Customer-Led Network Revolution

After Diversity Maximum Demand (ADMD) Report

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1 Introduction

After diversity maximum demand is used in the design of electricity distribution networks where demand is aggregated over a large number of customers. After diversity maximum demand (ADMD) accounts for the coincident peak load a network is likely to experience over its lifetime and as such is an overestimation of typical demand. The period of consideration used in this study was one whole year for each customer type. Not all customers coincide with the same year but do have the same winter period in which a peak demand is likely to occur. Peak electric vehicle charging is also shown to be seasonally dependent.

Network peak demand, considering diversity between customers is time coincident where within each household there are times, mainly the 4-8pm period, in which electricity is used simultaneously, for example when all appliances are used at the same time. An ADMD is normally 2kW when electric heating isn't present[1]. Generally it is shown that as the number of customers increases, the maximum time-coincident demand per dwelling falls and the uncertainty decreases.

1.1 Initial findings

- Demands stabilise at 1.5kW for the sample population of domestic customers. Note: no account for sample bias is accounted for in this study.
- Generally, analytical solutions in the form of a first term power model are good approximations to demand with i customer. An exception to this is for vehicle charging and home only demands for electrical vehicle customers.
- Fluctuations in demand between customer numbers i can be attributable to sample variation, larger sampling could limit this.
- Lower ADMD resulted for all three CLNR demographic income groups at the 100th customer level than with several groups in the mosaic demographics.
- Solar customers without any intervention (TC5) show the lowest demand of all customers with magnitudes resembling those of Active retirement.
- Solar customers with an in home display represent demands to Terraced melting pot customers
- Home only demand for EV customers are high demand customers (2kW at the 100th customer)

[1] T.Haggis. Network Design Manual, E.on, 2006. Available at: http://www.eon.uk.com/downloads/network_design_manual.pdf

1.2 Methodology

The ADMD is the mean demand of all peak demands for a group of customers i in the set of customers I under consideration for each time t over the yearly time domain T. The diversified maximum demand P for each customer is given by:

$$P_i = \max(\bar{d}_{i,t\rightarrow T}) \quad (1)$$

Where $\bar{d}$ is the average load at time t for i customers where T is the total time element under consideration and represents the 365 days with each day comprising 48 half hours. Having computed the peak average load across all times during a year for a set of customers $i \in I$ where $I = \{1,2, \dots 100\}$ their collective mean and variance of the maximum demands are obtained through:

$$\hat{d}_i = \frac{1}{N}\sum_{i=1}^{N} P_i \quad (2)$$

This approach was repeated $N = 1000$ times for each i in I. In this study it was assumed no homogeneity exists between customers on a feeder and the customers are independent. For this reason sampling with replacement was utilised as the bootstrap approach. Resampling without replacement showed the variance tended to zero at the maximum number of customers, this method also assumes covariance between customers. The standard error from the mean diversified maximum demand was computed from the array of customer maximum loads.

On residential developments the total load on the transformer shall be calculated according to[1]:

$$\mathrm{Load} = \mathrm{N} \cdot \mathrm{A} \cdot \mathrm{Ft} \cdot \mathrm{F2} \quad (3)$$

Where $\mathrm{F2}$ is a diversity factor and is given by $1 + \frac{12}{\mathrm{A}\cdot\mathrm{N}}$, N = number of customers, $\mathrm{A} = \mathrm{ADMD}$ in kW and Ft = 70%. The correction factor $\mathrm{Ft} \cdot \mathrm{F2}$ produces high multipliers for low customer numbers

2 Results

ADMD computations have been computed for three general customer types; Base domestic (TC1a), solar customers and those with electric vehicles (EV). Each customer type have specific parameter demand subsets, for instance in TC1a the mosaic demographics as previously elaborated[2] are classifications of an individual's lifestyle and behaviour. This data did not exist for the remaining test cells however there are two types of solar customers, with and without an intervention and demand compositions for electric vehicle customers, the EV and house demand, this comprises the total import power.

Sample metrics for the ADMD at selective customer levels are presented in the appendix. Specifically the ADMD of 1, 25, 50, 75 and 100 customers are depicted with the associated standard deviation which appears on the figures throughout the report.

2.1 CLNR base domestic customers

All mosaic demographic groups[3] have a stabilised ADMD at the 100th customer between 1.2 and 2kW. Several groups yield ADMD below 1.5kW, groups D, E, L and N (D Small town diversity, Active retirement, Elderly needs and Terraced Melting Pot). Suburban Mindsets and H New Homemakers had demands at 2kW with the whole population sample giving rise to an ADMD of 1.5kW. The small fluctuations between customer numbers i can be attributable to sample variation since $N = 1000$ may not be sufficient and further work to verify this number would be required.

For an individual customer the alpha territory (mosaic group A) has a higher demand than any other group (except those in rural solitude) at around 5.6kW with terraced melting pot the lowest maximum at circa 4kW.

Fitting a solution to the above figures individually a one term power model seems to be adequate with 3 out of the 16 groups providing a goodness of fit in excess of 0.9. The coefficients of the terms for each customer group with their respective R^2 values can be seen in .

With small numbers of customers the diversity between customers could be large, hence there is considerable uncertainty as to the maximum demand. As the number of dwellings increases, the maximum time-coincident demand per dwelling falls and uncertainty decreases.

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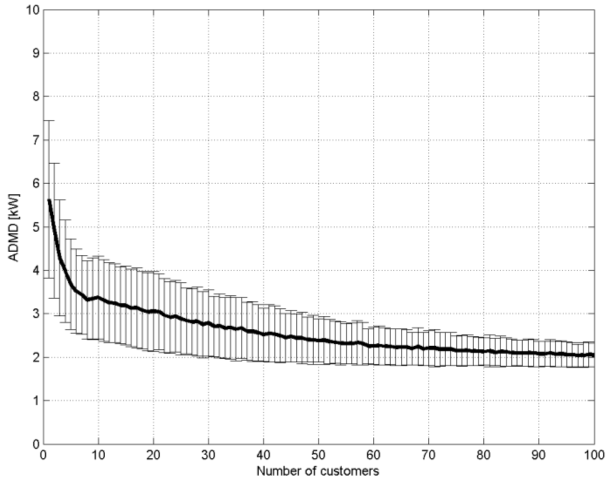
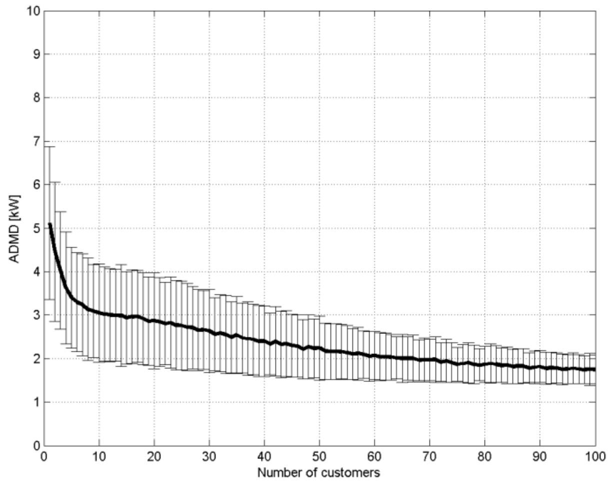
[2] TC1a insight report, Christian Barteczko-Hibbert et al

