Governments can nudge household solar energy adoption: Evidence from a field experiment in Switzerland

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The use of photovoltaic (PV) systems on residential buildings is a key element in the societal transition to renewable energies. However, despite economic and ecological benefits, many homeowners struggle to adopt PV due to technical complexity, administrative burden, and cognitive biases such as inertia. There is also a lack of research on this issue and on how interventions informed by behavioral science could help increase adoption. We address this gap in the literature by conducting a preregistered field experiment involving 600 homeowners in Switzerland, testing whether two types of personalized behavioral interventions, one based on prosocial motives and one focusing on self-interest, lead to tangible actions towards PV adoption. The results from our pilot study show that both interventions substantially increase adoption behavior compared to a control group and a group that received only general information on PV. The intervention focusing on self-interest, which highlighted homeowners' missed revenues in the past year and thereby invoked loss aversion, yielded the largest effect. In summary, our study contributes to a better understanding of how public organizations can use behavioral interventions to promote renewables without large subsidies.

Keywords: behavioral intervention; field experiment; renewable energy; loss aversion; social norms

1. Introduction

In light of the looming global climate crisis, caused in great part by the reliance on fossil fuels of our global energy systems [1], the need to reduce anthropogenic greenhouse gas emissions and to move towards renewable energies is more pressing than ever. This urgency is further underscored by the fact that greenhouse gas emissions have continued to rise between 2010 and 2019, instead of going down, threatening "the health and livelihoods of people around the globe, ecosystem health and biodiversity" [2, p. 44].

One area with great potential to produce renewable energy is the use of photovoltaic (PV) systems on residential buildings. For this reason, governments around the world have used a range of classic policy instruments such as monetary incentives (or "carrots"), mandates (or "whips"), and information campaigns (or "sermons") [3] to encourage homeowners to install such systems on their buildings. Mandates, which thus far have only been used rarely, mostly focus on the implementation of PV on new construction and do not usually target existing buildings. Moreover, while the abovementioned classic instruments (carrots, whips, and sermons) have been effective at stimulating growing rates of PV investment, for instance in Australia [4], Germany, Norway, the UK [5], India [6], Malaysia, Malta [7], Sub-Saharan Africa [8], and Vietnam [9], they have not been enough to obtain the level of penetration needed, leading substantial potentials to be untapped [7].

One possible explanation for the inadequate PV uptake among homeowners to date is that the use of carrots, whips and sermons as policy instruments rests on the assumption that the decision-making regarding whether or not to install PV on a home is guided predominantly by rational considerations [3] coupled with little attention to administrative burden [10]. Indeed, subsidies and information campaigns are often designed to speak to rational motives (while mandates have so far been rarely used to promote PV). However, as abundant research in behavioral science demonstrates, human decision-making often deviates from rational principles due to limited cognitive abilities or time, cognitive biases, bounded willpower, and limited self-interest, among others [11,12]. Thus, although the decision to adopt PV would often be rational from a return-on-investment perspective and although many households state they have intentions to invest in renewables, a great majority of house owners may be overwhelmed by the administrative burden [10] associated with installing solar modules [13]. Moreover, they may be limited in their attention to the issue, suffer from inertia or present bias, held back by cultural influences, or be unable to deal with the technical complexity [13,14]. In addition, literature on transaction costs, the latter being defined as "the sum of the direct and indirect costs of making economic transactions on a market" also depicts the complexity of decision-making according to specificity, frequency, and uncertainty [15, p. 2]. The required knowledge for solar panels is not easily reusable in other contexts, and the frequency of such investments is low. Moreover, "uncertainty can increase transaction costs when transaction partners have limited and/or asymmetric information about cost structures, prices, and potential profits of the transactions" [15, p. 9]. A cost-benefit analysis with the aim of obtaining a detailed view of the profits of solar energy is particularly intricate for homeowners. Transaction cost aversion might affect the decision-making process.

This study investigates the research question of how a fourth type of policy instrument, nudge interventions [3], can be used by governments to encourage homeowners to adopt PV.[1] A nudge is “any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives” [17, p. 6]. Nudges consider the bounded rationality of people and as such can be seen as an intervention on certain cognitive biases to direct individuals’ decisions and actions towards desired outcomes [11]. To answer our research question, we run a pilot study involving a field experiment in the Swiss city of Schaffhausen to test whether two specific types of individualized nudges, addressing the cognitive biases of loss aversion and social norms, perform better than a generic information campaign in terms of activating homeowners to take actual behavioral steps towards PV adoption. As such, the present study fills an important gap in the literature regarding how nudges can reflect certain cognitive biases to direct the decisions and behavior of homeowners towards investing in renewable energy systems, in what is a complex decisional situation laden with administrative burden.

2. Theory

2.1 Loss aversion and social norms

Investing in energy-efficient technologies can be a complex issue for homeowners, even though such investments often make sense economically. While, homeowners frequently state intentions to invest in technologies such as PV when asked, they often do not act accordingly due to administrative burden leading to inertia, procrastination, and postponing these effortful tasks further and further into the future [13]. While

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[1] Note that some studies such as [16] regard nudges as a novel sub-type of sermons, while others such as [3] explicitly regard it as a separate policy instrument category. In the present study, we adopt the latter perspective.

reducing administrative burden may be one avenue to increase the uptake of PV [13], this often involves changes at the policy level (e.g. simplifying or cutting regulations to reduce learning and compliance costs) which takes time and requires political will. The use of nudges, on the other hand, may be a quicker and easier-to-implement way in many cases, as often it can be done without any changes to policies. Despite recent evidence that the effectiveness of behavioral interventions can vary greatly, and that such interventions in the area of decision assistance, which is closely related to the intention-behavior gap described above, tend to produce smaller effects than in the areas of decision structure and decision information [18], there are still many examples of effective interventions. Two examples of this are the use of commitment devices to strengthen self-control [19] and the use of reminders [20].

