Electricity pricing in future power markets

Efficiency of consumer reaction to future tariff designs in system with increasing share of renewables.

Séminaire PSL

Clément Cabot & Manuel Villavicencio

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Motivation: European policies

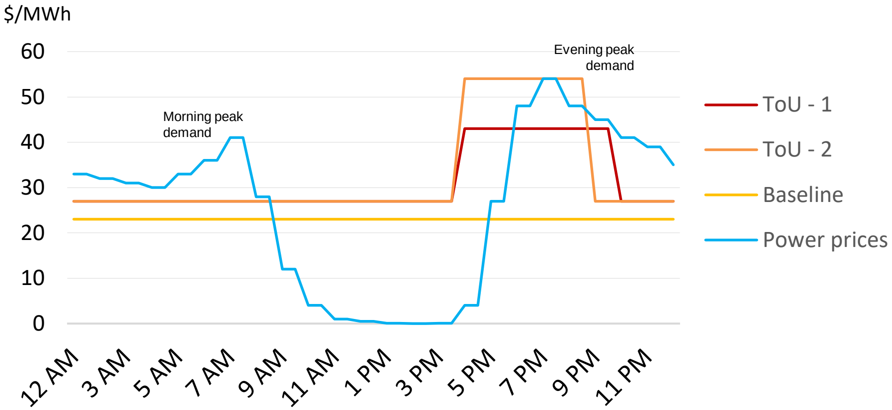
- Smart-meter rollout has been completed in many countries.
  - ➢ It allows proposing innovative rates, with a finer temporal resolution of the electricity price
  - ➢ Price signals could be sent to end-users to shift their consumption when there is generation scarcity

- EU-level agreement: Energy companies with more than 200,000 clients will be obliged to provide households with at least one offer comprising dynamic price contracts

- Yet, inelasticity of the demand in the power market is a common assumption

Consumers still face an (almost) flat price

CAISO market prices and retail rate plane available to consumers



Motivation

Actu

Électricité : le mauvais plan des heures creuses

Heures pleines, heures creuses : la moitié des Français payent l'électricité trop cher !

2 décembre 2020

franceinfo:

Énergie : un nouveau fournisseur propose de l'électricité à prix coûtant

Publié le 01/03/2021 17:00 Mis à jour le 01/03/2021 17:17

Le fournisseur Barry met fin à son activité en France

THE CONVERSATION

What's behind $15,000 electricity bills in Texas?

24 février 2021, 14:29 CET

Research question

- The European Commission (2019) indicates an annual saving of 22-70% of the energy supply component in the annual bill for small consumers, or about 15-80€ per year, thanks to dynamic pricing.

- The wholesale price will be subject to more volatility in the future:
  - Increased renewable generation → near-zero marginal price occurrence
  - Increased carbon price → higher peak prices

➔ Are current rates well suited for the evolution of power markets?

➔ Are consumers elastic enough to see bill savings materialize?

Focus of this research

- Develop a model of the wholesale market & demand-side
  - Impact of renewable deployment and carbon price increase on the hourly power prices
  - Demand-side response to hourly power prices

- Analysis of different dynamic tariff
  - Current flat rate
  - Time-of-Use
  - Real-Time prices

Literature Review

- **Applied worked on electricity pricing**: First simulation framework found notable gains of RTP, notably compared to ToU. Range of elasticities were considered, including varying elasticity with regards to demand level. (Borenstein, S.,2005 ; De Jonghe et al., 2012; Gamberdella and Pahle, 2018, Léautier, 2012; Astier, 2021)

- **Empirical evidence**: Evidence of consumer elasticity when facing dynamic pricing (CPP, PTR, ToU, RTP); Peak load reduction (Faruqui, 2010; Wolak, 2010; Allcott, 2011).

- **Consumer elasticity:** (Burke and Abayasekara, 2018, Knaut, 2016, Aalami et al., 2010; Lijesen, M.G., 2007; Auray, 2020)

Main results

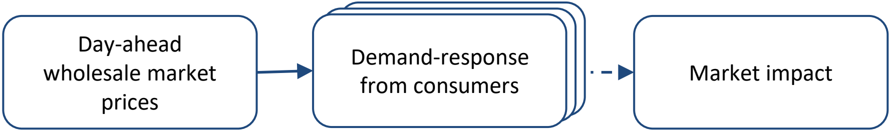
- Current residential time-of-use doesn't provide the right incentive in France, at an aggregated level, considering an increase renewable generation/carbon price
  - Consumers capture more expensive market price under ToU compared to flat rate (+2%)

- Real-Time Pricing delivers increasing benefits, but bill savings estimated are close to 5%. Savings envisaged by the European Commission would require significantly more price-elasticity.

