Zürcher Hochschule
für Angewandte Wissenschaften

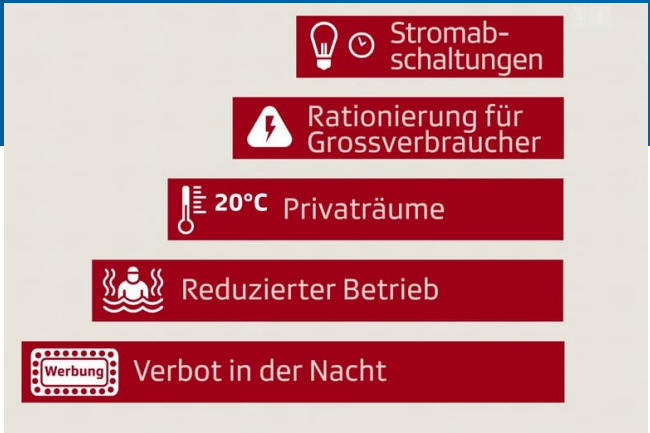
School of
Management and Law

Households revealed willin ss to pay during winter electricity shortages

Building Competence. Crossing Borders.

Dr. Nina Boogen, Dr. Christian Winzer
Zentrum für Umwelt und Energie, ZHAW

Introduction



- Increasing **energy efficiency** → strategy to reduce the emissions of greenhouse gases (while also reducing local air pollution and improving energy security).
- 2022: Russia's war on Ukraine led to a significant energy crisis with global shocks in energy prices → particularly severe effects in Europe for the natural gas and electricity markets.
- Expected shortages in winter 2022 due to the heating period → because of good preparation and a mild winter in most parts of Europe, there were no blackouts or major shortages.

→ What about this winter?

Goals of the study

- Electricity shortage in winter: Who forgoes/curtails electricity in a shortage situation?
- Savings potential if households not only receive savings message (e.g. by the government) but also compensation.
- In this study we implement a field experiment to test:

  Measuring the willingness of households to turn down their heat pumps when there is a shortage of electricity in winter (e.g. indoor temperature 1°C lower)

- The field experiment is part of the SNF-Project «Positive Energy District Algorithms for Load forecasting and Optimal dispatch» (PEDALO)

Literature

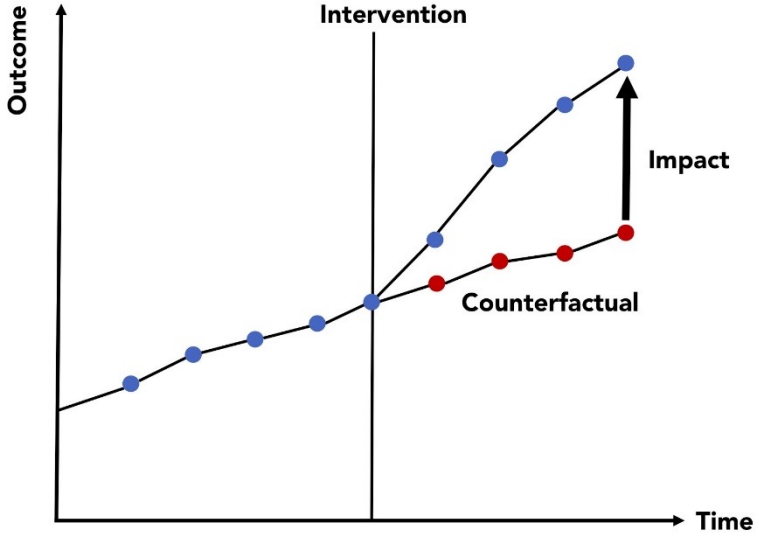
- Kubli et al. (2018):
  - measures the willingness to co-create distributed flexibility using a series of choice experiments with 902 study participants in three main domains of residential energy prosumption: (1) solar PV plus storage, (2) electric mobility, (3) heat pumps.
  - They find that electric car and solar PV users exhibit a higher willingness to co-create flexibility than heat pump users.
- Motz (2021):
  - estimated the willingness- to-accept (WTA) of Swiss households for variations in the frequency and duration of blackouts using a discrete choice model including latent classes.
  - She estimates a wide range of WTA – depending on the characteristics of both blackouts, and respondents – from slightly negative values up to ten times the household's electricity prices.
- Winzer et al. (2023):
  - used a discrete choice experiment to estimate a compensation of about CHF 60 per year for a weekly one-hour load shift for heat pumps.