[3] http://www.experian.co.uk/assets/business-strategies/brochures/Mosaic_UK_2009_brochure.pdf

A Alpha territory

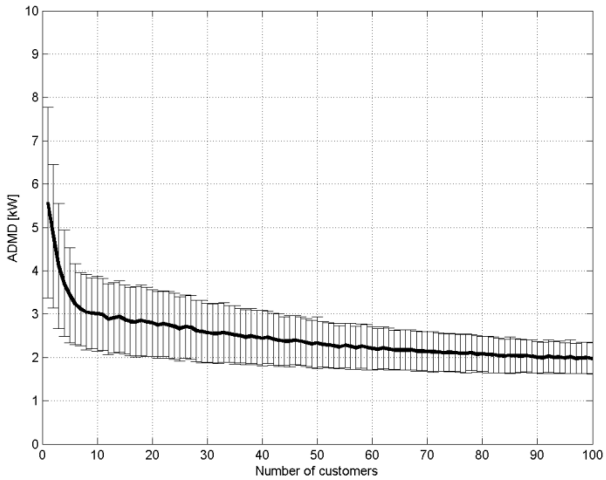
B Professional rewards

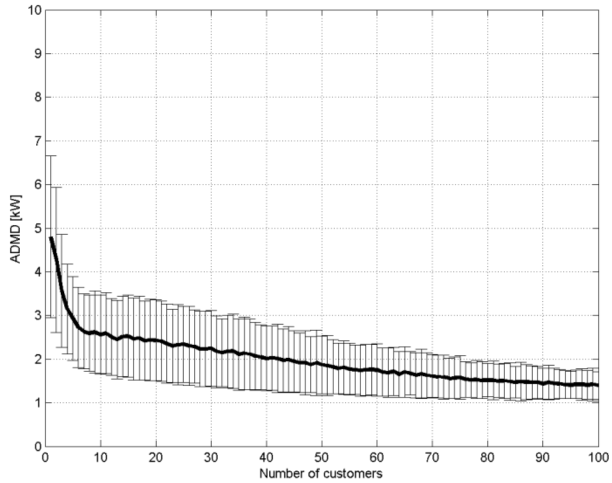




C Rural solitude

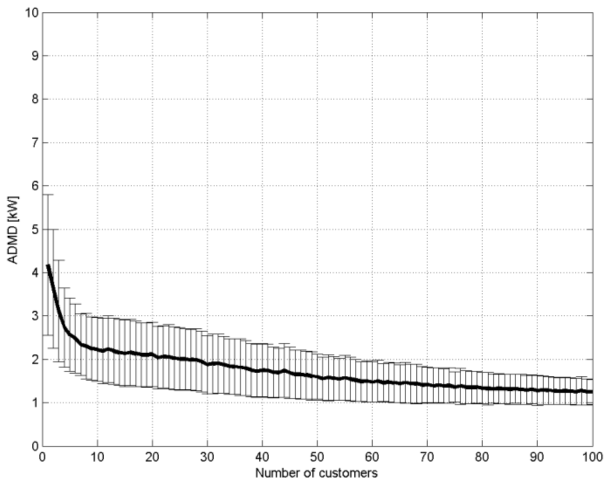
D Small town diversity

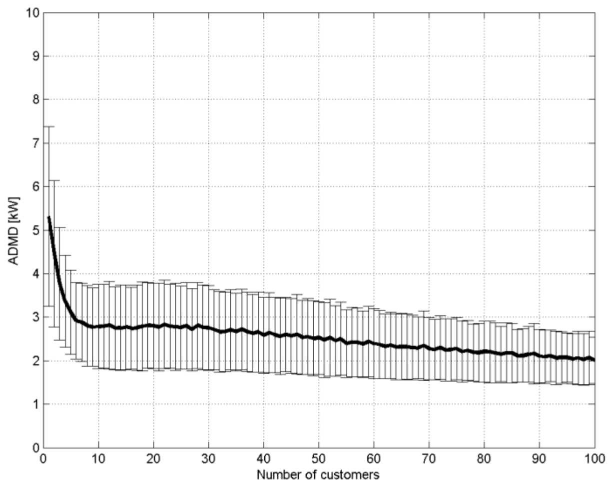




E Active retirement

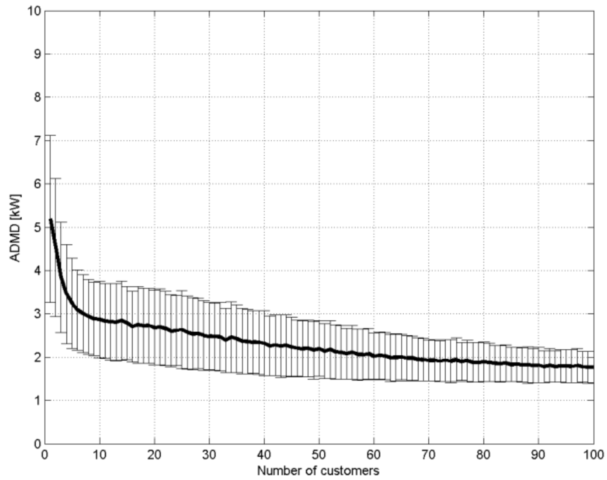
F Suburban mind sets



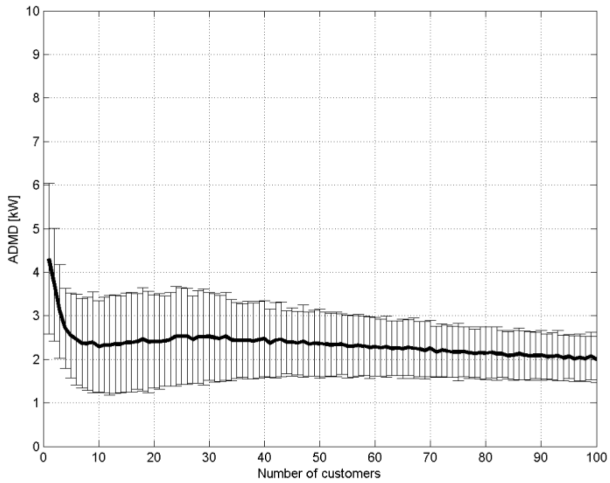


G Careers and kids

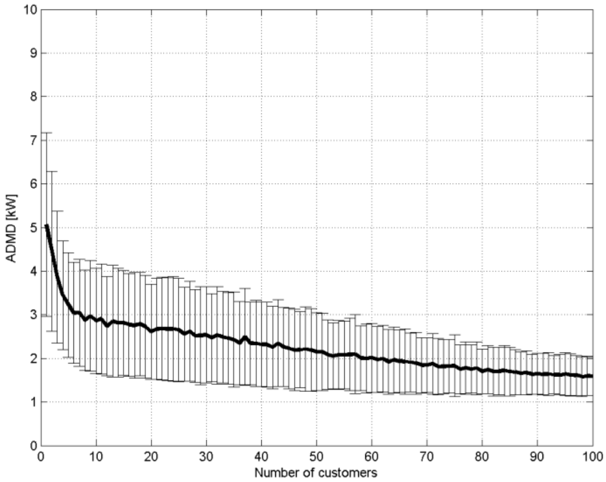
H New homemakers



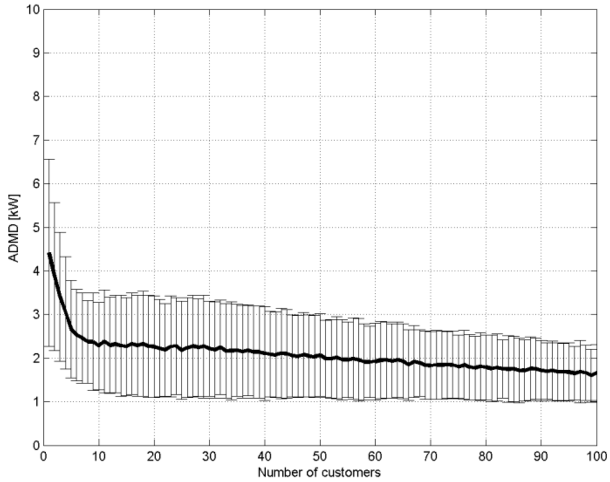
I Ex-council community



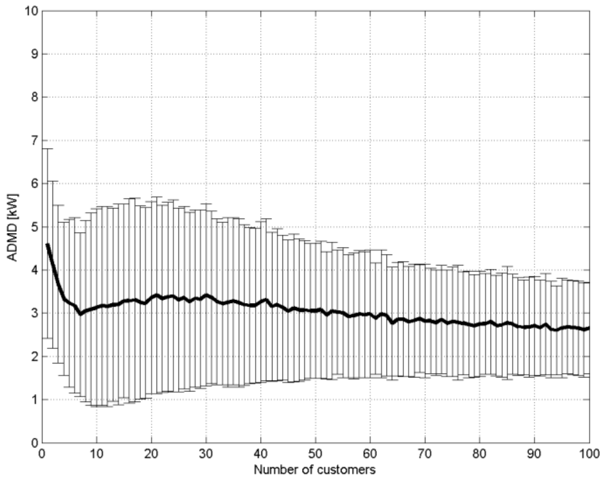
J Claimant cultures



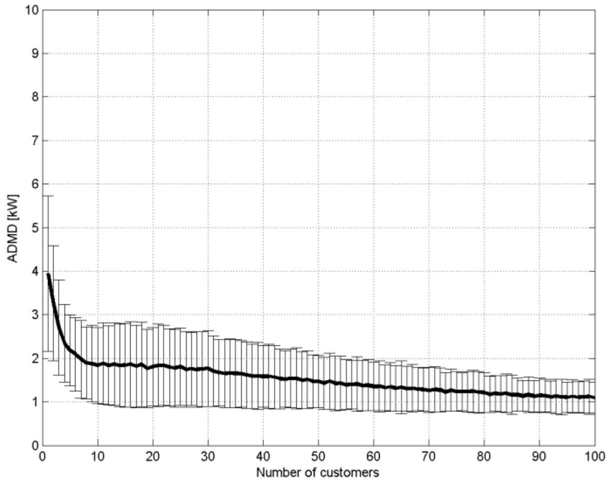
K Upper floor living



L Elderly needs



M Industrial heritage



N Terraced melting pot

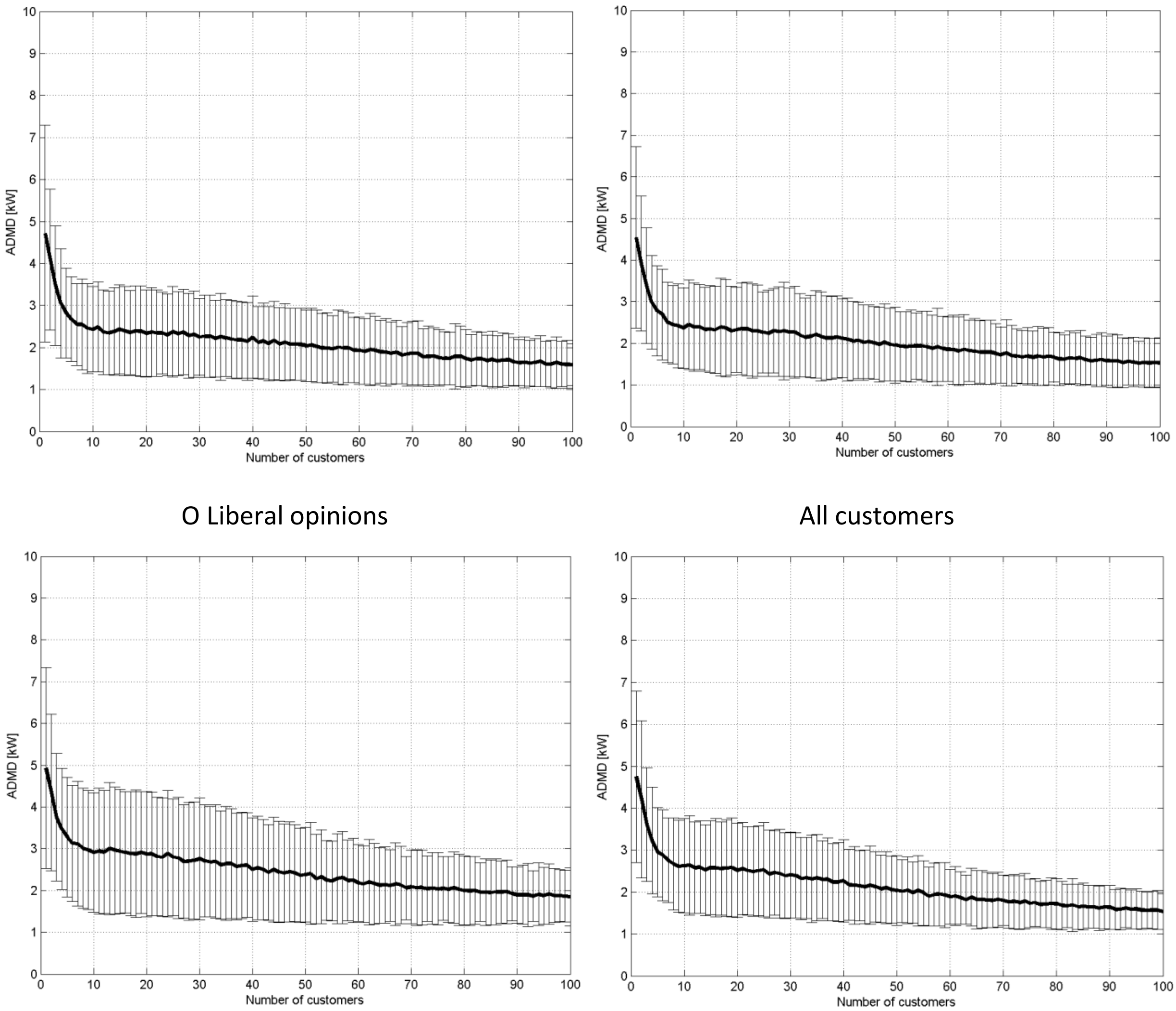


Figure 1: ADMD curves for the base domestic customers and split by the mosaic categories

