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Social Norms and Energy Conservation Beyond the US

Abstract

The seminal studies by Allcott and Mullainathan (2010), Allcott (2011), and Allcott and Rogers (2014) suggest that social comparison-based home energy reports (HER) are a cost-effective non-price intervention to stimulate energy conservation. The present paper demonstrates the context-dependency of this result. We show that, outside the US, electricity consumption levels and carbon intensities are typically much lower and, hence, HER interventions can only become cost-effective when treatment effect sizes are substantially higher. Yet, our evidence from a large-scale randomized controlled trial in Germany suggests that effect sizes are actually much lower than in the US.

JEL Classification: D12, D83, L94, Q41.

Keywords: Social norms; energy demand; external validity; randomized field experiments; non-price interventions.

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1. Introduction

A large literature has shown that social norms can affect individual choices in a variety of domains such as water use (Ferraro et al. 2011, Ferraro and Price 2013, Jaime Torres and Carlsson 2016) and charitable giving (Frey and Meier 2004, Shang and Croson 2009). A prominent example is the social comparison-based home energy report (HER) that the company *Opower* mailed to millions of US households in order to reduce their electricity consumption. Evaluations of *Opower's* HER have documented considerable reductions in electricity consumption of 1.4-3.3% that are also persistent over time (Allcott 2011, Allcott and Rogers 2014). Given the low intervention costs of HER, this finding suggests that HER are a cost-effective policy instrument to combat climate change (Allcott and Mullainathan 2010, Allcott 2011).

In this paper, we assess the cost-effectiveness of HER interventions in industrialized countries other than the US. While our paper does not question the internal validity of the Allcott (2011) and Allcott and Rogers (2014) findings, we complement their work by testing the external validity and transferability to other contexts. We thereby also contribute to the growing literature on the context-dependency of causal effects measured in a particular policy population (e.g. Allcott 2015, Dehejia et al. 2015, Gechter 2016, Vivalt 2015).

Our analysis proceeds in three steps. In Section 2, we first show that US electricity consumption and carbon intensity levels exceed those in virtually all other industrialized countries. We demonstrate that this particular context decisively co-determines the cost-effectiveness of HER in the US. In other countries, treatment effects would have to be substantially larger to make HER a cost-effective climate policy intervention.

In a second step, we test for the effectiveness of HER in Germany, a country with electricity consumption levels that better match the OECD average (Section 3). Based on data from a randomized controlled trial among 11,630 households, we estimate the average treatment effect of HER on electricity consumption. We find that HER reduce the electricity consumption of German households by 0.7%, less than half of the average reductions observed in the *Opower* studies. While this treatment effect estimate is certainly context-specific itself, it complements our descriptive analysis and reinforces the view that HER are most likely not a cost-effective climate policy instrument in many industrialized countries beyond the US.

In a third step, Section 4 tests the sensitivity of our cost-effectiveness assessments to the relaxation of two assumptions. We allow for time-persistent treatment effects beyond the year of the treatment (as observed in Allcott and Rogers 2014) and, following Allcott and Kessler (2015), we expand the cost-effectiveness analysis to a welfare analysis. The conclusion in Section 5 summarizes our findings and discusses policy implications.

2. Context-Dependency of HER Interventions

The cost-effectiveness of HER as a climate policy intervention crucially depends on three factors. First, it is strongly influenced by the treatment effect of HER on recipients' electricity consumption. Since no empirical estimates exist for countries beyond the US, we simply take the full range of treatment effects observed in the Opower studies (1.4-3.3%, see Allcott 2011). A second factor is the average electricity consumption level. On the one hand, higher average electricity consumption levels translate a given effect size (in relative terms) into higher absolute electricity savings in terms of kilowatt-hours (kWh). On the other hand, households with higher consumption levels tend to exhibit higher behavioral and technical savings potentials and thus can realize higher effect sizes (Allcott 2011). As a third factor, the carbon intensity of electricity generation determines the extent to which electricity savings translate into mitigation of carbon dioxide (CO_2) emissions. Power sectors with large shares of lignite- and hard coal-fired power plants, for example, are much more carbon-intense than those relying on hydropower and nuclear energy. As a result, even similar absolute electricity savings can yield widely diverging CO_2 abatement effects in different countries.[1]