- Estimated peak reduction could reach 8 to 18% compared to the baseline but don't necessarily coincide with the system peak load

Methodology

Research framework



Wholesale day-ahead market

We use a unit commitment (UC) model, minimizing the cost of producing electricity, considering operational range of the different production units.

$$\min(TotalCost) =$$

$$\sum_{t,k,z} Prod_{t,k,z} * (VC_{t,k,z} + EF_k * ETS_{t,k} + Markup_{t,k,z}) + \sum_{t,k,z} UC_{t,k,z} + \sum_{t,z} LL_{t,z} * VoLL_t$$

- $Prod_{t,k,z}$: Hourly production of a given technology cluster of a market area
- $Markup_{t,k,z}$: calculated price mark-up based on historical data
- $VC_{t,k,z}$: variable cost of a unit, composed of fuel price and variable O&M
- EF_k : emission factor in tCO2(eq) of a given technology cluster
- $ETS_{t,k}$: market price of the carbon emission allowances
- $UC_{t,k,z}$: technical costs
- $LL_{t,k}$: lost load
- $VoLL_t$: value of lost load

- Firms offer all their available capacity on the day-ahead market, at their short-run marginal cost
- Market price resulting from the UC model is the marginal value of the supply and demand constraint

Demand-side response model

Consumers response to day-ahead market prices according to their initial flat retail price (Doostizadeh and Ghasemi , 2012; Aalami et al., 2010; De Jonghe, 2012):

$$d_c(t) = d_{0c}(t) * (\, 1 + \varepsilon_c(t) * \frac{p(t) - p_{wg}(t)}{p_{wg}(t)} + \sum_{h \neq t}^{h=t-x \ldots t+x} \varepsilon_c(t,h) * \frac{p(h) - p_{wg}(h)}{p_{wg}(h)})$$

$d_{0c}(t)$: Reference demand of a consumer

$\varepsilon_c(t)$: self elasticity of the consumer considered

$p(t)$: day-ahead market price

$p_{wg}(t)$: flat tariff proposed to the consumer, equal to the demand weighted average price of energy of the consumer.

- Cross-elasticity $\varepsilon_c(t,h)$ is disregarded in the current framework (Allcott, 2011)

- We distinguished elasticity per consumer segment according to the value provided by Burke and Abayasekara (2018), aligned with estimate used in De Jonghe et al. (2012) and Gambardella and Pahle (2018)

Data

Wholesale market model data

- ENTSO-E Transparency data (2020) for hourly data for load, renewables infeed, and power exchange capacities for each European market area.
- Technical parameters used for the Unit Commitment equations come from Schill et al. (2017), JRC (2015).
- Power plant database used for the technology clustering comes from the open energy modeling initiative (2020).
- Scenarios have been defined as follow:

Category	Description	Key figures
Historical	2018 historical market prices	23.6 GW 16€/tCO2(eq)
Basecase	2018 Model prices	23.6 GW
RES20	+20% RES in France	28.3 GW
RES40	+40% RES in France	33 GW
RES80	+80% RES in France	42.5 GW
RES100	+100% RES in France	47.2 GW
RES100.3	+100% RES in France Carbon price x3	47.2 GW 47 €/tCO2(eq)

***Table 1**: Scenario considered in the study*

***RES** recovers here PV and Wind Onshore/offshore capacity

Consumer segment considered

- To avoid double-counting price responsiveness of demand when considering elasticities, we only selected the first category across each consumer segment, as being the closer to flat tariff as of today (segment 1)
- All values come from Enedis Open-data. It provides aggregated consumption by segment (Residential, Professional and Industrial) and voltage level at a half-hourly granularity in France

Category	Segment	Description
RES1	Residential	Résidentiel Base ≤ 6 kVA
RES11	Residential	Résidentiel Base + WE
RES2	Residential	Résidentiel HP / HC
PRO1	Professional	Professionnel Base
PRO2	Professional	Professionnel HP / HC
ENT1	Enterprise	Entreprise1 Basse Tension
ENT2	Enterprise	Entreprise2 Basse Tension