Table 1: Coefficients and the goodness of fit to the closed form solution $y = a \cdot x^b$

customer	coef a	coef b	Rsquare
A Alpha Territory	5.531	-0.214	0.985
B Professional Rewards	5.217	-0.223	0.961
C Rural Solitude	5.152	-0.208	0.969
D Small Town Diversity	4.764	-0.247	0.954
E Active Retirement	4.128	-0.246	0.967
F Suburban Mindsets	4.540	-0.163	0.867
G Careers and Kids	4.982	-0.218	0.970
H New Homemakers_	3.431	-0.106	0.672
I Ex-Council Community	5.074	-0.229	0.943
J Claimant Cultures	3.963	-0.181	0.912
K Upper Floor Living	4.035	-0.074	0.580
L Elderly Needs	3.612	-0.241	0.934
M Industrial Heritage	4.297	-0.201	0.926
N Terraced Melting Pot	4.239	-0.207	0.934
O Liberal Opinions	4.827	-0.190	0.934
All TC1a customers	4.647	-0.218	0.939

In a similar manner ADMD was computed for the CLNR income categories, Figure 2 to Figure 4 illustrates these. High income customers at the 100th customer level give an ADMD of 1.62kW which is much lower than some mosaic groups where the ADMD of group ‘K’ and ‘A’ gave 2.62kW and 2.05kW.