There are reasons to hypothesize that two cognitive biases could play a major role. Loss aversion and social norms that are relevant within a given community have been demonstrated to produce some of the most robust results in previous literature [21,22]. Moreover, social environment and loss framing may potentially play a role in limiting procrastination [see for instance 23,24]. These insights could be used to direct the attention of homeowners, which is a scarce resource, to the issue of installing PV and to remove the inertia. While calling on loss aversion is closely related to self-interest, social norms often pertain to prosocial motives, resulting in the fact that we test two competing approaches in our study [cf. 25,26].

Regarding loss aversion, prospect theory [27] posits that losses loom larger than gains, meaning that we tend to react more strongly emotionally to losses than we do in the domain of gains. Another central tenet is that losses and gains are evaluated against a reference point, the latter of which can be shifted by framing. As such, prospect theory can be used to address homeowners in a way that specifically focuses on loss aversion, thereby activating (some) homeowners to overcome their inertia and to make actual behavioral steps towards installing PV on their roofs. More specifically, feelings of loss aversion may be induced by informing citizens about the specific amount of energy they have missed to produce in the past year, thereby setting a reference point. Such a nudge is multidimensional because it clearly identifies the actual loss of energy and money but also emphasizes it in such a way that the individual perceives it as a loss rather than a potential gain. As a result, homeowners should perceive every month they remain without PV as a loss, increasing the pressure to act. This type of nudge calls on self-interest, as opposed to prosocial interests [cf. 25].

Regarding social norms, we set out by the assessment that we, as humans, are strongly influenced by what others do. As Vlaev et al. [28, p. 554] put it, "[b]ecause of innate impulses to belong and to seek affiliation with groups and similar others, the influence of what others around us are doing can be a powerful driver of our own behavior". This notion is also captured by the theory of social contagion [29–31]. One example of the social contagion theory is what is often described as a community motivation in the voluntary development of open source software [32]. In the context of residential PV, the behavior of one's neighbor who has already installed solar modules on their roof may influence a person's decision to also adopt this technology through social interactions within the community. Thus, social contagion theory may help to activate social norms regarding one's community by creating transparency regarding how many neighbors have already installed PV systems in the immediate vicinity, thereby creating an urge to act similarly. This perspective is focused on prosocial, community-oriented motives rather than on self-interest [cf. 25]. In a previous study that compared messaging approaches contrasting self-interest and prosocial motives to promote household adoption of solar in the US, both types of messages were effective, although the self-interest-based messaging was found to be effective at double the rate [26]. In said study, a field experiment involved a multi-media campaign undertaken by a solar energy promoter differentiated between the relative effectiveness of different messages; what was not addressed, and which we do address here, is whether a far more limited campaign based on letters, undertaken by the municipal government, can also have a meaningful effect. Another key difference to the present study is that we draw on prospect theory [27] to specifically frame our self-interested messages as losses to maximize the effect on adoption behavior. Moreover, there is recent evidence that the spread of household PV installations occurs in geographical clusters, suggesting there is a distance-related social diffusion and there may be potential to "seed" PV installations in a community in an effort to promote this technology [33].

2.2 Hypotheses

Based on the above considerations, we designed two nudges in the form of different personalized letters, one intended to invoke loss aversion and the other to invoke social norms, assuming that they will increase the likelihood that homeowners will take actual behavioral steps towards PV adoption. We also designed a third, non-personalized letter that serves as a comparison, containing only general information on the benefits of PV, meaning that no nudging techniques were used. To test the effects of the different letters, we formulate three sets of hypotheses based on three different outcome variables, namely taking a one-to-one PV consulting session offered by a neutral public organization (H1a-c), requesting a tender for a PV installation after the consulting session (H2a-c), and stating one's propensity for PV adoption after the consulting session (H3a-c). The hypotheses are as follows:

- H1a: Receiving personalized information accentuating one's actual losses in the previous year from failing to invest in PV will increase the probability that homeowners take PV-related counseling, compared to not receiving any information.

- H1b: Receiving personalized information highlighting social norms will increase the probability that homeowners take PV-related counseling, compared to not receiving any information.
- H1c: Receiving general information highlighting the potential benefits of investing in PV will slightly increase the probability that homeowners take PV-related counseling, compared to not receiving any information.

Talking to an expert in a counseling meeting is a first behavioral step towards PV adoption, which we see as a strong proxy that a homeowner has overcome the inertia and started taking actions towards adoption. However, what we are also interested in is homeowners' propensity to request a tender for a PV installation on their roof after counseling and how this interacts with the different letters. After counseling, it may be that the interventions lead to spillover effects: "the effect of nudges on subsequent similar choices once they have been removed" [34, p. 9]. As such, the nudges may also influence several subsequent choices after the counseling session in the whole decision-making process. Thus, we hypothesize:

- H2a: Receiving personalized information accentuating one's actual losses in the previous year from failing to invest in PV will lead to a high probability that homeowners request a solar PV tender (after counseling).
- H2b: Receiving personalized information highlighting social norms will lead to a high probability that homeowners request a PV-related tender (after counseling).
- H2c: Receiving general information highlighting the potential benefits of

investing in PV will lead to a medium-high probability that homeowners request a PV-related tender (after counseling).

