Large and Persistent Effects of Green Energy Defaults in the Household and Business Sector

Ulf Liebe[1,*], Jennifer Gewinner[2], Andreas Diekmann[2, 3]

[1] Department of Sociology, University of Warwick, Coventry, UK
[2] Department of Humanities, Social and Political Sciences, Swiss Federal Institute of Technology (ETH) in Zurich, Zurich, Switzerland
[3] Institute for Sociology, University of Leipzig, Germany

[*]Corresponding author

E-mail: Ulf.Liebe@warwick.ac.uk (UL)

Abstract: Non-monetary incentives that encourage pro-environmental behavior can contribute to combating climate change. Here, we investigated the effect of green energy defaults in the household and business sector. In two large-scale field studies in Switzerland (with over 200,000 households and 15,000 enterprises) we found that presenting renewable energy to existing customers as the standard option made around 80% of the household and business sector customers stay with the green default, and the effects were considerably stable over a timespan of at least four years. We found only weak effects of electricity consumption on default acceptance. Our data do not indicate moral licensing: accepting the green default did not lead to a disproportional increase in electricity consumption. Compared with men, women in both the household and business sector were slightly more likely to accept the green default. Overall, non-monetary incentives can be highly effective in both the household and business sectors.

Keywords: Businesses, green default, moral licensing, renewable energy, temporal stability

Main

Combating climate change is one of the major challenges of societies around the globe and promoting pro-environmental and sustainable behavior is a key part of mastering this challenge. Yet, this involves a well-known social dilemma: an improved environmental quality is a collective good and also those who do not participate in pro-environmental activities benefit from the effects of pro-environmental behavior by others[1,2]. Consequently, providing the collective good is endangered by free-riding behavior and, if many in a population free ride, there will be an underprovision of the good. Relying on people's pro-environmental attitudes to avoid free-riding behavior is not sufficient: while studies document relatively high levels of environmental concern in many nations[3,4], these pro-environmental attitudes do not automatically translate into corresponding pro-environmental behavior. This is indicated, among others, by nation's persistent ecological footprints well above carrying capacity, and fossil fuel energy production and consumption are important components of these high footprints[5-7].

Against this background, the fundamental question of how to overcome the social dilemma of climate change mitigation and create effective institutions and incentives to promote pro-environmental behavior is on top of the research agenda of (environmental) behavioral sciences[1,8]. Besides well-known economic measures, there are cost-effective non-monetary incentives such as giving information feedback, using descriptive norms or default options[9,10]. Research from behavioral sciences suggests that cues in a decision environment can promote sustainable behavior like green energy uptake and hence contribute to combating climate change[10,11].

Default settings, the topic of this paper, is one of the most established behavioral mechanisms, which proved highly effective in influencing decision-making in diverse settings such as organ donations, giving to charity, saving paper, and reducing fossil energy[9,12-17]. They are related to the status-quo bias in decision making[18]: the tendency to stick to the current or standard option in order to avoid losses, for instance[19,20]. Other explanations include: "inertia", costs of information on alternative choices, interpreting the standard option as a recommendation[21], and moral costs of opting out[15]. If green energy is presented as the standard option to households, previous research[12,15,17,22-24] suggests that individuals stick to this option even if it is costlier than alternative options such as conventional energy (for an overview, see also ref. [24]). Past research showed this potential of green energy defaults for new customers in the household sector, without taking into account temporal (in)stability and, hence, possible behavioral change over time as well as moral licensing behavior.

In this study, we make four contributions to research on non-monetary incentives in the context of climate change mitigation, pro-environmental and sustainable behavior. First, we tested the effectiveness of green energy defaults in the business sectors, next to the household sector. Do entrepreneurs accept green defaults comparable with private households? This is not a trivial question as many studies suggest that individuals with a business/economics background act more in accordance with homo oeconomicus or hold different economic beliefs than individuals with a non-business/economics background[25-29] and, given the social dilemma of climate change mitigation, entrepreneurs might be prone to more free-riding or to less bias in decision making. Yet, it is also possible that accepting green defaults helps entrepreneurs to signal their social responsibilities to customers[30,31]. Second, we studied the effects of green energy defaults in existing customer populations. Since most individuals stay at their place of residence for long time spans, it is crucial to find ways to motivate a change of their behavior towards more sustainable energy usage. Third, we analyzed the stability of default effects over time, up to four years. Based on panel data, we found out whether and how customers in the household and business sector change their behavioral choices over time. Intervention studies, and lab experiments in particular, often focus on short time spans, and effects that are large right after an intervention may fade over time[9,32,33]. Thus, intervention effects are often grossly overstated. Fourth, the literature suggests that moral licensing can be an unintended effect of green energy defaults: by doing something good for the environment an increased level of resource consumption might be perceived as legitimate[34,35]. We tested whether this is indeed the case. Our analysis is based on field data, where experimenter demand effects are excluded[36]. Previous research has demonstrated the risk of a “Hawthorne effect”; being part of a research study may account for a decrease of household's energy consumption[37].

Our field-study data was collected in Switzerland, where electricity production depends largely on hydropower (56.4%) and nuclear energy (35.2%)[38]. While hydropower was always the main source of electricity production, the share of other renewables such as solar power considerably increased in the past two decades. This is in line with Swiss energy policy, namely the "Swiss Energy Strategy 2050", proposed after the Fukushima catastrophe in 2011 and approved in a referendum in May 2017, which has the goal to abandon nuclear energy production and to reduce greenhouse gas emissions to zero until 2050. Also, green default options are part of the Swiss energy strategy. They were introduced by an electricity supplier for the first time in 2003[39]; in 2018 more than 25 suppliers offered green defaults with opt-out and 25 suppliers without opt-out (out of over 300, figures based on a market analysis, see ref. [40]). In 2018, 30% of the overall electricity consumption of 57.647 TWh/a consisted of renewable energy products including those with opt-out options, and the sale of products with green energy defaults increased from a volume of 0.004 TWh/a in 2001 to 17.271 TWh/a in 2018[40].

To this date, the Swiss electricity market has only been liberalized for commercial business customers that consume more than 100,000 kWh per year; these customers are not restricted to the regulated market. In contrast, households as well as small and medium sized enterprises receive electricity from their local supplier, determined by their place of residence, and cannot switch the electricity provider when confronted with a green energy default.

We obtained data from two Swiss electricity suppliers with a total of 10,659 households and 1,139 businesses for supplier A, and 223,248 households and 7,633 businesses for supplier B (see Supplementary Table 1 for descriptive figures). Both data sets have attractive and complementary features. Data set A enabled the analysis of the panel data of households' energy choices over a long time span, while the large data set B increased the precision of estimates and made it possible to study subgroups of electricity consumers. The data included the type of energy package and amount of electricity consumption per customer and year. The data used in the present paper covers six years for supplier A and three years for supplier B. In the second year of study – year 2009 for supplier A and year 2016 for supplier B – the companies changed their electricity packages and introduced a green default option. While the households and enterprises in our field data are not fully representative for Switzerland, they show variance on several characteristics (see Methods for more details). Supplier A operates in a more urban area, has a lower share of enterprises in the primary sector (agriculture) and higher share in the tertiary sector (service) than supplier B that operates in a more rural area. As our data cover all enterprises with electricity consumption below 100,000 kWh per year, they include small enterprises, where single owners make all business decisions, as well as enterprises where we can assume that a management team makes corresponding decisions.