***Table 2**: Consumer segment considered in the study*

Load profile (Heat Map)

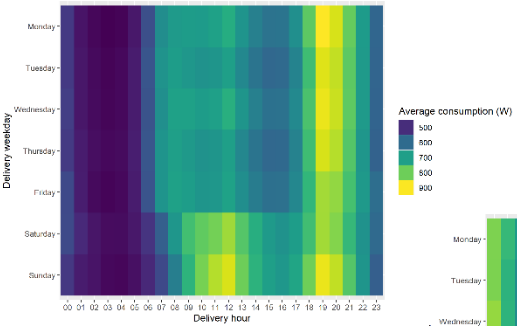


***Figure 3**: RES1 heat map*

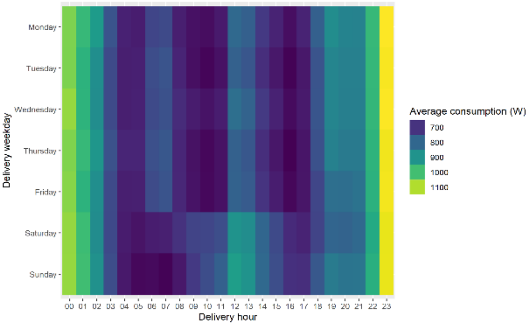


***Figure 4**: RES2 heat map*

Consumer elasticity

- Little data on hourly price elasticity to our knowledge, most used annual, bi-annual prices as being the only available evidence (Auray, 2020; Faruqui, 2010; Lijesen, M.G., 2007)
- Cross-elasticities across hours are assumed to be zero following (Borenstein, 2005; Allcott, 2011)
- We use Burke and Abayasekara (2018), who estimate real-time elasticity in the US per consumer segment and is aligned with De Jonghe et al. (2012) and Gambardella and Pahle, (2018) hypothesis. Values are conservative with regards to the range considered by Borenstein (-0.025 to -0.500)

- We perform a sensitivity on the iso-elasticity assumption following Knaut profile (2016) and for a higher level of self-elasticity

	Self-elasticity
Residential	*-0.11*
Professional	*-0.05*
Industrial	*-0.11*

Table 3: *Elasticity considered in the study (Burke, 2018)*

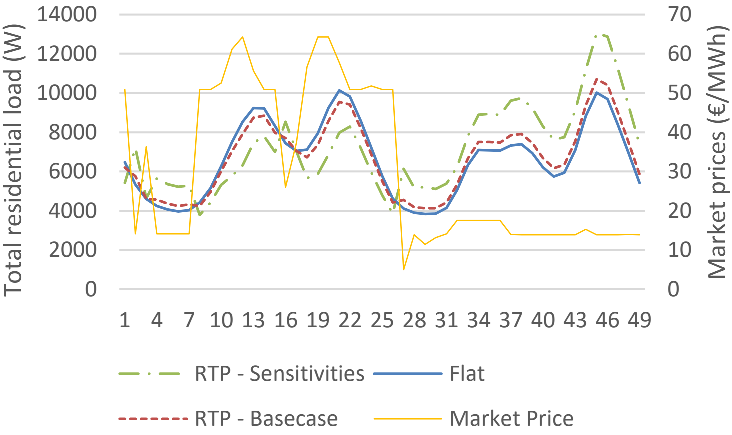


Figure 5: *Load reduction for residential consumer with short-term elasticity of -0.44 in RES100.3 scenario*

Results

Detailed results for ToU stability over scenario considered

		Historic Price	Basecase	RES40	RES80	RES100	RES100.3
Residential	Flat rate	51.76	48.88	38.37	30.96	27.72	38.46
	ToU price difference (%)	-3%	-0.3%	0.2%	1%	2%	2%
	Consumer bill impact (€)	-7.5	-0.9	0.3	1.6	2.4	3.3
Professional	Flat rate	52.63	48.62	38.05	30.43	27.07	37.83
	ToU price difference (%)	-2%	-1%	-1%	-1%	-1%	-1%
	Consumer bill impact (€)	-11.6	-6.6	-5.3	-4.0	-3.4	-5.0