In addition to requesting a tender, we also asked homeowners after they received counseling how likely they were to install PV in the near future. As “[p]eople are more likely to engage in activity if someone elicits their implementations or intentions” [35, p. 128], we believe that this is another strong predictor of adoption. In line with this, we hypothesize:

- H3a: Receiving personalized information accentuating one’s actual losses in the previous year from failing to invest in PV will lead to a high probability that homeowners are prone to adopt PV (after counseling).
- H3b: Receiving personalized information highlighting social norms will lead to a high probability that homeowners are prone to adopt PV (after counseling).
- H3c: Receiving general information highlighting the potential benefits of investing in PV will lead to a medium-high probability that homeowners are prone to adopt PV (after counseling).

Please note that we consider hypotheses H1a-c as our main hypotheses, while hypotheses H2a-c and H3a-c are secondary hypotheses for which we will not be able to use our full sample as we will only be able to collect data from individuals who contacted the counseling service. As such, the secondary hypotheses cannot be tested with the same rigor as the main hypotheses.

3. Methods and experimental design

3.1 Methodology

The hypotheses are evaluated through a field experiment. To analyze the potential dissimilarities in behaviors between the different groups, a linear probability model

(LPM) is employed [36,37]. The principal dependent variable of interest in H1a-c is a dummy variable denoting if the individual i took on the offer for free PV-related counseling ($P_i^{Counseling}$). The explanatory variable is categorical (*Category*), representing the different studied groups of homeowners (1 = no letter received, which is the baseline, 2 = basic information letter, 3 = letter based on loss aversion and 4 = letter focused on social norms). Two control variables are added to include the factors that may also impact the way participants will respond to the letters. First, it can be assumed that a decision is more difficult to make when two people jointly own. For that reason, a variable equal to 1 if there is only one owner (*OneOwner*) is included. Another dummy variable is included and is equal to 1 when the situation of the roof for PV panels is excellent as opposed to just very good or good (*ExcellentRoof*).

In addition to assessing if people are inclined toward counseling (H1a-c), two other dimensions related to tender requests (H2a-c) and potential future adoption (H3a-c) are evaluated. The first one is a dummy variable equal to 1 if the respondents state during the counseling meeting, that they wish to receive the list of regional solar companies. The second measurement is based on a scale of 1 to 10 indicating homeowners' propensity to install PV panels in the next three years. However, the data are only available for those who decide to contact the counseling service in the first instance (H1a-c). One-way ANOVA and Pearson chi-square are employed to highlight the average responses of the various groups and to analyze potential variations of behaviors between them.

3.2 Study setting

In collaboration with Schaffhausen, a city in the German-speaking part of Switzerland, we designed and carried out the field experiment. The residential electricity price in

Schaffhausen lies very close to the European average, making investment decisions for PV systems similar to those in other countries. The design of the study was preregistered before data collection [reference deleted to maintain the integrity of the review process]. The city administration sent out letters to 450 homeowners in June 2022. The recipients did not know they were participating in the experiment, as the correspondence simply mentioned the existence of a research project. A provider-neutral energy consultancy was hired to conduct free and non-binding telephone counseling meetings for interested participants until the end of August 2022. For consistency reasons, the same person executed the counseling in most cases and a pre-prepared interview guideline was followed. To create the sample of homeowners taking part of the experiment, the city administration provided a list of more than 10'000 houses located in the city, from which we selected 600 homeowners to participate in the study after data filtering and random selection. The land registry and the office for monument protection also provided us with additional data. Data sampling was fashioned around the randomization of four distinct groups of participants to test the above-mentioned hypotheses and to verify the impact of each type of letter.

3.3 Designs of the letters

Among the four studied groups, the first one (G1) is considered as the control group as they did not receive any letter. In the three other groups (G2-G4), a particular treatment was assigned to each of them. *Table 1* summarizes the different letters, which are also available in full in *Appendixes A, B, and C*. In G2, participants received an information letter that portrayed the benefits of solar PV panels in a general fashion. A visual example of a rooftop with solar cells (retrieved from Guide-toiture [38]) was illustrated and the contact details of the counseling service were communicated at the end of the writing. This very general letter did not contain any nudge, qualifying it as a sermon [3].

Table 1. Design of the experiment

Group	Participants' number	Nudge	Letter	Traceable link	kWh/CHF expected	Visual content	Textual content	Invitation to contact
G1	150	-	-	-	-	-	-	-
G2	150	-	Basic information	Yes	-	A general photo of a rooftop with solar cells	General information only	Phone number and email
G3	150	Yes	Loss aversion	Yes	Yes	A location map of the owner's house and a graph of the electricity production missed out the last twelve months	Emphasis on the electricity production and financial opportunities that are missed due to the lack of solar panels	Phone number and email
G4	150	Yes	Social norms	Yes	-	A location map of the owner's house and the aerial view of three neighbors' houses that already have solar panels	Emphasis on the good example of neighbors who already are equipped with solar panels	Phone number and email

In G3, recipients received a letter containing a loss-aversion nudge. It was explained how much electricity (in kilowatt-hours / kWh) and money (in Swiss Francs / CHF) a rooftop PV system could generate per year. The values were based on data from the Swiss Confederation [39]. Focused on the principle of loss aversion, the letter emphasized that the homeowner has missed out on substantial revenue over the past 12 months as a result of not having PV on their roof. Finally, participants in G4 received a letter containing a nudge based on social norms. In this letter, we visually and textually highlighted that some exemplary neighbors of the recipient have already installed PV.

