The Value of Lost Load in a decarbonised power sector

Mathilde Fajardy, David Reiner

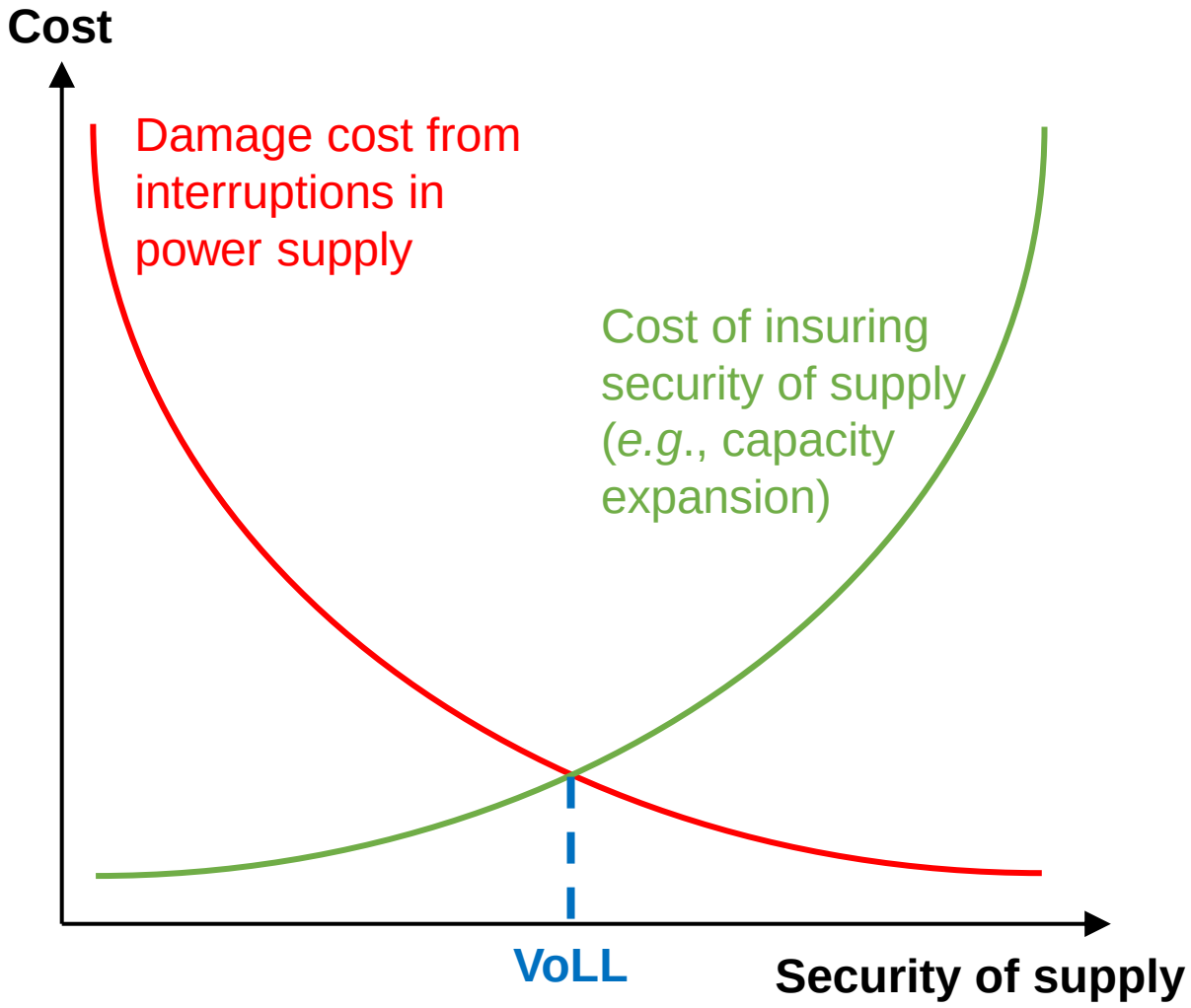
Energy Policy Research Group, Judge Business School

University of Cambridge

What is VoLL?

- **Optimal level of security** required to supply peak electricity demand is based on **Value of Lost Load (VoLL)**

- Maintaining **traditional standards** for security of electricity supply might not be appropriate given the **increased costs of maintaining such standards in a deeply-decarbonised system**