Table 4: *Average price of electricity per consumer segment – ToU case*

Detailed results for RTP gain over scenario considered

		Historic Price	Basecase	RES40	RES80	RES100	RES100.3
Residential	Flat rate	51.76	48.88	38.37	30.96	27.72	38.46
	RTP price difference (%)	-1.4%	-0.9%	-2.1%	-3.0%	-3.5%	-4.2%
	Non isoelastic (%)	-1.5%	-1.0%	-2.1%	-3.0%	-3.5%	-4.2%
	Consumer bill impact (€)	-3.75	-2.28	-3.87	-4.48	-4.63	-7.86
Professional	Flat rate	52.63	48.62	38.05	30.43	27.07	37.83
	RTP price difference (%)	-0.7%	-0.4%	-0.9%	-1.3%	-1.6%	-1.8%
	Consumer bill impact (€)	-3.78	-2.33	-3.75	-4.45	-4.70	-7.69
Enterprise	Flat rate	52.81	48.78	38.24	30.64	27.30	38.10
	RTP price difference (%)	-1.4%	-0.9%	-2.0%	-3.0%	-3.5%	-4.2%
	Consumer bill impact (€)	-8.09	-4.99	-8.29	-9.81	-10.29	-17.10

Table 5: *Average price of electricity per consumer segment – RTP case*

Elasticity sensitivities on RES100.3 scenario

- We assess the impact of increased price elasticity for both RES100.3 and Historic prices
- Situation where consumers reduce their energy consumption by as much as 50% in some timestep is reached in the latest scenario. This however doesn't reach the 20% bill rebate foreseen.

		RES100.3 ε_1	$1.5 * \varepsilon_1$	$2 * \varepsilon_1$	$3 * \varepsilon_1$	$4 * \varepsilon_1$
Residential	Flat rate (€/MWh)	38.46				
	RTP price difference (%)	-4.2%	-6.3%	-8.4%	-12.4%	-16.4%
	Consumer bill impact (€)	-7.86	-11.8	-15.72	-23.2	-30.7
Professional	Flat rate (€/MWh)	37.83				
	RTP price difference (%)	-1.8%	-2.7%	-3.6%	-5.4%	-7.2%
	Consumer bill impact (€)	-7.69	-11.5	-15.38	-23.1	-30.8

***Table 6:** Sensitivities on price elasticity for RES100.3 scenario*

Sensitivities on long-term electricity mix

- We assess long-term power systems, with different fuel prices, demand levels and thermal capacities, based on the three TYNDP scenarios for the year 2040.
- Savings found in the long-term scenario are much lower than in the stylized scenario, with a reduction of less than 5% compared to the 16% found in RES100.3.

		Historic Price	DE ε_1	DE $4 * \varepsilon_1$	GA ε_1	GA $4 * \varepsilon_1$	NT ε1	NT 4 * ε1
Residential	Flat rate	51.76	92.6		100.9		90.5	
	RTP price difference (%)	-1.4%	-1.1%	-4.7%	-1.2%	-5%	-1.1%	-4.6%
Professional	Flat rate	52.63	94.5		103		92.4	
	RTP price difference (%)	-0.7%	-0.5%	-2%	-0.5%	-2.1%	-0.5%	-2%

Table 7: *Sensitivities on long-term electricity mix*

System impact of price-responsive user

- We assess the impact of having 100% of the flat rate consumer switching to RTP
- The wholesale market model is used to estimate the market price difference resulting from the RTP adoption

	RES100	RES100.3
Range of maximum load reduction (%)	-8%/-18%	-9%/-18%
Market price difference (%)	-3%	-1%
Peak Load reduction (%)	-0.8%	-1.0%
Peak Load reduction (GW)	-0.80 GW	-0.96 GW
Max Load reduction (GW)	-1.6 GW	-2.9 GW

Table 6: *Price-reactive impact on wholesale market and load*

Conclusion and discussion

- Current residential time-of-use doesn't provide the right incentive, at an aggregated level, to an increase renewable generation/carbon price

- Real-Time Pricing delivers increasing benefits, but bills savings estimated never reach more than 5% for all segment
  - ❖ Current assumptions of load elasticity / load shifting potential doesn't trigger, at an aggregated level, the expected gain

Conclusion and discussion

- Estimated peak reduction for a given consumer segment could reach 8 to 18% compared to the baseline, but don't necessarily coincide with the system peak load

- Maximal peak reduction reaches 2.9 GW when all segment 1 reacts to prices. This would be valuable (~3 nuclear units) yet has little chance to materialize because of consumer heterogeneity.