For our descriptive analysis, we consider the ten OECD countries with the largest total residential electricity consumption (WEC 2016). In addition, we include Poland, an OECD country with low average electricity consumption, but very carbon-intense electricity generation, and Sweden, a country with high average consumption, but low carbon intensity. Our projections bound the cost-effectiveness of HER in these countries, assuming treatment effects of 1.4-3.3% (Allcott 2011). Average electricity consumption levels and carbon intensities are drawn from official data sets (WEC 2016 and IEA 2016). For simplicity, we assume printing and mailing cost of 1 US$ per letter in all countries (as in Allcott 2011), and neglect any administrative cost. As quarterly reports have achieved the highest cost-effectiveness in previous studies (Allcott

[1] There is a literature that discusses whether cap-and-trade schemes, such as the European Union Emissions Trading System, and energy saving policies, like HER, are complements (e.g. Dietz et al. 2009) or rather substitutes (e.g. Goulder 2013). Some even argue that energy saving policies that shift demand away from sectors subject to a cap increase aggregate emissions (Perino 2015). We take the most favorable stance for HER and treat them as complements to cap-and-trade schemes in our cost-effectiveness calculations.

Table 1: International Cost-Effectiveness Comparison of HER Interventions

	(1)	(2)	(3)	(4)	(5)
Country	Average Electricity Consumption in kWh	CO_2 Emissions in g / kWh	Cost in Cent / kWh Saved	Abatement Cost in $ / t CO_2	CO_2 Abatement Cost Relative to US
Canada	11,379	158	1.1 – 2.6	67 – 162	3.3
United States	12,293	489	1.0 – 2.4	20 – 49	1.0
France	5,859	64	2.1 – 5.0	323 – 779	16.0
Germany	3,304	486	3.7 – 8.8	75 – 182	3.7
Italy	2,542	343	4.8 – 11.5	139 – 335	6.9
Poland	1,935	769	6.3 – 15.1	81 – 196	4.0
Spain	4,040	247	3.0 – 7.2	121 – 293	6.0
Sweden	8,025	13	1.5 – 3.6	1,162 – 2,799	57.6
United Kingdom	4,145	459	2.9 – 7.0	64 – 153	3.2
Japan	5,434	572	2.2 – 5.4	39 – 94	1.9
South Korea	3,489	536	3.5 – 8.4	65 – 156	3.2
Australia	6,959	798	1.7 – 4.2	22 – 53	1.1

Notes: Our calculations assume printing and mailing cost of 1 US$ per report, four reports per year and average electricity reductions of 1.37-3.30%. Average electricity consumption and CO_2 intensities of electricity generation correspond to the most recently available data (for 2013), as documented in WEC (2016) and IEA (2015), respectively.

2011), we presume that four reports are sent within one year.

We then compare the HER abatement cost to the avoided social cost of carbon, the usual yardstick to assess the cost-effectiveness of climate change mitigation policies (Greenstone et al. 2013, Nordhaus 2014). Nordhaus (2014) estimates that the social cost of carbon in 2015 are at 19 US$ per ton, while US IAWG (2013) provide an estimate of 38 US$. For our assessments, we use the larger estimate of 38$, which is more favorable to the cost-effectiveness of HER.

Table 1 summarizes the descriptive statistics and our cost-effectiveness indicators. Average electricity consumption levels and carbon intensities are depicted in Column (1) and (2). By contrasting the cost of HER with the electricity savings for the range of effect sizes, we obtain a range of cost per kWh saved, which can be found in Column (3).

Column (4) of Table 1 depicts the resulting abatement cost ranges. It shows that HER are considerably less cost-effective in most countries other than the US. This finding demonstrates that the potential of HER as a cost-effective climate policy instrument hinges strongly upon both average electricity consumption levels and carbon intensities. In fact, our projections suggest that no country except the US and Australia reaches abatement cost levels that would justify the use of HER as a policy instrument to combat climate change when using social cost of carbon of 38 US$ as a yardstick.

This conclusion holds for the treatment effect sizes reported for the US and might change if HER were more effective in other countries. To explore this possibility, Column (5) presents a summary indicator: the CO_2 abatement cost relative to those in the US at a given treatment effect size. In Germany, for example, abatement cost of HER exceed those in the US by a factor of 3.7. In other words, to reach the same abatement cost level as in the Opower study, the effect size of HER in Germany would have to be at 6.3% (3.7 $\times$ 1.7%, assuming the estimated average effect size of 1.7% reported in Allcott 2011). For France and Sweden, the abatement costs exceed those in the US by a factor of 16.0 and 57.6, respectively, implying that HER are not cost-effective even under very optimistic assumptions. Abatement cost ratios are higher than 1.9 for all considered OECD countries except Australia so that effect sizes would have to be (at least) twice as high to reach the same CO_2 abatement cost as in the US.