Before the green default, was introduced both suppliers offered their customers two energy packages (see Table 1, left side). The first package contained conventional/non-renewable energy as a mix of nuclear power, fossil and undetectable energy sources, or non-certified hydropower, depending on the supplier (see Methods for more details). The second package comprised renewable plus energy, a premium renewable electricity product produced regionally from hydropower, solar power, wind energy or biomass, depending on the supplier. For both suppliers only a very small minority of customers had this package. In the second year, customers who had the first package received a letter announcing that the company will change its energy packages, with a renewable non-premium energy package as the standard product (see Table 1, right side), while the minority of customers who had the second package were announced that renewable plus will be their default package. Thus, customers had three options to choose from: conventional, renewable and renewable plus with the default option being the renewable. The green default included a small price surcharge of 0.01 CHF per kWh for households and businesses alike compared to the conventional energy package. This corresponds to a price increase of 3.6 to 8.3 per cent for households and 5.8 to 14.3 per cent for enterprises. Presumably most customers were therefore aware that the green standard package will be slightly costlier than the conventional energy package.

This decision situation can be described as an opt-out choice architecture[12,16]. It might be argued that, in a strict sense, the field data cannot clarify whether the default effect is due to the introduction of a new green default/standard package or the introduction of a new green package per se. Both aspects, the standard option and renewable energy package, changed between year 1 and year 2. However, also before year 2 customers could choose tailored energy packages in line with the green default (i.e., a combination of self-selected specific electricity products). Yet, almost none of the customers chose this option in an opt-in choice architecture, which supports the interpretation of a green default effect.

Results

Large and Temporally Stable Green Default Effects in the Household and Business Sector. For electricity supplier A, at the household level 97% had conventional energy and 3% renewable plus energy in the first year (see Fig. 1, upper part). In the second year, following the introduction of the green default option, 15% had conventional energy, 83% the green default option and 2% the renewable plus option. This is a large default effect and the figures for the following years show that it was stable over time, with 80% of the households having had the green default package in year six.

For small and medium-sized enterprises (electricity consumption per year < 100.000 kWh), we found the same pattern, but the default effect was somewhat weaker (see Fig. 1, upper part). In the first year 97% had conventional energy and 3% renewable plus energy, in year two 75% accepted the green default, 23% used conventional energy and 2% renewable plus energy. Again, this default effect was considerably stable over time. In year six, 71% still had renewable energy.

For electricity supplier B, at the household level 98.8% had conventional energy, 0.9% renewable energy, and 0.3% renewable plus energy (see Fig. 1, lower part). In the second year, following the introduction of the green default option, 11% had conventional energy, 88.6% the green default option and 0.4% the renewable plus option. One year after the green default introduction, 88% had the green default option indicating that not many customers changed their energy package after initially accepting the green default.

For small and medium-sized enterprises, we found the same pattern, but the default effect was again somewhat weaker (see Fig. 1, lower part). In the first year 99.3% had conventional energy, 0.4% renewable energy and 0.3% renewable plus energy, in year two 84.5% accepted the green default, 15.3% used conventional energy and 0.2% renewable energy plus. This default effect was considerably stable within one year: one year after the renewable default introduction, 82.7% still had renewable energy.

There is no plausible alternative explanation of this large and temporally stable effect. We are not aware of any other factors that may have biased the size of the default effect. During the time of the study, in Switzerland renewable energy production increased steadily, and there were no distortions by changes in relative prices. Furthermore, supplier A implemented the green default seven years before supplier B's switch to the green default; the probability is very low that distorting factors would have produced an upward bias of similar size in both years.

In the following, we combine renewable energy and renewable energy plus choices as the latter was also offered as a default choice and both comprise renewable energy. Based on this binary data (conventional energy versus renewable energy), fixed effects regression models with time trends provide a statistical test that the default effect in year 2 is statistically significant (supplier A, households: $\beta = 11.943$, SE = 0.354, $p < 0.001$, 95% CI [11.25,12.64]; supplier A, small and medium-sized enterprises: $\beta = 9.868$, SE = 0.690, $p < 0.001$, 95% CI [8.52,11.22]; supplier B, households: $\beta = 8.368$, SE = 0.094, $p < 0.001$, 95% CI [8.18,8.55]; supplier B, small and medium-sized enterprises: $\beta = 10.679$, SE = 1.027, $p < 0.001$, 95% CI [8.67,12.69]; Supplementary Table 2).

The Amount of Electricity Consumption Has a Weak Effect on Green Default Acceptance in the Household Sector Only. One may reason that households and businesses with low levels of electricity demand will be overrepresented among the green energy customers. For both electricity suppliers A and B, we studied whether the levels of electricity consumption had an effect on the acceptance of the green energy default. We included the variables on electricity consumption in year 1 in binary logit models on the acceptance of the green default option in year 2. The results are presented as predicted probabilities in Figure 2 (Supplementary Table 3 shows the underlying binary logit models and additional models excluding the lowest and highest 5% of electricity consumption).

The main result of Figure 2 is that for households and businesses of both suppliers the overall acceptance of green defaults is high for all electricity consumption levels. For supplier A, Figure 2 shows a pattern of declining demand for the household sector ($\beta = -0.0000493$, SE = 5.47e-06, $p < 0.001$, 95% CI [-0.00006,-0.0000385], Supplementary Table 3). The predicted probability of accepting the green default in year 2 decreased slightly with increasing energy consumption levels in year 1. The predicted probability of accepting the green default was 87% (95% CI 85.98–87.43%) at a consumption level of 1,000 kWh and reached 81% (95% CI 80.37–82.63%) at the level of 9,000 kWh per year. For small and medium-sized enterprises, we found a slightly positive effect which is statistically insignificant ($\beta = 5.84\text{e-}06$, SE = 4.15e-06, $p = 0.159$, 95% CI [-2.29e-06,0.000014], Supplementary Table 3); however, consuming 1,000 kWh and 41,000 kWh was associated with an estimated probability of 76% (95% CI 73.11–79.28%) and 80% (95% CI 75.92–84.39%), respectively.

Also, for supplier B, Figure 2 shows a slight decrease for the household sector (β = -0.0000372, SE = 1.06e-06, p < 0.001, 95% CI [-0.000039,-0.000035], Supplementary Table 3). The predicted probability of accepting the green default was 90% (95% CI 89.99–90.28%) at a consumption level of 1,000 kWh and reached 86% (95% CI 86.09–86.50%) at the level of 11,000 kWh per year. The effect for the small and medium sized enterprises is not significant (β = -7.09e-07, SE = 1.66e-06, p = 0.670, 95% CI [-3.97e06,2.55e-06], Supplementary Table 3); consuming 1,000 kWh was associated with an estimated probability of 85% (95% CI 83.01–86.29%) of accepting the green default, consuming 51,000 kWh with 84% (95% CI 83.07–85.30%).