To compare participants' behavior, homeowners were invited to contact the counseling service at the end of each letter. Moreover, a traceable Uniform Resource Locator (URL) was inserted in each of them to guide people to an internet page for cost calculations and PV production simulations [40], while keeping track of the number of views per group. During the counseling sessions, employees of the counseling service filled out a form after each appointment. They recorded the address of the homeowners, which enabled us to match them with the treatment and control groups (related to H1a-c). Moreover, the employees asked homeowners if they wanted to receive a list of 38 companies that could provide them with a concrete tender. Evaluating to what extent homeowners are inclined toward tender requests (H2a-c) was ascertained by asking people if they wanted to receive the list. The consultants also asked homeowners how likely they were to install a PV system in the next three years on a scale from 1 to 10 (H3a-c).

3.4 Data filtering and description

The raw data required filtering to retain only houses with layouts that were exploitable for the study. Three types of criteria (characteristics of the houses, of the homeowners and of the owners' addresses) have been used. The first included the characteristics of the houses themselves as they needed to be suitable for PV panels. They had to be not under construction (already listed in the directory although not ready-to-move-in), not already equipped with PV, nor located in protected areas. Moreover, the roof needed to be suitable for solar panels according to the calculator of the Swiss Confederation [39] presented below. The second filtering criterion focused on the characteristics of the homeowners. Only properties with one or two private owners were considered, as the decision-process becomes more complicated with an increasing number of stakeholders. Finally, we were attentive to the characteristics of the owners' addresses to ensure that the letters were not delivered to people living abroad or that multiple letters were not sent to a recipient owning several proprieties.

Among the components of the filtering process listed above, the existence of protected zones and the degree of roof suitability were two of the most important ones. In some historic places, it would be harder for the homeowners to respond positively to the letter because the possibilities of installing solar panels are noticeably reduced and a possible construction procedure would involve additional work. Therefore, we did not include them as potential participants. Moreover, only houses that have well-suited roofs for PV installations (from good to excellent potential) were considered. A web-based “solar calculator” is made available by the Swiss Confederation [39] which explains, for each address, to what degree the roof is suited for the installation of solar panels, and to what extent this would be productively and financially beneficial. According to the indicator [39], “[a] roof’s suitability is determined by its exposure to solar radiation, its orientation, pitch and exposure to shade”. To automatically collect information from the solar calculator and to filter the roofs according to their suitability, a code was written in Python by [name and reference deleted to maintain the integrity of the review process]. The code is publicly available and was created with the aim of making similar projects easily feasible.

By performing statistical power analyses with G*Power [41], we estimated that 600 participants would be an adequate sample size to work on the principal hypotheses H1a-c. In fact, the priori power analysis with ANOVA (fixed effects, omnibus, one-way) showed that a total sample size of 180 letters were necessary to conduct the analysis related to an alpha of 0.05, 4 groups, and a medium effect size ($f = 0.25$). The latter has been set to 0.25 in accordance with the general convention [42]. After executing the filtering process presented above, 1’651 houses remained available. By a randomized process, 600 addresses were selected and divided into four groups of equal size (150 each). The descriptive statistics and randomization checks are presented in *Table 2*. Statistical tests were used to validate between-group similarity [43], namely analyses of variance (F-statistics) and chi-square tests for independence. As no statistically significant difference is found between the groups, we assume that the randomization was successful.

Table 2. Descriptive statistics and randomization checks

		G1 No letter	G2 Basic information	G3 Loss aversion	G4 Social norms	Randomization checks	
						Pearson chi2	Pr
Ownership	1 homeowner	43%	41%	39%	38%	0.9085	0.823
	2 homeowners	57%	59%	61%	62%		
Roof's suitability	Good	31%	23%	33%	26%	7.7970	0.253
	Very good	63%	64%	59%	66%		
	Excellent	6%	13%	8%	8%		
Year of construction*	1790-1880	2%	1%	1%	0%	4.2550	0.642
	1881-1970	41%	37%	37%	38%		
	1971 or more	57%	62%	61%	62%		
						ANOVA	
						F	P > F
Building area in square meters (mean)		117.67	110.99	110.93	110.36	0.94	0.668
Monetary value (mean in CHF/year) if house façade fully covered		1664.27	1770.00	1822.20	1497.93	0.97	0.565