3. Treatment Effects of HER in Germany

3.1. HER Design in the German Experiment

In cooperation with the German firm *Grünspar*, a service provider for utilities, we designed the HER for our study in a way that matches the *Opower* intervention closely, but not perfectly. We conducted a "natural field experiment" (Levitt and List 2009), where households were not informed about randomization. Households in the treatment group received four quarterly letters, while households in the control group did not receive any letter beyond the utility's regular communication. Just as the *Opower* reports, our HER provided electricity-saving tips and compared the household's consumption with that of its neighbors, as visualized in Figure 1. The four HER are comprehensively documented in the online appendix. The following features of our HER were not contained in the *Opower* HER: First, our reports announce an individualized electricity consumption objective for each recipient household (10% less than the previous year) and additionally offer rebates for the purchase of energy efficient appliances.[2]

[2]Table A1 provides a detailed comparison between our HER and the one sent out by *Opower*.

As goal setting and subsidies have generally positive effects on the uptake of energy efficient durables and energy conservation (e.g. Davis et al. 2014, Harding and Hsiaw 2014), we expect this deviation to intensify the effectiveness of HER, but only slightly.

Figure 1: Social Comparison Element in HER (Translation of the Original German Version)

Second, while meters in the *Opower* population were read on a monthly or quarterly basis and electricity consumption information could be updated in each letter, annual meter reading cycles in Germany do not allow for such intra-year updates. Therefore, we repeat the social comparison based on the most recently available annual electricity consumption in the first three reports. We expect that the absence of intra-year updates might lead to a slight decrease of the energy conservation effect. Third, the last of the four HER contains "testimonials", i.e. exemplary descriptions of electricity-saving actions implemented by households ("We have recently bought a new energy-efficient refrigerator that saves us around 60 EUR per year").

3.2. Experimental Design and Data

For the implementation of the study, we cooperated with a medium-sized electricity provider located in Kassel, Germany, with around 135,000 residential customers. In total, the trial was implemented in a study sample of 11,630 residential electricity consumers. We randomized the HER intervention among those households that received their annual bill between November 2014 and April 2015. Households in the treatment group received the four HER within one year, while households in the control group did not receive any report or communication other than the business-as-usual correspondence with the electricity provider. We sent the first HER shortly after the household's annual meter reading, which is the baseline of our analysis. Endline data is retrieved from the annual business-as-usual metering one year later, between November 2015 and April 2016. Our sample includes only those households that had been

Table 2: Balance of Baseline Characteristics Between Treatment and Control Group

	Treatment Group	Control Group	Difference (Std. Error; p-Value)
Baseline Consumption (2014), in kWh	2,281.3	2,279.3	2.0 (29.62; 0.95)
Baseline Billing Period Length, in Days	362.7	362.6	0.1 (0.12; 0.47)
Number of Households	5,808	5,812	

with the electricity provider for at least one year, so we can make use of baseline consumption data. In addition, as in the *Opower* programs, households with more than one meter were excluded from the sample. The randomization was stratified by households' baseline electricity use and billing month.

Table 2 illustrates that baseline electricity consumption and billing period length are perfectly balanced across treatment and control group. Furthermore, the table shows that households in our sample consume on average 2,300 kWh per year and hence far less than the 12,000 kWh consumed by the average US household, but also less than the German average of around 3,300 kWh per year (depicted in Table 1). The reason for this is that our study's target area, Kassel and its surrounding suburbs, is an urban area where households are typically smaller than the average German household. We examine the representativeness of our study region compared to the rest of Germany, using the microm dataset that offers socio-demographic variables at the regional zip code level. Beyond the lower electricity consumption, we find that our sample provides a fair representation in terms of key socio-demographic variables, such as percentage of retirees, unemployment rate, purchasing power, and non-German citizenship (see Table A2 in the appendix).

4. Results

To determine the Average Treatment Effect (ATE) of the HER on electricity consumption, we estimate the following differences-in-differences regression model:

$$\Delta Y_i = \alpha + \delta T_i + \epsilon_i \tag{1}$$

Table 3: Average Treatment Effect (ATE) on Households' Electricity Consumption

	(1)	(2)	(3)
ATE	-0.719*	-0.620**	-0.684**
Standard Error	(0.383)	(0.270)	(0.269)
95% Conf. Interval	[-1.469,0.032]	[-1.150,-0.090]	[-1.212,-0.156]
Outliers Removed	-	✓	✓
Time Controls	-	-	✓
R^2	0.0003	0.0005	0.025
Number of Obs.	11,620	11,388	11,388