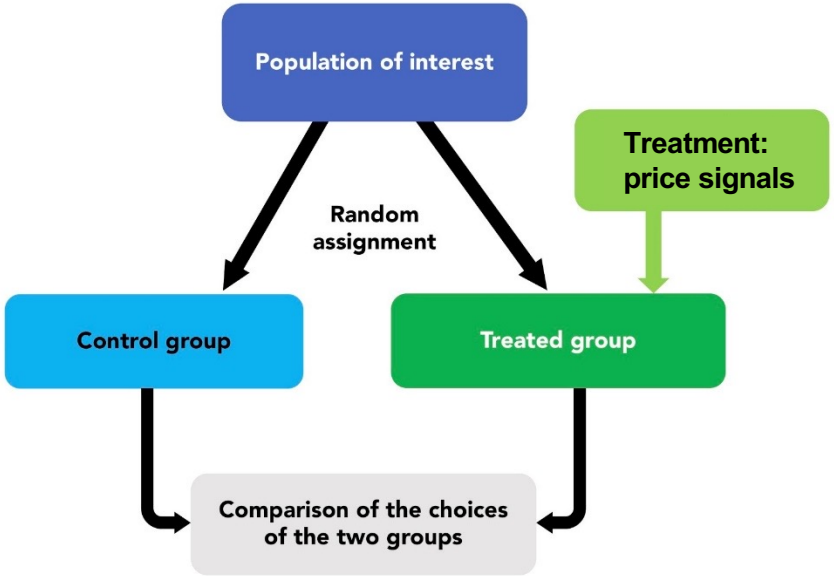
Contributions

The contribution of this study to the literature is twofold:

- **Firstly**, elicit consumers' willingness to reduce their heat pumps electricity consumption during winter electricity shortages using a sample of Swiss households.
- As far as we are aware, there are no previous studies that tested households' reactions to such high prices (which might occur during a winter shortage situation) using revealed preferences.
- **Secondly**, assess the bias of a *stated preferences* elicitation compared to *revealed preferences* approaches by comparing a survey-based evaluation approach to an elicitation of revealed preferences in an incentive-compatible field-experiment.