Overall, we only find a significant relationship between electricity consumption and default acceptance for the household sector, but not the business sector. However, these significant effects are still rather small in terms of effect size. The differences between low and (very) high consumption levels in predicted probabilities amount to 6%. In general, overall acceptance levels across the household and business sector are still around 80%.

Large Green Default Effects Even for Large Enterprises. As the default change included only a small price surcharge, we tested whether we find similar results for companies that consume large amounts of electricity, i.e., over 100,000 kWh per year. This indicates to what extent stake sizes might matter for green default effects. We obtained data for 414 business customers of electricity provider B which can be classified as large consumers (minimum of 100,081 kWh per year, maximum of 3,790,160 kWh, mean value of 248,648, standard deviation of 355,801). This is a selective group because not all large enterprises chose to stay in the regulated market and to receive electricity from their local supplier. Yet, our data do not allow to estimate the extent of such a selection bias. However, we found the same large effects for large enterprises as for small and medium-sized enterprises: before the introduction of the green default option in year 1, 99.5% of the enterprises consumed conventional energy; after introducing the green default, in the years 2 and 3 87.2% and 83.8% had green energy, respectively. These companies order green energy despite paying on average a surcharge of 2,301 Swiss Francs (about 2,353 US $). Further, similar to small and medium-sized enterprises, we found an insignificant relationship between electricity consumption levels in year 1 and default acceptance in year 2 (binary logit model with β = -8.30e-07, SE = 5.70e-07, p = 0.146, 95% CI [-1.95e-06,2.88e-07]), excluding the 1% with highest consumption levels (kWh > 1,851,424). Only the five largest consumers in the dataset showed a remarkable lower probability of accepting the green default. And this effect was driven by the two largest consumers (with kWh of 3,079,334 and 3,790,160, respectively) which did not accept the green default, resulting in a 60% default acceptance.

Weak Gender, and Moderate Attitudinal Effects on Green Default Acceptance. Additionally, for supplier B, based on data on saturations used by the suppliers to communicate with customers, we were able to obtain information about the gender of the main contact in each household and business. We can differentiate between women, men, women and men, or families, as well as those without information about their gender. Table 2 provides the results for the household and business sector. In the household sector, women were 6% more likely to accept the green default compared to men. This gender difference amounted to 8% in the business sector. The differences between women and "families/women and men", and the "gender not known" group were lower. The results in Table 2 indicate a significant association between gender and default acceptance (X^2(3df) = 1.1e+03, p<=0.001 for households, and X^2(3df) = 39.6567, p < 0.001 for small and medium-sized enterprises).

In order to shed further light on the determinants of the acceptance of green energy defaults we analyzed data from the Swiss Environmental Survey 2018, a nationwide population survey with 1,098 respondents (n = 942 with no missing values for the present analysis, see Methods). As part of the survey, respondents were asked whether they are in favor or disfavor of a policy tool where electricity suppliers are requested to employ green electricity as a standard option. The overwhelming majority of respondents (76%) were in favor. Table 3 reports the results of binary logit models on green default acceptance for individuals with and without business background as well as a pooled model. By using a variable that measures whether respondents were self-employed at the time of the survey, we identified 134 respondents with a business background. Besides gender we included age in years, education (1 = higher education) and environmental concern (scale from 1 to 5) as explanatory variables. The results in Table 3 indicate, in line with our field data, that men were less likely to respond positively to the introduction of green energy defaults as a policy tool compared with women. We also found positive effects for higher education and environmental concern. In the pooled model, the average marginal effects for gender and education amounted to -8% (β = -0.078, SE = 0.025, p = 0.002, 95% CI [-0.13,0.03]) and +8% (β = 0.076, SE = 0.026, p = 0.003, 95% CI [-0.13,-0.03]), respectively. The effect for a unit-increase of environmental concern was 12% (β = 0.123, SE = 0.017, p < 0.001, 95% CI [0.09,0.16]). The direction of the effects was similar for individuals without and with business background. Yet for the latter only the effect of environmental concern was significant at the 5% level (average marginal effect of 13%, $\beta = 0.126$, SE = 0.049, p = 0.049, 95% CI [0.03,0.22]). Age did not seem to be a relevant predictor of the acceptance of green energy defaults as a policy tool. Most notably however is the consistency of the gender effect in both the field and survey data.

To find out what might explain this gender difference, we tested whether the gender effect is mediated by environmental concern, given that research on environmental behavior suggests that women express a stronger environmental concern than men[41]. We compared the models in Table 3 with models which do not include environmental concern (Supplementary Table 4) and followed, based on 3,000 bootstrap replications, an approach for mediation analysis for binary logit models proposed by Buis[42], generalizing the approach suggested by Erikson[43]. In this approach, the direct effect of gender on environmental concern is estimated by comparing the log odds for women and men, assuming the distribution of environmental concern for one of the categories; the indirect effect is based on comparing the log odds for one of the gender categories with and without assuming the distribution of environmental concern of the other category. As both women and men can be the focal category for comparison, we report the average effect of both comparisons. This mediation analysis revealed that for households 31% (SE=11.33, p=0.006, 95% CI [8.66,53.07]) and the pooled data 30% (SE=10.86, p=0.005, 95% CI [9.12,51.71]) of the gender effect are mediated by environmental concern. For the self-employed, we do not find a significant mediation effect due to the non-significant main effect of gender.

No Evidence of Moral Licensing. It has been suggested that moral licensing[34,35] might outweigh the positive effects of pro-environmental behavior. Therefore, we checked whether choosing to stick with renewable energy and thereby expressing an altruistic self-concept might have (un)consciously led to higher electricity consumption levels, which were perceived as legitimate in the light of the prior pro-environmental choice to not opt-out from the green default. We conducted this analysis for electricity supplier A for which we can compare electricity consumption levels across 6 years. We compared electricity consumption levels in year 1 to the average of consumption levels between year 2 and year 6 (see Supplementary Table 5). The households who chose the green default consumed on average 53.16 kWh (SD = 469.90) less electricity per year, those with renewable plus energy consumed 154.96 kWh (SD = 497.97) less per year and those with conventional energy consumed 65.17 kWh (SD = 492.63) less per year. The difference between renewable plus energy and renewable energy was statistically significant (diff.=-101.81, SE=41.78, p=0.015, 95% CI [-183.69,-19.91]); the difference between renewable energy and conventional energy was statistically insignificant (diff.=-12.01, SE=14.88, p=0.419, 95% CI [-41.17,17.15], see regression models in Supplementary Table 6). In the business sector we found an overall increase in electricity consumption levels comparing year 1 to the average of consumption levels between year 2 and year 6. Yet this increase was with an average of 844.07 kWh (SD = 2149.53) per year larger for those businesses which consumed conventional energy. The values for those with renewable energy (the green default) and renewable plus energy were 48.17 kWh (SD = 1997.58) and 79.67 (SD = 1761.64), respectively. The difference between conventional and renewable energy was statistically significant (diff.=795.90, SE=167.40, p<0.001, 95% CI [466.70,1123.86]); the difference between renewable plus energy and renewable energy was statistically insignificant (diff.=31.50, SE=450.17, p=0.945, 95% CI [-852.73,914.48], see regression models in Supplementary Tables 6). These figures for both, the household and business sector, did not support moral licensing because those who chose renewable energy did not increase their electricity consumption more than those who consumed conventional energy.