Notes: The outcome variables is the change in a household's annual electricity consumption between the treatment and baseline period, divided by the average control group consumption in the post period (both in kilowatt-hours), and multiplied by 100 to ease the readability as percentage changes. **,* denote statistical significance at the 5% and 10% level, respectively. Heteroscedasticity robust standard errors are in parantheses.

where $\Delta Y_i = (Y_i^{2015} - Y_i^{2014})/Y_{i,c}^{2015}$ corresponds to the change in the annual electricity consumption of household i before (Y_i^{2014}) and after the HER treatment (Y_i^{2015}), T_i is the treatment dummy variable that equals unity for households that received the HER, and ϵ_i designates an idiosyncratic error term. We divide the difference between annual consumptions by the average post-period control group consumption, $Y_{i,c}^{2015}$, so that the ATE identified by δ expresses average electricity savings as a percentage of the average consumption level. Furthermore, to account for different billing period lengths, we normalize all yearly electricity consumptions to 365 days.

Table 3 presents the results and shows that the average HER treatment effect is a 0.7% reduction and statistically significant at the 10 percent level (Column 1). In Columns (2) - (3) we trim our sample by excluding outliers and include weekly time dummies for both the baseline and the treatment period as further control variables.[3] This change does not markedly alter the effect size, but increases precision considerably.

Moreover, throughout the specifications of Table 3, the 95% confidence intervals allow us to exclude average reductions in electricity consumption of around 1.5% – and hence nearly the entire range of effect sizes that have been documented by Allcott (2011) for the US. Because of the large differences in average consumption levels between German and US households,

[3]Observations are removed as outliers when the change in the electricity use from 2014 to 2015, normalized by the average consumption of control households in 2015, fell below the 1% percentile (-68.1%) or exceeded the 99% percentile (+52.7%). Such large changes in consumption can arise when dwellings remain uninhabited for a longer time period, for example, and are very unlikely a consequence of receiving HER. To control for time effects, we include weekly dummies that equal 1 if a week falls into the respective billing period. Weekly dummies are included for both billing periods.

Table 4: Average Treatment Effects (ATE) in Subsamples Based on Households' Baseline Consumption in 2014

	(1) Full Sample	(2) Above Median $Y_i^{2014} > p_{50}(Y_i^{2014})$	(3) Above top Quartile $Y_i^{2014} > p_{75}(Y_i^{2014})$	(4) Above top Decile $Y_i^{2014} > p_{90}(Y_i^{2014})$
ATE	-0.684**	-0.910**	-1.544**	-3.058**
Standard Error	(0.269)	(0.454)	(0.725)	(1.347)
95% Conf. Interval	[-1.212,-0.156]	[-1.801,-0.020]	[-2.965,-0.123]	[-5.702,-0.415]
Outliers Removed	✓	✓	✓	✓
Time Controls	✓	✓	✓	✓
R^2	0.025	0.037	0.067	0.133
Number of Obs.	11,388	5,695	2,847	1,139

Notes: The outcome variable is the change in a household's annual electricity consumption between the treatment and baseline period, divided by the average control group consumption in the Post period (both in kilowatt-hours), and multiplied by 100 to ease the readability as percentage changes. **,* denote statistical significance at the 5% and 10% level, respectively. Heteroscedasticity robust standard errors are in parantheses. The median of baseline consumption, $p_{50}(Y_i^{2014})$, is 1,883 kWh, the top quartile is 2,794 kWh and the top decile is 3,921 kWh.

absolute electricity savings from HER diverge even more strongly. Our ATE of around 0.7% translates into an absolute average electricity reduction of around 16 kWh per year or 0.04 kWh per day, which is equivalent to turning off a 30 Watt light bulb for some 90 minutes every day. For comparison, the Allcott (2011) treatment effect for quarterly reports of a 1.7% reduction translates into absolute savings of 191 kWh per year (0.52 kWh per day) in the US.

The considerably higher absolute consumption levels in the US might also partly explain the higher treatment effects in relative terms. As Figure 2 in Appendix A illustrates, US households consume at least twice the electricity of German households in every domain except for cooking. In particular, space cooling is virtually absent in Germany, also owing to different climatic conditions, but accounts for more than 2,000 kWh in the US. Such differences indicate that households with high consumption levels may also have larger saving potentials.

To test this hypothesis empirically, we estimate the ATE in subsamples of households that use more than the median, the top quartile, and the top decile of baseline electricity consumption, respectively. Indeed, as Table 4 illustrates, households with larger baseline consumptions realize more pronounced electricity savings on average. For households above the median, we observe a statistically significant reduction of 0.9% that even reaches 1.6% and 3.1% in the top quartile and top decile, respectively.