Method – field experiment





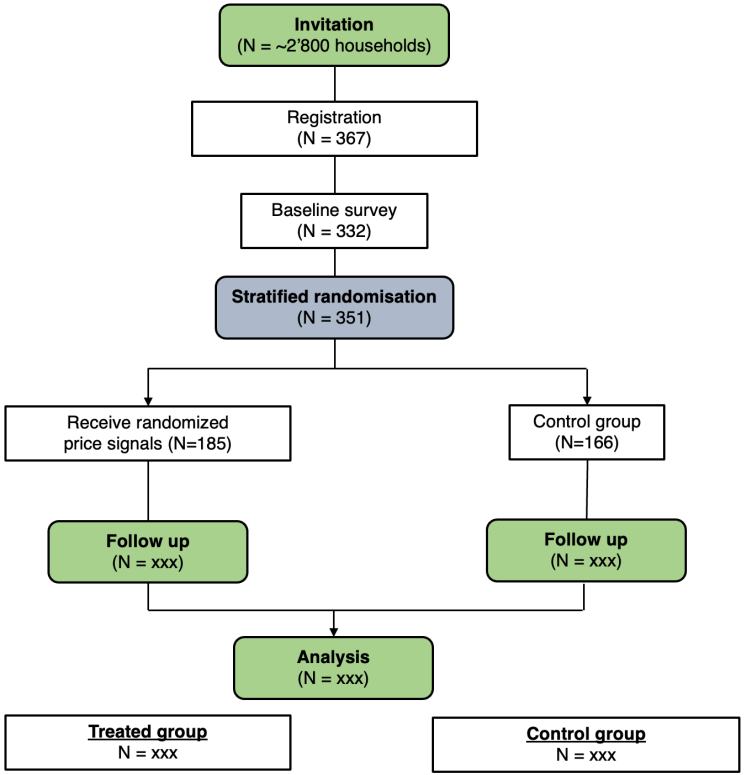
Experimental design – In a nutshell

December 2023

January 2024

15- January – 30. April 2024

May 2024



Step 1 – Recruitment/Invitation

Step 2 – Study registration

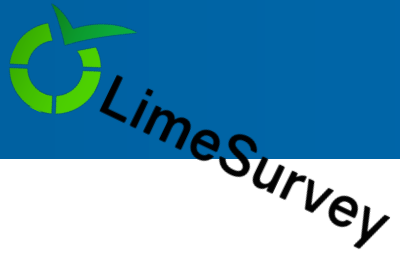
Step 3 – Baseline survey

Step 4 – Stratified randomisation

Step 5 – Main intervention period

Step 6 – Follow-up survey

Experimental design – Baseline questionnaire



Survey content:

- Information on dwelling
- «Attitudes»: personal norms, social norms, environmental self-identity, status-quo bias, how individuals approach decision situation, political attitude
- Financial and energy-related investment literacy
- Stated preferences → Discrete choice & contingent valuation questions
- Energy-related behaviour
- Socio-economics: Gender, education, household size and type, occupation, income, abundance at home

Bias reduction techniques:

- Cheap talk script (DC), consistency check (CV)

Experimental design – Stratified randomisation

Variables used for the stratification:

- Gender: female
- Household size (1-2, 3-4, 5 and more people)
- Income (<5’000, 5’000-10’000, >10’000, no answer)
- Heat pump type: water or air
- Age of the house: older or younger than 2001
- Minergie label (yes/no)
- Age of respondent: above or below median
- Main residence (yes/no)
- Floor area: smaller or larger than 200m2
- Smart meter: abundant or need to be installed

Experimental design – Intervention

- Treated households get a **virtual study budget** of 1’500 CHF
- Each week from Jan–April 2024 they receive a **price signal** which is valid for 3 days

- Households then decide each week whether
  - to pay the price/consumption → deduction from virtual study budget (price*kWh)
  - or to reduce their consumption by setting the heat pump to a lower indoor temperature → lower deduction (price*kWh)

- «Observe behaviour»: Smart meter data provided by the utility → compare daily consumption for heating between treated and control group.
- Rest of the virtual study budget → pay out (incentive compatible)

Experimental design – Intervention

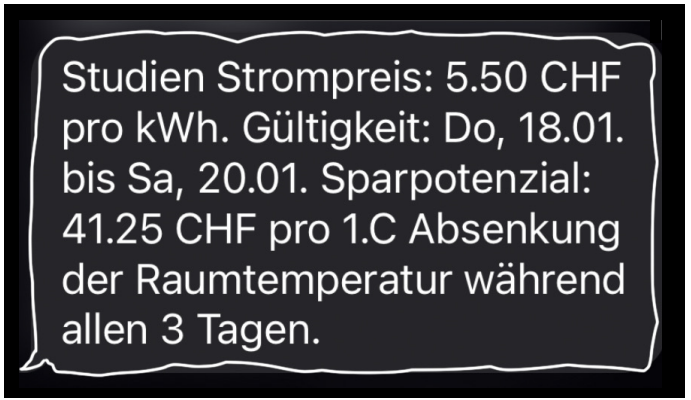
- SMS to the treatment group to inform them on the weekly study electricity price.

- The price signals will be in a bandwidth between 1.00–7.00 CHF per kWh [1.00 | 2.50 | 4.00 | 5.50 | 7.00 CHF/kWh].