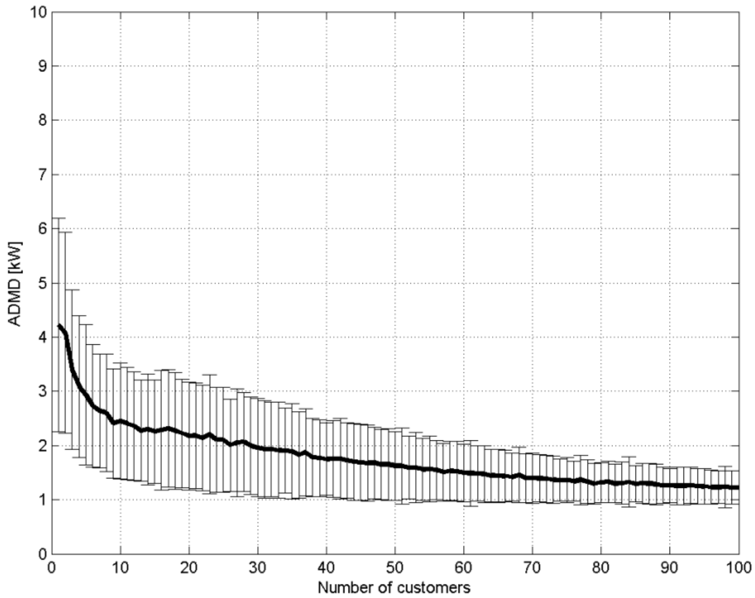


Figure 2: ADMD for low income customers

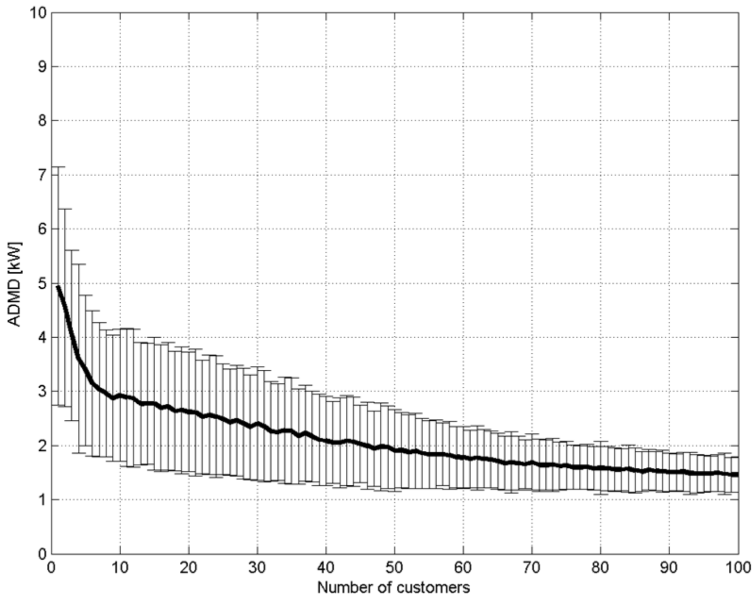


Figure 3: ADMD for medium income customers

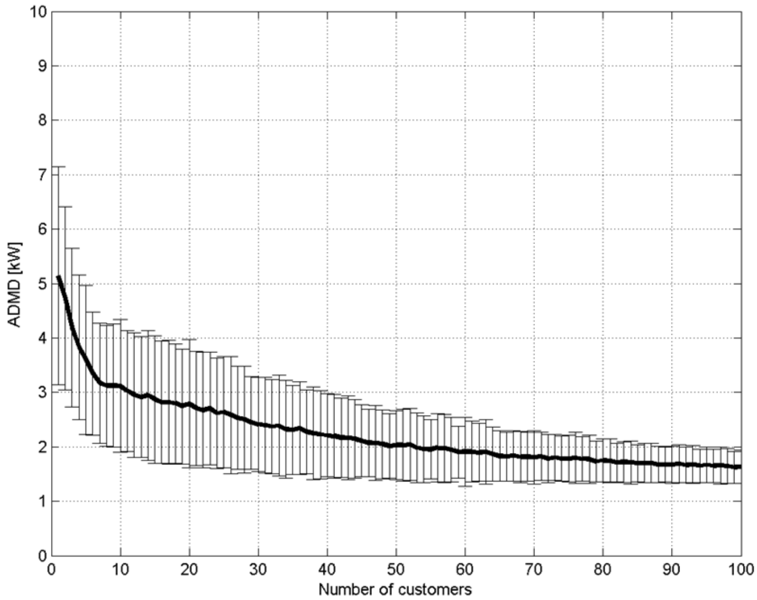


Figure 4: ADMD for high income customers

Table 2: Coefficients and the goodness of fit to the closed form solution $y = a \cdot x^b$ for the CLNR income customers

Meter type	Coefficient a	Coefficient b	R squared
Low income	4.600833	-0.269337	0.967967
Medium income	5.325037	-0.261999	0.964752
High income	5.488207	-0.252630	0.979109

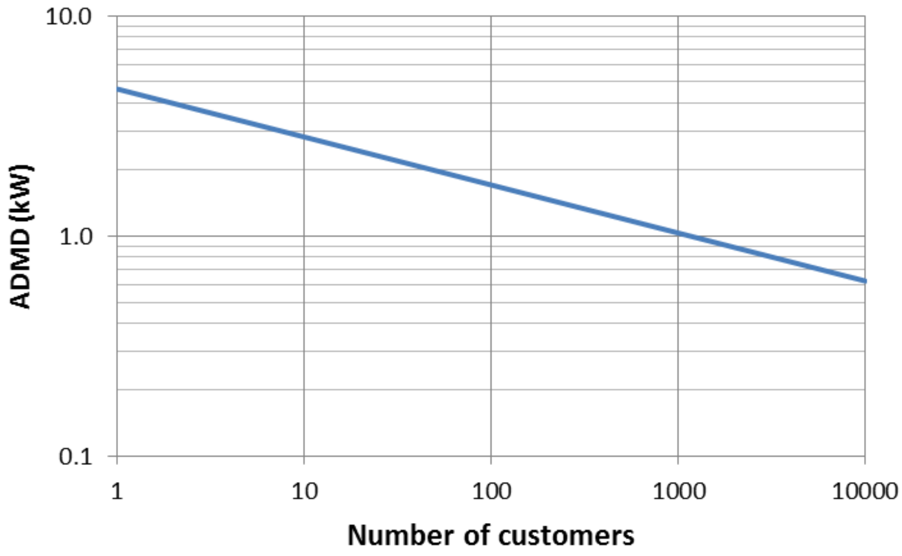


Figure 5: ADMD relationship with increased number of customers in logarithmic scale using the coefficients for the sample population customers as in Error! Reference source not found.

2.2 CLNR solar customers

Because ADMD assesses demand then whole house demand is examined for the different solar customers only. It is the view of the authors that using this method for generation isn't as feasible due to the seemingly stochastic nature of meteorological factors. This approach may not be