Based on our estimated HER treatment effect, we now update the cost-effectiveness analysis presented in Table 1 for Germany. We divide the annualized cost of the reports by the average amount of kilowatt-hours saved per year, again assuming printing and mailing cost of 1 US$ per report. Our estimates imply intervention costs per saved kWh of around 0.25 US$ (4 US$/16 kWh), compared to only around 0.01-0.05 US$ in the US *Opower* samples (Allcott 2011). Dividing the cost estimates by the carbon intensity – which is virtually on a par for the US and Germany – yields the cost per mitigated ton of CO_2 of 505 US$ in Germany, compared to 25-105 US$ in the US *Opower* samples. This finding reinforces our assessment from Section 3 that HER are not a cost-effective climate policy instrument in Germany.

5. Sensitivity Analysis

Our cost-effectiveness projections in Section 2 rely on a set of assumptions, most of which are conservative in the sense of favoring the cost-effectiveness of HER. For example, we ignore administrative cost and consider the maximum effect size found in the literature. In this section, we test the sensitivity of our conclusion concerning two aspects where our calculations might be overly pessimistic: persistency in electricity savings beyond the treatment year (Allcott and Rogers 2014) and the consideration of a broader set of benefits and cost for welfare analysis (Allcott and Kessler 2015).

First, we have only considered electricity savings and thus CO_2 mitigation in the year of the treatment. To calculate the HER abatement costs under an optimistic persistency scenario, we assume that HER do not only decrease electricity consumption in the year of the treatment, but persist over the following years (as reported for the US *Opower* sample in Allcott and Rogers 2014 and Brandon et al. 2017). In line with the upper persistency bound observed by Allcott and Rogers (2014), we assume that effect sizes attenuate linearly by 15 percentage points per annum and set discount rates to zero. Electricity savings then increase by a factor of 3.85 and the abatement costs decrease accordingly.[4] Even under such favorable assumptions about the persistency of electricity savings, HER would never be cost-effective in France and Sweden, as we document in Appendix A3. For the remaining European countries, as well as Canada, Japan and South Korea, only effect sizes in the first year close to the maximum of 3.3% can bring down CO_2 abatement cost below the 38 US$ yardstick.

[4] In the absence of discounting and with effect sizes that attenuate linearly by 15 percentage points per annum, the total amount of saved electricity is $(1 + 0.85 + 0.70 + 0.55 + 0.40 + 0.25 + 0.1) * ATE_1$, where ATE_1 is the average electricity saving in the first year.

Second, our analysis has focused on CO_2 abatement costs and only incorporated the immediate costs of HER (postage and printing) as well as the climate relevant benefits, i.e. mitigated CO_2. Allcott and Kessler (2015) suggest considering not only climate policy externalities but all costs and benefits on the supply and demand side when assessing climate policy instruments (see Ito 2015, for a similar discussion). On the demand side, for example, consumers benefit from electricity savings in form of reduced energy costs, but bear adjustment costs such as investments for more efficient appliances and loss of utility from forgone energy services. On the supply side, electricity savings can influence the size of a potential dead-weight loss from taxes and other mark-ups.

In the following, we test the sensitivity of our cost-effectiveness calculations to the incorporation of this broader welfare perspective. The calculation is presented in more detail in Appendix B. For the supply side, we retrieve country-specific electricity prices, as well as production costs, and use their difference to approximate the dead-weight loss. On the demand side, the costs and benefits are typically unobservable. We therefore refer to Allcott and Kessler (2015), who estimate the net welfare effect on consumers by eliciting the recipients' willingness-to-pay for a continued delivery of HER. They find that recipients' average willingness-to-pay amounts to 54% of the electricity cost savings from receiving HER. Accordingly, the remaining 46% reflect the consumers' costs from HER.

As can be seen in Table A4 in the appendix, this extended welfare perspective improves the cost-effectiveness of HER for all countries. The underlying reason is that HER reduce demand- and supply-side imperfections beyond carbon externalities. Nevertheless, even under generous assumptions, we find that HER induce negative welfare effects for all included European countries. In Australia, Canada, Japan, the US, and South Korea welfare effects can become positive in favorable effect size scenarios.

6. Conclusion

This paper has examined whether the core result from the *Opower* experiments in the US, the cost-effectiveness of social comparison-based home energy reports (HER) as a climate policy instrument, is transferable to other contexts. In a descriptive analysis, we show that lower electricity consumption levels and carbon intensities of electricity generation make HER a cost-ineffective climate policy instrument in the majority of industrialized countries beyond the US.