Conclusion and discussion

- Compared to the European Union, we found significant less bill reduction at the aggregated level: -7€/-30€ compared to the estimated -15/-80€ per year

- Other studies from the literature found similar expected change in the bill. Gambardella (2018), using 74 German residential load profile found more than 80% of the bill change would be less than 5%

- We therefore postulate that EU expectation of consumer gain of switching assume an important reduction of yearly electricity consumption linked to the adoption of new tariffs

Further research

- Wholesale market prices generated are not fully representative of day-ahead market prices (lack of sector coupling, feed-in tariffs, strategic bidding, out-of-market power contract…) (Ward, 2019).

- The hypothesis made on the consumer elasticities and shifting capabilities might be quite conservative, as ToU shows important load profile differences compared to the flat rate.

- Electric vehicles will represent an important share of electricity consumption for all segments in the future.

- An important focus for further research is to assess whether EV should receive the same signal based on day-ahead wholesale market prices
  ➔ risks of rebounds effect

Thank you

Questions ?

clement.cabot@mines-paristech.fr

Annexes

Wholesale day-ahead market

The market price resulting from the UC model is the marginal value of the supply and demand constraint:

$$\sum_{t,k,z} Prod_{t,k,z} + Import_{z,z} + LL_{t,z} = Load_{\,t,z} + Export_{z,z} + \sum_{t,s,z} CH_{t,s,z} \qquad \begin{array}{l} \forall k \in \kappa, \\ \forall t \in \tau, \\ \forall z \in Z \end{array}$$

- $Load_{t,z}$: hourly demand of a market area, considered inelastic
- $Import_{z,z}$ and $Export_{z,z}$: power exchanges between different market area
- $CH_{t,s,z}$: charging/discharging power flows of storage technologies

- Demand is inelastic in the day-ahead market

Summary Statistics

Summary statistics of French, UK, Germany electricity consumption in 2018

Country	**United Kingdom**	**France**	**Germany**	**Austria**
Annual electricity demand (TWh)	305.05	475.70	498.90	70.98
Average hourly consumption (GW)	34.82	54.30	56.95	8.10
Standard Deviation (GW)	7.42	12.30	9.86	1.55
Minimum consumption (GW)	12.56	30.45	35.18	4.73
Maximum consumption (GW)	54.52	96.33	76.79	11.92

TYNDP scenarios

Summary of load considered for long-term scenario based on TYNDP20 for the year 2040

TYNDP20 - 2040		FR				UK				DE			
		2018	GA	DEn	NT	2018	DEn	GA	NT	2018	DEn	GA	NT
TWh	Annual load	475	502	560	502	305	380	397	336	517	788	571	625
%	Percentage increase from 2018	-	6%	18%	6%	-	25%	30%	10%	-	52%	10%	21%

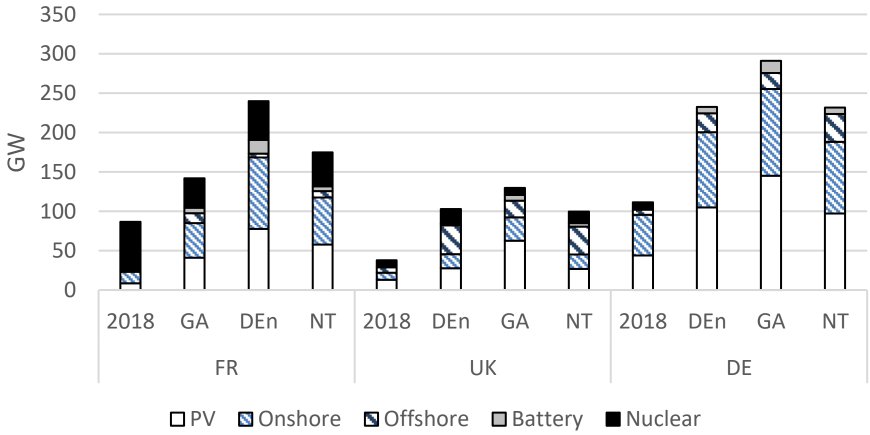
Summary of fuel prices considered for long-term scenario based on TYNDP20 for the year 2040

TYNDP20 - 2040		2018	GA	DEn	NT
€/GJ	Natural Gas price	6.2		7.31	
€/GJ	Coal price	2.65		6.91	
€/tCO2	CO2 price	15.7	80	100	75