Discussion and conclusions

Summarizing, the data from the field studies show large green-default effects in existing customer populations in the business and household sectors. Moreover, the choice to stick to renewable energy was stable over time, for at least four years, and there was no indication of moral licensing following green default choices. Electricity consumption had a weak effect on green default acceptance and only in the household sector. We furthermore found weak gender differences regarding green default acceptance. Environmental concern is not only a strong predictor of the acceptance of green non-monetary incentives as a policy tool, it also mediates the gender effect, at least for households in our study.

The large default effects for the business sector are notable because business decision makers might have been expected to be more price sensitive than private households. On the other hand, price sensitivity might differ between companies and depend on their energy usage. This should be studied in future research to provide deeper insights into decision-making processes in enterprises to better understand green energy choices and moral licensing.

The green default in our study was associated with price surcharges of 3.6 to 8.3 per cent for households and 5.8 to 14.3 per cent for enterprises. These price surcharges are higher than in previous field studies[12]. Future research might uncover to what extent default effects depend on relative prices[44] or income[45]. Our data from both electricity suppliers indicate that price might have played a role because households who consumed more electricity and therefore paid more had a slightly higher likelihood to opt out than those who consumed less electricity. However, the default effect is much stronger than the price effect. More than 80% of households stick to the green default option even when consuming large amounts of electricity. In the business sector (small and medium sized as well as large enterprises) we found no indications for electricity-consumption effects. The large default effects in this study suggest that green defaults can be successfully implemented even with a considerable price difference at the beginning.

The two electricity suppliers introduced the green default at the same time point within the study but at seven years distance. Yet, we found similar default effects. The stability of the effects across time indicates that it is very unlikely that policy interventions or market dynamics affected the results of the field studies. Also, we are not aware of any intervention, dynamic and events that might have influenced the default effects. While one supplier operates in a more urban area compared with the average Swiss population, the other supplier operates in a more rural area. Accordingly, one supplier has a higher share of enterprises in the first economic sector and the other supplier in the tertiary sector. Our main results regarding the default effect, as well as effects of electricity consumption on default acceptance, hold in both contexts supporting the validity and robustness of our findings. It is a characteristic of the Swiss electricity market that households and small and medium sized enterprises with electricity consumption levels below 100,000 kWh per year cannot freely choose their electricity supplier, their supplier being determined by the place of residence. Default effects for the household sector had been shown in previous research for Germany[12], where customers can freely choose their electricity supplier. It is therefore likely that our findings extend beyond the Swiss context; yet this needs to be shown in future research, especially for the business sector.

In the case at hand, the question that emerges is how the customers can be directed in the future from the green default using renewable energy to the renewable plus energy mix. This could be achieved in the long run by slowly changing the energy mix of the green default including subsequently higher shares of regional energy. Together with previous evidence[12,24], green defaults can be considered a powerful tool for policy making directed towards increasing renewable energy consumption. The conclusions of this research are that green default effects also unfold their power in the business sector, are stable over time, and do not induce moral licensing. Recent polls in various countries across the globe[46-50], and our own survey in Switzerland, indicate that citizens support the use of green defaults strengthening their legitimacy.

On the one hand, as part of combating climate change, it seems important that citizen and economic decision makers change their attitudes, lifestyle and consumption behavior towards more sustainability. On the other hand, this typically includes long-term processes of socialization and value change[51]. Choice architectures informed by behavioral research can reveal remarkable and lasting effects without changing citizens' and decision makers' attitudes and preferences. These effects can be large. In our field study, conventional energy consisted of a high share of nuclear power and, hence, the reduction of CO_2 emissions due to the non-monetary incentive are relatively low. The International Renewable Energy Agency (IRENA)[52] estimates that for 2016, Switzerland's generated renewable electricity avoided 18.30 million tonnes CO_2 emissions by fossil fuel with a mix of natural gas (94.3%) and oil (5.7%). These figures are much larger for countries with higher shares of coal production. For example, the US generated renewable electricity in 2016 was estimated to have replaced 493.4 million tonnes CO_2 emissions with an assumed fossil fuel mix of coal (58.9%), natural gas (39.8%) and oil (1.3%). China's electricity generated from renewables in 2016 avoided 1,494 million tonnes CO_2 emissions with an assumed fossil fuel mix of coal (97.5%), natural gas (2.3%) and oil (0.2%). These figures already indicate large effects of renewable energy consumption on the reduction of CO_2 emissions; clearly these effects will be even larger if the overwhelming majority of household and business decision makers in a country opt for renewable energy. For example, private households' demand of electricity in Germany amounts to 127 TWh in 2018 with a CO_2 emission factor of 512 g/KWh[53]. Based on figures from the Environmental Agency, we calculated a CO_2 emission factor of 67.94 g/KWh for the German renewable energy mix (Supplementary Table 7). Hence, using renewable energy saves 444.06 g of CO_2 per KWh (87%) of CO_2 emissions. It is noteworthy that the effect declines with a decreasing emission factor. Based on the above figures, for a default effect of 80% in renewable energy consumption, the total CO_2 reduction would be about 45 million tonnes. A conservative estimate of the social cost of carbon in the range of 50 Euro and surplus costs for renewable energy of 1 Euro Cent result in a positive welfare effect of 1240 million Euros for private households only (Supplementary Table 8).

Complementing other promising non-monetary as well as monetary behavioral incentives[54-57] including social norms, price incentives and information provision, green defaults can have an immediate and persistent impact and might, therefore, be an important cornerstone in solving societies' urgent problems with respect to climate change and resource overuse. While the effects of non-monetary incentives for pro-environmental behavior are context-dependent and such incentives might not always work[58,59], the cumulative evidence across several fields suggest a great potential of default options[13-16,24]. This potential is clearly not limited to the household sector.

Methods

This study is based on fully anonymized field data provided by two Swiss companies and a standard population survey. Answering each question in the survey was voluntary (i.e., each respondent had the opportunity to not answer a particular question). The survey was conducted in line with the standards/ethics recommended by AAPOR. At the universities, where this study has been conducted, such research based on field data and population surveys did not need specific ethical approval, and we therefore did not seek ethical approval in this case.

We obtained data from two Swiss electricity suppliers with a total of 10,659 households and 1,139 businesses for supplier A and 223,248 households and 7,633 businesses for supplier B (see Supplementary Table 1 for descriptive figures). Compared with the average for the Swiss population, supplier A operates in a more urban area and supplier B in a more rural area, indicated by above-average and below-average population densities, respectively. Regarding age structure, the population of the catchment area of both suppliers is fairly close to the Swiss average (age between 0-19: 17% Supplier A, 20% Supplier B, 20% Swiss pop.; age 20-64: 60% A, 61% B, 62% Swiss pop.; age 64+: 22% A; 18% B, 17% Swiss pop; values from around 2013, obtained from ref. [60]). In terms of enterprises per primary (agriculture), secondary (industry) and tertiary (service) sector both suppliers' customers differ from the Swiss average. Supplier A (being more urban) has with 1% a lower share of enterprises in the primary sector and supplier B (being more rural) with 15% a higher share in the primary sector compared with the Swiss average of 9%. For the secondary sector, both suppliers' shares are rather close to the Swiss average of 15% (14% Supplier A; 17% Supplier B). The share of enterprises in the tertiary sector is with 85% above-average for supplier A und with 68% below-average for supplier B, compared with the Swiss average of 76%.

