Energy Policy 182 (2023) 113761

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

When do circular business models resolve barriers to residential solar PV adoption? Evidence from survey data in flanders

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ARTICLE INFO

Keywords:
Energy transition
Solar PV
Product service system
Residential PV
PV reuse
Circular business models

ABSTRACT

Solar energy is an important renewable energy source to support a decarbonization of our energy mix. Although the uptake of solar PV surged in the last decade, many households face significant barriers to invest in solar energy. Circular business models may mitigate the upcoming PV waste problem and increase energy and resource independence. In this paper, we investigate when circular business models may also lower barriers for residential PV-adoption. We use survey data (n = 3996) from Flanders (Belgium), controlling for personal and housing characteristics, and institutional trust parameters. Our results suggest that upfront costs, a lack of trust in governments, technological obsolescence, and a perceived lack of profitability constitute the main barriers for residential solar PV investments. Circular business models, including product service systems and PV reuse, appear to resolve only the former barrier. Our results show the importance of trust in service providers and technology, and the complex relationship between trust in governments and solar PV investments. We recommend policymakers to coordinate energy, environmental, and social policy initiatives aimed at enhancing solar PV adoption in a sustainable manner. Moreover, we recommend to invest in legal complementarity and legal certainty, enabling households to regain trust to adopt new and sustainable technologies.

Credit author statement

W.V.O; Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft preparation, Writing – review & editing,A.S.; Validation, Resources, All authors have read and agreed to the published version of the manuscript.

1. Introduction

Solar Photovoltaics (PV) has been identified as a significant contributor to the renewable energy transition, supporting the achievement of the United Nation's Sustainable Development Goals (SDGs) in a cost-efficient way (Global Solar Council, 2020; (IEA, 2021). In 2022, around 130 GW of PV systems have been deployed by households, accounting for 25 million units (IEA, 2022). Residential solar PV investments have been stimulated by a broad range of policy measures, including net metering, tradeable green current certificates, feed-in-tariffs, direct capital subsidies, and tax credits (Dusonchet and Telaretti, 2015; Pereira da Silva et al., 2019; Verbruggen and Laes, 2021). Nevertheless, many households do not have access to solar PV because of financial, technical, or legal barriers. Although many supporting policy instruments focused on PV ownership, evolving market conditions and policies alter incentives such that access to solar power becomes more relevant than owning a PV installation.

The success of solar PV deployment also results in an environmental challenge. Estimations on the accumulation of PV waste vary from 1.7 to 8 million tons of waste by the end of 2030, and 60 to 78 million tons of cumulative waste by 2050 (Gautam et al., 2021; IRENA and IEA-PVPS, 2016). Circular economy strategies and business models may mitigate this waste problem with improved recycling options and longer product lifetimes realized by reuse and repair strategies (Tsanakas et al., 2020). Circular economy strategies in solar energy may also contribute to increase energy and resource independence, which has been shown to be very relevant in times of geopolitical conflicts such as the war in Ukraine (Nygaard, 2022; Steffen and Patt, 2022), and prospects of a nuclear phase-out (de Frutos Cachorro et al., 2019).

Circular business models often include product-service systems (PSS), allowing customers to benefit from solar energy without having to purchase a PV installation, and giving service providers an incentive to optimize product lifetimes (Tukker, 2015). There are multiple PSS

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https://doi.org/10.1016/j.enpol.2023.113761
Received 1 November 2022; Received in revised form 23 July 2023; Accepted 2 August 2023
Available online 9 August 2023

configurations possible for solar PV (see Emili et al., 2016 for an overview of 15 PS S models for distributional renewable energy). The most common PSS configurations for solar energy are Power Purchasing Agreements (PPA), which is a result-oriented PSS, and leasing, which is a use-oriented PSS (Tukker, 2004). In a PPA set-up, the customer pays a predetermined fee per kWh of electricity generated by the PV system. These fees are often lower than grid prices and contracts typically run for 15–20 years. In a leasing model, the customer pays a monthly or yearly fee in exchange for access to a PV system and the energy it produces. Other forms of Third-Party Ownership (TPO) include Energy Savings Companies (ESCOs) and business models for demand response. ESCOs develop, install, and finance performance-based projects centered around improving the energy efficiency of customer facilities (Vine, 2005). Demand Response Business Models (DBRM) incentivize consumers to make temporary reductions in their energy demands to balance grid supply and demand (Hamwi et al., 2021).

PSS models can also enable PV reuse, unburdening sourcing, maintenance, and repair concerns of customers when adopting second life PV panels. The reuse of PV panels can be defined as the utilization of discarded PV modules that are still in a working condition (Rabaia et al., 2022), but have been decommissioned for reasons of repowering, early defects, insurance claims, etc. (Radavičius et al., 2021). In order to contribute to a circular economy, PSS models have to be designed carefully, as PSS does not imply a sufficient condition to contribute to a sustainable development. One of these design parameters are the end-of-life options in a PSS contract, varying from a transfer of ownership (with or without a service contract for the rest of the product lifetime) to removal of the installation (Chowdhury et al., 2020; Contreras Lisperguer et al., 2020).

Literature on barriers and enablers for residential solar PV adoption is well developed (Best and Chareunsy, 2022; Jacksohn et al., 2019; Rai et al., 2016; Wolske, 2020; Wolske et al., 2017) but largely neglects enabling value propositions that may stem from circular business models. Literature on solar circular economy solutions, on the other hand, made significant progress on technical and technological challenges of PV recycling and remanufacturing (Contreras-Lisperguer et al., 2021; Deng et al., 2019; Farrell et al., 2020; Rabaia et al., 2022; Radavičius et al., 2021), but underexplores the enabling potential of circular business models among residential end-consumers. Demand side parameters of solar PSS models have been studied extensively (Drury et al., 2012; Överholm, 2015; Palm, 2020; Schmidt et al., 2016) but rarely from a circular economy lens, neglecting end-of-life solutions and PV reuse. Recently, focus group research was used to study enabling value propositions of circular solar solutions within organizational market segments (Van Opstal and Smeets, 2023). A similar study on residential market segments, however, has not been published yet.

In this paper we explore whether circular business models can resolve barriers for residential solar PV adoption. We use survey data from 3996 households in Flanders (Belgium) where we gathered data from both non-adopters, households who own solar PV, and households who are currently in a solar PSS contract. Our survey includes questions on reasons for non-take-up and value propositions, barriers, and enablers of circular solar solutions, controlling for personal and housing characteristics and institutional trust parameters.

The objective of this study is to identify what barriers for solar PV adoption can be mitigated by circular business models, and to identify which customer segments are most in favor of these circular solar business models. Our results should support solar service providers to identify promising market segments for market entry, and to improve their product-market fit when designing circular solar business models. For policymakers, this study aims to provide useful insights to design energy policies that enhance the uptake of renewable energy in general and improve grid resilience and reduce energy poverty more specifically. Moreover, our research aims to provide insights on public support for circular alternatives that may mitigate the upcoming PV waste problem.

Circular business model features discussed in this paper include solar PSS models, PV reuse, and different end-of-life strategies. For solar PSS we opted to survey household interest in a use-oriented PSS model (PV rental with a transfer of ownership after 20 years), which is by far the dominant solar PSS model for residential market segments in Flanders. Other solar PSS models are mostly considered by organizational market segments and are therefore less relevant for the scope of this work (Van Opstal and Smeets, 2022). For PV reuse, we surveyed customer interest in second life PV panels in the context of a use-oriented PSS model, where the operation of these panels would be guaranteed by the supplier. The latter both unburdens customers and incentivizes circularity outcomes regarding repair and maintenance. As markets for PV reuse for residential applications are incomplete and immature in most parts of the industrialized world, this study is the first to our knowledge to capture customer interest and potential value propositions. Regarding end-of-life specifications, transfer of ownership is the dominant model in solar PSS contracts in Flanders. In our survey we opted to broaden the choice set to PV removal and a transfer of ownership for the post-PSS period, allowing us to identify customer interest and discuss circularity considerations.

We consider Flanders as a relevant geographical area to study industrialized regions. Flanders is a densely populated, highly educated, open, and industrialized economy that operates in a complex and multilayered policy environment. In Belgium, renewable energy is a competence of the regional governments. Recent policy reforms include a fading out of tradeable green current certificates and net metering, and the introduction of a prosumer tariff. These reforms caused political commotion, resulting in the dismissal of the minister of energy in 2016, and a ruling by the Belgian Constitutional Court in 2021 that caused the Flemish Government to revoke on earlier promises to safeguard net metering advantages for a long period of time. This resulted in a strong increase of popular distrust in solar PV (De Groote et al., 2022; Juwet and Deruytter, 2021; Stam, 2018). Yet, solar energy uptake in Flanders is high, with an installed power of 788 W/capita, and 120 installations per 1000 inhabitants in May 2023 (Flemish Government, 2023).