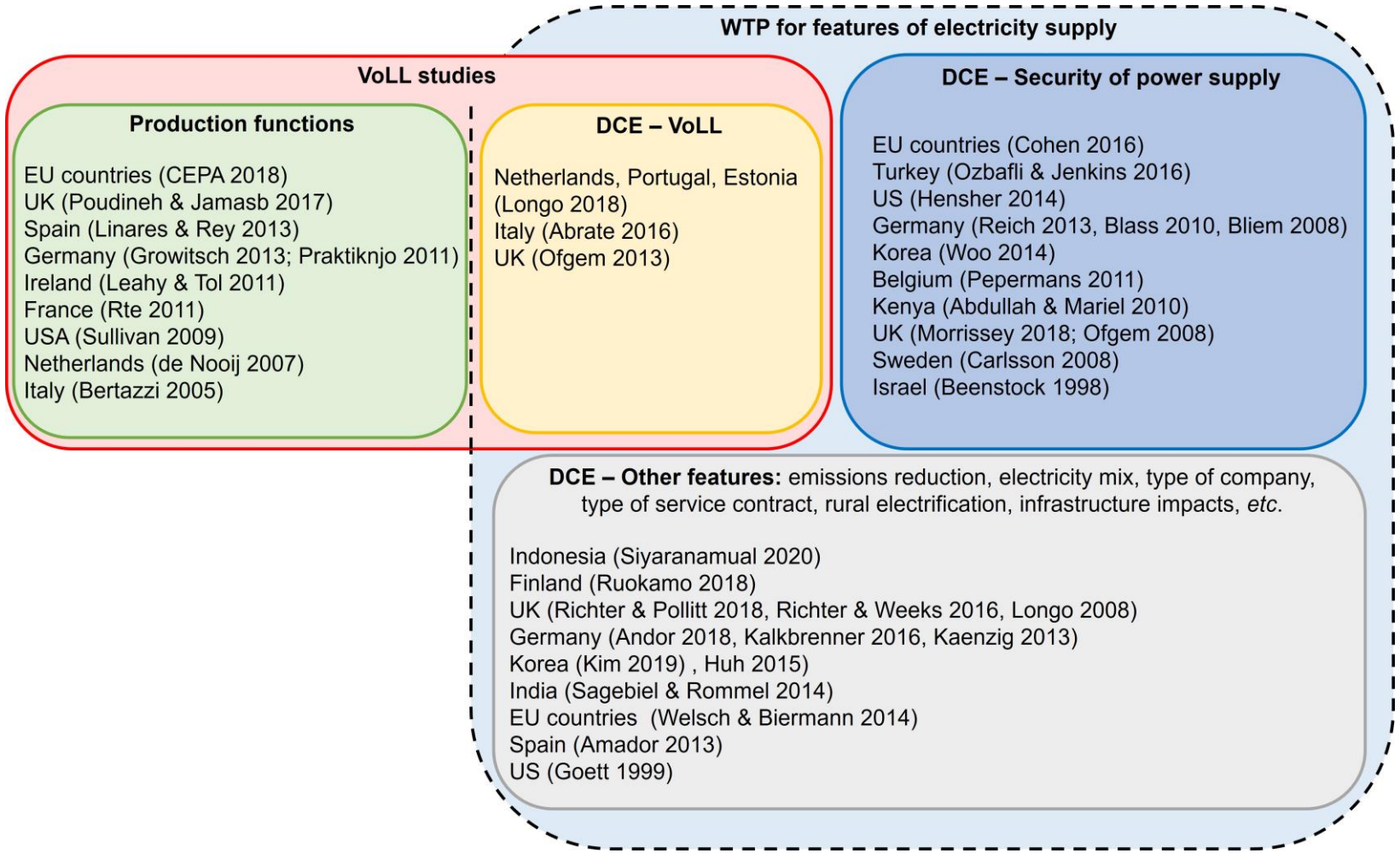
VoLL in Great Britain

- GB's **current VoLL** for domestic and commercial consumers is an **average annual value** determined by a **discrete choice experiment** (DCE) in 2013 (Ofgem 2013) performed on both commercial and domestic consumers

- Ovaere *et al*. (2019) shows that using a more segmented and time-varying VoLL could lower operational costs of the electricity system by 40%, which suggests that there is a need for time-varying and segmented VoLL studies at the country level

- Currently no study assessing how domestic VoLL might be impacted by renewable share in the grid

VoLL literature landscape



- **Two main approaches**:
  - Indirect: production functions
  - Direct: contingent valuation and **Discrete Choice Experiments (DCE)**
- **Very few explicit VoLL studies** using a **DCE approach**
- Many willingness-to-pay studies (WTP) on the security of electricity supply, but **few include the share of renewable** or CO_2 emissions as an attribute

WTP for renewable integration

- Only one study on the WTP to avoid interruptions featuring emissions reduction as an attribute (Ofgem 2008): showed that WTP is the highest for the emissions reduction attribute
- Among studies WTP for electricity services, **respondents are WTP a premium for renewable integration in higher-income countries**
- This **premium** is typically **lower** than the **actual cost** of **renewable integration**
- In lower-income countries, no significant WTP for renewable in India (Sagebiel 2014), and consumers care more about urban electrification than renewable integration in Indonesia (Siyaranamual 2020)
- Past studies show a **non-linear relationship between WTP and renewable integration** (slope decreases with increasing share) (Goett 2000): suggests that respondents care more about the **"concept of renewables" than their environmental impact**

Study objectives and limits

1) Explore how **VoLL of GB households** might **have evolved** since the last time it was quantified in 2013 by the UK network operator (Ofgem) by emulating their method
2) Determine **how VoLL might be impacted by an increasing share of renewable electricity in the grid**
3) Provide insights into how VoLL **might vary across different population segments**

- The study does not pretend to provide the UK's network operator with an updated VoLL, as it suffers from two limitations: 1) it only covers **domestic consumers**, and 2) **internet-based surveying methods** under-represent poorly connected areas

Methods

- Online survey on a UK representative sample of **3,016 respondents**
- 2 different DCE on each half of the sample: **1,500 with the 'season' version**, **1,516 with the 'renewable' version**
- **'Loss aversion' bias** (Beenstock 1998): half of the choice cards formulated as WTP, and half as WTA
- **'Status-quo' bias** (Hartman 1991): respondents cannot choose to keep their current system, but can respond "I don't know"
- **Mixed-logit** formulation to capture heterogeneity in respondent's valuation (Train 2003), all variables are random
- **WTP space** to analyse the distribution of the WTP and VoLL (Richter 2018, Hole 2007)
- **Duration variable interacted** with frequency, time of year, time of day and share of renewable to evaluate VoLL for different time/share of renewable (Ofgem 2013)
- **Heterogeneity** explored with interactions between price and duration and key covariates (selected based on previous studies)

Methods – survey questions

1. **Housing characteristics**: dwelling type, dwelling age, dwelling floor area, number of rooms, energy performance certificate rating, heating technology
2. **Attitude towards energy**: knowledge about energy supply, energy consumption, smart metering ownership, time of peak energy demand, fuel consumption, heating patterns
3. **Environmental concern/knowledge**: climate change concern, share of renewables in electricity supplier, voting preference
4. **Socio-demographics**: age, income, gender, occupation, tenure type, financial situation, geographic location
5. **VoLL DCE specific attributes**: duration of interruption, frequency of interruption, season of interruption, time of day of interruption, share of renewables in electricity grid