The Choice Architecture of Electricity Supplier A. Before the green default was introduced in 2009 supplier A offered its customers two energy packages (see Table 1, left side). The first package contained conventional/non-renewable energy as a mix of nuclear power, fossil and undetectable energy sources. The second package comprised renewable plus energy, a premium renewable electricity product, which is produced regionally from hydropower, solar power, or a mix of water and solar power. In the second year, each customer received a letter announcing that the company will change its energy packages and a renewable non-premium energy package will be the standard product (see Table 1, right side) which every customer receives automatically except they choose another package. Now, customers had three options to choose from: conventional, renewable and renewable plus with the default option being the renewable. Customers who had renewable plus energy before the introduction of the green default received this product as their new standard product. The green default includes renewable energy mainly from hydropower produced in Switzerland including the region in which the electricity provider is located as well as a small share of solar energy, wind energy and biomass. The green default included a price surcharge of 0.01 CHF per kWh for households and businesses alike compared to conventional energy (this corresponds to a price increase of 4.2%, daytime tariff, and an increase of 8.3% for households' nighttime tariff. For businesses the increase is 5.8% and 9.1%, respectively). This price difference was stable over time.

The Choice Architecture of Electricity Supplier B. Before the green default was introduced in 2016 supplier B offered its customers different energy tariffs that can be categorized as having three distinct different energy source mixes which we labeled conventional, renewable and renewable plus (see Table 1, lower left part). The conventional package contained conventional energy as a mix of at least 75% nuclear power and non-certified hydropower, both not solely produced in Switzerland. The renewable package comprised 100% renewable energy which is made up by 90% hydropower which is certified "naturemade basic", 7.5% hydropower which is certified "naturemade star" where 0.01 CHF per kWh of the hydropower is invested in an ecological fund that funds environmental projects and 2.5% renewable energy that is certified “naturemade star” (solar energy/wind energy/biomass). The energy is mainly produced in Switzerland but not limited to Switzerland. The renewable plus package is made up by at least 50% solar energy and maximal 50% hydropower. The solar energy is mainly but not solely produced in Switzerland and the hydropower is only produced in Switzerland. Both energy sources in this tariff are certified as “naturemade star”; 0.01 CHF per kWh of the hydropower is invested in an ecological fund that funds environmental projects.

In the second year, each customer received a letter announcing that the company will change its energy packages and a renewable energy package will be the standard product (see Table 1, lower right part) which every customer receives automatically except they choose another package. Apart from the default product which was the renewable package, the other options were the conventional and the renewable plus package as described above. The green default is described as above, made up by 100% renewable energy sources mainly from hydropower produced in Switzerland. The green default included a small price surcharge of 0.01 CHF per kWh for households and businesses alike compared to conventional energy package (this corresponds to a price increase of 3.6%, daytime tariff, and an increase of 5.6% for households’ nighttime tariff. For businesses the increase is 9.1% and 14.3%, respectively). The price difference was stable over time.

Swiss Environmental Survey 2018. This survey is the third wave of a Swiss panel survey which started in 2007 (n = 3,478), followed by the second wave in 2011 (n = 1,945). In the second wave, 1,639 respondents did not reject the request to take part in a third wave sometime in the future. In 2018 these persons were contacted again by mailing an invitation letter along with the questionnaire. As reported by the post office, 167 addresses were not valid anymore, from 40 persons we got a notice of decease. However, 1,098 persons sent us back completed questionnaires. This results in a minimum response rate of 1,098/1,639 = 67% and an adjusted response rate of 1,098/(1,639 – 167 – 40) = 77%.

Regarding sample characteristics, 47% of the respondents were men (and 53% women), mean age amounts to 60.83 years (standard deviation of 13.97, minimum of 25 and maximum of 93), 54% have higher education, i.e., at least a university-entrance diploma, and 12% of the respondents were self-employed. The measurement of general environmental concern was based on nine items from a scale proposed by Diekmann and Preisendörfer[61]. These items were answered on a five-point response scale (1=strongly disagree, 5=strongly agree) and focused on emotional aspects (feelings of fear, anger, etc.), cognitive aspects (insight into endangerment) and conative aspects (lifestyle changes). The items are: “It bothers me when I think about the environmental conditions in which our children and grandchildren will probably have to live.” “If we continue down the same path, we are heading toward an environmental catastrophe.” “If I read news or watch TV news reports about environmental problems, I often become outraged and angry.” “There are limits on growth that our industrialized world has already exceeded or will soon reach.” “Most people in this country still do not act in an environmentally conscious way.” “In my opinion, many environmentalists exaggerate claims about environmental threats. (Item was reverse-scored before creating the index.)” “Politicians still do not do enough to protect the environment.” “In order to protect the environment, we should all be willing to reduce our current standard of living.” “Actions to protect the environment should be implemented even if they cause job losses.” An index was computed with higher values indicating a higher concern for the environment. The resulting scores theoretically range from 1 to 5, i.e., the sum of response scores divided by the number of items. The mean value of the index (n=1,076) is 3.634, with a standard deviation of 0.711.

Data Availability

The data was obtained by two Swiss electricity companies, is anonymized and part of non-disclosure agreements. Upon request and depending on consent from the companies, the data can be made available for replication. Replication data and code for the population survey will be made available using a data repository.

Code availability

Code used in this study is available from the authors upon request.

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Author contributions

U.L., J.G. and A.D. designed research and statistical analysis, U.L. and J.G. analysed data, U.L. led the writing of the paper, U.L., J.G. and A.D. contributed to writing.

Competing interests

The authors declare no competing interests.

Figure 1. Shares of energy packages per supplier, sector and year. The shares of conventional, renewable, and renewable plus energy packages per year for households (left), and small and medium-sized enterprises in the business sector (right) are shown. Households and enterprises were customers over a timespan of six years for supplier A (top) and three years for supplier B (bottom). The green default option was introduced in year 2. Small and medium-sized enterprises have an electricity consumption below 100,000 kWh per year. The figure is based on data on 10,659 households and 1,139 enterprises for supplier A, and 223,248 households and 7,633 enterprises for supplier B.

Figure 2. Predicted probabilities of green default acceptance per kWh. Predicted probabilities and 95% CIs for renewable versus conventional energy package choices of households and small and medium-sized businesses in year 2, dependent on kWh in year 1. The green default was introduced in year 2. The predicted probabilities are based on binary logit models which are shown in Supplementary Table 3; this table also contains additional models excluding the lowest and highest 5% of electricity consumption. The figure is based on data on 10,622 households and 1,133 enterprises for electricity supplier A, and 221,465 households and 7,142 enterprises for electricity supplier B.

Figure 3. Shares of energy packages for large enterprises per year. Presented are the shares of conventional and renewable energy packages per year for large enterprises which have an electricity consumption greater than 100,000 kWh per year. Enterprises were customers over a timespan of three years. The green default option was introduced in year 2. The figure is based on data on 414 enterprises.