The rest of the paper is structured as follows. In section 2 we provide a short overview of relevant literature on barriers and enablers for residential investments in solar PV, and on value propositions of circular solar solutions. In section 3 we give background information on our survey of which the results are reported and discussed in section 4. In section 5 we conclude with policy recommendations and identify limitations and novel research gaps.

2. Literature

2.1. Barriers and enablers for residential investments in solar PV

Residential markets for solar PV have been studied extensively, mostly focusing on homeowners in industrialized countries. Many authors have used survey data to assess value propositions, barriers, and enablers for solar PV adoption. Thereby, they control for personal and housing characteristics, and differentiate by focusing on peer effects and the influencing role of installers (Rai et al., 2016), the role of pro-environmental norms and trust (Wolske et al., 2017), membership of renewable energy cooperatives (Bauwens, 2019), or the income position of PV adopters (Best and Chareunsy, 2022; Wolske, 2020). Most studies find out that household decisions to invest in PV systems are mainly driven by economic factors, as is also confirmed by survey panel data from Germany (Jacksohn et al., 2019). Recent survey research focuses on barriers and enablers to increase self-consumption (and thus increase the economic benefits) of solar PV production (Colasante et al., 2022), including motivations for battery energy storage adoption (Alipour et al., 2022) or behavioral change (Colasante et al., 2021). Research on solar PV investments in non-residential market segments is far more limited and utilizes qualitative research techniques such as interviews (Reindl and Palm, 2021) and focus groups (Van Opstal and Smeets, 2022).

Other studies use administrative data to learn about the role of personal and housing characteristics on solar PV investment decisions. This allows to explore the impact of local policies and assess the dynamics of supporting policy measures over multiple years (De Groote et al., 2016; De Groote and Verboven, 2019). Administrative data has also been linked to local voting behavior as a proxy for environmental preferences (Palm, 2020). Recently, machine learning techniques have been applied to administrative data to understand the regional disparity of residential solar adoption in Australia (Lan et al., 2021). Nevertheless, despite the completeness of administrative data on actual choices, it is hard or impossible to use it to learn about value propositions and non-revealed preferences of households (Bocken et al., 2019).

Review studies on drivers, barriers, and opportunities of renewable energy adoption include studies from both industrialized and developing countries (Engelken et al., 2016; Korsten et al., 2018). For developing countries, main barriers include corruption and weak electricity grids, while in industrialized countries, thought patterns and high costs of energy storage are indicated as main barriers. Main issues include financial aspects, peer effects, generation and age, and belief systems. In a recent meta-analysis of residential PV adoption, results imply that enabling measures should primarily focus on enhancing the perception of benefits of solar PV adoption (Schulte et al., 2022).

Research on enabling policies to stimulate residential solar PV adoption focus on the optimal design or evaluation of specific measures, such as tradeable green current certificate systems (Verbruggen, 2004; Verbruggen and Laes, 2021) and subsidized tax deductions (D'Adamo et al., 2022), or the possibility to create renewable energy communities (Conradie et al., 2021; Felice et al., 2022). Other studies focus on comparisons between countries (De Boeck et al., 2016; Huijben et al., 2016), unintended consequences of support mechanisms (Boccard and Gautier, 2021), and on the importance of trust in governments when designing and implementing supportive policies (De Groote et al., 2022). Supportive policies are also relevant from a perspective of energy poverty, as they may mitigate or conversely worsen demographic inequities and unfair adoption patterns within social groups (Best, 2022; Best et al., 2023; Sovacool et al., 2022). Nevertheless, most studies mentioned in this overview do not explore the potential of circular economy strategies in general or circular business models in particular.

2.2. Literature on circular solar solutions

Many studies on circular solar solutions focus on technological innovations to foster circular outcomes in solar PV design, production, use, and recycling. It is estimated that up to 80% of the PV waste stream can consist of products that got defected or failed during production, transportation, or their first operational years (IRENA and IEA-PVPS, 2016). Experts estimate that about 45%–65% of these panels can be repaired or refurbished (Tsanakas et al., 2020). Recent studies address challenges and opportunities to alter PV panel design for repair, design for reuse, and design for recyclability (Radavičius et al., 2021), end-of-life strategies to stimulate closed-loop recycling (Contreras Lisperguer et al., 2020; Contreras-Lisperguer et al., 2021), and improved recycling techniques (Chowdhury et al., 2020; Deng et al., 2019; Farrell et al., 2020; Heath et al., 2020). Rabaia et al. (2022) review technical challenges to enhance circular solar solutions and present a circular PV industry business model to align incentives along the PV value chain (Rabaia et al., 2022). Mathur et al. (2023) propose an integrated model to assess product recovery pathways for the case of solar PV panels. Their model evaluates environmental trade-offs for alternative product recovery strategies including remanufacturing of product, sub-assemblies, components, and materials (Mathur et al., 2023). In a recent contribution, the use of digital platforms is discussed to foster data-enhanced circular practices, including the creation of digital product passports and the design of online PV reuse marketplaces (Boukhatmi et al., 2023).

Regarding circular solar business models, a strand of academic literature investigates the perspective of service providers. This includes studies on solar product service systems, characterizing typologies (Emili et al., 2016), barriers for service providers (Lundqvist, 2020), and alliance formation by intermediary ventures (Överholm, 2017). Other work focuses on business models to implement circularity enhancing solutions such as demand response technologies (Hamwi et al., 2021; Hamwi and Lizarralde, 2017) and integrated wind and solar energy business models (Mendoza and Ibarra, 2023). Important barriers to introduce circular solar business models include supply chain and sourcing barriers, regulatory hurdles, lack of market acceptance and trust, limited access to financing, liability risks due to limited certification opportunities (Lundqvist, 2020; Van Opstal et al., 2022).

Studies on the demand side of circular solar solutions are important to learn about both social and environmental challenges that follow from the deployment of solar PV. Research on solar PSS models in residential markets validates its ability to reduce or eliminate up-front adoption costs, facilitating PV adoption among younger, less affluent, and less educated households (Drury et al., 2012; Palm, 2020; Schmidt et al., 2016; Schmidt-Costa et al., 2019). Solar PSS models also have been shown to reduce maintenance concerns (Rai et al., 2016; Rai and Sigrin, 2013) and learning costs (Överholm, 2015). Value propositions that stem from PV reuse within circular business models remain underexplored (Rabaia et al., 2022). An exception to this are studies on organizational market segments, including companies, schools, social housing associations, and public sector buildings, focusing on market-specific barriers and enablers (Van Opstal and Smeets, 2022), and the way circular solutions can remove barriers for solar PV investments (Van Opstal and Smeets, 2023). To the best of our knowledge, a similar study on residential applications for homeowners has not been performed earlier.

3. Methodology

This survey has been prepared in close collaboration with industry partners that participate in a Horizon 2020 project on solar circular business models (https://circusol.eu). In a first stage, we developed a questionnaire that has been tested in the city of Eeklo (Belgium). Evaluating the quality and interpretability of these results ($n = 59$) allowed us to refine our questionnaire into three answer pathways for respectively (1) households with no solar PV, (2) households who own solar PV, and (3) households who already have a solar PSS contract.

With respect to personal characteristics, we included often used covariates such as gender, age, activity status, educational attainment, household size, and net monthly household income. We also asked a question on the migration background of the respondent, asking whether one of the grandparents of the respondent is born outside the European Union. To capture previous experiences with PSS models, we included questions on experiences with Netflix, Spotify, or car lease. We also used a proxy for risk aversion by asking respondents to position themselves on a continuous scale between two lotteries: receiving 1 million euro with a 1% probability and receiving 100 euro with certainty. Finally, we asked whether respondents were a member of a renewable energy citizen cooperative (Huybrechts and Mertens, 2014).

To capture housing characteristics, we asked questions about ownership status, housing type, the number of building layers, construction year, roof type, and a self-assessment of the roof quality on a scale of 0–100. We also asked the ZIP code, enabling us to identify whether respondents live in a city or not, and complemented this with a question whether respondents consider themselves living in an urban, a semi-urban, or a rural area. Finally, we controlled for institutional trust parameters, asking to indicate trust on a 5-point Likert scale in governments, service suppliers, nuclear energy, technology, and the green political party. The latter trust parameter is included as a proxy for environmental preferences, in line with earlier research in Sweden (Palm, 2020). Summary statistics on these variables can be found in Appendix A.

Our online survey has been set up using SurveyMonkey and was distributed via the most important newsletters on building and reconstructing in Flanders (Livios, Ilumen, and Bouwen en Wonen), via direct mailings of our project partners towards their members and clients (Ecopower and Futech), and via the newsletter and social media of our research institute. We tested profile differences and preferences according to the response collection channel respondents used to reach our online survey. The survey was online between January 3rd, 2022 and February 28th, 2022, resulting in 3996 responses of which 3583 full responses. Respondents provided their informed consent and were incentivized with a lottery of 20 sets of 6 LED lamps (E27 fitting) that were drawn by an independent colleague using a random number generator on a set of available e-mail addresses that were collected with this purpose. We believe this material incentive did not bias non-response profiles, since almost any household in Flanders can make use of this type of lamp.