Discrete choice experiment – ‘season’

Choice card (example)	A	B
Duration of interruption	20 minutes	4 hour
Time of day	Peak (3pm-9pm)	Off-Peak (10pm-2pm)
Frequency of interruption	Once every 2 years (“1-in-2”)	Once every 4 years (“1-in-4”)
Season of interruption	Off-winter	Winter
Price to pay to avoid interruption (4 cards out of 8)	£1 one-off payment	£10 one-off payment
Which option do you prefer?	☐	☐

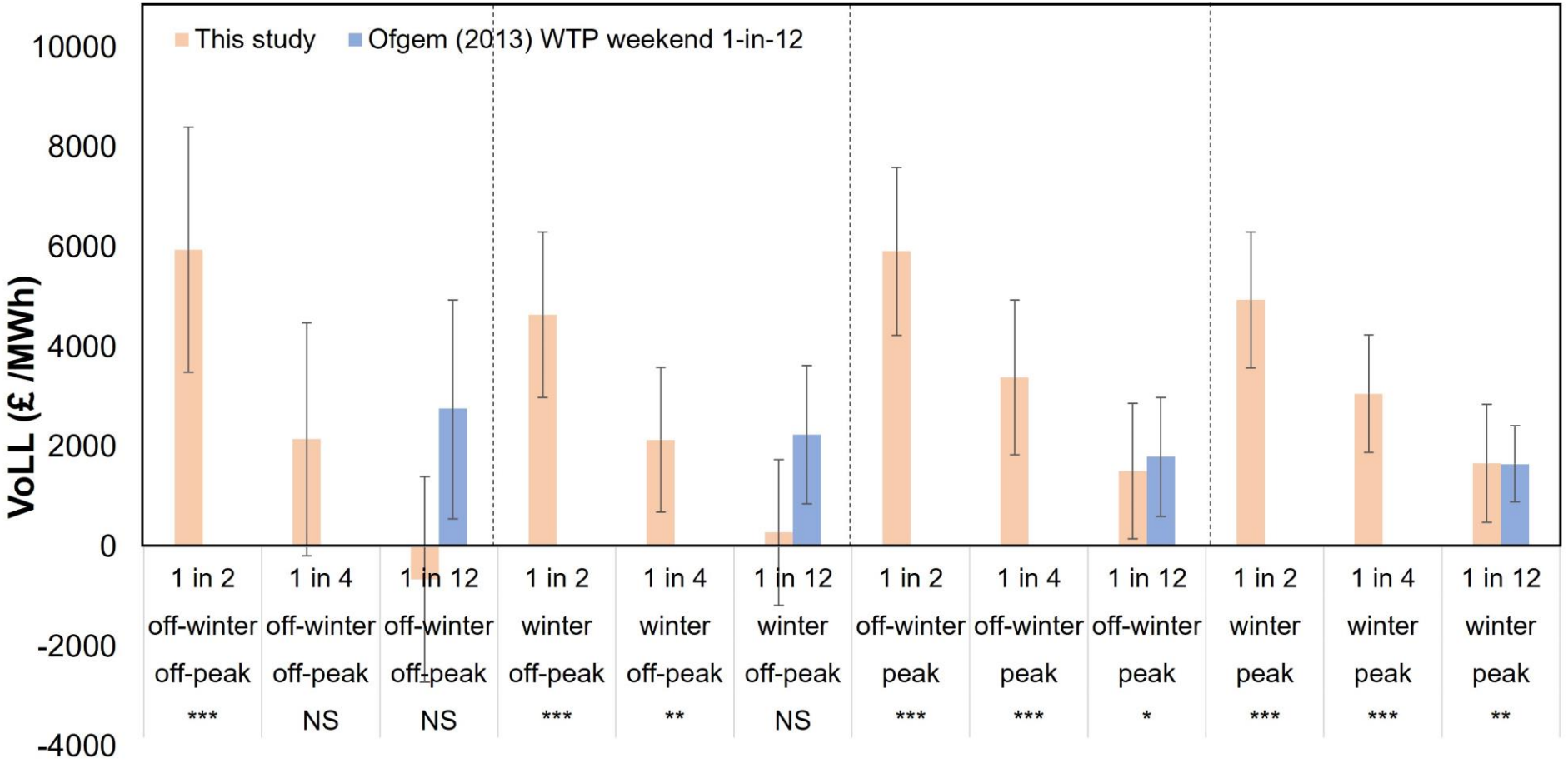
☐ I Don’t know

Discrete choice experiment – ‘renewable’

Choice card (example)	A	B
Duration of interruption	20 minutes	4 hour
Time of day	Peak (3pm-9pm)	Off-Peak (10pm-2pm)
Frequency of interruption	Once every 2 years (“1-in-2”)	Once every 4 years (“1-in-4”)
Share of renewables in the grid (50% of the sample)	99%	50%
Price to pay to avoid interruption (4 cards out of 8)	£1 one-off payment	£10 one-off payment
Which option do you prefer?	☐	☐