Table 1. Energy packages and average prices per kWh for households (H) and businesses (B) before (year 1) and after the introduction of a green default option (year 2)

Electricity supplier A					
Before, year 1			After, year 2		
Package	Prices per kWh		Package	Prices per kWh	
	Day	Night		Day	Night
Conventional	H: 0.22 CHF B: 0.16 CHF	H: 0.11 CHF B: 0.11 CHF	Conventional	H: 0.24 CHF B: 0.17 CHF	H: 0.12 CHF B: 0.11 CHF
			Renewable	H: 0.25 CHF B: 0.18 CHF	H: 0.13 CHF B: 0.12 CHF
Renewable plus	H: 0.26 CHF B: 0.20 CHF	H: 0.15 CHF B: 0.15 CHF	Renewable plus	H: 0.27 CHF B: 0.20 CHF	H: 0.15 CHF B: 0.14 CHF
Electricity supplier B					
Before, year 1			After, year 2		
Package	Prices per kWh		Package	Prices per kWh	
	Day	Night		Day	Night
Conventional	H: 0.26 CHF B: 0.12 CHF	H: 0.17 CHF B: 0.08 CHF	Conventional	H: 0.28 CHF B: 0.11 CHF	H: 0.18 CHF B: 0.07 CHF
Renewable	H: 0.29 CHF B: 0.15 CHF	H: 0.20 CHF B: 0.11 CHF	Renewable	H: 0.29 CHF B: 0.12 CHF	H: 0.19 CHF B: 0.08 CHF
Renewable Plus	H: 0.33 CHF B: 0.19 CHF	H: 0.24 CHF B: 0.15 CHF	Renewable Plus	H: 0.32 CHF B: 0.15 CHF	H: 0.21 CHF B: 0.11 CHF

Table 2. Gender and the acceptance of green energy defaults in percent, supplier B

	Women	Men	Women and men, or families	Gender not known	Total
Households (n=221,465)	92.7% (n=33,974)	86.7% (n=83,749)	87.4% (n=27,091)	90.0% (n=51,479)	88.6% (n=196,293)
SMEs (n=7,142)	89.1% (n=179)	80.9% (n=2,080)	83.5% (n=334)	86.4% (n=3,431)	84.4% (n=6,042)

Note: Shares of customers who accepted the green default. SMEs = small and medium-sized enterprises.

Table 3. Binary logit models on green default acceptance, Swiss Environmental survey

	Households		Self-employed		Pooled	
	Beta	AME	Beta	AME	Beta	AME
Men (vs. women)	-0.491	-0.083	-0.210		-0.463	-0.078
Standard error	(0.162)	(0.027)	(0.447)		(0.152)	(0.025)
P-Value	0.002	0.002	0.638		0.002	0.002
95% CI	[-0.81,0.17]	[-0.14,-0.03]	[-1.09,0.67]		[-0.76,0.16]	[-0.13,-0.03]
Age in years	0.000239		-0.0180		-0.00127	
Standard error	(0.006)		(0.019)		(0.006)	
P-Value	0.967		0.355		0.818	
95% CI	[-0.01,0.01]		[-0.06,0.02]		[-.01,0.01]	
Higher education	0.491	0.083	0.151		0.448	0.076
Standard error	(0.163)	(0.027)	(0.456)		(0.153)	(0.026)
P-Value	0.003	0.002	0.741		0.003	0.003
95% CI	[0.17,0.81]	[0.03,0.14]	[-0.74,1.04]		[0.15,0.75]	[0.02,0.13]
Self-employed (vs. not self-employed)					0.117	
Standard error					(0.233)	
P-Value					0.614	
95% CI					[-0.34,0.57]	
General environmental concern	0.731	0.124	0.775	0.126	0.730	0.123
Standard error	(0.115)	(0.018)	(0.316)	(0.049)	(0.107)	(0.017)
P-Value	<0.001	<0.001	0.014	0.009	<0.001	<0.001
95% CI	[0.50,0.96]	[0.09,0.16]	[0.16,1.40]	[0.03,0.22]	[0.52,0.94]	[0.09,0.16]
Constant	-1.954		-0.589		-1.807	
Standard error	(0.665)		(1.619)		(0.599)	
P-Value	0.002		0.716		0.003	
95% CI	[-3.22,0.69]		[-3.76,2.58]		[-2.98,0.63]	
Pseudo R^2	0.067		0.060		0.065	
N	942		134		1076	

Notes: The dependent variable refers to a question on green default acceptance as a policy tool: respondents were asked whether they are in favor or disfavor of a policy tool where electricity suppliers are requested to employ green electricity as a standard option. AME refers to average marginal effects in percent. Reported p-values are for two-tailed tests

Large and Persistent Effects of Green Energy Defaults in the Household and Business Sector

Supplementary Tables

Ulf Liebe[1,*], Jennifer Gewinner[2], Andreas Diekmann[2, 3]

[1] Department of Sociology, University of Warwick, Coventry, UK
[2] Department of Humanities, Social and Political Sciences, Swiss Federal Institute of Technology (ETH) in Zurich, Zurich, Switzerland
[3] Institute for Sociology, University of Leipzig, Germany

Supplementary Table 1: Descriptive figures for customers of suppliers A and B

		Electricity supplier A		Electricity supplier B	
		Households	SMEs	Households	SMEs
Green energy year 1 (1=yes)	Mean	0.03	0.029	0.012	0.01
Green energy year 2 (1=yes)	Mean	0.85	0.77	0.89	0.84
Electricity consumption year 1	Mean	3616.15	14123.31	4850.11	34154.22
	SDV	4181.47	18479.38	5126.83	19475.10
	Median	2610	6862	3464	28722
	Min	171	1	0.17	6
	Max	94062	99633	98961	99914
Electricity consumption year 1, excluding lowest and highest 5%	Mean	3065.41	11540.71	4210.11	32884.26
	SDV	1821.02	12281.99	2899.81	14775.16
	Median	2619.50	6862	3464	28722
	Min	658	418	523	8649
	Max	8995	55502	13944	76634
Women				16.55%	2.81%
Men				43.63%	36%
Women and men / Family				14%	5.6%
Saturation not known				25.83%	55.59%

Note: SMEs = small and medium-sized enterprises. Case numbers range between 10,659 and 10,622 (households, supplier A); 1,139 and 1,019 (SMEs, supplier A); 223,248 and 199,289 (households, supplier B); 7,633 and 6,426 (SMEs, supplier B).