adequate predict the likely diversified generational peak since parameters such as cloud cover and latitudinal position will vary somewhat between customers as their geographical location is unknown but is understood to be UK wide.

With two distinct solar customer groups, base solar customers and customers with an intervention by the means of an 'in home display' the two groups could feasibly possess different diversified demands. The analytical solution in the form $y = a \cdot x^b$ does a good job in predicting demand out to the i^{th} customer with an R^2 of 0.95 for both TC5 and TC20 manual customers.

2.2.1 Base solar customers

These customers have a diversified maximum demand akin to groups G and N – careers and kids and terraced melting pot in TC1a. However the demand for an individual customer is akin to alpha territory.

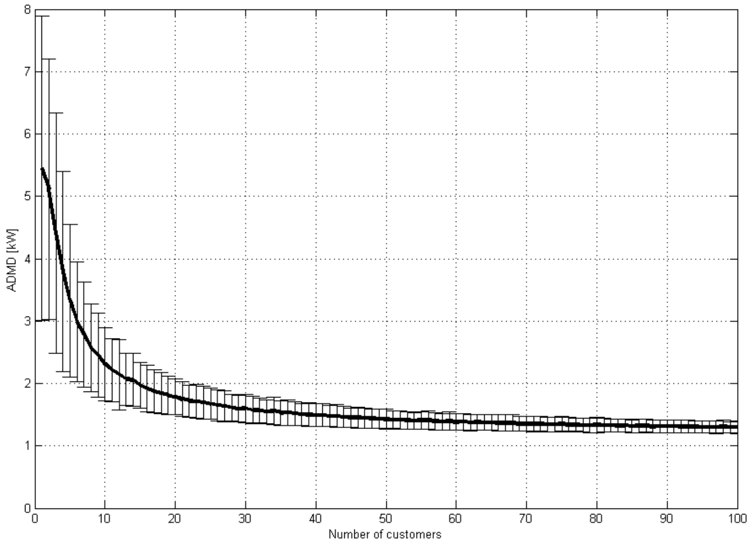


Figure 6: ADMD curve for the base solar customers (TC5)

Table 3: Coefficients and the respective goodness of fit to the closed form solution $y = a \cdot x^b$ for TC5 customers' whole house demand