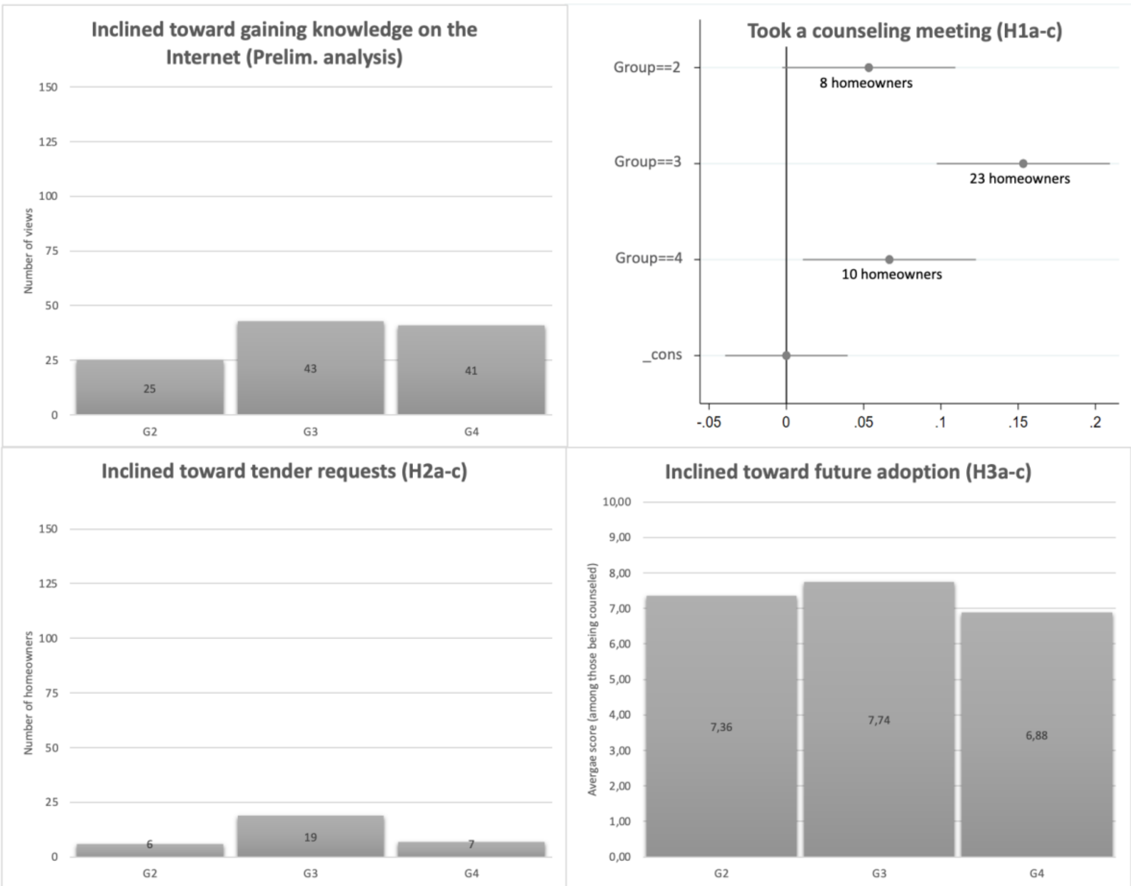
Note: *Considering the full sample, 40 houses have been renovated since then.

4. Results

Before running regressions, a first look at the data on the URLs included in the letter leads to a positive assessment as a preliminary analysis. The links demonstrate that the letters based on both loss aversion and social norms have generated more views. The URLs have been consulted over a hundred times in total. As illustrated in *Figure 1*, *Prelim. analysis*, about one quarter of the views come from G2, the remainder being equally divided among G3 and G4. Pearson chi-square test among the three groups (chi2 = 7.0704, Pr = 0.029) and Fisher's exact tests between G3 and G4 (Fisher's exact = 0.898) and G2 and G3 (Fisher's exact = 0.019) confirm that the nudged groups (G3 and G4) have similar means but that there are statistically significant dissimilarities to the one containing just general information.

The data collected from the counseling service point in the same direction, namely that the information letter had a smaller effect than the letters containing nudges. However, the impact of one nudge was greater, which is depicted in *Figure 1, H1a-c*. In total, 48 citizens contacted the service for advice during the time of the experiment. Of these, 7 were not in any treatment/control group (as the service is open to the entire population) and 41 were in our sample of the 600 participants. Most of them come from G3 (23 participants), the group that received a letter based on loss aversion. 8 people are from G2 and 10 from G4, while none are from G1.

Figure 1. Participants' proportion of being inclined toward PV technology



Notes: The graph related to H1a-c is based on the linear probability regression without control variables and includes 95% confidence intervals.

The regressions presented in *Table 3* show details regarding which interventions were most effective. The results are very similar between the regression that does not include control variables and that which does. We focus our discussions on the latter one. The letter on loss aversion is determined to have the greatest effect on the dependent variable as it statistically significantly increases the probability that the homeowner will contact the service by 15.2 percentage points compared to not receiving any letter. The letter based on social norms statistically significantly increases the same probability by only 6.48 percentage points. Therefore, H1a and H1b are both supported but the first hypothesis is corroborated in a more pronounced way. The letter containing basic information does not yield statistically significant results, which partially supports H1c. An additional analysis using a probit model, available in *Appendix D*, also confirms those findings. The control variables of *OneOwner* and *ExcellentRoof* are not significant, neither in LPM nor in the probit model.

Table 3. Linear probability regressions

	$P^{Counseling}$	$P^{Counseling}$
2.Category (Basic)	0.0533	0.0511
	(1.87)	(1.79)
3.Category (Averse)	0.153***	0.152***
	(5.37)	(5.31)
4.Category (Social)	0.0667*	0.0648*
	(2.34)	(2.27)
OneOwner		-0.0276
		(-1.34)
ExcellentRoof		0.0280
		(0.78)
Constant	-8.47e-16	0.0101
	(0.00)	(0.46)
N	600	600
R-squared	0.0476	0.0515
Adj R-squared	0.0428	0.0435

Notes: * $p < .05$, ** $p < .01$, *** $p < .001$. T statistics appear in the parentheses below the means. 1.Category (No letter received) is the baseline.