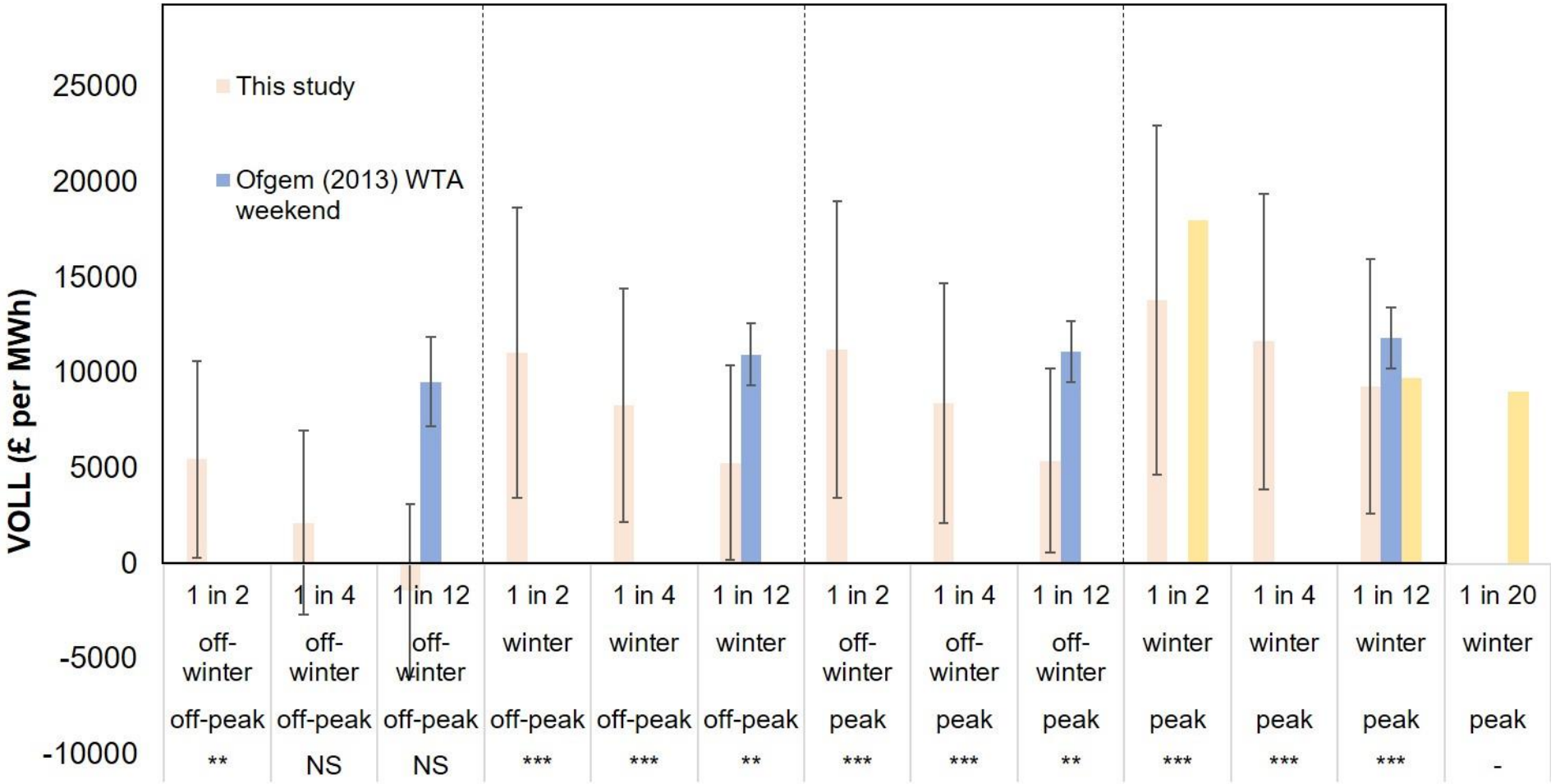
☐ I Don’t know

1. VOLL today *vs*. Ofgem 2013



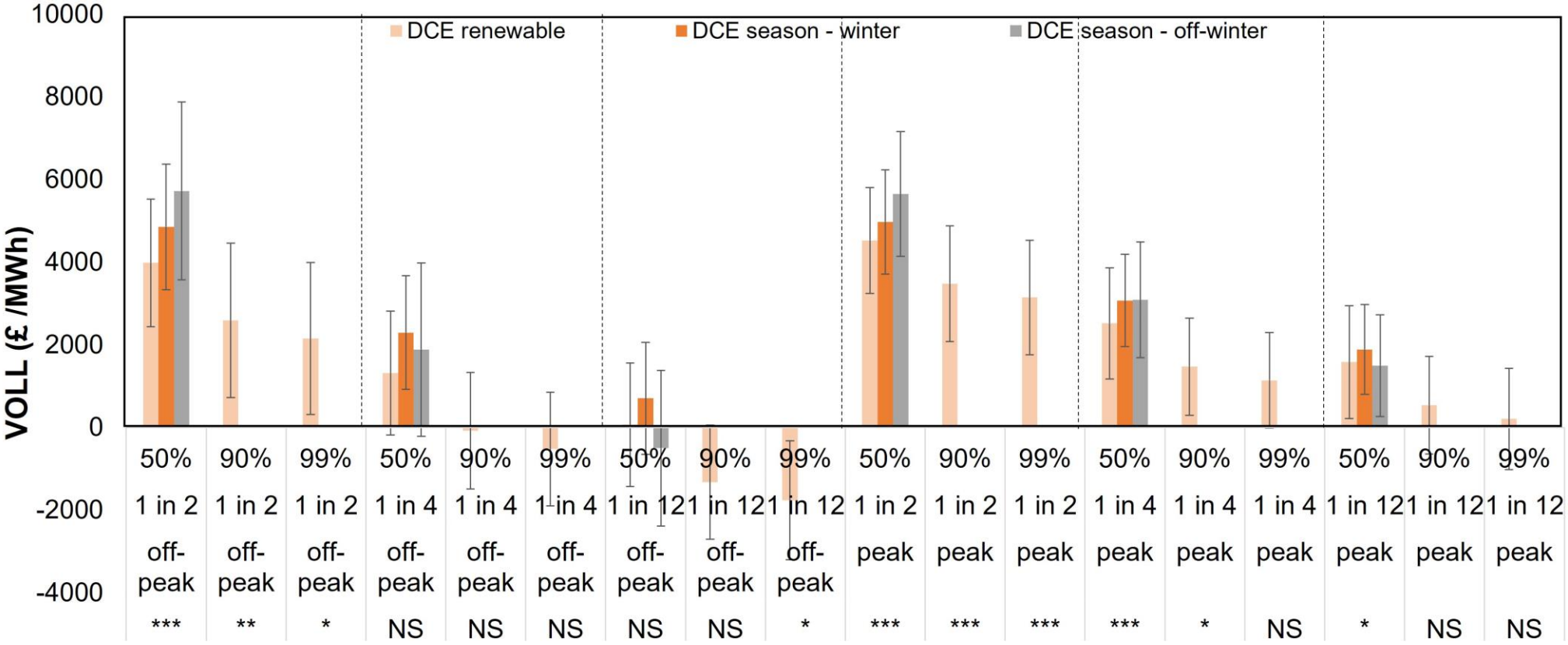
- Results in line with the Ofgem 2013 study
- VoLL is within the confidence interval
- VOLL increases linearly with frequency