Coefficient a	Coefficient b	R squared
5.675244	-0.351813	0.954020

2.2.2 Intervention solar customers

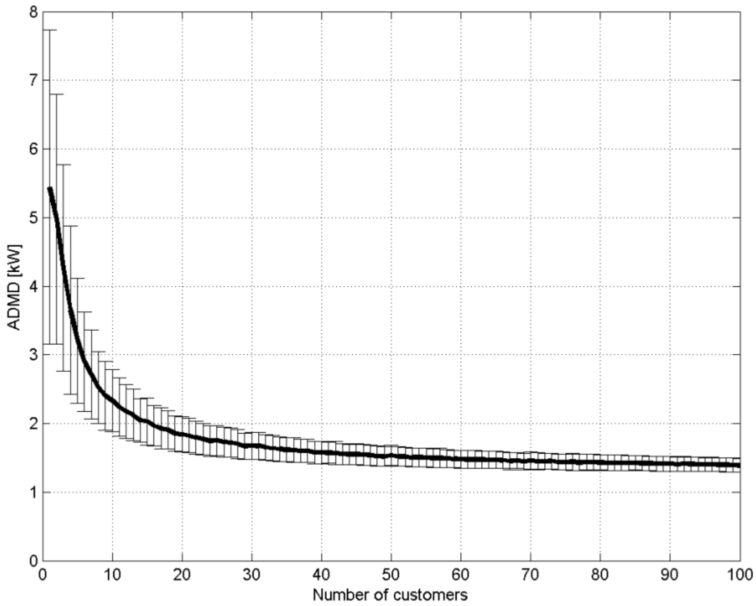


Figure 7: ADMD curve for the intervention test cell solar customers (TC20 manual)

Table 4: Coefficients and the respective goodness of fit to the closed form solution $\mathbf{y = a \cdot x^b}$ for TC20 manual customers' whole house demand

Coefficient a	Coefficient b	R squared
5.402428	-0.324481	0.946493

2.3 Electric vehicle customers

Because customers with electric vehicles can be composed into two separate demands, EV charging and house demand, three separate ADMD computations are performed. Figure 8 to Figure 9 and **Error! Reference source not found.** depict the results with fitted model parameters.

For the electric vehicle charging:

- Per-customer demand increases, stabilising at the 3rd customer level and at the 20 customer level looks to decrease.
- The variance is largest again for one customer and is indicative of the variable supply conditions (voltage, variation in and between charger models) at each customer's house since the rated current capacity of the charger is 16A.
- The time-coincident peak demand decreases as customer numbers on the feeder surpass 20 leading to a decrease in maximum demand and a higher variance

- A second-order exponential function appears a good fit for the prediction of the demand for i customers
- The maximum demand will be limited by the nominal power rating of the charger. In this study 3.6kW nominal power was used by all electric vehicles

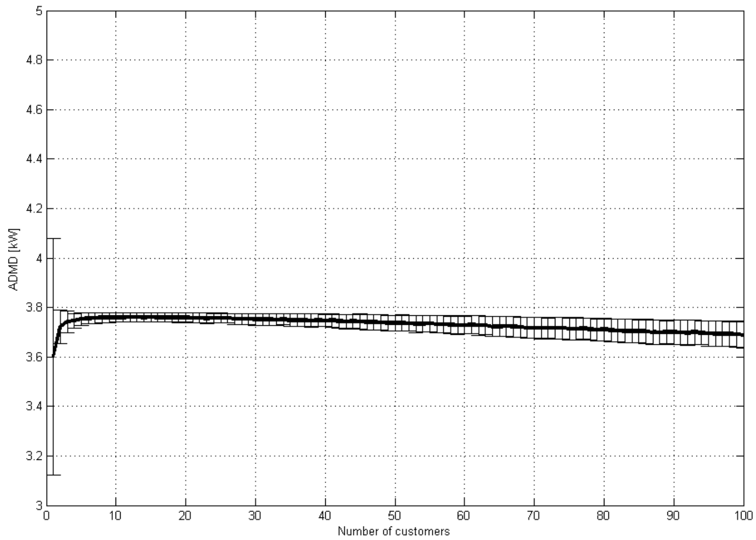


Figure 8: ADMD curve for EV chargers over the year 1st July 2013 to end June 2014

- The EV customers without any charging gives an ADMD of 2kW
- The standard deviation of the diversified maximum demand is around 0.5kW for all customers
- Demands of these customers are akin to New homemakers

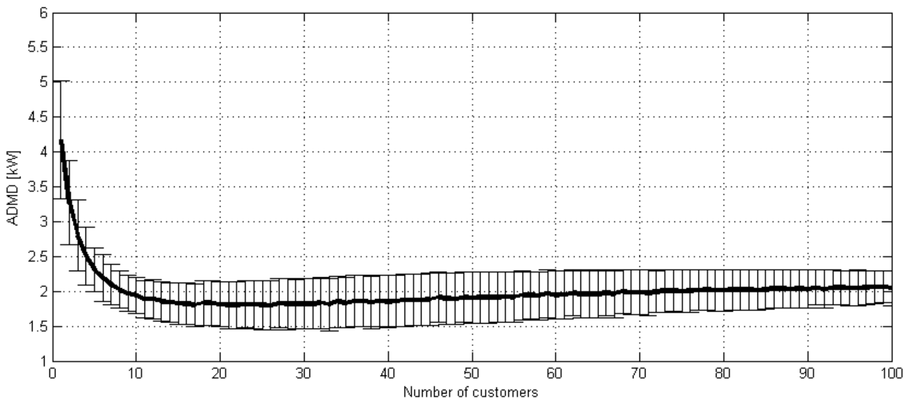


Figure 9: ADMD curve for home only (EV excluded) customers over the year 1st July 2013 to end June 2014

Combining house and EV demand it is seen that:

- The standard deviation is greater than 0.5kW at the 10th customer; ADMD does become stable at the 50th customer with a tailing off of the standard error.
- An ADMD of circa 3.8kW is obtained

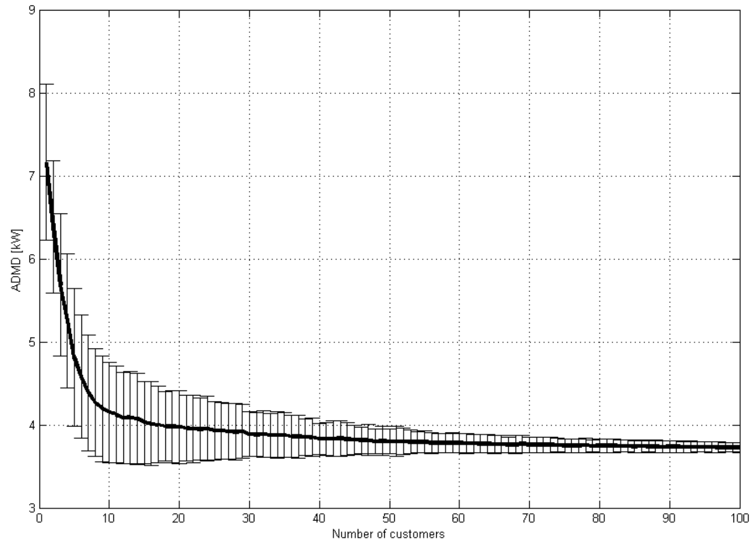


Figure 10: ADMD curve for whole house power import (house demand plus charger) over the year 1st July 2013 to end June 2014