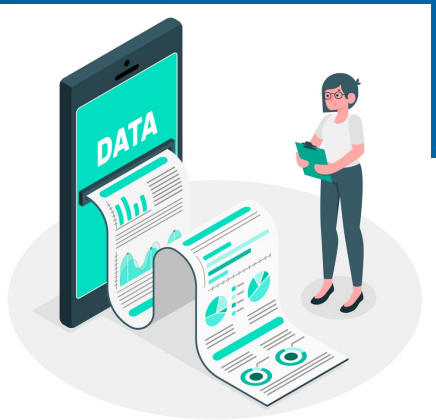
- 5 groups with different sequences

The SMS text includes:

a. Study electricity price
b. Days of validity
c. Estimated savings during 3-day period, when room temperature is reduced by 1°C



Expected dataset and analysis



Combine data from (and link by customer/meter number):

- the baseline household survey
- the smart meter data provided by the utility
- and the follow-up survey

Estimate the treatment effects:

- Dichotomous treatment (between subjects)
  - Difference in means of outcomes between the treatment and control group (Duflo et al., 2007).
  - Regressions with explanatory factors (Angrist & Pischke, 2009, p.23).
- Continuous treatment (within subjects)
  - Exploit the variation of the price signals and the panel structure by using panel data regressions where the treatment is used as covariate.

First results: baseline household survey

	Variable	Obs	Mean	Std. Dev.	Min	Max
	Besitzer:in	352	0.980	0.1398	0	1
	Anzahl Räume	324	5.525	1.0886	2	7
	Minergie	321	0.087	0.2826	0	1
	Wasser-Wärmepumpe	352	0.162	0.3689	0	1
Baujahr	Vor 1940	352	0.045	0.2086	0	1
	Zwischen 1940 – 1970	352	0.085	0.2796	0	1
	Zwischen 1971 - 2000	352	0.386	0.4876	0	1
	2001 oder später	352	0.403	0.4913	0	1
	Keine Angabe / Weiss nicht	352	0.000	0.0000	0	0
	Alter	315	56.248	12.4118	0	85
	Weiblich	352	0.145	0.3525	0	1
	Haushaltsgrösse	315	2.883	1.1574	1	7
Haushaltstyp	Ein-Personen-Haushalt	352	0.054	0.2263	0	1
	Ein-Personen-Haushalt mit einem oder mehreren Kindern	352	0.048	0.2147	0	1
	Paarhaushalt ohne Kinder	352	0.347	0.4766	0	1
	Paarhaushalt mit einem oder mehreren Kindern	352	0.403	0.4913	0	1
	Sonstiges (z. B. Wohngemeinschaft)	352	0.034	0.1817	0	1
	Ich möchte mich nicht äussern	352	0.006	0.0753	0	1

First results: baseline household survey

	Variable	Obs	Mean	Std. Dev.	Min	Max
Einkommen	unter 3 000 CHF	352	0.006	0.0753	0	1
	3 001 – 5 000 CHF	352	0.043	0.2023	0	1
	5 001 – 6 500 CHF	352	0.080	0.2710	0	1
	6 501 – 7 500 CHF	352	0.071	0.2572	0	1
	7 501 – 8 500 CHF	352	0.071	0.2572	0	1
	8 501 – 9 500 CHF	352	0.085	0.2796	0	1
	9 501 – 10 500 CHF	352	0.088	0.2838	0	1
	10 501 – 12 000 CHF	352	0.088	0.2838	0	1
	12 001 – 14 000 CHF	352	0.111	0.3143	0	1
	14 001 – 20 000 CHF	352	0.105	0.3071	0	1
	über 20 000 CHF	352	0.026	0.1581	0	1
	Keine Angabe	352	0.122	0.3279	0	1
Bildung	Sekundarstufe I (obligatorische Schule)	352	0.006	0.0753	0	1
	Berufliche Grundbildung, z. B. Eidg. Berufsattest, Fähigkeitszeugnis	352	0.327	0.4697	0	1
	Gymnasiale Maturität, Fach-, Berufsmaturität; Fachmittelschulausweis (FMS)	352	0.085	0.2796	0	1
	Hochschulabschluss (Universität, ETH, FH) oder höhere Fachprüfung (eidg. Diplom)	352	0.463	0.4993	0	1
	Keine Angabe / Weiss nicht	352	0.014	0.1185	0	1
	Spende an Umweltzweck	315	0.356	0.4794	0	1

Thank you for listening! Questions?