2. WTP vs. WTA



- The WTA version is also consistent with the Ofgem study
- As in the Ofgem study, we find a large difference between WTP and WTA values

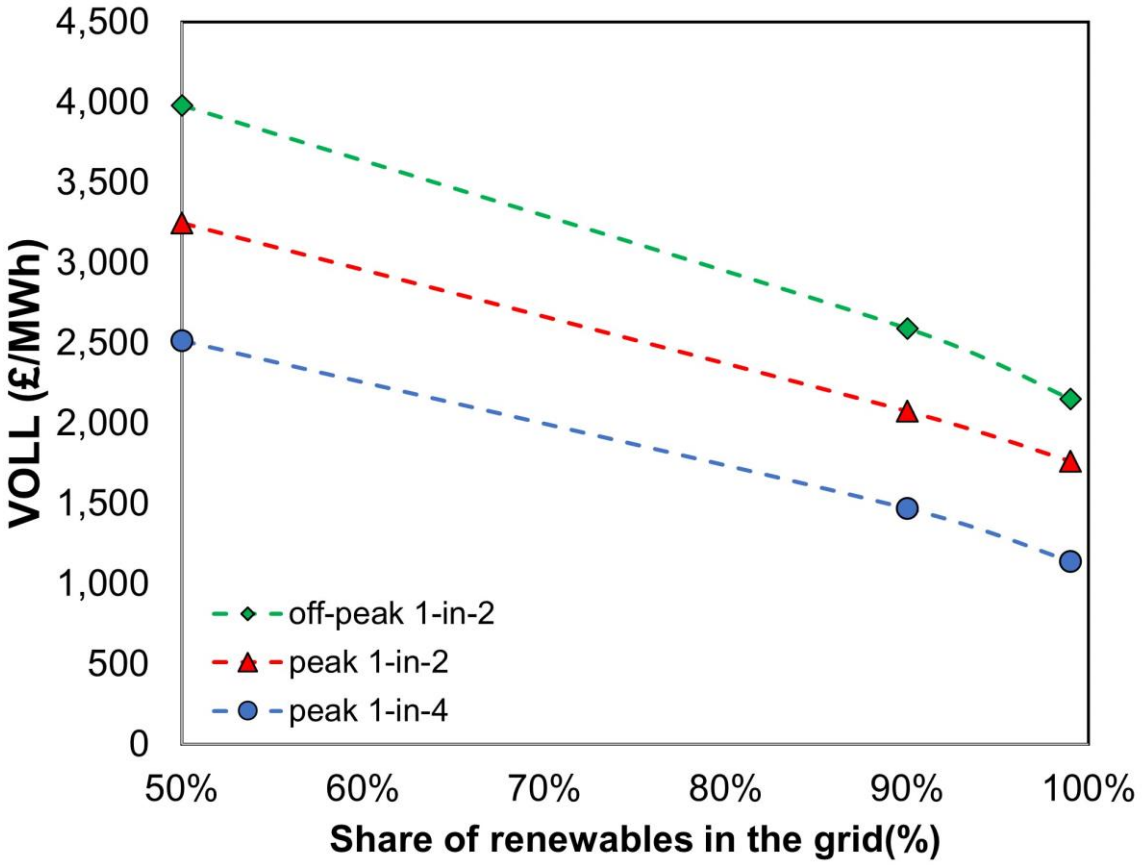
3. The impact of renewable integration



- Respondents do value the share of renewable electricity in the grid, and are ready to lower the current standard of electricity supply to increase this share.

- WTP to avoid an interruption occurring during peak time every 4 years but with a 90% renewable grid is found lower than for one occurring every 12 years but with a 50% renewable grid.

VoLL and renewables



- VOLL decreases roughly linearly with the increasing share of renewables in the grid
- Clear change in perception of renewable from past studies (Goett 2000)

4. Drivers of heterogeneity – 'season'

DCE-S, frequency effect	Segments	WTP (£/h)	[95% Conf.	Interval]	VOLL (£/MWh)	Significance
peak winter 1-in-2	Others	2.09	1.33	2.84	3660	***
	age5	5.49	1.59	9.39	9625	***
	highinc	3.38	2.30	4.46	5919	***
	age1	1.60	0.90	2.31	2814	***
	ownelec	0.98	0.60	1.36	1715	***
peak winter 1-in-4	Others	1.15	0.47	1.83	2016	***
	age5	3.94	0.90	6.98	6908	***
	highinc	2.44	1.45	3.43	4275	***
	age1	0.88	0.32	1.45	1550	***
	ownelec	0.54	0.21	0.87	945	***
peak winter 1-in-12	Others	0.40	-0.28	1.07	698	NS
	age5	2.70	0.24	5.16	4730	**
	highinc	1.69	0.71	2.66	2957	***
	age1	0.31	-0.22	0.83	537	NS
	ownelec	0.19	-0.13	0.50	327	NS

