# Disaggregated Consumption Feedback and Energy Conservation: Evidence from a Randomized Controlled Trial

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# Background

- Consumers are imperfectly informed about the inputs required for energy services
- Feedback can foster consumer learning and induce behavioral change (e.g. Jessoe & Rapson 2014)
- Aggregated feedback has only limited potentials (Buchanan et al. 2015, Degen et al. 2013)
- Potential solution: behavior-specific feedback (Tiefenbeck et al. 2016, Ascensio & Delmas 2015)

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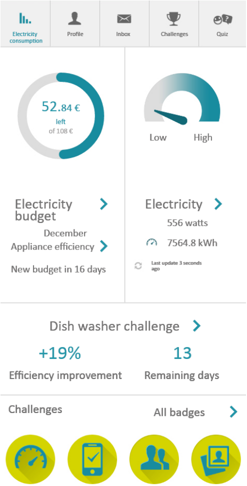
## Research question

What is the impact of disaggregated appliance use feedback on electricity consumption?

# Approach and main findings

- We randomize information provision on a smartphone app
- Disaggregated feedback reduces electricity consumption strongly in the short run ($\approx$ 10%)
- Conservation effect for at least 6 months, yet declining
- (Persistently) less use of highly energy-intensive appliances (dryer)



# Experimental design

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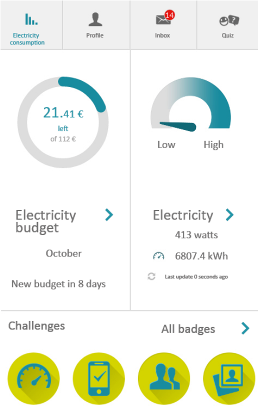
- Participants are customers of a large German utility
- Receive smart meter, internet gateway and smartphone app
- Five experimental conditions:

| | Control | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|
| Aggregated feedback | ✓ | ✓ | ✓ | ✓ | ✓ |
| Disaggregated feedback | - | ✓ | ✓ | ✓ | ✓ |
| Efficiency Challenges | - | - | ✓ | ✓ | ✓ |
| Monetary Incentives | - | - | ✓ | - | ✓ |
| Ranking | - | - | - | ✓ | ✓ |

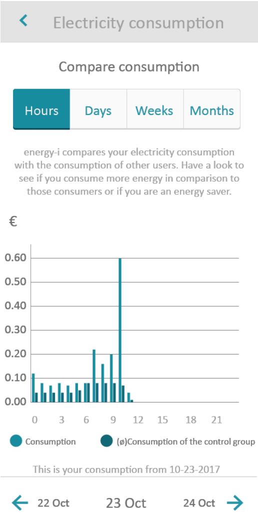
# Control condition

- Participants observe remaining part of monthly advance payments (budget)
- Observe current wattage
- Can do a energy-related quiz
- Obtain badges for filling out their profile, etc.



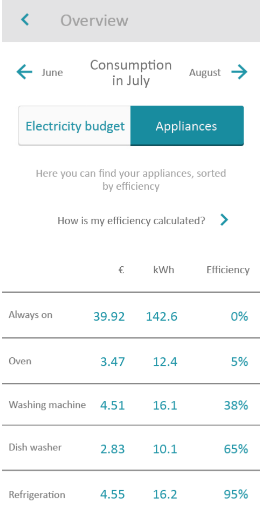
# Control condition

- Participants obtain aggregate electricity use feedback
- Observe total consumption (and electricity cost)
- Can compare it to other app users and their history



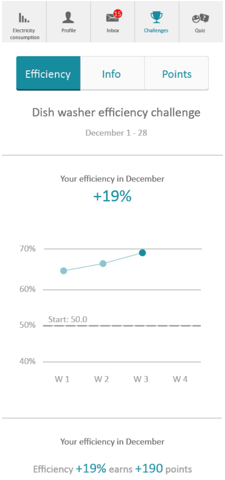
# Disaggregation condition (T1)

- Additional display of appliance-level consumptions
- Disaggregation is based on a commercial machine-learning algorighm
- Available for: refrigeration, dishwasher, washing machine, dryer, always-on (and oven)
- Calculation of efficiency scores (0: very inefficient, 100: very efficient)



# Efficiency Challenges (T2-T4)

- Participants enter monthly challenges to improve the efficiency of a certain appliance use
- Challenges start on the 1st of a month, given that at least one month of data is available
- T2: financial **incentives** (1 EUR per 1% of efficiency improvement)
- T3: display of **rank** compared to other study participants
- T4: **competition** for rank improvements (with financial reward per improved rank position)