Comparing sample characteristics with the population in Flanders, highly educated, male, and older individuals are overrepresented (Rousseau and Raïsa, 2021). An analysis of item nonresponse learns that survey dropouts are relatively older, less educated, and lower income respondents. We also notice lower item nonresponse rates among members of renewable energy citizen cooperatives. Since we do not aim to extrapolate our results to infer frequencies of the entire population, and since we do not aim to study household behavior at extreme distributional tails of personal or housing characteristics, we did not apply imputation techniques to resolve item nonresponse (Chen and Haziza, 2019). For similar reasons, we did not apply weights to survey respondents, as we do not seek to extrapolate our results to infer macro-economic statistics. Instead, we use survey data to explore decision making at the micro-economic level, controlling for personal and housing characteristics. Finally, in our statistical analysis, we tested for heteroskedasticity in linear regressions using a Breusch-Pagan test and corrected whenever appropriate with robust standard errors. Likewise, we tested for collinearity problems by performing a VIF-test.

4. Results and discussion

4.1. Barriers for solar PV adoption

In our survey, we asked households with no solar PV to indicate the main barriers for PV adoption. As shown in Fig. 1, the main barrier appears to be the upfront capital expenditure (CAPEX) of the installation. Other major barriers include a lack of trust in governments, a belief in more efficient future technologies, and insufficient financial benefits. Of all respondents, 4.58% do not own the house they live in. Of respondents that did not adapt solar PV, 6.39% mentioned not being a homeowner as a barrier. Since tenants are often not even permitted to adopt solar PV installations on the roofs they do not own, we continue our analysis with homeowners (n = 3813).

The four major barriers are no surprise. Financing upfront capital expenditures has been identified earlier as a major barrier for solar PV adoption (Alipour et al., 2022; Överholm, 2015; Rai et al., 2016; Wolske, 2020). A lack of governmental trust also has been identified earlier as an important barrier for solar PV adoption (Petrovich et al., 2021). In Flanders, this can be explained because of a strong increase in popular distrust after major reforms including a withdrawal of earlier promises to safeguard net metering advantages for a long period of time (De Groote et al., 2022; Juwet and Deruytter, 2021; Stam, 2018). The latter example may have caused a shift in expectations on the financial advantages of PV adoption, triggering dynamics of loss aversion (Klein and Deissenroth, 2017).

Finally, it is no surprise either that a subset of the population waits for improved technologies, as solar PV panels have been shown to benefit from increased efficiency innovations for many years, rendering solar PV an increasingly cost effective energy resource that takes up less and less roof space (IEA PVPS, 2021). In open comment fields, respondents also indicated to be waiting on cost efficient battery storage systems, as the recent abolishing of net metering in Flanders led to an increased attention to maximize self-consumption. This is illustrated by the following respondent *"I am no longer convinced of the cost-effectiveness now that net metering has been abolished. This makes a home battery almost a necessity and I fear that the investment and payback time will be too high …"*

To deepen our understanding of these barriers, we performed a Probit regression to compare profiles of households with and without solar PV installations. Likewise, we investigated the relationship between the indication of these barriers by respondents and their planned timing of investing in solar PV. These results can be found in Appendix B (Tables B.1 and B.2).

4.2. When do solar PSS models resolve these barriers?

Survey respondents were asked about their interest in a use-oriented PSS model (PV rental with a transfer of ownership after 20 years) on a 0 to 100 scale. When we apply a linear regression on this value among households with no PV, we see a lower interest among male respondents and respondents who live in recently built houses (see Table 1). Interest in PSS is significantly higher among respondents living in a house with a

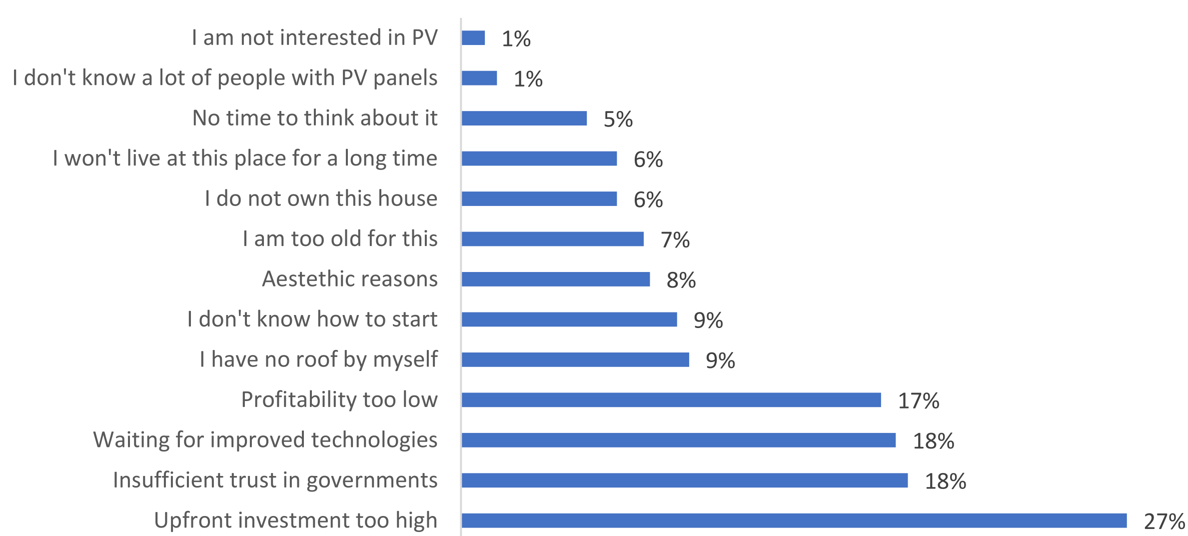

Fig. 1. Barriers towards PV adoption (n = 814).

Table 1
OLS and Probit regression estimates on profile differences of preferences for solar PSS contracts among homeowners without solar PV.

	Interest in PSS (OLS)	High PSS interest (Probit)	No PSS interest (Probit)
n =	651	651	651
Prob > chi^2	0.0000	0.0001	0.0000
Adjusted R^2	0.0860		
Pseudo R^2		0.1065	0.1242
Constant term	**44.48 (14.03)****	**−2.8080 (0.6859)****	**−2.8003 (0.7048)****
Male	**−10.42 (3.1435)****	**−0.3643 (0.1398)****	**0.4528 (0.1696)****
Age	−0.1264 (0.1430)	0.0078 (0.0066)	0.0116 (0.0073)
Activity status: white collar worker (omitted)			
Activity status: independent	−10.52 (5.4765)	−0.5249 (0.2910)	0.4444 (0.2559)
Activity status: blue collar worker	−4.7904 (8.0589)	−0.3749 (0.4066)	0.2190 (0.3877)
Activity status: civil servant	−2.5072 (3.9409)	0.0225 (0.1799)	0.1125 (0.2090)
Activity status: inactive	2.3831 (4.5420)	−0.0113 (0.2087)	0.0533 (0.2256)
Education: no higher education (omitted)			
Education: higher education	0.2787 (3.8304)	0.0580 (0.1731)	−0.0069 (0.1830)
Education: university	−3.2670 (3.7989)	−0.1610 (0.1752)	−0.0536 (0.1839)
Migrant background	−4.5843 (5.5949)	−0.2280 (0.2702)	−0.2256 (0.3355)
Household size	2.4007 (1.3224)	0.0552 (0.0599)	−0.0335 (0.0686)
Income (ordinal)	−0.9137 (1.1717)	−0.0216 (0.0539)	−0.0199 (0.0562)
Risk aversion	−0.0088 (0.0432)	0.0027 (0.0021)	0.0033 (0.0021)
RESCOOP member	−3.6458 (3.2061)	−0.2314 (0.1441)	**0.3523 (0.1674)***
City	0.1889 (2.8243)	−0.0649 (0.1331)	0.0730 (0.1364)
Type: apartment	10.0667 (6.8638)	−0.1477 (0.3258)	−0.5240 (0.3582)
Type: closed	2.1718 (4.0963)	−0.1733 (0.1908)	−0.1401 (0.2063)
Type: semi-open	1.2712 (3.6421)	−0.0269 (0.1653)	0.0765 (0.1765)
Type: open (omitted)			
Building layers	−2.4694 (2.2764)	0.0476 (0.1052)	0.1617 (0.1168)
Flat roof	**11.9524 (3.6751)****	**0.6630 (0.1586)****	−0.2525 (0.1949)
Roof quality	−0.0160 (0.05788)	0.0032 (0.0027)	**0.0091 (0.0030)****
Construction year (ordinal)	**−1.9964 (0.6180)****	**−0.0653 (0.0289)***	0.0367 (0.0308)
Trust in government	−1.4964 (1.6172)	−0.1123 (0.0747)	0.0024 (0.0787)
Trust in service suppliers	3.3170 (1.7117)	**0.1923 (0.0797)***	0.0106 (0.0815)
Trust in nuclear energy	0.0317 (1.2502)	0.0483 (0.0585)	−0.0396 (0.0602)
Trust in technology	2.8275 (1.9284)	**0.2333 (0.0940)***	−0.02496 (0.0922)
Trust in green political party	2.5543 (1.4700)	0.0554 (0.0677)	**−0.1869 (0.0738)***
Experience: car lease	−1.8148 (3.1765)	−0.0582 (0.1497)	0.0278 (0.1587)
Experience: Netflix	**10.2343 (3.1430)****	**0.3918 (0.1450)****	**−0.3421 (0.1616)***
Experience: Spotify	2.2848 (3.1277)	0.1205 (0.1429)	0.0759 (0.1597)

Note: * significant at the 5% level, ** significant at the 1% level. Standard errors between brackets.

flat roof, and Netflix-users. Note that the user experience of Netflix differs from Spotify and car lease. Unlike Netflix, Spotify is also accessible for users who do not pay, and respondents who have experience with car lease often did not have to pay themselves for the lease program.