(ENTSO-e, ENTSOG, 2020)

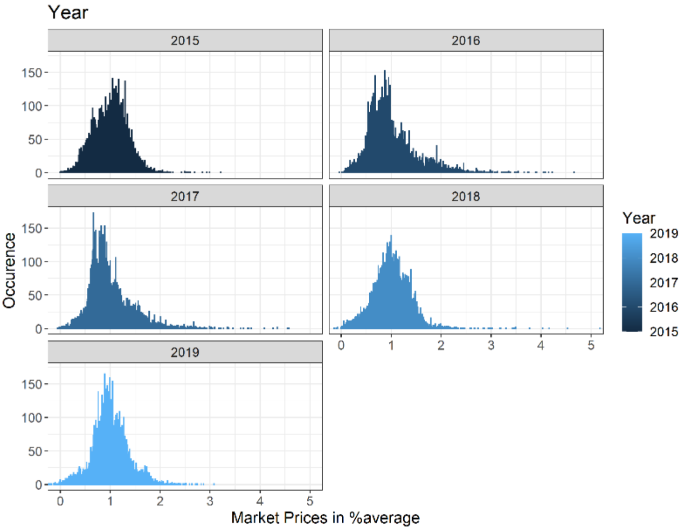
TYNDP Capacities

Summary of installed capacity considered for long-term scenario based on TYNDP20 for the year 2040



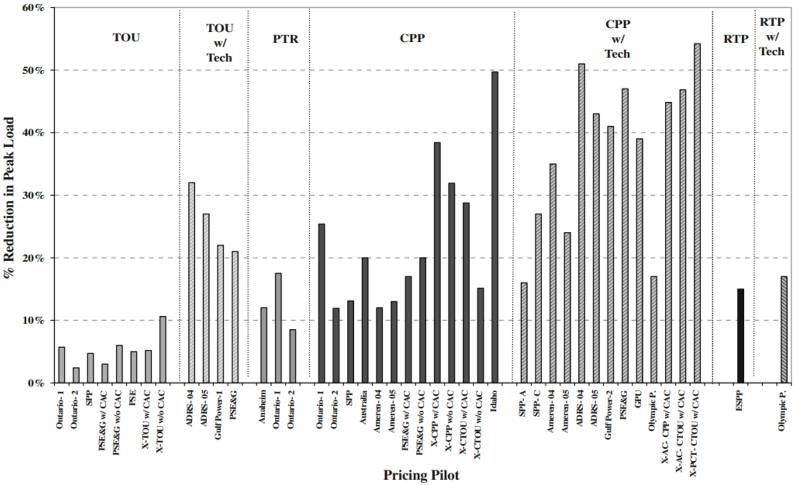
(ENTSO-e, ENTSOG, 2020)

Historical Market prices



Survey of experiments

Household response to dynamic pricing of electricity: a survey of 15 experiments



(Faruqui, 2010)

ToU

- For residential ToU, we based it on the Low Carbon London initiatives who assess response of ToU depending on season and hour.

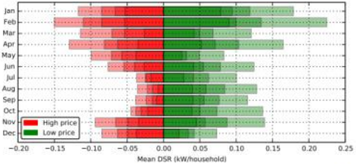


Figure 5.21: Mean DSR by month. Bars, from lighter to darker shading, represent the average for subgroups of the most engaged 25%, 50%, 75% and 100% of responders.

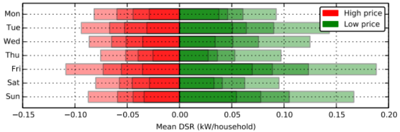


Figure 5.22: Mean DSR by day of week. Bars, from lighter to darker shading, represent the average for subgroups of the most engaged 25%, 50%, 75% and 100% of responders.

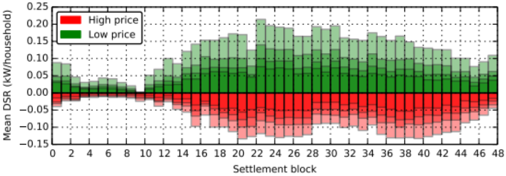


Figure 5.23: Full year mean DSR by settlement block. Bars, from lighter to darker shading, represent the average for subgroups of the most engaged 25%, 50%, 75% and 100% of responders.

Ward methodology