NS: not significant, *** if p<0.001, ** if p<0.01, * if p<0.05; age1: age<24, age5: age>65, highinc: income > £50k, ownelec: produces own electricity, envi: concerned by climate change

- Producing own electricity has an important impact of the VoLL in spite of representing small fraction of the population

- Age and income effects in both versions of the DCE:
  - Younger respondents are WTP less, while older respondents are willing to pay more
  - Higher income respondents are WTP more

4. Drivers of heterogeneity – ‘season’

DCE-R, renewable effect	Segments	WTP (£/h)	[95% Conf.	Interval]	VOLL (£/MWh)	Significance
peak 1-in-2 50% renewable	Others	1.82	1.11	2.52	3133	***
	age5	4.59	1.91	7.26	7918	**
	highinc	2.71	1.70	3.71	4669	***
	envi	1.46	0.81	2.11	2520	***
	age1	1.24	0.75	1.73	2144	***
	ownelec	1.10	0.64	1.56	1898	***
peak 1-in-2 90% renewable	Others	1.30	0.58	2.02	2251	***
	age5	3.76	1.39	6.14	6494	**
	highinc	2.20	1.19	3.21	3790	***
	envi	1.05	0.42	1.67	1810	**
	age1	0.89	0.39	1.39	1540	***
	ownelec	0.79	0.34	1.24	1363	**
peak 1-in-2 99% renewable	Others	1.13	0.42	1.83	1945	**
	age5	3.48	1.20	5.75	6001	**
	highinc	2.02	1.02	3.02	3484	***
	envi	0.91	0.30	1.51	1564	**
	age1	0.77	0.28	1.26	1331	**
	ownelec	0.68	0.25	1.12	1178	**

NS: not significant, *** if p<0.001, ** if p<0.01, * if p<0.05; age1: age<24, age5: age>65, highinc: income > £50k, ownelec: produces own electricity, envi: concerned by climate change

- Similar trends in DCE ‘renewable’
- Environmental concern which was not a driver of heterogeneity in DCE ‘season’ has an impact on VoLL in DCE ‘renewable’
- Environmental concern could further decrease VoLL

Conclusions 1/2

- VoLL within **the 95% confidence interval of Ofgem (2013)** which confirms the **robustness of DCE** to assess GB domestic VoLL

- **Frequency is a key driver of VoLL,** with a linear relationship between VoLL and frequency

➢ Suggests a potentially high increase in VoLL should the transition to a low carbon grid cause an increase in blackout frequency

➢ Highlights the need to explore VoLL response to higher frequencies (infra year)

- Domestic **VoLL decreases linearly with renewable integration** (from 50% to 99%):

➢ **important paradigm shift** compared to existing studies pointing out to the fact that respondents only value how green the electricity grid is to a certain point (Goett 2000)

Conclusions 2/2

- **WTP to avoid more frequent interruptions** (1-in-4) but occurring on a **cleaner grid** (90%) is found **lower than WTP to avoid less frequent interruptions** (current frequency standard 1-in-12) occurring on **a grid with less renewable (50%)**

➢ Renewable integration could **compensate the effect of higher blackout frequency** on domestic VoLL

- Heterogeneity driven by the same effects across both DCEs, mainly **income and age**: overall, older and higher income respondents are willing to pay more to avoid blackouts, while younger respondents are willing to pay less
- **Environmental concern was only found statistically significant in DCE 'renewable'** which confirms that renewable integration could further decrease VoLL

Appendix

Quality control

- Compute versions 1 and versions 2 separately (different sets of respondents)
- Compute WTP and WTA choice cards separately (compare WTP and WTA)
- Take out respondents with random answering behaviour among the 8 choice cards
- In each WTP/WTA subgroup, take out respondents who show non-engagement (4 “I don’t know” out of 4

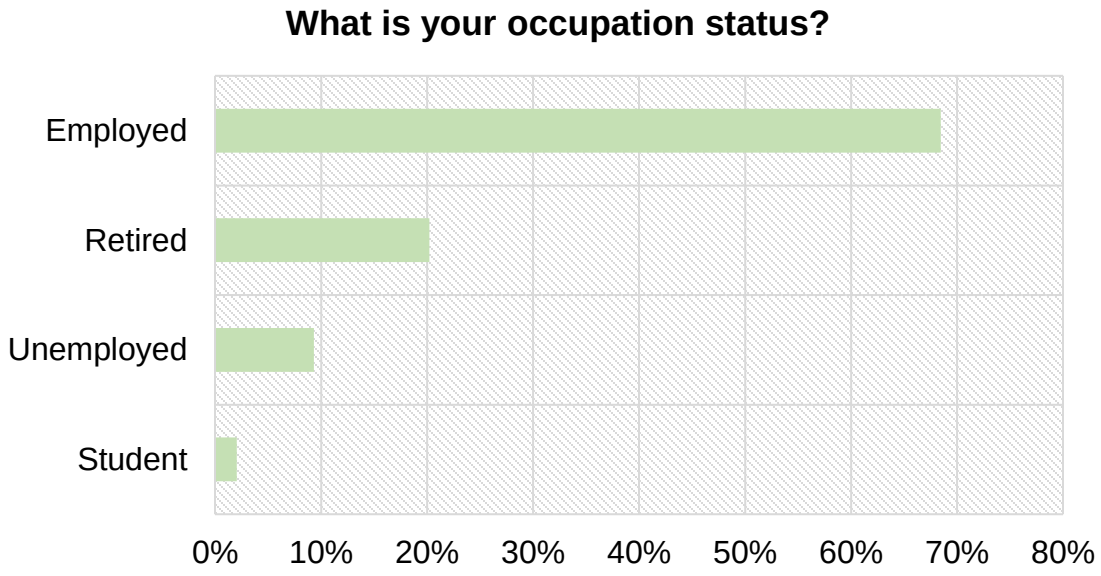
	Number of respondents				Number of observations			
Total	3016				72784			
	Version 1		**Version 2**		**Version 1**		**Version 2**	
0. Season vs renewable versions	1500		1516		36000		36384	
1. Take out respondents with random answers								
8 "A" out of 8 choice cards	1470		1487		35280		35688	
8 "B" out of 8 choice cards	1440		1475		34560		35400	
8 "NoChoice" out of 8 choice cards	1331		1346		31944		32304	
2. WTP/WTA differentiations	**WTP**	**WTA**	**WTP**	**WTA**	**WTP**	**WTA**	**WTP**	**WTA**
	1331	1331	1346	1346	15972	15972	16152	16152
3. Take out respondents who showed non-engagement (more than 3/4 I don't knows)	1287	1309	1303	1312	15444	15708	15636	15744