During the counseling meeting, most people answered positively to the question whether they wanted to obtain a list of regional solar companies (see *Figure 1, H2a-c*). One-way ANOVA shows that there is no statistically significant difference of behavior between the three groups who received a letter. This means that H2a-c are not supported as the way the letter was presented did not influence the decisions people made at the end of the counseling meeting. The same conclusion applies for H3a-c, regarding the extent to which people think they are willing to install PV panels in a few years (see *Figure 1, H3a-c*). Indeed, G2, G3, and G4 state similar levels of adoption propensity, averaging 7 on a 10-point scale. ANOVA and Pearson tests are depicted in *Table 4*. Participants in the experiment who requested a counseling meeting but did not want to answer the questions related to the study (7 out of 41 people) are not considered in the calculations. The corresponding high p-values (0.26 and 0.52 respectively) show that there is no statistical difference between the means among the three recipients' groups. After the first decision to take a consulting session with energy professionals, the type of letter does not influence how people react regarding tender requests and future potential adoption. However, these results must be interpreted with great caution as the sample sizes for hypotheses H2a-c and H3a-c were very small and not covered by our power analysis, which focused on our main hypotheses H1a-c.

Table 4. Pearson chi-square and one-way ANOVA

	Inclined toward tender request		**Inclined toward future adoption**			
	Mean	Std. dev.	Mean	Std. dev.	Min	Max
G2	0.857	0.378	7.36	1.44	5	9
G3	1.00	0.000	7.74	1.88	3	10
G4	0.875	0.354	6.88	1.83	5	9
	Pearson chi2	Pr	F	Prob>F		
	2.7132	0.258	0.67	0.5213		

Note: Pearson chi2 was employed for the independent dummy variable and one-way ANOVA for the scale-related variable.

5. Discussion

The research question of this study is how governments can use nudges to encourage homeowners to adopt PV. Our results show that using framing that induces loss aversion by informing citizens about the specific amount of energy and money they missed to produce in the past year by not possessing a PV system in a personalized letter yielded by far the largest effect. With a 15 percentage point change, this self-interested type of nudge increased the pressure to act. In comparison, a second group which received a personalized letter activating social norms regarding one's community by demonstrating how many of one's neighbors have already installed PV produced smaller, yet still statistically significant effects with about 6.5 percentage point change. This second type of nudge called on prosocial, community-oriented motives rather than on self-interest. Our findings are important as they provide governments with a concrete additional tool, nudging, which stands next to incentives, mandates and information campaigns, and which leverages psychological insights [3] to motivate homeowners to adopt PV. As such, our approach is a valuable addition to government toolboxes for their efforts to reduce anthropogenic greenhouse gas emissions.

Moreover, we found that a letter containing only information on the benefits of PV led to a 5 percentage point change, although this was not statistically significant, and that nobody from the control group (G1) took behavioral steps in the observed period. Additionally, we found that after the first behavioral step, taking PV consulting, there were no marked differences between the groups, for instance in their propensity to request a tender or in their stated likelihood to purchase a PV system in the next years, suggesting that getting homeowners to overcome inertia is key.

Our findings are notable from an administrative burden perspective [10]. In Switzerland, as in many other countries, the decision to install PV as a homeowner remains intricate on all three dimensions of the concept [13]. First, regarding learning costs, there are many complex technical and administrative costs associated with the decision to adopt PV, such as whether a roof is suitable and where to find this information, or whether one is eligible for government subsidies. Second, regarding psychological costs, the decision on whether a homeowner will get state subsidies is only taken after a PV system was installed in Switzerland, reducing one's sense of autonomy, and leaving homeowners with the feeling of taking a risk when investing in PV. And third, regarding compliance costs, there is a lot of paperwork to do and regulations in construction and income taxation on generated energy to be followed. We indirectly add to the literature on administrative burden by illustrating how proactively sending personalized information on the PV potential of one's roof combined with nudges may help to reduce administrative burden [see also e.g., 44,45], particularly learning and compliance costs, and how this stimulates adoption behavior among a considerable share of the target population in our study.

Our results are also in line with previous studies that have tested behavioral interventions to incite homeowners to adopt renewable energy technologies. For instance, Bollinger et al. [26] found that self-interested messaging was twice as effective as community-oriented, prosocial messaging in grassroots movements that tried to induce residential solar adoption in a large field experiment in the USA. A key difference of this study to the present article, however, is that we drew on prospect theory [27], which posits that losses loom larger than gains, and specifically framed our self-interested messages as losses to maximize the effect on adoption behavior. Moreover, we used letters instead of grassroots movements, which was likely easier and faster to implement.

In addition, several studies found spatial clustering in the diffusion of PV technology within urban areas, suggesting that there is an important influence of neighbors, peer interactions and social learning, as well as the built environment and policy aspects [33,46–49]. This clustering as well as the effects of our prosocial nudge can be explained by social contagion theory [29]. Thereby, the effectiveness of social information interventions depends, among others, on avoiding uncertainty about reference networks, relying on credible, trusted sources of information such as neighbors who have pioneered PV adoption in the local context, and pointing to examples of positive behavior [50,51]. However, there seems to be a decay radius of about 210 meters (in the U.S. context) for neighborhood-related effects [33], meaning that a critical mass of PV systems needs to be present in a given city for such effects to become powerful. This may not sufficiently have been the case in the city we studied, which could explain that the effect from our prosocial nudge was relatively small.

To make the written communication with homeowners as effective as possible, it would be conceivable to combine both inputs related to loss aversion and social norms in one letter. We may expect an increase in interest in solar panels greater than the largest effect observed in this study (namely with the letter on loss aversion) due to a consolidation of the positive effects of both stimuli. Literature is still scarce in terms of the impact that nudges can have when applied together [52]. A crowding out phenomenon, meaning that the nudges' effects decrease when used simultaneously, does not seem to be empirically noticed [52,53]. In that direction, a combining approach may be advantageous if applied by means of a concise content to avoid burden among readers.