Table 5: Coefficients and the respective goodness of fit to the closed form solution for EV customers with home and whole home power import

Meter	Analytical solution	Coefficients				R squared
		a	b	c	d	
EV	$a \cdot exp^{b \cdot x} + c \cdot exp^{d \cdot x}$	3.774	-0.0002108	-0.459	-0.9407	0.9729
House	$\mathbf{y = a \cdot x^b} + c$	2.357	-1.231	1.906	-	0.843
Import	$\mathbf{y = a \cdot x^b} + c$	3.918	-0.7261	3.569	-	0.9753

2.4 Heat pump customers

As with the previous section, ADMD is computed for each house, heat pump and total property. The results are depicted in Figure 11 to Figure 13. The ADMD for heat pumps alone does not yield (approach) the value of an individual customers' maximum likely half hour load of 4.18kW which was the maximum in the sample over the yearly period beginning 1st May 2013.

The house only demand, excluding heat pump load, gives a high ADMD at the individual customer level of 4.8kW which falls between the low and medium income customers demand. At the 10th customer level the ADMD decreases to just below 3kW akin to the medium customer category.

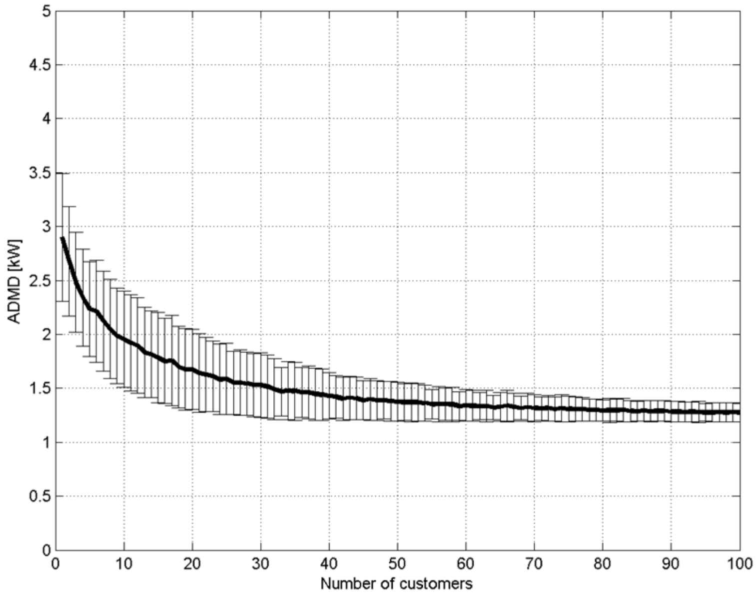


Figure 11: ADMD curve for heat pumps over the period 1st May 2014 to end April 2014

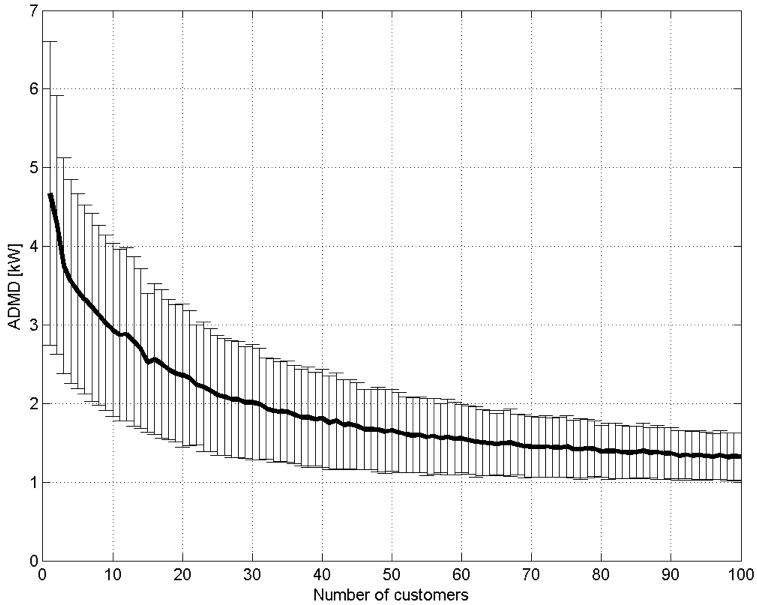


Figure 12: ADMD curve for house only over the period 1st May 2014 to end April 2014

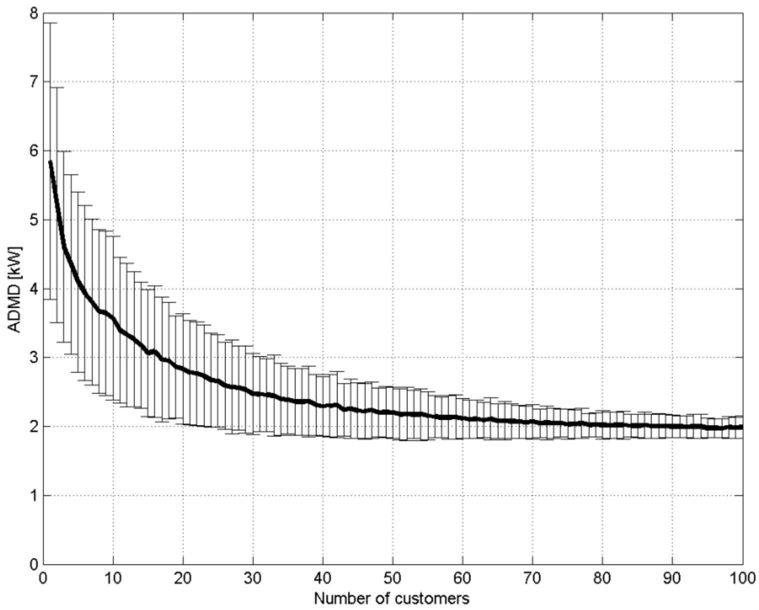


Figure 13: ADMD curve for total property over the period 1st May 2014 to end April 2014

Table 6: Coefficients and the respective goodness of fit to the closed form solution $y = a \cdot x^b$ for TC3 customer's whole house demand

Meter type	Coefficient a	Coefficient b	R square
Heat pump	3.012998	-0.195356	0.989503
House only	5.318812	-0.292871	0.969651
Total property	6.092822	-0.254775	0.991619

3 Conclusions

A series of after diversity maximum demand (ADMD) computations were performed for the various different customer types in the CLNR trials. In a separate study it was shown that demand and energy consumption varies between the demographic groups[4]. For this work only the Mosaic demographics were considered as it is feasible that people who are classified as belonging to a certain group will most likely reside to others similar, i.e. their property size, age and income will not be too dissimilar.