# Data

- High-resolution smart meter data on electricity consumptions
- “Appliance use events”: use and time-of-use of appliances
- Three surveys: baseline, after 3 months, after 6 months (socio-demographics, attitudes, electricity-saving behaviors)
- Billing information: billed annual consumption
- App analytic: page views

# Timeline

- First participants installed the app in November 2016 (majority in January 2017)
- Field experiment was ended in September 2017

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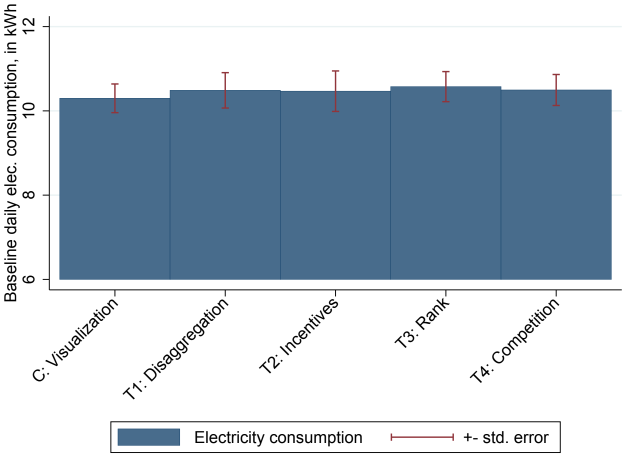
Three phases in the experiment:

- Month 1: Disaggregation for T1–T4
- Month 2–6: Challenges for T2–T4
- Month 7+: Persistency phase

# Balancing




- F-statistic of a test for mean equality: 0.34 (p-value: 0.85)

# Empirical strategy

- Estimation of ATE, relative to visualization only
- Control for baseline electricity use (from billing data)
- Standard errors clustered at individual level

## Estimation equation:

$$Y_{it}^{norm} = \alpha Y_i^{bill} + \sum_{d=1}^{4} \beta^d T_i^d + \nu_t + \epsilon_{it}$$

- $Y_{it}^{norm}$: Electricity use of participant i in month t (normalized by control group mean)
- $Y_i^{bill}$: Billed electricity use in baseline year
- $T_i^c$: Treatment group indicators
- $\nu_t$: Month fixed effects

# Effect on electricity consumption

| | Short Term (M1) | |
|---|---|---|
| T1-T4: Joint spec. | -0.106*** | |
| | (0.033) | |
| T1: Disaggregation | | -0.114*** |
| | | (0.036) |
| T2: Incentives | | -0.127*** |
| | | (0.047) |
| T3: Rank | | -0.111*** |
| | | (0.036) |
| T4: Competition | | -0.071* |
| | | (0.041) |
| Baseline elec. use | ✓ | ✓ |
| Month fixed effects | ✓ | ✓ |
| $R^2$ | 0.6667 | 0.6681 |
| Number of obs. | 577 | 577 |
| Number of participants | 577 | 577 |

*Notes:* ***, **,* denote statistical significance at the 1%, 5%, 10% level, respectively. Standard errors are in parantheses and clustered at the individual level.

# Effect on electricity consumption

| | Short Term (M1) | | Medium Term (M2-6) | |
|---|---|---|---|---|
| T1-T4: Joint spec. | -0.106*** | | -0.050*** | |
| | (0.033) | | (0.017) | |
| T1: Disaggregation | | -0.114*** | | -0.037* |
| | | (0.036) | | (0.022) |
| T2: Incentives | | -0.127*** | | -0.060** |
| | | (0.047) | | (0.026) |
| T3: Rank | | -0.111*** | | -0.070*** |
| | | (0.036) | | (0.022) |
| T4: Competition | | -0.071* | | -0.029 |
| | | (0.041) | | (0.023) |
| Baseline elec. use | ✓ | ✓ | ✓ | ✓ |
| Month fixed effects | ✓ | ✓ | ✓ | ✓ |
| $R^2$ | 0.6667 | 0.6681 | 0.7054 | 0.7065 |
| Number of obs. | 577 | 577 | 3,132 | 3,132 |
| Number of participants | 577 | 577 | 691 | 691 |

*Notes:* ***, **,* denote statistical significance at the 1%, 5%, 10% level, respectively. Standard errors are in parantheses and clustered at the individual level.