Our study has several strengths and limitations. Regarding the strengths, and given that our research is a field experiment, we may say that the external validity of our results is high, at least in the Swiss and Western European context (while, naturally, the internal validity is reduced), and that we heed the call for more causal research in energy social science [54]. Moreover, our study draws from theories and debates from multiple fields, namely Energy Research, Public Administration, and Behavioral

Economics, providing an interdisciplinary perspective. Additionally, our study is of high relevance for practitioners, especially in local governments, who strive to accelerate the adoption of renewable energies in their contexts. In that direction, “lessons can be translated into concrete products” [55, p. 182], which is of utmost importance for long-lasting improvements in the public sector. Lastly, we preregistered our field experiment to increase the credibility of our research [56].

Regarding the limitations, we were unable to obtain data on participants’ demographic characteristics, which would have been interesting control variables. However, one ad-hoc finding is that several senior citizens called the counseling service to say that they were not interested in adopting PV due to their age. Second, while we did calculate a power analysis to determine the necessary sample size for our main hypotheses, our sample consists of only 600 individuals and the power analysis did not cover the secondary hypotheses which rely only on a sub-sample. Therefore, why we characterize our study as a pilot study intended to serve as a basis for larger studies. Moreover, the letters involving nudges (B and C) were also personalized (showing the owners’ roofs as well as their suitability for PV, neighbors with PV, etc.) while the letter containing only information (A) was not. Thus, we cannot fully separate the effects of the nudges from the type of letter personalization. However, the two personalized letters differed markedly in their results on our main set of hypotheses (H1a-c), meaning that especially the loss aversion nudge had a significant effect beyond the effect of personalization. Another limitation is that both the likelihood to request a tender (H2a-c) and propensity for future PV adoption (H3a-c) were analyzed based only on participants who contacted the counseling service, substantially reducing the number of observations for these hypotheses. Furthermore, we measured the use of PV counseling sessions as our main dependent variable, which is only a behavioral proxy for adoption, which typically follows many months or even years later. In the field of energy, the issues of persistence and latency, as well as the necessity for individuals to "continue their learned behaviors throughout the rest of their life", must still be addressed [57, p. 123]. Moreover, we cannot rule out that some homeowners in our sample requested tenders without going through the counseling process, in which case we would have been unable to observe this behavior. Lastly, our data collection period happened to coincide with the 2022 war in Ukraine, leading to concerns about energy security in Europe, which may have affected our results. While dependence on fossil fuel imports on the one hand and rising energy prices on the other may influence public opinion, a population survey in Switzerland demonstrated that the war in Ukraine has increased the acceptance of solar energy policies [58].

Future research should intensify the analysis of psychological factors in decisions for or against renewable energy systems adoption. This could include, for instance, leveraging cognitive biases other than loss aversion or social norms, testing a combination of the two, or extending these approaches to other target groups such as small or mid-sized businesses. It would also be interesting to see more qualitative, observational research on social contagion effects in such decisions, which could help us improve our understanding of the underlying mechanisms and design guidelines for how to best use these effects for accelerated adoption.

6. Conclusion

Governments around the world need to urgently step up their efforts to accelerate the societal transition to renewable energies and to cut anthropogenic greenhouse gas emissions. They need to do this with classical policy instruments [3], but can complement these efforts by nudging citizens to also contribute their share. In line with this, our study contributes to a better understanding of how public organizations can use behavioral interventions to promote renewables without large subsidies. To do this, personalized and proactive messaging based on self-interest or, more specifically, invoking loss aversion, is what we found to work best. As such, our approach is a valuable addition to government toolboxes in fighting the climate crisis, while keeping in mind that "residential rooftop solar alone will not solve the world's dependency on fossil fuels" alone [47, p. 7110].

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Appendixes

A. Basic letter (G2)

The city of Schaffhausen is committed to more solar energy

Good afternoon [first and last name]

You may have already thought about **installing a photovoltaic system on the roof of your house** to generate solar power. As part of a project with the University of Lausanne and the ETH Zurich, the city of Schaffhausen supports homeowners in planning and implementing their own solar power system.

With your own solar power system, you could **generate yourself clean electricity for remunerated exportation to the grid or for self-consumption**, e.g. to operate a heat pump or to charge an electric vehicle. In this way, you could become less dependent on energy sources such as oil or gas from abroad and at the same time make a valuable contribution to climate protection and reduce your CO_2 footprint.

A photovoltaic system is also very suitable as an investment1. Check the profitability for your house roof here: [https://www.energieschweiz.ch/tools/solarrechner/ with personalized URL]. The investment costs for solar systems on existing building are also deductible from income taxes, which means that on average around 20% of the investment costs can be saved in tax expenses.

A rooftop with solar cells.

The city of Schaffhausen accompanies you on the way to your own solar system and shows you all the necessary steps in a simple manner.

We would be pleased to invite you to a free, non-binding and provider-neutral initial meeting, during which we will answer your questions and discuss the possible course of action. To **schedule an appointment**, please contact **by 08.07.2022 at the latest**:

Address mail (preferred), telephone number and contact details
To enable a more detailed counseling, let us please find out your annual electricity consumption in kWh during the conversation. Alternatively, you can also have your last electricity bill ready.
Thank you very much!

We look forward to hearing from you.