Nina Boogen
Center for Energy and the Environment
Gertrudstrasse 8
8400 Winterthur
Telefon +41 58 934 49 95
annina.boogen@zhaw.ch

The field experiment was registered in the AEA RCT Registry (ID: AEARCTR-0012277)

References

Angrist, J. D., & Pischke, J.-S. (2009). *Mostly harmless econometrics: An empiricist's companion*. Princeton university press.

Degen, K., Efferson, C., Frei, F., Goette, L., & Lalive, R. (2013). *Smart Metering, Beratung oder sozialer Vergleich: Was beeinflusst den Elektrizitätsverbrauch*. Swiss Federal Office of Energy (SFOE).

Duflo, E., Glennerster, R., & Kremer, M. (2007). Using randomization in development economics research: A toolkit. *Handbook of Development Economics*, *4*, 3895–3962.

Grüner, S. (2020). Sample Size Calculation in Economic Experiments. *Jahrbücher Für Nationalökonomie Und Statistik*, *240*(6), 791–823. https://doi.org/10.1515/jbnst-2019-0020

Kubli, M., Loock, M., & Wüstenhagen, R. (2018). The flexible prosumer: Measuring the willingness to co-create distributed flexibility. *Energy Policy*, *114*, 540–548.

Miller, K. M., Hofstetter, R., Krohmer, H., & Zhang, Z. J. (2011). How should consumers' willingness to pay be measured? An empirical comparison of state-of-the-art approaches. *Journal of Marketing Research*, *48*(1), 172–184.

Motz, A. (2021). Security of supply and the energy transition: The households' perspective investigated through a discrete choice model with latent classes. *Energy Economics*, *97*, 105179.

Schlemminger, M., Ohrdes, T., Schneider, E., & Knoop, M. (2022). Dataset on electrical single-family house and heat pump load profiles in Germany. *Scientific Data*, *9*(1), Article 1. https://doi.org/10.1038/s41597-022-01156-1

Winzer, C., Ludwig, P., Auer, S., & Hlawatsch, A. (2023). *NETFLEX: effiziente Netzentgelte für flexible Konsumenten* (Final report). Swiss Federal Office of Energy (SFOE).

Experimental research involving humans: Ethic issues

- Official bodies such as the Cantonal Ethics Committee (KEK) exist for the ethical assessment and approval of research projects (e.g. clinical trials).
- Apart from the legally required approval by an external ethics body, an assessment may also be necessary or at least useful in other case:
  - for publication in scientific journals
  - or for AEA RCT Registry
- Since 2022 ZHAW has an ethics committee.
- In our case the process was helpful for data privacy issues.

Pre-Analysis Plan – Field experiment

(1) Descriptive statistics: outcome variables, socio-economic variables as well as other explanatory variables.

(2) Check outcome variable (especially heat pump consumption) for their distributions. Outcomes we measure are twofold:

- heat pumps electricity consumption and
- self-reported change of heating settings (elicited in the follow-up survey).

(3) Balance check on observables: Do treatment and control group really have the same characteristics?

(4) Estimate the treatment effects:

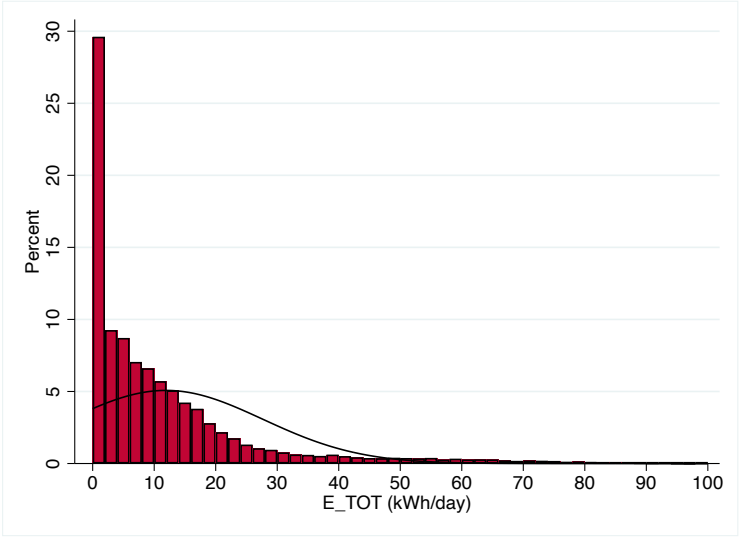
i. Dichotomous treatment (between subjects)
   - Difference in means of outcome variables between the treatment and control group (Duflo et al., 2007).
   - Regressions with explanatory factors (Angrist & Pischke, 2009, p.23).