To refine our insights, we created dummy variables for respondents with high PSS interest (values of 80 or higher on 100) and respondents with no PSS interest (a value of 0 on 100). A high interest in PSS models is found significantly more often among female respondents, and respondents living in houses with a flat roof, an older dwelling, having experience as a Netflix user, having high trust rated in energy suppliers and technology. The latter comes to no surprise, since long-term PSS contracts require a sufficient amount of trust in service suppliers and in the technologies included (Inagaki et al., 2022; Vermunt et al., 2019; Yang and Evans, 2019). Having no interest in solar PSS is found to be related with respondents who are a member of a renewable energy citizen cooperative, living in houses with a good roof quality, having no Netflix subscription, and low trust rates in the Green political party.

We also asked our respondents to identify major enablers and disablers solar PSS may offer to adopt solar PV. In Table 2 we report barriers and enablers for homeowners without solar PV and compare them with homeowners who already own solar PV. Likewise, we reported differences between respondents indicating high interest or no interest in solar PSS at all. We also included results on the limited subset of respondents who already have a solar PSS contract.

Generally, solar PSS models are considered not interesting by people who like to own the installation themselves, have a preference to remain as independent as possible from energy suppliers, or consider ownership as financially more rewarding. As expressed by a respondent: "*A rental company also wants to make profit, so to what extent can I still benefit?*". Although other studies report similar barriers (Inagaki et al., 2022), PSS models, however, can be efficiency enhancing lowering costs for users as well (Yang and Evans, 2019).

For households who have a high interest in solar PSS, not knowing anyone else in a PSS model is a major barrier. The role of peer effects in solar PV adoption has been acknowledged for a long time already (Bollinger and Gillingham, 2012; Mundaca and Samahita, 2020; Noll et al., 2014; Palm, 2017), and information sharing between peers has been identified as an important driver for solar PSS adoption as well (Schmidt-Costa et al., 2019). Regulatory uncertainties are also considered as major barriers to opt for solar PSS as a gateway to solar PSS adoption. Examples in open comment fields include questions on the freedom of choice of the system, damage policies, and the movable or immovable character of the system on residential real estate.

The most enabling features of solar PSS, considered by non-owners with high interest in solar PSS, are the unburdening of upfront CAPEX and of technical risks. As illustrated by one respondent: "*If it is just as interesting financially, and less of a headache, then I don't see why I should own something that I can also rent*". Interestingly, half of these respondents identify environmental benefits as an enabling feature, while current PSS contractors hardly refer to environmental benefits.

We also compared interest in PSS among homeowners with no solar PV according to the barriers they experienced for solar PV adoption. The violin plots in Fig. 2 show differences in kernel density estimates of interest in solar PSS between respondents indicating these barriers and respondents that do not. As can be seen visually, respondents that indicated CAPEX as a barrier for solar PV adoption show a higher interest in solar PSS than other respondents. Our results suggest that solar PSS does not lower the other three major barriers. This has been confirmed by performing Kruskal-Wallis tests, showing a chi^2 value of 23.45 ($p < 0.001$) for CAPEX and chi^2 values between 1.41 ($p = 0.2350$) and 1.93 ($p = 0.1652$) for the other barriers.

4.3. Circularity enhancing business model features: barriers or enablers?

While solar PSS is not a novel innovation, it is relatively new for

Table 2
Major enablers and disablers for solar PSS among homeowners with and without solar PV, according to their interest in solar PSS models.

	Homeowners without solar PV		Homeowners who own solar PV		Homeowners in a PSS contract (n = 52)
	High PSS interest (n = 144)	No PSS interest (n = 124)	High PSS interest (n = 231)	No PSS interest (n = 748)	
Barriers					
Regulatory uncertainties	31.94%	**20.16%***	43.72%	**36.90%****	42.31%
Technical risks	18.75%	**8.06%****	14.29%	10.43%	19.23%
Bad when market prices drop	18.75%	**7.26%****	16.02%	**10.03%****	6.25%
Ownership is financially more rewarding	**22.92%****	33.06%	**25.97%****	**48.4%****	9.62%
Contractual uncertainties	13.19%	9.68%	19.91%	16.84%	1.92%
I prefer to own my installation	**19.44%****	**47.58%****	**25.54****	**62.83%****	15.38%
Uncertainty about quality	10.42%	8.87%	**15.58%***	9.22%	3.85%
Preference to remain independent	15.28%	33.87%	**20.78%****	**45.05%****	3.85%
Lack of trust	24.31%	**17.74%***	27.27%	28.74%	9.62%
I don't know anyone in a PSS model	**41.67%****	**9.68****	**22.94%***	**17.38%****	3.85%
Unclear situation in case of moving or death	20.83%	**15.32%***	**36.9%****	**13.50%****	7.69%
Enablers					
Fewer regulatory uncertainties	13.19%	16.94%	21.21%	21.12%	1.92%
Fewer technical risks	57.64%	**38.71%****	**63.20%****	**32.89****	48.08%
Fixed prices	**43.75%****	**11.29%****	**37.23%****	**11.76%****	42.31%
No upfront investment needed	**59.03%****	**17.74%****	**48.48%****	**20.59%****	46.15%
Environmentally beneficial	**50.69%****	**25.81%****	**37.66%****	24.33%	11.25%
Contractual stability	**16.67%****	8.06%	**14.29%***	8.16%	1.92%
Time saving	**44.44%****	**17.74%****	**32.03%****	12.30%	7.69%
Quality assurance	**25.69%***	**6.45%****	**26.41%****	**13.10%****	7.69%
Positive image	4.17%	0.81%	4.33%	1.87%	0.00%
Better monitoring and steering	**20.14%****	**4.03%****	**40.26%****	**12.17%****	1.92%
Trust in the service provider	17.36%	8.87%	**20.78%****	**7.09%****	1.92%

Statistical differences between i and -i, compared to all homeowners with a similar PV status (no PV, owning PV, PSS PV) are based on two-sided F-tests (* significant at the 5% level, ** significant at the 1% level).

residential applications in Flanders. Moreover, solar PSS can only be considered as an enabler for circularity but by no means as a sufficient condition to achieve superior environmental outcomes. Therefore, we also included more specific circular solutions, including PV reuse and circularity-enhancing end-of-life solutions.

4.3.1. *Preferences for PV reuse*

We asked survey respondents to indicate their preference for second life PV panels on a 0 to 100 scale. In our survey, PV reuse was presented within the framework of a use-oriented PSS model, to unburden potential risks of malfunctioning PV panels. Although our question did not include technical or financial details, it stressed that the operation of second-hand solar panels would be guaranteed by the supplier. This allows us to investigate potential value propositions and barriers of a new versus a reuse option (see infra).

