	(0.50)
House ownership	0.29	0.29	0.48	0.29	0.15
	(.45)	(.45)	(.50)	(.45)	(.36)
Lives in countryside	0.29 (0.45)	0.24 (0.43)	0.25 (0.44)	0.20 (0.40)	0.14 (0.35)
Accommodation with solar panels	0.18	0.18	0.27	0.14	0.16

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Variable	Segment				
	Segment 1: *Car defenders*	Segment 2: *Cooperative with car flexibility*	Segment 3: *Private and autonomous*	Segment 4: *No cooperative PV, Public transit*	Segment 5: *Community-focused*
	(0.39)	(0.39)	(0.44)	(0.35)	(0.36)
Households living in German-speaking Switzerland	0.72	0.81	0.75	0.76	0.78
	(0.46)	(0.39)	(0.44)	(0.43)	(0.41)
Household with three or more people	0.31	0.43[f]	0.36	0.27	0.27[g]
	(0.46)	(0.50)	(0.48)	(0.45)	(0.44)
Adopter segment	3.21	3.06	3.11	3.187	3.192
	(1.1)	(.96)	(1.13)	(1.15)	(1.104)
Intention to reduce carbon footprint	3.01	3.25	3.23	3.11	3.39
	(1.10)	(1.05)	(1.00)	(1.18)	(1.03)
Values					
Hedonic values	3.77	3.72	3.76	3.59	3.67
	(0.73)	(0.75)	(0.70)	(0.85)	(0.73)
Egoistic values	2.73	2.74	2.81	2.70	2.5
	(0.75)	(0.73)	(0.71)	(0.79)	(0.66)
Altruistic values	3.9	3.99	3.86	3.95	4.22
	(0.68)	(0.66)	(0.63)	(0.79)	(0.60)
Biospheric values	3.95	4.09	4.03	4.07	4.24
	(0.77)	(0.71)	(0.64)	(0.835)	(0.65)
Norms					
Descriptive norms	3.38	3.39	3.38	3.41	3.44
	(0.87)	(0.87)	(0.86)	(0.92)	(0.90)
Injunctive norms	3.22	3.38	3.40	3.40	3.45
	(1.00)	(0.86)	(0.82)	(0.97)	(0.98)

[a] N = 380.
[b] N = 280.
[c] N = 132.
[d] N = 313.
[e] N = 235.
[f] N = 307.
[g] N = 249.

Appendix A6. Comparison of means using Tukey-Kramer test (only statistically significant differences are reported)

Variable	Means			
	Difference	Std. error		
Car ownership				
Car defenders vs.				
Utility-owned PV, public transit	0.213***	0.029	0.133	0.293
Community-focused	0.411***	0.033	0.322	0.500
Utility-owned PV, public transit vs.				
Cooperative with car flexibility	−0.134***	0.032	−0.221	−0.048
Private and autonomous	−0.193***	0.040	−0.304	−0.082
Community-focused vs.				
Cooperative with car flexibility	−0.332***	0.035	−0.428	−0.237
Private and autonomous	−0.391***	0.042	−0.508	−0.274
Utility-owned PV, public transit	−0.198***	0.034	−0.290	−0.106
House ownership Private and autonomous vs.				
Car defenders	0.189***	0.0423	0.072	0.306
Cooperative with car flexibility	0.190***	0.045	0.067	0.312
Utility-owned PV, public transit	0.186***	0.044	0.066	0.306
Community-focused	0.324***	0.047	0.196	0.451
Community-focused vs.				
Car defenders	−0.134**	0.035	−0.231	−0.038
Cooperative with car flexibility	−0.134**	0.038	−0.237	−0.031
Utility-owned PV, public transit	−0.138**	0.037	−0.238	−0.038
Accommodation with solar panels Private and autonomous vs.				
Utility-owned PV, public transit	0.126**	0.037	0.024	0.229
Community-focused	0.110*	0.040	0.001	0.218
Income Utility-owned PV, public transit vs.				
Car defenders	−1119.991***	245.333	−1790.12	−449.862
Cooperative with car flexibility	−1105.001***	264.381	−1827.158	−382.843
Private and autonomous	−1044.692*	333.560	−1955.814	−133.570
Live in countryside Car defenders vs.				
Utility-owned PV, public transit	0.085*	0.030	0.004	0.293
Community-focused	0.149***	0.033	0.058	0.500
Household with 3 or more people Cooperative with car flexibility vs.				
Car defenders	0.125**	0.034	0.030	−0.048
Utility-owned PV, public transit	0.157***	0.036	0.058	−0.082
Community-focused	0.161***	0.040	0.053	−0.237
Intention to reduce carbon footprint Cooperative with car flexibility vs.				