ii. Continuous treatment (within subjects)
   - Exploit the variation of the price signals and the panel structure by using panel data regressions where the treatment is used as covariate.

Field-study design: Power calculations

Open Data

- 34 single family homes with heat pumps, 2018–2020
- Located in Hameln, Lower Saxony, Germany
- Electricity consumption: aggregation to daily consumption (kWh/day)
  - Mean: 12.09476
  - Median: 6.713637
  - S.D.: 16.30193
  - Varianz: 265.7528
- Weather data: outside temperature in municipality



Schlemminger et al (2022), Dataset on electrical single-family house and heat pump load profiles in Germany, Nature Scientific Data 9:56, https://doi.org/10.1038/s41597-022-01156-1.

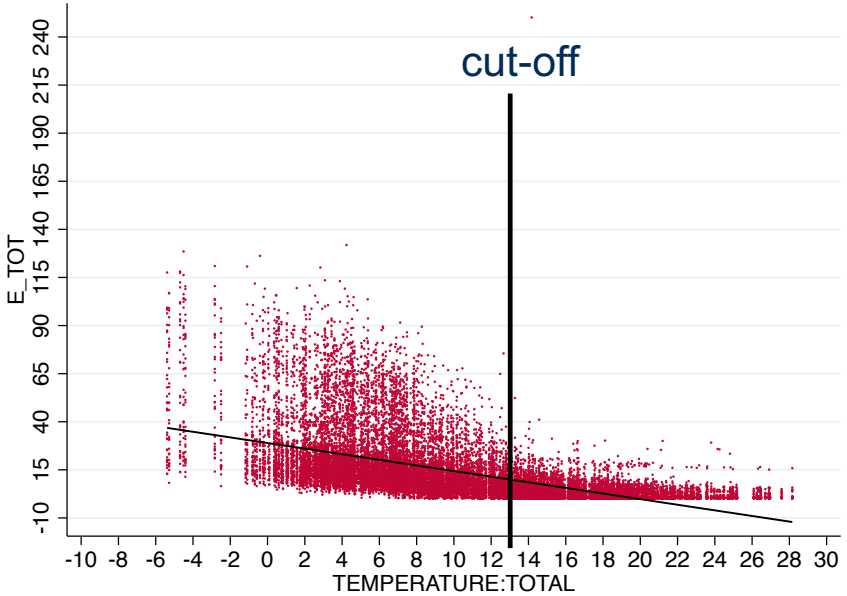
Field-study design: Power calculations

Minimal effect size:

- Heat pump setting = –1°C = …kWh/day?
- Assumption –1°C inside ≈ –1°C outside
- Regress the average daily outdoor temperature to the daily heat pump consumption in Kilowatt-hours (kWh).

Group sizes:

- Using the formula for the power function (Duflo et al. (2007), Grüner (2020)) and assuming a significance level of $\alpha = 0.05$ and power of $1-\beta = 0.80$



Field-study design: Power calculations

	Level			First differences		
Germany N = 34 t_average = 827 days	Mean	$\mu = 12.09$	kWh/24h	Mean	$\mu = 0.0024$	kWh/24h
	SD	$\sigma = 16.30$	kWh/24h	SD	$\sigma = 4.82$	kWh/24h
	Variance	$\sigma^2 = 265.75$	kWh/24h	Variance	$\sigma^2 = 23.21$	kWh/24h
	Significance level	$\alpha = 0.05$		Significance level	$\alpha = 0.05$	
	Power	$1-\beta = 0.80$		Power	$1-\beta = 0.80$	
	Min. effect size	$\delta = 2.16$	kWh/24h	Min. effect size	$\delta = 0.88$	kWh/24h
	Calculated sample size for each group N = 898			Calculated sample size for each group N = 475		