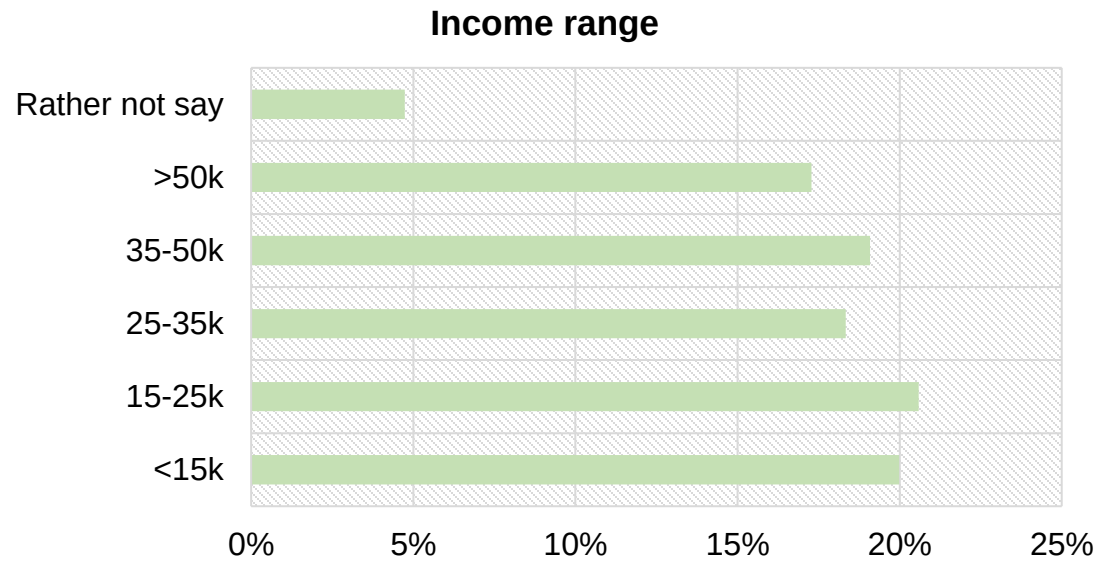
Potential drivers of heterogeneity
General statistics

- A priori identification of potential heterogeneity among population:
  - **General statistics**: age, whether there are children in the household, education, dwelling environment
  - **Reliance on electricity**: whether produces own elec, whether is electrically heated or cooled
  - **Occupation and income**
  - **Attitudes towards the environment:** green energy plan subscription, concern about climate change
  - **Peak electricity demand time** (attribute in DCE)

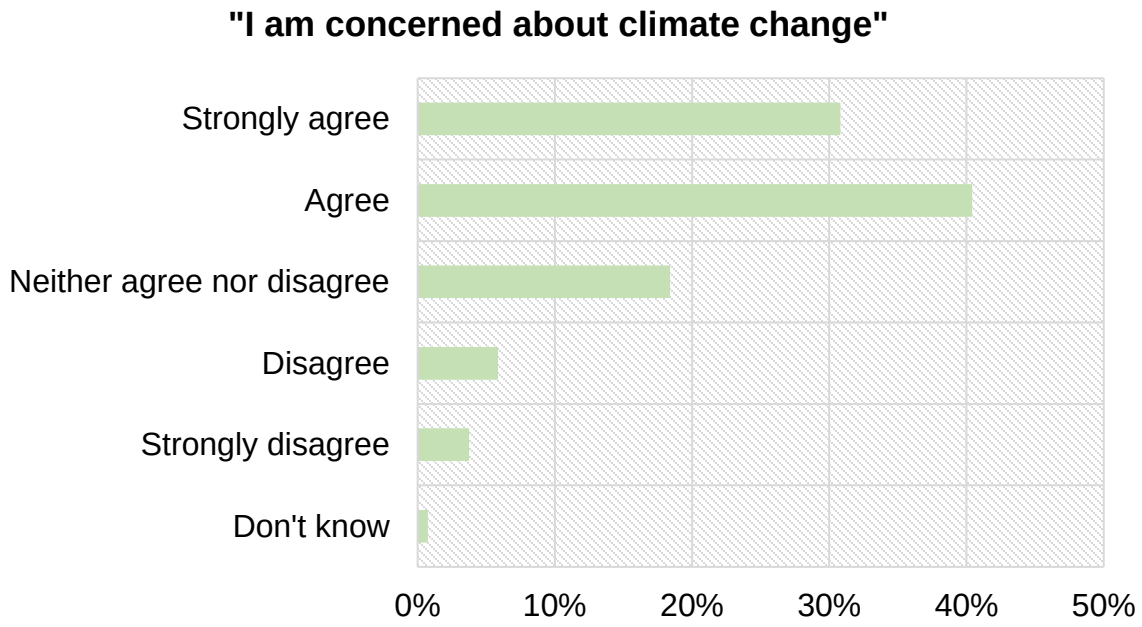
	V1 (season)	V2 (renewables)
Population	1331	1346
Age		
18-24	11%	11%
25-34	16%	17%
35-44	16%	16%
45-64	33%	34%
65-	23%	23%
Children	33%	35%
High education	43%	42%
Setting		
Rural	21%	22%
Urban	79%	78%
Elec heating	10%	9%
Own elec	3%	4%
AC owner	8%	8%