In particular, they can barely become cost-effective in European countries. This finding holds even under very optimistic time-persistency assumptions and when a broader cost-benefit perspective is applied – unless HER treatment effects become very large.

We estimate the average treatment effect of HER in Germany by means of a large-scale randomized controlled trial, in which we evaluate a HER intervention similar to the US-*Opower* experiments. Our estimates imply only modest average reductions in electricity consumption of 0.7%, less than half of what was observed in the US. In addition, we show that relative electricity savings are much larger for households with higher electricity consumption levels. This finding indicates that higher electricity consumption levels are associated with larger saving potentials – a mechanism that also can explain why effect sizes are lower in Germany, compared to the US.

From a policy perspective, our results cast doubt on the potentials of HER as a climate policy instrument to curb residential electricity consumption in many industrialized countries beyond the US. Moreover, the context variables we have presented in this paper – electricity consumption levels and carbon intensities – are also relevant for the assessment of many other climate policy instruments targeting the electricity sector. For example, behavioral instruments other than HER, but also price-based approaches, such as subsidies, will most likely be considerably less cost-effective in industrialized countries other than the US.

On a more general note, our paper contributes to the emerging literature on the transferability of causal effects across settings (Allcott 2015, Deaton and Cartwright 2016, Gechter 2016, Hotz et al. 2005, Leviton 2017, Muller 2015, Peters et al. 2016, Pritchett et al. 2015, Vivalt 2015). Even if a proof-of-concept is furnished with high internal validity for one policy population – as it was done in different evaluations of the *Opower* case for the US – the transferability to other policy populations can prove difficult. In particular, we show that not only the average treatment effect is heavily context-dependent, but also other components of a cost-effectiveness analysis. In particular, low electricity consumption levels and carbon intensities can preclude the cost-effectiveness of HER as a climate policy instrument already a priori in many countries. Yet, prudence in terms of external validity also applies to this present paper: Digitalization of daily routines through smart metering and digital information gadgets might alter both the costs and the effectiveness of information campaigns for energy conservation (see Tiefenbeck et al. 2016, for example).

A. Appendix

Table A1: Comparison of HER Elements

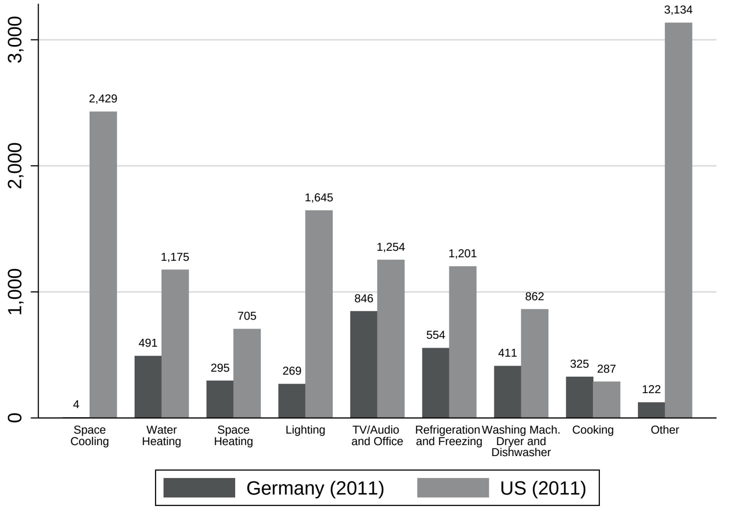
	Our report	*Opower* (Allcott 2011)	Would we expect the differences to increase the effectiveness of our report?
Common Elements			
Social (neighborhood) comparison	x	x	·
Electricity consumption feedback	x	x	·
Electricity saving tips	x	x	·
Diverging Elements			
Possibility to get updated social comparisons and more energy saving tips via an app	x		+ (can trigger continuous engagement with the information from the letters)
Price discounts for energy efficient products in the online shop of the electricity provider	x		+ (Davis et al. 2014)
Frequency of letters	quarterly	monthly - quarterly	- (Allcott 2011)
Update of information (comparison electricity consumption feedback)	yearly	monthly - quarterly	-
Calculation of typical household sizes associated with electricity consumption	x		+ (additional intuitive comparison)
Testimonials (electricity saving actions that other households have implemented)	x		+
Communication of a 10% electricity saving goal within one year	x		+ (Harding and Hsiaw 2014)
Visualization of monthly electricity uses and comparison to last year's consumption		x	-

Table A2: Comparison of ZIP Code Characteristics between the Study Population and German Averages

	Estimation Sample	Germany
Population Density, in Persons per km^2	1,879	224
Percentage of Retirees	23.5%	20.5%
Unemployment Rate	6.8%	6.6%
Purchasing Power per Person, in 1000 EUR	22.0	21.3
Percentage of Foreign Household Heads	7.0%	7.5%

Source: microm (2015).