# Effect on electricity consumption

| | Short Term (M1) | | Medium Term (M2-6) | | Long Term (M7+) | |
|---|---|---|---|---|---|---|
| T1-T4: Joint spec. | -0.106*** | | -0.050*** | | -0.011 | |
| | (0.033) | | (0.017) | | (0.020) | |
| T1: Disaggregation | | -0.114*** | | -0.037* | | 0.017 |
| | | (0.036) | | (0.022) | | (0.026) |
| T2: Incentives | | -0.127*** | | -0.060** | | -0.012 |
| | | (0.047) | | (0.026) | | (0.026) |
| T3: Rank | | -0.111*** | | -0.070*** | | -0.017 |
| | | (0.036) | | (0.022) | | (0.026) |
| T4: Competition | | -0.071* | | -0.029 | | -0.030 |
| | | (0.041) | | (0.023) | | (0.025) |
| Baseline elec. use | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Month fixed effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| $R^2$ | 0.6667 | 0.6681 | 0.7054 | 0.7065 | 0.6705 | 0.6718 |
| Number of obs. | 577 | 577 | 3,132 | 3,132 | 2,998 | 2,998 |
| Number of participants | 577 | 577 | 691 | 691 | 607 | 607 |

*Notes:* ***, **,* denote statistical significance at the 1%, 5%, 10% level, respectively. Standard errors are in parantheses and clustered at the individual level.

# Empirical strategy II

- Analyze ATE at appliance level
- Control on baseline consumption and number of occupants

## Estimation equation:

$$Y_{ijt}^{norm} = \alpha Y_i^{bill} + \gamma X_i + \sum_{d=1}^{4} \beta^d T_i^d + \nu_t + \epsilon_{it}$$

- $Y_{ijt}^{norm}$: Electricity use of appliance j by participant i in month t (normalized by control group)
- $Y_i^{bill}$: Billed electricity use in baseline year
- $X_i$: Number of occupants fixed effects
- $T_i^c$: Treatment group indicators
- $\nu_t$: Month fixed effects

# Effect on appliances use (appliance specific, M1)

| | Always-On | Cooling | Dish-Washer | Washing | Dryer | Oven | Residual |
|---|---|---|---|---|---|---|---|
| T1: Disaggregation | -0.065 | -0.056 | 0.004 | 0.083 | 0.012 | -0.081 | -0.170*** |
| | (0.073) | (0.062) | (0.117) | (0.123) | (0.191) | (0.176) | (0.060) |
| T2-T4: Challenges | -0.099 | 0.004 | -0.063 | -0.093 | -0.199 | -0.002 | -0.140** |
| | (0.063) | (0.053) | (0.097) | (0.093) | (0.153) | (0.150) | (0.056) |
| Baseline elec. use | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Month fixed effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| $R^2$ | 0.416 | 0.182 | 0.220 | 0.147 | 0.039 | 0.094 | 0.538 |
| Number of obs. | 577 | 577 | 520 | 567 | 409 | 577 | 577 |
| Number of participants | 577 | 577 | 520 | 567 | 409 | 577 | 577 |

*Notes:* ***, **,* denote statistical significance at the 1%, 5%, 10% level, respectively. Standard errors in parantheses, clustered at the individual level.

# Effect on appliances use (appliance specific, M2-6)

| | Always-On | Cooling | Dish-Washer | Washing | Dryer | Oven | Residual |
|---|---|---|---|---|---|---|---|
| T1: Disaggregation | 0.053 | -0.003 | -0.149 | -0.037 | -0.495** | -0.059 | -0.068** |
| | (0.065) | (0.062) | (0.119) | (0.087) | (0.218) | (0.211) | (0.031) |
| T2-T4: Challenges | -0.027 | -0.013 | -0.150 | -0.065 | -0.541*** | -0.005 | -0.072*** |
| | (0.053) | (0.042) | (0.095) | (0.070) | (0.187) | (0.185) | (0.028) |
| Baseline elec. use | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Month fixed effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| $R^2$ | 0.379 | 0.146 | 0.177 | 0.133 | 0.167 | 0.101 | 0.547 |
| Number of obs. | 3,132 | 3,131 | 2,835 | 3,073 | 2,205 | 3,132 | 3,132 |
| Number of participants | 691 | 691 | 626 | 677 | 492 | 691 | 691 |

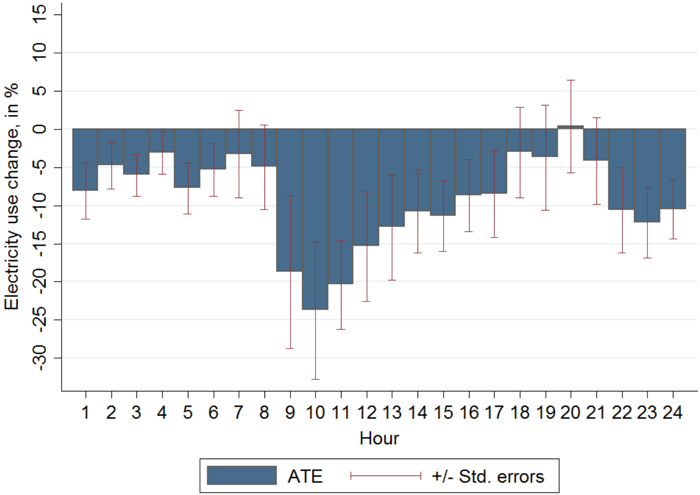
*Notes:* ***, **,* denote statistical significance at the 1%, 5%, 10% level, respectively. Standard errors in parantheses, clustered at the individual level.