Performing linear regression on this value reveals an increased interest among younger respondents, respondents with a university degree, respondents with lower incomes, and respondents with high trust levels in technologies and in the green political party (see Table 3). These results suggest a mix of value propositions stemming from environmental and economic benefits. With respect to housing characteristics, PV reuse receives most interest among owners of older dwellings, and houses with flat roofs. The latter result can be understood by the fact that the aesthetic consequences of a 2nd life installation with potentially

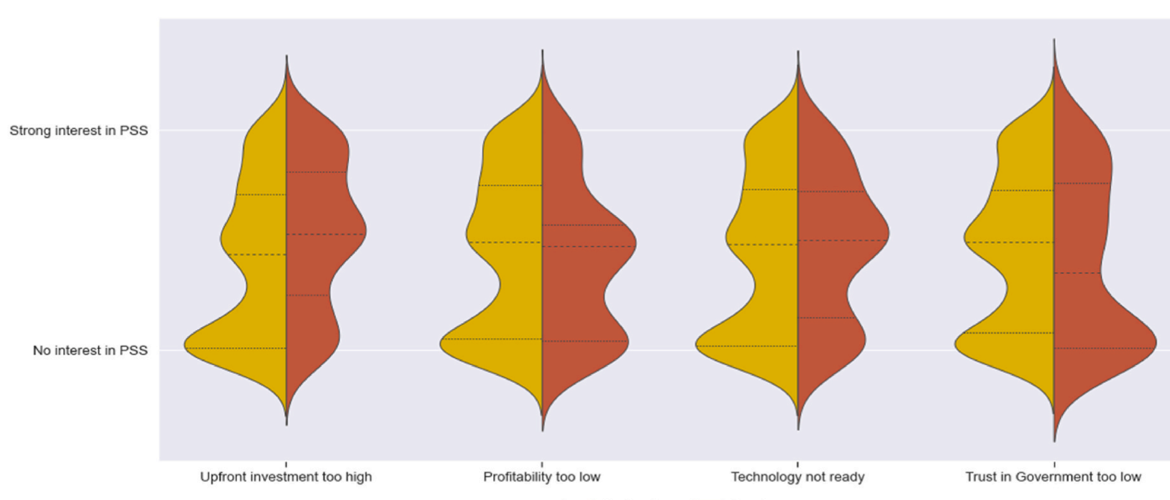

Fig. 2. Interest in PSS models according to barriers experienced for solar PV adoption, among homeowners with no PV.

Table 3
OLS and Probit regression estimates on profile differences of preferences for PV reuse among homeowners.

	Interest in 2nd life PV (OLS)	High 2nd life interest (Probit)	No 2nd life interest (Probit)
n =	3114	3114	3114
Prob > chi^2	0.0000	0.0000	0.0000
Adjusted R^2	0.1333		
Pseudo R^2		0.0711	0.0790
Constant term	**32.9059 (6.5746)****	**−1.6527 (0.3588)****	**−1.5892 (0.3178)****
Male	2.1790 (1.4982)	0.1283 (0.0855)	**0.1664 (0.0794)***
Age	**−0.4726 (0.0684)****	**−0.0152 (0.0036)****	**0.0116 (0.0033)****
Activity status: white collar worker (omitted)			
Activity status: independent	2.2970 (2.3620)	0.0318 (0.1153)	−0.0133 (0.1091)
Activity status: blue collar worker	2.7181 (3.2964)	0.0602 (0.1786)	0.1681 (0.1451)
Activity status: civil servant	0.4731 (1.6921)	−0.0520 (0.0883)	−0.1384 (0.0879)
Activity status: inactive	−0.5727 (1.9162)	0.0810 (0.1067)	0.1488 (0.0927)
Education: no higher education (omitted)			
Education: higher education	1.2267 (1.4516)	−0.0114 (0.0884)	−0.0228 (0.0687)
Education: university	**3.7542 (1.6019)***	**0.2229 (0.0896)***	−0.0776 (0.0751)
Migrant background	1.7316 (2.5500)	**0.2509 (0.1150)***	0.0283 (0.1079)
Household size	0.1671 (0.5721)	0.0024 (0.0305)	−0.0333 (0.0285)
Income (ordinal)	**−1.0548 (0.4670)***	−0.0357 (0.0252)	0.0396 (0.0219)
Risk aversion	−0.0078 (0.0185)	−0.0011 (0.0009)	**0.0020 (0.0008)***
RESCOOP member	2.0288 (1.2825)	**0.1804 (0.0785)***	−0.0232 (0.0607)
City	1.0413 (1.1704)	0.0188 (0.0640)	−0.0772 (0.0552)
Type: apartment	−3.3410 (3.7738)	−0.1894 (0.2055)	0.0530 (0.1817)
Type: closed	0.3671 (1.9688)	0.0941 (0.0970)	−0.0716 (0.0936)
Type: semi-open	−1.4927 (1.4068)	−0.0547 (0.0798)	0.0015 (0.0684)
Type: open (omitted)			
Building layers	1.5235 (1.0102)	0.0796 (0.0550)	−0.0181 (0.0482)
Flat roof	**6.7957 (1.8140)****	**0.2240 (0.0852)****	−0.1056 (0.0848)
Roof quality	0.0041 (0.298)	**0.0039 (0.0016)***	**0.0038 (0.0014)****
Construction year (ordinal)	**−1.1699 (0.2717)****	**−0.0381 (0.0137)***	0.0248 (0.0129)
Trust in government	0.7189 (0.6641)	−0.0338 (0.0347)	**−0.0707 (0.0310)***
Trust in service suppliers	1.3180 (0.6912)	**0.0775 (0.0363)***	0.0010 (0.0311)
Trust in nuclear energy	−0.6993 (0.5365)	−0.0362 (0.0278)	0.0407 (0.0240)
Trust in technology	**2.7166 (0.7936)****	**0.1102 (0.0456)***	−0.0388 (0.0368)
Trust in green political party	**4.8071 (0.6251)****	**0.1009 (0.0331)****	**−0.1448 (0.0289)****

Note: * significant at the 5% level, ** significant at the 1% level. Standard errors between brackets. The OLS regression reports robust standard errors, to correct for heteroskedasticity (Breusch-Pagan-test: chi(1) = 34.69, Prob > chi^2 = 0.0000).

heterogeneous PV panels are rather limited on houses with flat roofs.

Again, we ran Probit regressions to perform separate estimations to explain a high interest in PV reuse (a value of 80 or higher) and no interest in PV reuse (a value of 0). PV reuse is considered most interesting among respondents who are younger, have a university degree, a migrant background, membership of a renewable energy citizen cooperative, living in houses with a flat roof, with older construction years, or having high trust in service providers, technology, or the green political party. Conversely, interest in PV reuse is the lowest among male, older, or risk averse respondents, having low trust in government or in the green political party. The relation of roof quality and preferences for PV reuse appears to be ambiguous or non-linear.

In Table 4 we report frequencies of respondents indicating which value propositions appear convincing to them to consider PV reuse. Likewise, we report separate figures for homeowners with and without solar PV, having high or no interest in second life PV, and adding a column to report preferences of homeowners who already have a PSS contract. Here, we see a very strong relation between perceived environmental benefits and interest in PV reuse. People showing high interest in PV reuse also believe they are cheaper than new PV panels, largely neglecting the fast pace of efficiency enhancing technological developments in this area. Unburdening aspects with respect to potential PV panel failures and sourcing second life panels are identified as well as convincing value propositions among homeowners without no solar PV that show high interest in PV reuse. This underlines the importance of PSS models as an enabling carrier for PV reuse in residential applications.

In Fig. 3 we compare kernel density estimates on the interest in PV reuse between respondents that indicate the four major barriers for solar PV adoption and respondents that do not. Performing a Kruskal-Wallis test, we find a significant higher interest in PV reuse among respondents that identify CAPEX as a barrier for PV adoption ($p = 0.0115$). Conversely, we find a lower interest in PV reuse among respondents with a lack of government trust ($p = 0.0002$). For the other two barriers, we do not find significant differences ($p = 0.0529$ for profitability and $p = 0.5346$ for technology readiness).

Table 4
Convincing value propositions for 2nd life PV in a PSS model, according to current PV status.

	Homeowners without solar PV		Homeowners who own solar PV		Homeowners in a PSS contract (n = 51)
	High 2nd life interest (n = 89)	No 2nd life interest (n = 51)	High 2nd life interest (n = 303)	No 2nd life interest (n = 582)	
Environmental benefits	93.26%	32.28%	87.50%	26.37%	58.82%
Cheaper than new PV panels	77.27%	25.00%	81.73%	25.76%	45.10%
Pioneering in using 2nd life PV panels	64.77%	13.33%	59.41%	9.62%	30.00%
No risk (panels are tested)	62.79%	7.84%	50.33%	11.17%	32.00%
No risk (panels will be replaced if necessary)	89.66%	29.33%	82.08%	29.73%	52.94%
No time investment to find 2nd life panels	76.47%	25.50%	61.39%	19.42%	40.00%
Nobody will notice the difference on my roof	50.57%	17.45%	37.17%	15.20%	30.00%

Note: all differences between respondents with high 2nd life interest and no 2nd life interest are statistically significant at the 1%-level (using a two-sided F-test).

4.3.2. Preferences for end-of-life solutions

Since different end-of-life and end-of-contract arrangements affect incentives of service providers and households with respect to extending and optimizing product lifetimes, we asked survey respondents about their preferences on end-of-life solutions in a solar PSS contract. The waffle chart in Fig. 4 shows that 33% of our respondents have no opinion, while 13% are indifferent. A partial explanation of these high frequencies can be found in the open comment fields, where respondents expressed uncertainties about the remaining yield or pointed at a lack of information to express a preference. Another explanation stems from the old age of some respondents, resulting in an indifference about what will happen to the PV installation in the next decades. For many respondents, however, 20 years appears to be a time period that exceeds the mental horizon to envision decision-making over.