Figure 2: Composition of Electricity Consumption in Germany and the US



Notes: US data is based on the most recent domestic electricity consumption data from 2011, as documented in EIA (2013). For Germany, we construct the same consumption categories for the year 2011 using data documented in BDEW (2016), UBA (2011) and Destatis (2015).

Table A3: Abatement Cost under Different Scenarios on the Persistency of Treatment Effects

	No Persistence	15 Perc. Points Reduction in Effect Size per Year
Country	Abatement Cost in \$ / t CO_2	Abatement Cost in \$ / t CO_2
Canada	67 – 162	17 – 42
United States	20 – 49	5 – 12
France	323 – 779	84 – 202
Germany	75 – 182	20 – 47
Italy	139 – 335	36 – 87
Poland	81 – 196	21 – 51
Spain	121 – 293	32 – 76
Sweden	1,162 – 2,799	302 – 727
United Kingdom	64 – 153	17 – 40
Japan	39 – 94	10 – 24
South Korea	65 – 156	17 – 41
Australia	22 – 53	6 – 14

Notes: Following Allcott and Rogers (2014), the calculations in the table assume linear attenuation rates of 15%. The cost-effectiveness calculations extrapolate electricity reductions until linear decay rates lead to zero reductions. Assumptions about annual electricity uses, carbon intensities of electricity generation and the range of effect sizes are as in Table 1.

B. Welfare Calculations

We follow Allcott and Kessler (2015) and calculate the welfare implications of home energy reports by the following expression:

$$\Delta W = \Delta V - C_n + (\pi_e - \phi_e)\Delta\tilde{e},$$

where:

- ΔW: welfare change per participant induced by the intervention.
- ΔV: private welfare gain from receiving HER. We approximate it by the WTP measure from Allcott and Kessler (2015) that reflects all costs and benefits as perceived by the recipient households. More specifically, households value HER by 54% of the realized electricity cost savings, so that the consumer welfare gain of HER is $\Delta V = \Delta\tilde{e} \cdot 0.54 \cdot p_e$.
- C_n: annual cost of the HER per participant. We assume the cost per quarterly letter to be at 1 US\$ per letter, so that the annual cost are $C_n = 4\$$.

- $\pi_e = p_e - c_c$: mark-up of electricity retail prices p_e over production cost c_c.

- p_e: electricity retail prices that are taken from Eurostat (2016) and the IEA (2016).

- c_c: electricity generation cost. As electricity generation cost depends on the time-of-use of electricity and the time horizon of the analysis, finding a precise measure of generation cost c_c in electricity markets is inherently difficult. We do not want to take a stance on the question of whether levelized generation cost or spot prices are the more suitable electricity generation cost measure and thus present results for both approaches to approximate c_c. First, following Allcott and Kessler (2015) we use levelized generation cost and, second, annual spot price averages. A complete description of all data sources for spot prices and levelized cost is given in the notes to Table A4.

- ϕ_e captures the environmental externalities from electricity generation. We approximate ϕ_e by the social cost of carbon, estimated at around 38 US$ in 2015 IAWG (2013).

- $\Delta\tilde{e}$ denotes the average treatment effects of HER on electricity consumption (in kWh). To account for the different effect sizes in the *Opower* studies (e.g. Allcott 2011) and in this paper, we use the range of 0.7-3.3%.

As a reference point, Column 6 of Table A4 displays the welfare estimate when we only account for direct cost and climate benefits of HER. This is the welfare analysis that is commonly implemented in classical program evaluations of climate policy interventions and corresponds to our analysis in Section 2. The results show that – under these assumptions – welfare effects of HER are negative in all countries except for the US and Australia, where abatement cost of HER are lower than 38 US$ (Table 1).

Columns 7 and 8 show results for the expanded scope of the welfare analysis as suggested by Allcott and Kessler (2015) for spot prices and levelized cost, respectively. It shows that in a majority of countries HER are not welfare improving, even under optimistic assumptions on effect sizes. Only in South Korea can HER reach positive welfare changes, albeit only when the effectiveness of HER comes close to the upper bound of 3.3%. Using levelized cost in Column 8, the welfare implications of HER improve. Positive welfare effects are possible in Australia, Canada, the US, Japan, and South Korea. In all European countries, welfare effects are still negative, except for Sweden.