# Effect on appliances use (appliance specific, M7+)

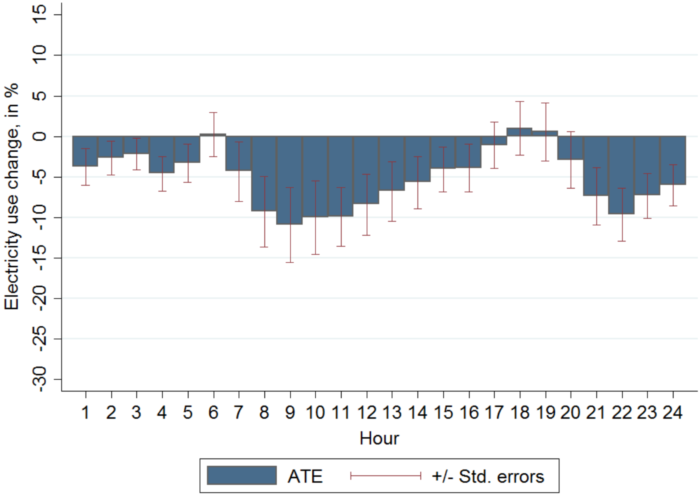
| | Always-On | Cooling | Dish-Washer | Washing | Dryer | Oven | Residual |
|---|---|---|---|---|---|---|---|
| T1: Disaggregation | 0.117* | -0.030 | -0.162 | -0.099 | -0.249 | -0.044 | 0.016 |
| | (0.068) | (0.049) | (0.113) | (0.080) | (0.224) | (0.157) | (0.032) |
| T2-T4: Challenges | 0.046 | -0.029 | -0.196** | -0.106 | -0.422** | 0.079 | -0.032 |
| | (0.055) | (0.038) | (0.089) | (0.065) | (0.168) | (0.140) | (0.026) |
| Baseline elec. use | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Month fixed effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| $R^2$ | 0.350 | 0.066 | 0.174 | 0.134 | 0.173 | 0.122 | 0.544 |
| Number of obs. | 2,638 | 2,638 | 2,401 | 2,588 | 1,876 | 2,638 | 2,638 |
| Number of participants | 604 | 604 | 551 | 595 | 430 | 604 | 604 |

*Notes:* ***, **,* denote statistical significance at the 1%, 5%, 10% level, respectively. Standard errors in parantheses, clustered at the individual level.

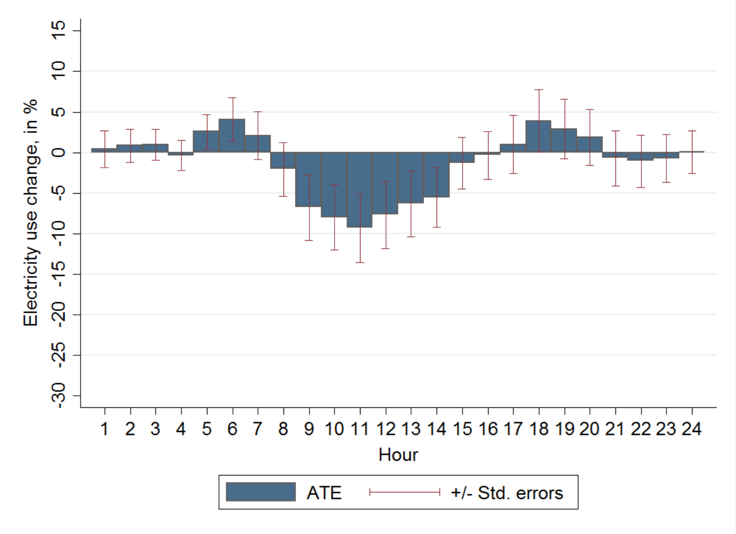
# Disag. effect by hour of day (M1)



# Disag. effect by hour of day (M2-6)



# Disag. effect by hour of day (M7+)



# Summary

- Disaggregation-based services achieve large short- and medium-run electricity savings ($\approx$ 5-10%) beyond visualization only
- Mechanism: Reduced use of highly electricity-using appliances (persistent over time)
- Efficiency challenges improve the effectiveness only slightly, monetary incentives are not more effective than social information

Thank you for your attention. Any comments?