Supplementary Table 2: Fixed effects panel models for green energy choices

	Electricity supplier A		Electricity supplier B	
	Households	SMEs	Households	SMEs
Year 2 (default introduction)	11.943	9.868	8.368	10.679
Standard error	(0.354)	(0.690)	(0.094)	(1.027)
P-Value	<0.001	<0.001	<0.001	<0.001
95% CI	[11.25,12.64]	[8.52,11.22]	[8.18,8.55]	[8.67,12.69]
Year 3	9.838	8.312	7.810	8.827
Standard error	(0.321)	(0.663)	(0.092)	(1.001)
P-Value	<0.001	<0.001	<0.001	<0.001
95% CI	[9.21,10.47]	[7.01,9.61]	[7.63,7.99]	[6.87,10.79]
Year 4	8.340	7.260		
Standard error	(0.310)	(0.648)		
P-Value	<0.001	<0.001		
95% CI	[7.73,8.95]	[5.99,8.53]		
Year 5	7.789	6.905		
Standard error	(0.301)	(0.637)		

P-Value	<0.001	<0.001		
95% CI	[7.20,8.38]	[5.66,8.15]		
Year 6	6.835	6.424		
Standard error	(0.271)	(0.615)		
P-Value	<0.001	<0.001		
95% CI	[6.30,7.37]	[5.22,7.63]		
LL_{Null_modell}	-537.65173	-119.47348	-3,004.882	-59.465
LL_{Full_model}	-435.36914	-107.34945	-2,584.054	-56.513
Observations	52,464	5,364	583,998	17,985
(n units)	(8,744)	(894)	(194,666)	(5,995)

Note: Binary dependent variable (0=conventional energy, 1=renewable energy); SMEs = small and medium-sized enterprises, unstandardized logit coefficients. Reported p-values are for two-tailed tests.

Supplementary Table 3: Acceptance of green default option, binary logit models, all observations and excluding observations with lowest and highest 5% of electricity consumption.

	Electricity supplier A				Electricity supplier B			
	Households	SME	Households Excl. 5%	SME Excl. 5%	Households	SME	Households Excl. 5%	SME Excl. 5%
Green energy year 1 (1=yes)	1.565	1.091	1.594	1.029	0.975	2.124	0.987	1.941
Standard error	(0.296)	(0.610)	(0.324)	(0.616)	(0.094)	(1.0116)	(0.097)	(1.014)
P-Value	<0.001	0.074	<0.001	0.095	<0.001	0.036	<0.001	0.056
95% CI	[0.99,2.14]	[-0.11,2.29]	[0.96,2.23]	[-0.18,2.24]	[0.79,1.16]	[0.14,4.11]	[0.80,1.18]	[-0.05,3.93]
Electricity consumption year 1	-0.0000493	5.84e-06	-0.0001444	0.000029	-0.0000372	-7.09e-07	-0.0000782	-1.95e-06
Standard error	(5.47e-06)	(4.15e-06)	(0.000015)	(7.47e-06)	(1.06e-06)	(1.66e-06)	(2.26e-06)	(2.30e-06)
P-Value	<0.001	0.159	<0.001	<0.001	<0.001	0.670	<0.001	0.397
95% CI	[-0.00006, -0.0000385]	[-2.29e-06, 0.000014]	[-0.0001738, -.000115]	[0.0000144, 0.0000437]	[-0.000039, -0.000035]	[-3.97e06, 2.55e-06]	[-0.0000826, -0.0000737]	[-6.45e06, 2.56e-06]
Constant	1.897	1.134	2.229	0.903	2.24	1.702	2.419	1.733
Standard error	(0.035)	(0.090)	(0.059)	(0.103)	(0.009)	(0.066)	(0.013)	(0.084)
P-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
95% CI	[1.83,1.97]	[0.96,1.31]	[2.11,2.34]	[0.70,1.11]	[2.22,2.26]	[1.57,1.83]	[2.39,2.44]	[1.57,1.90]
LL_{Null_modell}	-4,492.963	-604.167	-3,924.496	-545.419	-78,421.28	-3,098.817	-69,594.842	-2,801.722
LL_{Full_model}	-4,429.647	-601.005	-3,860.092	-534.981	-77,774.33	-3,094.0021	-68,952.787	-2,797.775
Pseudo R2	0.0141	0.0052	0.0164	0.0191	0.0082	0.0016	0.0092	0.0014
n	10,622	1,133	9,558	1,019	221,465	7,142	199,289	6,426

Note: SME = small and medium-sized enterprises, unstandardized logit coefficients. Reported p-values are for two-tailed tests.

Supplementary Table 4: Binary logit models on green default acceptance with and without environmental concern, Swiss Environmental survey

	Households		Self-employed		Pooled	
	Beta	Beta	Beta	Beta	Beta	Beta
Men (vs. women)	-0.674	-0.491	-0.318	-0.210	-0.636	-0.463
Standard error	(0.156)	(0.162)	(0.433)	(0.447)	(0.147)	(0.152)
P-Value	<0.001	0.002	0.463	0.638	<0.001	0.002
95% CI	[-0.98,-0.37]	[-0.81,0.17]	[-1.17,0.53]	[-1.09,0.67]	[-0.92,-0.35]	[-0.76,0.16]
Age in years	-.0013705	0.000239	-0.016	-0.0180	-.0023847	-0.00127
Standard error	(0.006)	(0.006)	(0.019)	(0.019)	(0.005)	(0.006)
P-Value	0.807	0.967	0.419	0.355	0.657	0.818
95% CI	[-0.01,0.01]	[-0.01,0.01]	[-0.05,0.02]	[-0.06,0.02]	[-0.01,0.01]	[-.01,0.01]
Higher education	0.489	0.491	0.407	0.151	0.476	0.448
Standard error	(0.159)	(0.163)	(0.434)	(0.456)	(0.149)	(0.153)
P-Value	0.002	0.003	0.348	0.741	0.001	0.003
95% CI	[0.18,0.80]	[0.17,0.81]	[-0.44,1.26]	[-0.74,1.04]	[0.18,0.77]	[0.15,0.75]
Self-employed (vs. not self-employed)					0.095	0.117
Standard error					(0.227)	(0.233)
P-Value					0.675	0.614
95% CI					[-0.35,0.54]	[-0.34,0.57]
Environmental concern		0.731		0.775		0.730
Standard error		(0.115)		(0.316)		(0.107)
P-Value		<0.001		0.014		<0.001
95% CI		[0.50,0.96]		[0.16,1.40]		[0.52,0.94]
Constant	0.825	-1.954	1.634	-0.589	0.888	-1.807
Standard error	(0.466)	(0.665)	(1.354)	(1.619)	(0.443)	(0.599)
P-Value	0.077	0.002	0.228	0.716	0.045	0.003
95% CI	[-0.09,1.74]	[-3.22,0.69]	[-1.02,4.29]	[-3.76,2.58]	[0.02,1.76]	[-2.98,0.63]
Pseudo R^2	0.026	0.067	0.015	0.060	0.024	0.065
N	942	942	134	134	1076	1076

Notes: The dependent variable refers to a question on green default acceptance as a policy tool: respondents were asked whether they are in favor or disfavor of a policy tool where electricity suppliers are requested to employ green electricity as a standard option. Reported p-values are for two-tailed tests.