[1] https://www.uvek-gis.admin.ch/BFE/sonnendach/?lang=de

B. Letter focused on loss aversion (G3)

Analysis of the potential of solar power system (Photovoltaic) for your house at [address]

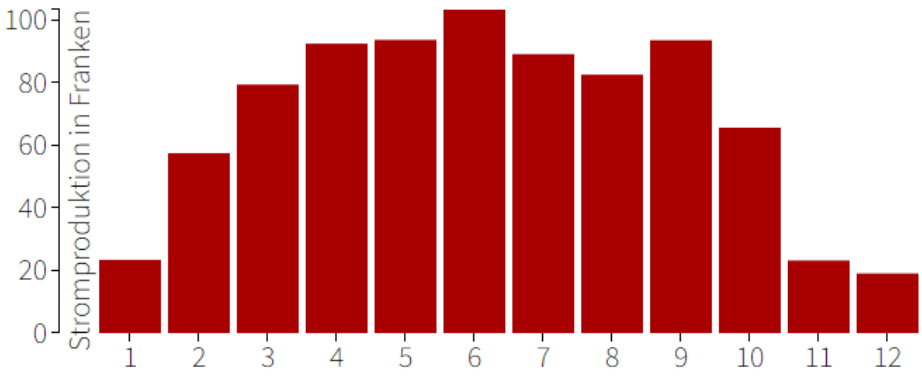
Good afternoon [first and last name]

Did you already know that you have untapped potential on your roof? As part of a project with the University of Lausanne and the ETH Zurich, the city of Schaffhausen draws your attention to the suitability of your roof for the production of solar energy. **According to the Federal Office of Energy, the suitability of your roof at [address] is considered as excellent.**[1]

Since you do not yet have a solar system, **you are missing out on 7900 kWh of solar electricity per year**, **worth around CHF 790**, as well as the opportunity to **generate yourself clean electricity for remunerated exportation to the grid or for self-consumption**, e.g. to operate a heat pump or to charge an electric vehicle. Don't miss the opportunity to become more independent from energy sources like oil and gas. Make a contribution to climate protection and reduce your CO_2 footprint.

For comparison: The typical consumption of a four-person household represents 3'500 kWh. A cost estimate for a turnkey solar system on your roof as well as the payback period can be found at [https://www.energieschweiz.ch/tools/solarrechner/ with personalized URL]. The investment costs for solar systems on existing building are also deductible from income taxes, which means that on average about 20% of the investment costs can be saved again in tax expenses.

[1] https://www.uvek-gis.admin.ch/BFE/sonnendach/?lang=de



Electricity production you missed out on your roof the last 12 months.

Do not miss out the unused potential of your roof any longer and take action! The city accompanies you on the way to your own solar system and shows you all the necessary steps in a simple manner.

We would be pleased to invite you to a free, non-binding and provider-neutral initial meeting, during which we will answer your questions and discuss the possible course of action. To **schedule an appointment**, please contact **by 08.07.2022 at the latest**:

Address mail (preferred), telephone number and contact details
To enable a more detailed counseling, let us please find out your annual electricity consumption in kWh during the conversation. Alternatively, you can also have your last electricity bill ready.
Thank you very much!

We look forward to hearing from you.

C. Letter focused on social norms (G4)

Analysis of the potential of solar power system (Photovoltaic) for your house at [address]

Good afternoon [first and last name]

Did you know that more and more homeowners in the city of Schaffhausen are opting for a solar power system? In your neighborhood, numerous systems on house roofs already produce clean electricity. There is also a lot of potential on your roof. As part of a project with the University of Lausanne and the ETH Zurich, the city of Schaffhausen draws your attention to the suitability of your roof for the production of solar energy. **According to the Federal Office of Energy, the suitability of your roof at [address] is considered as excellent.** [1]

For comparison: The typical consumption of a four-person household represents 3’500 kWh. A cost estimate for a turnkey solar system on your roof as well as the payback period can be found at [https://www.energieschweiz.ch/tools/solarrechner/ with personalized URL]. The investment costs for solar systems on existing building are also deductible from income taxes, which means that on average about 20% of the investment costs can be saved again in tax expenses.

[1] https://www.uvek-gis.admin.ch/BFE/sonnendach/?lang=de

Your neighbors are leading the way.

Follow the good example of your neighbors and take action! The city of Schaffhausen accompanies you on the way to your own solar system and shows you all the necessary steps in a simple manner.

We would be pleased to invite you to a free, non-binding and provider-neutral initial meeting, during which we will answer your questions and discuss the possible course of action. To **schedule an appointment**, please contact **by 08.07.2022 at the latest**:

Address mail (preferred), telephone number and contact details
To enable a more detailed counseling, let us please find out your annual electricity consumption in kWh during the conversation. Alternatively, you can also have your last electricity bill ready. Thank you very much!

We look forward to hearing from you.

D. Probit model

Categorical variable when no control variable is used	Margin	Delta-method std. err.	z	P>z	[95% conf. interval]	
Group==2	.0533333	.0183465	2.91	0.004	.0173749	.0892918
Group==3	.1533333	.0294191	5.21	0.000	.095673	.2109936
Group==4	.0666667	.020367	3.27	0.001	.0267481	.1065853
Categorical variable when control variables are used	**Margin**	**Delta-method std. err.**	**z**	**P>z**	**[95% conf. interval]**	
Group==2	.0501748	.0180133	2.79	0.005	.0148694	.0854802
Group==3	.1518612	.0294259	5.16	0.000	.0941875	.209535
Group==4	.066058	.020267	3.26	0.001	.0263355	.1057806
Control variables	**dy/dx**	**Delta-method std. err.**	**z**	**P>z**	**[95% conf. interval]**	
OneOwner	-.0381062	.0284523	-1.34	0.180	-.0938717	.0176593
ExcellentRoof	.0315762	.0428833	0.74	0.462	-.0524734	.1156259