While most residential solar PSS contracts in Flanders offer a transfer of ownership after 20 years, only 9% indicates this as their preference. Another 14% favors a transfer of ownership when a service contract can be agreed upon for the post-PSS period. Importantly, 32% would opt for removal of the installation at the end of the PSS contract. Responses in open comment fields mainly point at technological obsolescence, and the need to renovate the roof. One respondent illustrates this as follows: "*I would rather not become the owner of a worn-out installation and be responsible for its disposal and associated costs*."

We ran Probit regressions to explore profile differences between respondents who have no idea or are indifferent on end-of-life solutions, respondents who prefer ownership (with or without service contracts), and respondents who prefer removal of the installation at the end of a solar PSS contract. The results, as shown in Table 5, reveal that male respondents, young respondents, and respondents with trust in technology and experience as a Netflix user most often have a clear idea already about end-of-life preferences. Ownership transfer is preferred most by respondents with a university background and least by respondents living in closed housing types. Removal is most preferred by Netflix users (who are already used to decouple access to services and asset ownership) and least by respondents who have an independent activity status (i.e., self-employed) (who, as an entrepreneur, are more used to perform total cost of ownership calculations).

No significant differences are found between homeowners who already adopted solar PV and homeowners who did not adopt solar PV. Unsurprisingly, respondents with a high interest in PSS and respondents with a high interest in PV reuse appear to have clear-stated end-of-life preferences more often than other respondents (respectively 61,81% and 69.66% versus 52.36% and 52.08%, with $p < 0.05$ for PSS and $p < 0.01$ for PV reuse using two-sided F-tests). However, respondents with a high interest in PSS models tend to favor removal (40.28% versus 29.97% of other respondents, $p < 0.05$ using a two-sided F test) while respondents with a high interest in PV reuse tend to favor ownership transfer (34.83% versus 20.49%, $p < 0.01$, using a two-sided F-test).

5. Conclusions and policy implications

The objective of this study was to identify what barriers for solar PV adoption can be mitigated by circular business models, and to identify which customer segments are most in favor of these circular solar

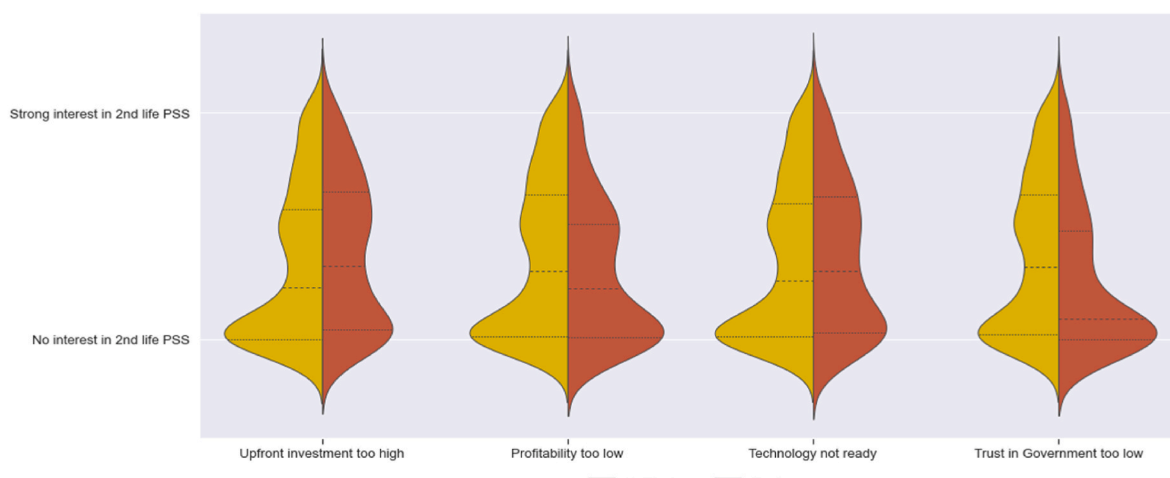

Fig. 3. Interest in 2nd life PSS models according to barriers experienced for solar PV adoption among homeowners with no PV.

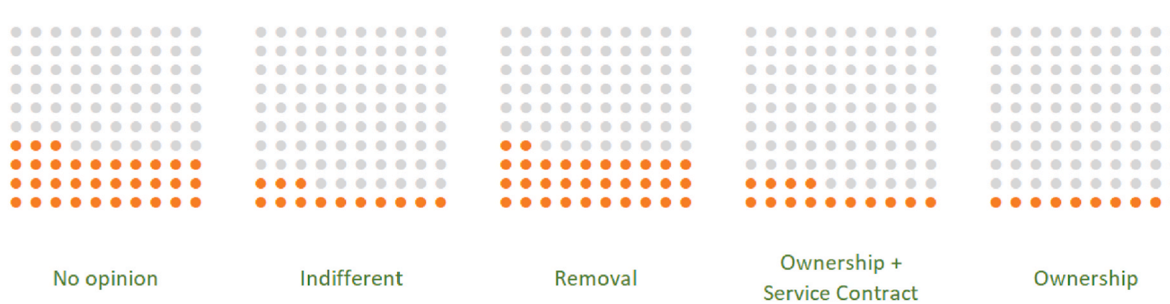

Fig. 4. Preferences for end-of-life solutions in solar PSS contracts (n = 3629).

Table 5
–Probit regression estimates on end-of-life preferences in solar PSS contracts among homeowners.

	No idea or indifferent	Ownership (w/o service contracts)	Removal
n =	3114	3114	3114
Prob > chi^2	0.0000	0.0000	0.0000
Pseudo R^2	0.0551	0.0351	0.0233
Constant term	−0.2870 (0.2778)	−0.5678 (0.2980)	−0.5814 (0.2841)
Male	**−0.1541 (0.0654)***	0.1242 (0.0719)	0.0532 (0.0675)
Age	**0.0209 (0.0030)****	**−0.0161 (0.0031)****	**−0.0071 (0.003)***
Activity status: white collar worker (omitted)			
Activity status: independent	−0.0744 (0.1373)	0.0939 (0.0972)	**−0.2408 (0.0972)***
Activity status: blue collar worker	−0.0032 (0.0738)	0.1881 (0.1428)	−0.0756 (0.1384)
Activity status: civil servant	−0.0230 (0.0812)	−0.0442 (0.0778)	0.0455 (0.0735)
Activity status: inactive	−0.0619 (0.0628)	0.0260 (0.0891)	−0.0209 (0.0837)
Education: no higher education (omitted)			
Education: higher education	−0.0619 (0.0628)	0.0816 (0.0708)	0.0025 (0.0648)
Education: university	−0.0793 (0.0678)	**0.1556 (0.0751)***	−0.0515 (0.0700)
Migrant background	0.0527 (0.958)	−0.0512 (0.1051)	−0.0023 (0.0977)
Household size	0.0183 (0.0242)	0.0233 (0.0255)	−0.0373 (0.0246)
Income (ordinal)	−0.0047 (0.0197)	−0.0352 (0.0215)	0.0370 (0.0201)
Risk aversion	−0.0004 (0.0007)	0.0000 (0.0008)	0.0004 (0.0008)
RESCOOP member	−0.0514 (0.0556)	0.0262 (0.0613)	0.0382 (0.0567)
City	−0.0710 (0.0489)	0.0238 (0.0531)	0.0535 (0.0499)
Type: apartment	0.0900 (0.1583)	−0.1389 (0.1740)	0.0180 (0.1633)
Type: closed	0.0709 (0.0790)	**−0.1844 (0.0856)***	0.0860 (0.0804)
Type: semi-open	−0.0089 (0.0606)	−0.0911 (0.0656)	0.0792 (0.0613)
Type: open (omitted)			
Building layers	−0.0220 (0.0422)	0.0379 (0.0459)	−0.0033 (0.0434)
Flat roof	0.0833 (0.0719)	0.0083 (0.0765)	−0.0914 (0.0734)
Roof quality	0.0001 (0.0012)	0.0001 (0.0013)	−0.0004 (0.0012)
Construction year (ordinal)	0.0041 (0.0110)	−0.0181 (0.01170)	0.0135 (0.0112)
Trust in government	−0.0485 (0.0271)	0.0493 (0.0292)	0.0082 (0.0277)
Trust in service suppliers	−0.0037 (0.0279)	0.0350 (0.0302)	−0.0266 (0.0286)
Trust in nuclear energy	0.0112 (0.0216)	−0.0244 (0.0234)	0.0076 (0.0220)
Trust in technology	**−0.1537 (0.0336)****	**0.0977 (0.0369)****	**0.0843 (0.0345)***
Trust in green political party	0.0009 (0.0256)	0.0359 (0.0278)	−0.0306 (0.0261)
Experience: car lease	−0.0997 (0.0566)	0.0265 (0.0605)	0.0905 (0.0572)
Experience: Netflix	**−0.1416 (0.0558)***	−0.0405 (0.0605)	**0.1813 (0.0563)****
Experience: Spotify	−0.0798 (0.0583)	0.0341 (0.0617)	0.0511 (0.0583)

Note: * significant at the 5% level, ** significant at the 1% level. Standard errors between brackets.

business models. Our survey among 3996 households in Flanders (Belgium) confirms that barriers for residential solar PV adoption mainly involve the cost of upfront capital expenditures, a lack of trust in governments, waiting for improved technologies, and a perceived lack of profitability. Our results suggest that circular business models only resolve the former barrier. Nevertheless, both solar PSS models and PV reuse show strong economic and environmental value propositions that appear to be most appealing to female customers and residents living in older houses, and houses with flat roofs. PV reuse in particular is considered most interesting among younger, highly educated, migrant, and less risk-averse customers segments.