Table A4: International Comparison of Welfare Effects of HER Interventions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Country	Average Electricity Consump-tion in kWh	Retail Price in $ / kWh	Spot Price in $	Levelized Cost of Marginal Plant in $ / kWh	CO_2 Emissions in g per kWh from Electricity Generation	Welfare Change, Considering only Environmental Externalities (as in the Main Text), in $	Welfare Change using Spot Price, in $	Welfare Change using Levelized Cost, in $
Canada	11,379	0.107	0.022	0.071	158	−3.1 – −1.7	−11.9 – −7.3	0.3 – 6.4
United States	12,293	0.127	0.035	0.071	489	−0.9 – 3.5	−5.9 – −4.8	1.2 – 8.5
France	5,859	0.186	0.043	0.101	64	−3.8 – −3.5	−11.8 – −7.2	−2.5 – −0.5
Germany	3,304	0.327	0.035	0.106	486	−3.2 – −2.0	−14.6 – −8.4	−6.8 – −5.2
Italy	2,542	0.269	0.058	0.099	343	−3.5 – −2.9	−8.5 – −5.9	−5.0 – −4.4
Poland	1,935	0.157	0.040	0.083	769	−3.2 – −2.1	−4.2 – −4.1	−2.9 – −1.4
Spain	4,040	0.263	0.056	0.083	247	−3.5 – −2.7	−11.4 – −7.1	−7.8 – −5.6
Sweden	8,025	0.208	0.024	0.114	13	−3.9 – −3.9	−22.8 – −11.8	−1.9 – 0.9
United Kingdom	4,145	0.242	0.062	0.108	459	−3.0 – −1.6	−8.4 – −5.8	−3.2 – −2.1
Japan	5,434	0.225	0.081	0.143	572	−2.4 – −0.1	−4.2 – −4.1	0.6 – 7.0
South Korea	3,489	0.103	0.090	0.130	536	−3.0 – −1.7	−1.0 – 3.3	0.9 – 7.9
Australia	6,959	0.216	0.082	0.108	798	−1.1 – 3.0	−2.7 – −0.9	−0.3 – 5.0

Notes: Our calculations assume printing and mailing cost of one dollar per report, four reports per year and average electricity reductions of 0.7-3.3%. Average electricity consumption and CO_2 intensities of electricity generation correspond to 2013, the most recently available year documented in WEC (2016) and IEA (2015), respectively.

Retail electricity prices for 2015 are drawn from Eurostat (2016) for EU-countries and from IEA (2016) for the remaining countries. Spot prices for electricity are annual spot price averages from the following sources: USA (unweighted mean of 8 price hubs from EIA (2017)); France, Germany and UK (EPEX 2016); Italy (GME 2017); Poland (PSE 2017); Spain (OMIE 2016); Sweden and Norway (unweighted mean of regional prices from Nord Pool (2017)); Japan (JEPX 2017); South Korea (KPX 2017); Australia (unweighted mean of regional prices from AEMC (2016)); Canada (unweighted mean of the Hourly Ontario Energy Price (Class B for residential Consumers) IESO (2015), and the Alberta Average Pool Price, AESO (2016)).

The levelized cost of energy (LCOE) are taken from OECD (2015). We assume combined cycle gas turbine (CCGT) as marginal power plant in the respective country, as for example Allcott and Rogers (2014) and Allcott and Mullainathan (2010). Note that combined cycle gas turbine (CCGT) tend to have larger production cost for electricity so that we tend to overestimate the welfare impacts of HER. Furthermore, we take the largest available production cost estimates, assuming a discount rate of 10%, which increases welfare further. Only in Poland, where natural gas power plants are virtually absent and coal power plants are predominant, we employ levelized cost of a hard coal plant (as we lack LCOE data for Poland, we approximate it by the LCOE of a hard coal power plant in Germany OECD (2015), where fuel cost for hard coal are very similar). In cases where estimates for 2015 are available, we use the latest available estimate from OECD (2015): Sweden (value from 2010), Spain (value from 1998) and Italy (value from 2010). As LCOE are unavailable for Australia in OECD (2015), we take the upper bound of the range provided in WEC (2013)), and approximate the LCOE in Canada by the LCOE in the US, which has been very similar in the past OECD (2015). Where applicable, we use average exchange rates for 2015, as provided by FED (2016). The 2015 average annual exchange rate for Poland (PLN) is provided by NBP (2017).

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