Supplementary Table 5: Mean electricity consumption levels in kWh per year, in total and separately for each type of energy package

Energy package	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Mean difference
Households	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Year 2 to 6 vs. Year 1
Conventional n = 1188	3319.329 (1753.248)	3279.929 (1743.890)	3337.846 (1796.061)	3230.238 (1715.155)	3236.202 (1733.793)	3186.572 (1737.795)	-65.172 (492.523)
Renewable (standard package), n = 6919	2859.616 (1606.923)	2842.807 (1609.103)	2884.671 (1636.683)	2789.356 (1571.425)	2785.801 (1566.876)	2729.654 (1565.242)	-53.159 (469.897)
Renewable- regional n = 131	2816.061 (1731.062)	2714.527 (1656.876)	2729.214 (1666.809)	2647.191 (1626.918)	2603.099 (1556.934)	2611.458 (1572.030)	-154.963 (497.966)
Total n=8238	2925.219 (1638.650)	2903.804 (1637.154)	2947.551 (1668.694)	2850.675 (1601.327)	2847.848 (1599.795)	2793.667 (1599.403)	-56.510 (473.804)
Businesses	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Year 2 to 6 vs. Year 1
Conventional n = 192	7226.104 (9057.785)	7864.182 (9262.342)	8203.792 (9518.807)	7957.013 (9102.957)	8104.786 (8658.252)	8221.109 (8879.218)	844.072 (2149.525)

Renewable (standard package), n = 627	10595.100 (10017.220)	11109.990 (10652.250)	10541.24 (10217.390)	10612.52 (10391.740)	10562.34 (10351.35)	10390.28 (10039.150)	48.172 (1997.58)
Renewable- regional n = 21	10838.860 (13705.640)	11399.710 (15026.810)	11504.48 (15056.890)	11540.86 (14817.940)	9519.381 (10993.53)	10628.19 (13973.150)	79.667 (1761.642)
Total n=840	9831.139 (10001.980)	10375.33 (10556.950)	10031.05 (10243.840)	10028.75 (10293.940)	9974.54 (10047.800)	9900.419 (9931.690)	230.879 (2052.97)

Notes: Excluding the 5% of lowest and highest consumption levels based on year 1, as reported under Supplementary Table 1. Mean difference refers to the average of consumption levels of years 2, 3, 4, 5, 6 minus the consumption levels of year 1, before the green default has been introduced. For example, the value of -53.159 kWh for households who had renewable energy means that their average electricity consumption in the years 2 to 6 was by 53.159 kWh per year lower than their average electricity consumption in year 1, before the green default had been introduced.

Supplementary Table 6: Ordinary least square regression models for the average decrease/increase of electricity consumption in kWh per year after introducing the green default

	Household sector	Household sector	Business sector	Business sector
Energy Package	Ia	Ib	IIa	IIb
	Excl. 5%		Excl. 5%	
Conventional	-12.013	-7.857	**795.901**	**523.99**
Standard error	(14.876)	(13.934)	**(167.403)**	**(159.91)**
P-Value	0.419	0.573	**<0.001**	**0.001**
95% CI	[-41.17,17.15]	[-35.17,19.456]	**[466.70,1123.86]**	**[210.19, 837.81]**
Renewable	**Ref.**	**Ref.**	Ref.	Ref.
(standard package)	**-53.159**	**-48.331**	48.172	111.858
Standard error	**(5.695)**	**(5.427)**	(81.10324)	(78.617)
P-Value	**<0.001**	**<0.001**	0.548	0.155
95% CI	**[-64.32,-41.10]**	**[-58.97,-37.69]**	[110.39,207.99]	[-42.42,266.14]
Renewable plus	**-101.805**	-65.283	31.495	238.778
Standard error	**(41.775)**	(38.323)	(450.1743)	(443.5152)

P-Value	**0.015**	0.089	0.945	0.590
95% CI	**[-183.69,-19.91]**	[-140.40,-9.84]	[-852.73,914.48]	[-631.59,1109.15]
Adjusted R^2	0.0005	0.0001	0.0241	0.0241
n	8,238	9,202	840	959

Notes: bold values represent $p < 0.05$; unstandardized coefficients; reported p-values are for two-tailed tests. Coefficients represent differences in kWh per year between average consumption levels of years 2 to 6, after the green default has been introduced, and the consumption level in year 1, before the green default has been introduced. The data for models Ia and IIa exclude the 5% of lowest and highest consumption levels based on year 1, as reported under Supplementary Table 1. Further, considered are all households and businesses which did not change their energy package after the introduction of the green default. Ref. refers to the reference energy package in the regression model. For example, Model Ia for the household sector shows that households who accepted renewable energy and, hence, the green default in year 2 consumed on average -53.159 kWh less energy per year in year 2 to 6 compared to year 1. Those who chose conventional energy consumed on average 12.013 kWh less per year than those with renewable energy. Yet this difference is statistically not significant. Households who had renewable plus energy consumed on average -101.805 kWh less than those with renewable energy and this difference is statistically significant. Models Ib and IIb present values for all customers in the dataset. The results show the same pattern of effects for both with and without exclusion of customers with very low and high consumption levels (except the non-significant effect for renewable plus energy for households).

Supplementary Table 7: Calculations of CO_2 emissions of renewable energy in Germany, 2018

Renewable energy	CO_2-Emissions g/KWh (A)	Percentage share of total energy production 2019	Percentage share of renewable energy (B)	Weighted CO_2-Emissions 100g/KWh (A) x (B)
Hydropower	4	3.5	8.31	33.24
Onshore wind energy	11	17.4	41.33	454.63
Offshore wind energy	6	4.3	10.21	61.26
Photovoltaics	67	8.2	19.48	1305.16
Biogenic solid fuels	74	1.8	4.28	316.72
Biogenic liquid fuels	203	0.1	0.24	48.72
Biogas	345	5.0	11.88	4098.60
Biomethan	291	0.5	1.19	346.29
Sewage gas	126	0.3	0.71	89.46
Landfill gas	126	0.05	0.12	15.12
Biogenic fraction of waste	5	1.0	2.38	11.90
Geothermal energy	183	0.03	0.07	12.81
Total		42.1	100.2	6793.91

Notes: Data are from ref. [1,2]; own calculations, total of B is greater than 100 due to rounding.

Supplementary Table 8: CO_2 reduction and welfare gain of renewable energy for private households in Germany, 2018

Default Effect in %	CO_2 reduction in tonnes[a]	Additional cost of renewable energy in Mio €[b]	Gross welfare gain in Mio €[c]	Net welfare gain in Mio €
100	56‘395620	1270	2820	1550
80	45’116496	1016	2256	1240
70	39’476934	889	1974	1085
60	33’837372	762	1692	930
50	28’197810	635	1410	775
40	22’558248	508	1128	620

Notes: [a] CO_2 emission of electricity mix (2018)[3]: 512g/kWh. CO_2 emission of renewable energy mix: 67.94 g/kWh (Supplementary Table 7). Reduction of CO_2 emission per kWh (2018): 444.06 g/KWh. Energy consumption of private households (2018): 127 TWh.[4] [b] Price difference of 1 Euro Cent per kWh assumed. [c] Product of CO_2 price covering externalities and amount of CO_2 reduction. The assumed price of 50 € per tonne of CO_2 is a conservative estimate concerning the range set by the Stern-Stiglitz-commission for 2020 (40 to 80 US $)[5]. Net welfare gains depend on estimates of social costs of carbon (SCC); ref. [6] reports estimates of 80 to 200 US $. Note that the CO_2 reduction depends on the amount of CO_2 emissions of the energy mix; for example, for 2019 these emissions were estimated at 427 g/KWh[3]. Thus, the default effect decreases with decreasing CO_2 emissions of the energy mix.

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