Concerning end-of-life options, respondents with a high interest in PSS tend to favor removal of PV panels after contract duration, while respondents with a high interest in PV reuse tend to favor a transfer of ownership. These and other results reflect important differences in preferences and beliefs. From a circular economy perspective, both models can foster an improved functionality preservation of solar PV panels if they are aligned with properly designed monitoring, repair, and maintenance strategies.

Another important result is that trust in both service providers and technology can be considered as necessary conditions for solar PSS and PV reuse. Our results also suggest a complex relationship between trust in governments and solar PV adoption. First, we see that trust in governments is higher among households that did not invest in solar PV. This may reflect confidence that government policies may result in a sufficient and reliable supply of affordable energy, hampering the feeling that one should invest in solar energy oneself to achieve independence and self-sufficiency. On the other hand, energy policy reforms of the last decade have led to a decline in governmental trust, triggering loss aversion and other strong negative feelings among homeowners regarding solar PV investments. A lack of governmental trust is also found to be related to a lack of interest in PV reuse.

As our results show that circular solar business models may mitigate the barrier of upfront costs for solar PV investments, we recommend policymakers in the fields of energy, environment, and social policy to align their efforts. Joint supportive initiatives by these policy domains may help to reduce energy inequities and foster sustainable development, as circular solar business models appear to address both environmental, financial, and social considerations. Moreover, our results underline the importance of regaining popular trust by developing credible energy policies that show complementarity across multiple policy levels and domains and provide legal certainty for households to invest in renewable energy solutions. This is crucial, not only because of the tremendous impact of surging energy prices and energy supply uncertainties, but also to provide a sustainable investment climate to adopt new technologies, enabling dynamic economies of scale, and stimulating the market development of sustainable circular business models. Furthermore, we recommend policymakers to share experiences of households that adopt solar PSS models, as a lack of experiences among peers seems to be a major barrier for the adoption of solar PSS. Showcasing circularity aspects of well-known PSS models such as Netflix, may help to alter beliefs and preferences regarding the role of ownership to gain access to renewable energy.

A limitation of our research is its geographical coverage. Flanders is a small, densely populated, open, and industrialized economy. It is therefore less suitable to study barriers and enablers in remote areas and developing countries, where the potential benefits of sustainable solar PV solutions may be more impactful. We also recommend replicating this study across multiple regions, allowing to identify the importance of contextual parameters next to demographic and housing characteristics. A second limitation of our research is that it predates the war in Ukraine and the energy crisis stemming from it. Nevertheless, the major boundaries expressed in this study are still present during the energy crisis, even aggravating purchasing power of lower- and middle-income groups as well as stressing the importance of circular solutions to regain resource and energy independence. Moreover, to understand the enabling potential of circular economy solutions, we should look beyond the challenges of today. Thirdly, our study did not investigate the role of installation parameters, including battery-configurations and the technological evolution of solar PV panels. Future research should therefore include aspects of technological obsolescence when considering market and policy perspectives of circular solar solutions, and test consumer preferences of more specific circular solar value propositions including financial and technical details.

Our results also reveal novel research gaps. Although many scholars explored the importance of demographic parameters on investment decisions in solar energy, empirical large N research on the relationship between demographics and the uptake of circular business models remains almost non-existent. Our results, however, reveal significant relations between gender, age, educational attainment, and migrant background of respondents, and circular value propositions. A second research gap concerns the housing type of households. While most policies supporting solar PV adoption focus on houses, a growing number of people is living in apartment buildings or collective housing settings. Both regulatory, technical, and socioeconomic parameters, however, may influence investment decisions in significant, but empirically underexplored ways. Finally, our results show that many respondents have no clear preferences on end-of-life strategies for solar PV installations. Given the increasing waste problem that stems from solar PV investments, policymakers and service providers should collaborate to design future-proof, sustainable, and incentive compatible contractual regulations enhancing improved recycling, remanufacturing, repair, and reuse, substantiated by policy-research.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

Data availability

Data will be made available on request.

Acknowledgements

This research has received funding from the European Union's Horizon 2020 research and innovation program (call: H2020-EU.3.5.4) under grant agreement 776680 (CIRCUSOL). The authors would like to thank Saskia Manshoven, and participants at the CIRCUSOL consortium meeting in Berlin (April 21–22, 2022) for valuable feedback and discussions. All remaining errors are the sole responsibility of the authors.

APPENDIX A

Survey variable (data type)	Model variable (data type)	Summary statistics
Gender (nominal)	Male (dummy)	Male: 82.69% Female: 16.94% Non-binary: 0.38%
Age (ratio)	Age (ratio)	Average: 56.66 Stdev.: 13.00 Median: 58
Activity status (nominal)	White collar worker (dummy) Independent (dummy) Blue collar worker (dummy) Civil servant / teacher (dummy) Inactive (dummy)	30.93% 7.66% 3.85% 15.52% 42.04%
Education (nominal)	No higher education (dummy) Higher education (dummy) University (dummy)	27.78% 35.69% 36.54%
Migrant background (dummy)	Migrant (dummy)	6,28%
Household size (ratio)	Household size (ratio)	Average: 2.69 Stdev: 1.25 Median: 2
Monthly net household income (ordinal)	Income (ordinal): < 1500 euro 1500 – 2500 euro 2500 – 3500 euro 3500 – 4500 euro 4500 – 5500 euro 5500 – 6500 euro 6500 – 7500 euro 7500 – 8500 euro I don't know (excluded)	 3.05% 19.15% 24.58% 21.67% 17.01% 8.68% 3.27% 2.58% 9.81%
Risk aversion (ratio)	Risk aversion (ratio)	Average: 66.88 Stdev: 32.18 Median: 75
Experience as a Netflix user (dummy)	Netflix (dummy)	37.71%
Experience as a Spotify user (dummy)	Spotify (dummy)	29.18%
Experience with car lease (dummy)	Car lease (dummy)	30.71%
Member of a renewable energy citizen cooperative (dummy)	RESCOOP member (dummy)	70.27%

Fig. A.1. Summary statistics of survey results: personal characteristics (n = 3996).

Survey variable (data type)	Model variable (data type)	Summary statistics
Ownership status (ordinal)	Homeowner (dummy)	97.10%
	Tenant (dummy)	1.76%
	Other (dummy)	1.15%
ZIP code (nominal)	City (dummy)	43.24%
Area (nominal)	Urban area (dummy)	25.08%
	Semi-urban area (dummy)	46.19%
	Rural area (dummy)	28.72%
Housing type (nominal)	Open (dummy)	54.67%
	Semi-open (dummy)	24.17%
	Closed (dummy)	16.91%
	Appartement (dummy)	4.18%
	Other (dummy)	0.01%
Number of building layers (ordinal)	Building layers (ordinal)	
	1	9.93%
	2	56.53%
	3	29.26%
	4	3.26%
	5 or more	1.02%
Roof type (nominal)	Flat roof (dummy)	13.32%
Roof quality (ratio)	Roof quality (ratio)	Average: 79.19 Stdev: 20.32 Median: 84
Construction year (ordinal)	Construction year (ordinal)	
	Before 1950	17.47%
	1950 – 1959	7.72%
	1960 – 1969	7.92%
	1970 – 1979	13.65%
	1980 – 1989	15.41%
	1990 – 1999	14.36%
	2000 – 2009	10.03%
	2010 or later	12.27%
	I don't know (excluded)	1.17%

Fig. A.2. Summary statistics of survey results: housing characteristics (n = 3927).

Survey variable (data type)	Model variable (data type)	Summary statistics
Trust in governments (ordinal)	Trust in governments (ordinal)	Average: 2.36 Stdev: 1.12 Median: 2
Trust in service suppliers (ordinal)	Trust in service suppliers (ordinal)	Average: 2.63 Stdev: 0.96 Median: 3
Trust in nuclear energy (ordinal)	Trust in nuclear energy (ordinal)	Average: 3.01 Stdev: 1.31 Median: 3
Trust in technology (ordinal)	Trust in technology (ordinal)	Average: 3.93 Stdev: 0.72 Median: 4
Trust in the green political party (ordinal)	Trust in the green political party (ordinal)	Average: 2.54 Stdev: 1.25 Median: 3

Fig. A.3. Summary statistics of survey results: institutional trust (n = 3583).