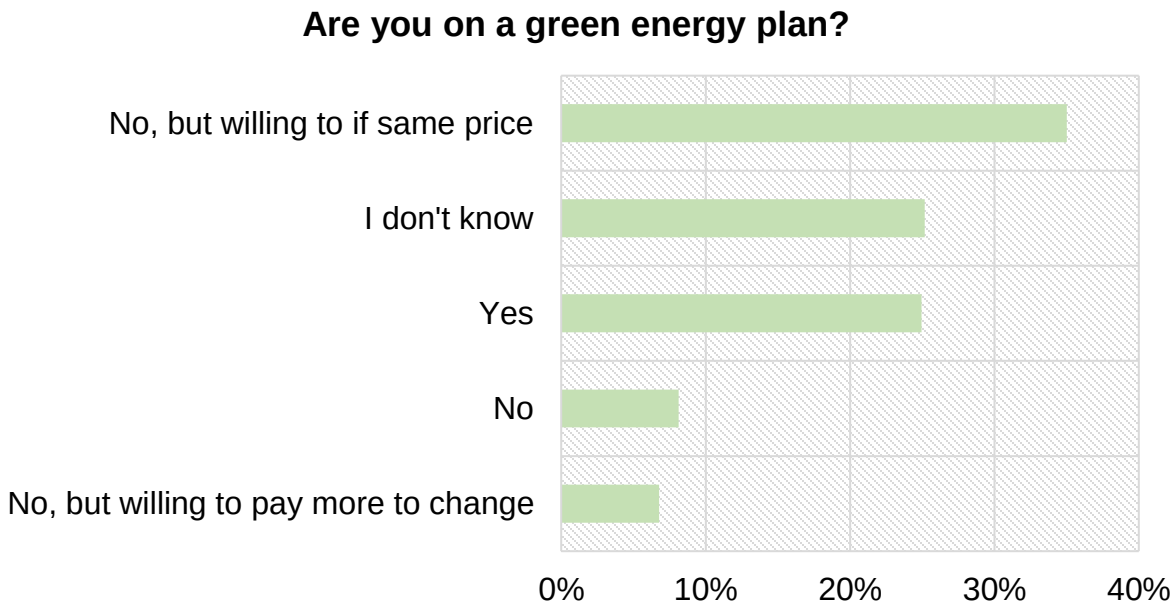
Potential drivers of heterogeneity
Occupation and income





Potential drivers of heterogeneity
Attitudes towards the environment (V2)

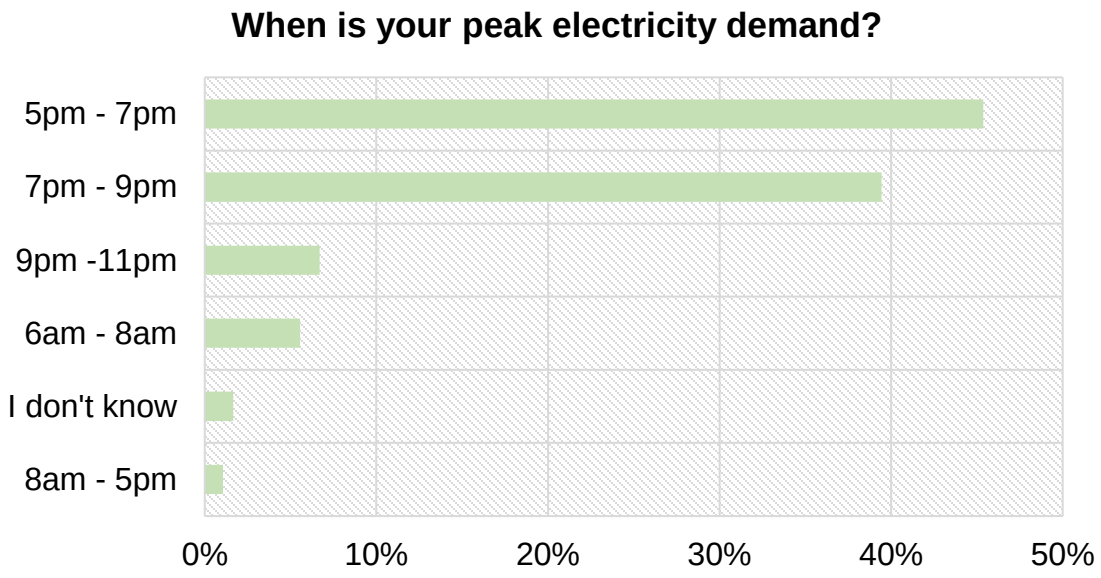




- Only 10% correlation between environmental concern and subscribers to a green energy plan
- Higher income respondents, the share of green energy plan subscribers increase to 28%, and the share of respondents not on a plan and willing to pay more increases to 9%
- Among higher education respondents, these values increased to 30% for green plan subscribers, and decreased to 5% for non-subscribers willing to pay more.

Potential drivers of heterogeneity

Peak demand information



- a large majority of the population (90-92%) have a peak electricity demand in the evening, with 43-45% between 5 and 7pm, 39-41% between 7 and 9pm and 7% between 9 and 11pm
- Only 6-7% of people claim to have their peak demand in the morning (6-8am), while a marginal amount claim their peak occur during the day (0-1%), or do not know when their peak is (2%).
- This confirms our choice of indicating that peak time occurred between 3 to 9pm in the survey.