It was shown through exploring these different Mosaic categories that maximum demand differs between groups with a 1kW difference. Larger maximum demands were not always correlated with groups known to consume more electrical energy, however such groups generally had a higher ADMD than others. Groups Alpha Territory and Rural Solitude were high maximum demand groups with Active Retirement and those defined as being in a Terraced Melting Pot having the lowest diversified maximum demand. Demands stabilise at 1.5kW for the sample population of domestic customers.

Generally, analytical solutions in the form of a first term power model showed to be good at approximating the mean demand given i customers. With EV charging an exponential model proved the best model at predicting demand. Of the LCT customer group's solar customers without any intervention showed the lowest demand of all customers with magnitudes resembling those of active retirement whilst with an in home display represent demands to Terraced melting pot customers. Home only demand for EV customers showed to be high consumers at peak with an ADMD of 2kW at the 100th customer.

4 Appendix

Table 7: ADMD metrics for one customer in the domestic test cell (TC1a)

Group	Mean	St.dev
All	4.779	2.034
A	5.818	1.902
B	5.124	1.837
C	5.618	2.267
D	4.787	1.904
E	4.158	1.830
F	5.236	1.991
G	5.135	1.736
H	4.337	1.677
I	5.066	2.159
J	4.566	2.192
K	4.809	2.138
L	3.744	1.715
M	4.654	2.511
N	4.517	2.208
O	4.830	2.259

Table 8: ADMD metrics for 25 customers in the domestic test cell (TC1a)

Group	Mean	St.dev
All	2.441	1.037
A	2.931	0.841
B	2.717	0.911
C	2.704	0.732
D	2.309	0.934
E	1.968	0.690
F	2.767	0.982
G	2.620	0.869
H	2.411	1.051
I	2.607	1.118
J	2.315	1.209
K	3.396	2.187
L	1.773	0.904
M	2.384	1.053
N	2.283	1.022
O	2.763	1.448

Table 9: ADMD metrics for 50 customers in the domestic test cell (TC1a)

Group	Mean	St.dev
All	2.073	0.830
A	2.347	0.483
B	2.250	0.735
C	2.325	0.554
D	1.866	0.671
E	1.626	0.568
F	2.495	0.853
G	2.156	0.617
H	2.372	0.759
I	2.152	0.864
J	2.079	0.996
K	3.050	1.674
L	1.474	0.661
M	2.047	0.874
N	1.988	0.908
O	2.432	1.177

Table 10: ADMD metrics for 75 customers in the domestic test cell (TC1a)

Group	Mean	St.dev
All	1.722	0.581
A	2.148	0.339
B	1.918	0.451
C	2.115	0.431
D	1.542	0.444
E	1.376	0.387
F	2.217	0.705
G	1.889	0.453
H	2.184	0.618
I	1.786	0.591
J	1.838	0.835
K	2.714	1.210
L	1.218	0.453
M	1.780	0.724
N	1.718	0.728
O	2.001	0.768

Table 11: ADMD metrics for 100 customers in the domestic test cell (TC1a)

Group	Mean	St.dev
All	1.570	0.487
A	2.054	0.295
B	1.727	0.289
C	1.986	0.362
D	1.409	0.322
E	1.250	0.306
F	2.037	0.607
G	1.773	0.372
H	2.010	0.526
I	1.596	0.482
J	1.625	0.607
K	2.619	1.066
L	1.091	0.338
M	1.542	0.487
N	1.558	0.601
O	1.874	0.684

Table 12: ADMD metrics for various customer levels over the 3 income categories within the domestic test cell (TC1a)

Metering system	Cutomer number	Mean	St.dev
Low Income	1	4.29	2.02
Low Income	25	2.14	1.01
Low Income	50	1.63	0.68
Low Income	75	1.37	0.45
Low Income	100	1.21	0.31
Medium Income	1	4.98	2.36
Medium Income	25	2.47	1.02
Medium Income	50	1.95	0.75
Medium Income	75	1.63	0.49
Medium Income	100	1.47	0.33
High Income	1	5.25	1.96
High Income	25	2.57	0.93
High Income	50	2.05	0.67
High Income	75	1.77	0.43
High Income	100	1.62	0.28

Table 13: ADMD metrics for various metering systems and customer's numbers for the heat pump (TC3) customer set

Metering system	Cutomer number	Mean	St.dev
Heat pump	1	2.844	0.576
Heat pump	25	1.580	0.317
Heat pump	50	1.389	0.192
Heat pump	75	1.304	0.109
Heat pump	100	1.276	0.092
House only	1	4.800	2.039
House only	25	2.138	0.758
House only	50	1.626	0.511
House only	75	1.403	0.340
House only	100	1.312	0.293
Total property	1	5.728	1.980
Total property	25	2.661	0.673
Total property	50	2.207	0.387
Total property	75	2.048	0.221
Total property	100	1.980	0.128

Table 14: ADMD metrics for various metering systems and customer's numbers for the electric vehicle (TC6) customer set

Metering system	Cutomer number	Mean	St.dev
EV	1	3.587	0.549
EV	25	3.756	0.021
EV	50	3.737	0.031
EV	75	3.713	0.044
EV	100	3.688	0.053
House only	1	4.113	0.769
House only	25	1.799	0.343
House only	50	1.929	0.358
House only	75	1.993	0.311
House only	100	2.066	0.229
Total Property	1	7.210	0.900
Total Property	25	3.943	0.363
Total Property	50	3.802	0.150
Total Property	75	3.757	0.087
Total Property	100	3.732	0.062

Table 15: ADMD metrics for various customer numbers for the solar intervention (TC20 manual) customer set

Customer number	Mean	St.Dev
1	5.401	2.251
25	1.730	0.216
50	1.520	0.136
75	1.441	0.115
100	1.40	0.098

Table 16: ADMD metrics for various customer numbers for the base solar (TC5) customer set

Customer number	Mean	St.Dev
1	5.727	2.697
25	1.690	0.295
50	1.420	0.152
75	1.353	0.121
100	1.303	0.098

Customer-Led Network Revolution

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