APPENDIX B

In Table B1 we see higher PV adoption probabilities for male, older, and high-income respondents, and members of renewable energy citizen cooperatives. Surprisingly, we see lower PV adoption probabilities for respondents with a university background. With respect to housing characteristics, we see higher PV adoption probabilities among respondents who live in new houses or indicate to have high quality roofs. Conversely, we see lower PV adoption probabilities among respondents living in apartment buildings, closed housing types, and houses with many building layers. Exploring the relation with institutional trust parameters, we find a higher probability to adopt solar PV among respondents with high trust in technology, and a lower probability to adopt solar PV among respondents with high trust in governments.

In Table B1, we also report Probit regressions among non-PV owners to explore profile differences between households for the four major barriers that have been indicated. A high upfront cost was mostly mentioned by female, young, and low-income respondents, and least by respondents with a university degree, or a migrant background. Insufficient trust in governments appears a barrier that is more often expressed by male respondents and respondents with large household sizes. The latter result is not surprising, since unexpected policy shifts leading to a sudden reversal of net metering in Flanders affected large households most (De Groote et al., 2022). Next, it appears that mostly respondents living outside cities and risk averse respondents tend to wait for improved technologies. A low profitability is considered a barrier mostly by younger respondents, and respondents with limited trust in governments. Respondents living in an appartement dwelling show a significant lower probability to indicate one of these four barriers. This should not come as a surprise, as technical and regulatory barriers render other barriers more important for appartement occupants (Komendantova et al., 2018).

Table B.1
Probit regression estimates on profile differences of homeowners who do not have solar PV, and their major barriers

	No solar PV	Barrier 1 CAPEX too high	Barrier 2 Insufficient trust in governments	Barrier 3 Waiting for improved technologies	Barrier 4 Profitability too low
n =	3114	651	651	651	651

(continued on next page)

Table B.1 (*continued*)

	No solar PV	Barrier 1 CAPEX too high	Barrier 2 Insufficient trust in governments	Barrier 3 Waiting for improved technologies	Barrier 4 Profitability too low
Prob > chi^2	0.0000	0.0000	0.0000	0.0034	0.0004
Pseudo R^2	0.1353	0.0986	0.2220	0.0781	0.0924
Constant term	**1.3544 (0.3122)** **	**1.1677 (0.5908)***	0.2017 (0.6221)	−0.9248 (0.6368)	−0.3937 (0.6597)
Male	**−0.2518 (0.0706)** **	**−0.3552 (0.1286)** **	**0.5268 (0.1785)****	−0.1255 (0.1416)	−0.1249 (0.1481)
Age	**−0.0103 (0.0032)****	**−0.0185 (0.0058)** **	0.0034 (0.0072)	0.0014 (0.0064)	**−0.0175 (0.0066)****
Activity status: white collar worker (omitted)					
Activity status: independent	−0.0824 (0.1111)	−0.2948 (0.2333)	−0.4175 (0.2794)	0.0355 (0.2339)	0.1173 (0.2499)
Activity status: blue collar worker	−0.1081 (0.1594)	−0.2801 (0.3282)	−0.01406 (0.3584)	−0.1912 (0.3522)	−0.3120 (0.3848)
Activity status: civil servant	−0.0661 (0.0808)	−0.0188 (0.1550)	−0.0596 (0.1924)	**−0.4325 (0.1752)***	0.1606 (0.1730)
Activity status: inactive	−0.1431 (0.0939)	0.0107 (0.1907)	0.3934 (0.2321)	**−0.4153 (0.2050)***	0.3027 (0.2141)
Education: no higher education (omitted)					
Education: higher education	−0.0223 (0.0757)	−0.2824 (0.1584)	−0.0149 (0.01883)	0.0841 (0.1735)	0.1144 (0.1788)
Education: university	**0.1628 (0.0788)***	**−0.3591 (0.1581)***	0.0653 (0.1846)	−0.1560 (0.1729)	−0.0006 (0.1788)
Migrant background	−0.0603 (0.1164)	**−0.5826 (0.2659)***	−0.2175 (0.3193)	−0.4130 (0.3021)	−0.2003 (0.2817)
Household size	−0.0484 (0.0279)	0.0898 (0.0545)	**0.1649 (0.0640)****	−0.0298 (0.0581)	−0.0181 (0.0612)
Income (ordinal)	**−0.1103 (0.0233)****	**−0.1241 (0.0501)***	−0.0690 (0.0556)	−0.0003 (0.0510)	0.0235 (0.0522)
Risk aversion	0.0011 (0.0009)	0.0035 (0.0019)	−0.0027 (0.0021)	**0.0045 (0.0021)***	0.0015 (0.0020)
RESCOOP member	**−0.1918 (0.0651)****	−0.0631 (0.1332)	0.0729 (0.1623)	0.0356 (0.1471)	0.1801 (0.1512)
City	0.0373 (0.0575)	−0.1458 (0.1189)	−0.1745 (0.1383)	**−0.3785 (0.1288)****	−0.0301 (0.1293)
Type: apartment	**1.3201 (0.01732)** **	**−0.7222 (0.3263)***	**−0.9026 (0.4525)***	**−1.1657 (0.4194)****	**−0.9474 (0.4221)***
Type: closed	**0.2198 (0.0873)***	0.1084 (0.1688)	−0.2102 (0.2082)	0.1291 (0.1817)	−0.0846 (0.1922)
Type: semi-open	0.0965 (0.0710)	0.0381 (0.1505)	0.0140 (0.01716)	0.0497 (0.1620)	**0.3201 (0.1608)***
Type: open (omitted)					
Building layers	**0.1055 (0.0491)***	−0.0301 (0.0991)	−0.0806 (0.1205)	0.1811 (0.1129)	−0.0523 (0.1148)
Flat roof	0.1516 (0.0812)	0.2100 (0.1531)	−0.0053 (0.1953)	−0.1221 (0.1781)	−0.1820 (0.1816)
Roof quality	**−0.0068 (0.0013)****	0.0020 (0.0024)	0.0005 (0.0028)	0.0010 (0.0027)	**0.064 (0.0028)***
Construction year (ordinal)	**−0.0817 (0.0126)****	−0.0428 (0.0261)	−0.0085 (0.0313)	0.0178 (0.0278)	0.0184 (0.0283)
Trust in governments	**0.1065 (0.0320)** **	0.0598 (0.0681)	**−0.6179 (0.0881)****	0.0292 (0.0748)	**−0.2129 (0.0776)****
Trust in service suppliers	−0.0242 (0.0334)	−0.1034 (0.0728)	0.1188 (0.0814)	−0.0727 (0.0789)	0.0307 (0.0794)
Trust in nuclear energy	−0.0213 (0.0255)	0.0417 (0.0517)	0.0047 (0.0609)	−0.0456 (0.0566)	0.0979 (0.0581)
Trust in technology	**−0.1001 (0.0394)***	0.0332 (0.0808)	0.0027 (0.0935)	−0.0076 (0.0891)	−0.0480 (0.0897)
Trust in green political party	−0.0064 (0.0302)	−0.0667 (0.0618)	−0.0334 (0.0735)	−0.0071 (0.0667)	0.0101 (0.0690)

Note: Probit regression results, * significant at the 5% level, ** significant at the 1% level. Standard errors between brackets.

Respondents that did not invest in solar PV have divergent perspectives on potential future investments. Note that the self-selective nature of an online survey causes a non-response bias, mainly attracting households that have either a sufficient interest in the topic, or strong opinions they want to share. Therefore, we report in Table B2 figures on the planned timing of investing in solar PV. In general, 44% of non-PV households express plans to install solar PV within 3 years while less than 9% of our respondents state they never want to invest in solar PV. We also compare planned timing results among households that indicate different kinds of barriers, which shows significant differences. Respondents who are waiting for technology improvements appear to be determined to invest at some point in time. The same holds for people who consider the investment too costly at this point.

Table B.2
Planned timing of investing in solar PV, by respondents indicated barriers

	No solar PV	Barrier 1 CAPEX too high	Barrier 2 Insufficient trust in governments	Barrier 3 Waiting for improved technologies	Barrier 4 Profitability too low
<1 year	21.50%	14.86%	15.44%	17.93%	11.43%
1–3 years	22.97%	24.77%	22.82%	34.48%	19.29%
Maybe someday	23.34%	30.63%	29.53%	31.03%	36.43%
Never	8.72%	4.05%	11.41%	2.07%	11.43%
Don't know	23.46%	25.68%	20.81%	14.48%	21.43%
Fisher's exact (p)		0.000	0.083	0.000	0.000

Note: n = 814 respondents without solar PV. Reported F-statistics refer to comparing percentages for each barrier with the general percentages, as presented in the first column.

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