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Variable	Means			
	Difference	Std. error		
Car defenders	0.240*	0.081	0.017	0.462
Community-focused vs. Car defenders	0.381***	0.087	0.144	0.618
Utility-owned PV, public transit	0.279*	0.090	0.034	0.524
Age Cooperative with car flexibility vs.				
Car defenders	−4.030**	1.154	−7.181	−0.880
Private and autonomous	−4.970*	1.561	−9.232	−0.707
Utility-owned PV, public transit	−6.910***	1.198	−10.181	−3.637
Community-focused vs.				
Utility-owned PV, public transit	−4.169**	1.270	−7.639	−0.699
Values: Hedonic values				
Utility-owned PV, public transit vs.				
Car defenders	−0.178*	0.055	−0.328	−0.029
*Values: Egoistic values*Community-focused vs.				
Car defenders	−0.232*	0.059	−0.393	−0.072
Cooperative with car flexibility	−0.239**	0.063	−0.410	−0.067
Private and autonomous	−0.306**	0.077	−0.518	−0.094
Utility-owned PV, public transit	−0.195*	0.061	−0.361	−0.029
Values: Altruistic values Community-focused vs.				
Car defenders	0.315***	0.055	0.165	0.465
Cooperative with car flexibility	0.229**	0.059	0.070	0.390
Private and autonomous	0.356***	0.072	0.159	0.553
Utility-owned PV, public transit	0.272***	0.057	0.117	0.427
Values: Biospheric values Community-focused vs.				
Car defenders	0.292***	0.060	0.129	0.454
Injunctive norms				
Community-focused vs. Car defenders	0.230*	0.076	0.022	0.438

Comparisons of means have been carried out for all variables listed in Appendix A2. This table reports only variables for which differences in means are statistically significant according to the Tukey–Kramer test for of multiple comparisons.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Consistent with their preference for public-transit only, the *Community-focused* segment exhibit a significantly lower mean car ownership relative to all other segments. Respondents in this segment also show a significantly higher intention to reduce their carbon footprint relative to *Car defenders* and the *No cooperative PV, Public transit* segment. The *Community-focused* segment exhibited a significantly lower average score on egoistic values relative to all other segments and a significantly higher average score on altruistic values. The number of home owners in this segment was significantly lower relative to all other segments.

On the other hand, the *Car defenders* segment demonstrated significantly higher average car ownership relative to all other segments, consistent with findings about their attribute preferences. They were more likely to live in the countryside than the *No cooperative PV, Public transit* and *Community-focused* segments. They also scored significantly lower on average scores in biospheric values and injunctive norms compared to the *Community-focused* segment and had a lower average intention to reduce their carbon footprint compared to the *Community-focused* segment and the *Cooperative with car flexibility* segment. The *Car defenders* segment had a higher average hedonic score relative to the *No cooperative PV, Public transit* segment.

Respondents in the *Cooperative with car flexibility* segment were, on average, significantly younger than most segments (*Car defenders*, the *Private and autonomous* segment, and the *No cooperative PV, Public transit* segments). They also had a significantly higher average number of households with three or more people compared to most segments (*Car defenders*, *No cooperative PV, Public transit*, and *Community-focused*).

Respondents in the *No cooperative PV, Public transit* segment were among the oldest in the sample, significantly older than respondents in both the *Cooperative with car flexibility* segment and the *Community*-focused segment. They also had significantly lower average car ownership and significantly lower average income compared to all segments but the *Community-focused* segment.

The *Private and autonomous* segment had high average house ownership relative to all other segments and significantly higher car ownership compared to the *No* cooperative *PV, Public transit* and *Community-focused* segments. Respondents in the segment also had higher average number of households equipped with solar panels relative to *No cooperative PV, Public transit* and *Community-focused* segments.

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