- It is known that electricity consumption patterns show extremely dispersed distributions.
- Degen et al. (2013) → cut down on group size by focusing on changes (first differences) → We use day-to-day changes.
- However, we send weekly price signals during a 15-week study period → two types of treatments:
  1) a dichotomous treatment (or between-subject) as participant gets signals or not and
  2) a continuous treatment (or a within-subject treatment) through the variation and repetitions of the price signals.
- With continuous treatments, it is very likely to gain power (also because it is within-subject). A simple power analysis that does not take the panel structure into account is per-se not wrong (quasi like "pooled OLS") but simply rather conservative.

Backup: Stated preferences – Discrete choice

Auf den folgenden 5 Seiten werden Ihnen jeweils drei neue Stromtarife für Ihre Wärmepumpe vorgestellt. Bei diesen Tarifen gestatten Sie Ihrem Stromversorger, dass er Ihre Wärmepumpe 24 Stunden lang extern steuern kann, um die Überlastung der Stromnetze zu vermeiden. Dafür erhalten Sie für die Wärmepumpe einen reduzierten Strompreis, was zu Einsparung bei Ihren Stromkosten führt. Sie werden spätestens 12 Stunden vor dem Beginn der Beeinflussung informiert. Die vorgeschlagenen neue Stromtarife zeigen jeweils:

- den Wochentag an dem Ihre Wärmepumpe extern gesteuert wird;
- die minimale Raumtemperatur, die Ihnen der Stromversorger garantiert;
- die Einsparungen durch die Gestattung der externen Steuerung.

	Tarif 1	Tarif 2	Tarif 3	Keinen der Tarife
Wochentag	[Systematische Variation]	[Systematische Variation]	[Systematische Variation]	
Temperaturabsenkung	[Systematische Variation]	[Systematische Variation]	[Systematische Variation]	
Einsparung (wir berechnen darunterliegenden Preis)	[Systematische Variation]	[Systematische Variation]	[Systematische Variation]	

Welchen Tarif würden Sie wählen?				

Backup: Stated preferences Contingent valuation

Die Energiekrise im Winter 2022/23 ist zum Glück mild verlaufen – die Lage bleibt aber angespannt. Daher stellt sich noch immer die Frage, ob wir diesen Winter vermehrt Energie sparen müssen, um hohe Energiekosten oder eine Strommangellage zu vermeiden?

Bitte nehmen Sie an, dass im kommenden Winter tatsächlich eine Strommangellage eintritt. Ihr Energieversorger will diese Strommangellage möglichst abwenden, und muss daher Ihrer Wärmepumpe für drei Tage extern steuern. Er garantierte Ihnen dabei eine Raumtemperatur von entweder 16°C, 18°C oder 20°C.

Finden Sie, dass 5 / 10 / 20 / 40 / 80 / 120 CHF pro Tag eine angemessene Entschädigung dafür darstellt?

Bei garantierter Raumtemperatur von:	Ja	Nein
22°C	☐	☐
20°C	☐	☐
18°C	☐	☐
16°C	☐	☐

Backup: Stated preferences Contingent valuation

[Wenn Nein:] Sie sagten, dass Sie nicht bereit wären, 5 / 10 / 20 / 40 / 80 / 120 CHF pro Tag als Entschädigung zu akzeptieren, dass Ihr Stromversorger Ihre Wärmepumpe extern steuert. Was war der Grund für Ihre Antwort?

- ☐ Es ist die Pflicht des Stromversorgers mir genügend Strom zur Verfügung zu Stellen.
- ☐ Die garantierte Raumtemperatur ist mir zu niedrig.
- ☐ Ich habe das Szenario nicht verstanden.
- ☐ Sonstiges (bitte angeben): _____