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DEVELOPING A BENCHMARKING TOOL FOR MEASURING THE EFFECTIVENESS OF LOCAL AUTHORITY DOMESTIC ENERGY REDUCTION POLICIES

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Abstract: The Department of Energy and Climate Change (DECC) promote Local Authorities as their preferred route for implementing policies aimed at reducing domestic sector energy consumption, and delivering the Government's 2050 energy and climate targets. DECC provide data at lower layer super output area (LSOA) to aid monitoring strategies. These data in principle enable the change in energy demand over time and the relative energy use in different regions to be understood. However there is at present little incentive for Local Authorities to initiate local domestic reduction policies. Furthermore it remains unclear if national datasets are suitable for measuring and monitoring the success of Local Authorities. This paper argues the need for an improved benchmarking tool to measure the effectiveness of Local Authorities in this task. It utilises data – covering demographic, economic and climatic factors – to calculate descriptive statistics, and correlation and regression analysis to examine the relationships between these factors and domestic energy consumption. The analysis is to be expanded, incorporating further demographic, economic and built form data to try and develop a stronger statistical model, while collaboration with Local Authorities is to be sought in order to develop practical applications.

Keywords: *Household socio/economic/cultural characteristics, Policies and Targets, Energy Information and Feedback, Statistical Modelling*

1. Introduction

The ESPRC 4M Project: '4M: Measurement, modelling, mapping and management – An Evidence Based Methodology for Understanding and Shrinking the Urban Carbon Footprint' (4M 2011) is situated in the policy context of the UK Government's 2007 *Meeting the Energy Challenge* White Paper, which set out legally

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binding plans to reduce the UK's carbon dioxide (CO_2) emissions by 60% from 1990 levels, subsequently revised upwards to 80% in 2008 (HM Government 2008). This paper describes progress towards developing a benchmarking tool that will enable Local Authorities to compare their CO_2 emissions from the domestic (housing) sector, set reasonable reduction targets, and then monitors their progress against those targets, in an equitable way. The UK's domestic sector accounts for 30% of the final total energy consumption and almost 25% of the UK's CO_2 emissions. CO_2 emissions in this instance are allocated to the domestic sector by the point of consumption (i.e. through electricity and gas consumption in individual houses) and converted to CO_2 emissions using the Carbon Trust's conversion factors (Carbon Trust 2010).

2. Policy Context

The Department of Energy and Climate Change (DECC) indicate that Local Authorities are to become the *front line* in efforts to reduce national CO_2 emissions (DECC 2010a). They believe Local Authorities have a clear advantage over centralised Government as they can tailor CO_2 reductions to achieve objectives that benefit local residents. Under the previous Labour Government, the Department for Communities and Local Government (DCLG) introduced Local Area Agreements (LAA) which included 198 National Indicators (NI), obliging Local Authorities to select 35 indicators against which their local polices would be assessed (DCLG 2009). It is NI 186 (per capita reduction in CO_2 emissions in the Local Authority area) which takes the focus of this paper. To aid with reporting against NI 186 targets, DECC began to publish data on domestic electricity and gas consumption at LSOA level[5], which is discussed further in section 4. However NI 186 was not compulsory and there were no guidelines on how to set appropriate targets. DCLG feedback sessions with 10 Local Authorities indicated a growing interest in the relationship between economic development and environmental sustainability but little interest in NI 186 – in particular due to concerns over data availability appropriate to the local economy and funding available to deliver beneficial outcomes (DCLG 2009).

Despite the expiration of Local Area Agreements and NI 186 targets in particular, the Conservative-led coalition Government affirmed their commitment to the overall carbon reduction target in their *Pathway to 2050* document, outlining various potential strategies to achieve an 80% CO_2 cut by 2050 (HM Government 2010). Alongside this, DECC published *Warm Homes, Greener Homes* which outlines plans for a large scale refurbishment of housing to improve the energy efficiency of the housing stock (DECC 2010a). A year earlier, Firth and Lomas (2009) described how an approximate 40% reduction in CO_2 emissions can be achieved by improving the thermal properties of housing and introducing more efficient appliances. Their study of Leicester showed this reduction resulted from: (1) insulating all solid and cavity walls; (2) installing 300mm thick insulation in all lofts; (3) converting all boilers to condensing gas boilers; (4) replacing all windows with double glazing; and (5) having

[5] LSOAs are Census Geography areas consisting of approximately 1500 people, or 500 households based on similar housing and tenure types (ONS 2010a)

100% uptake of low energy lights and low standby power devices. To make an impact towards meeting the 80% target, the schemes outlined above would require significant uptake but at present there is no framework through which this could happen (HM Government 2010). This is further complicated by the constituent countries which make up the United Kingdom (England, Northern Ireland, Scotland and Wales) operating with different legislative powers. In this context, the work reported here focuses on England, which is administered directly by the UK Government rather than a devolved parliament or governing body.

3 Improving Energy Efficiency in the Domestic Sector

Domestic energy is a ‘derived demand’; it is demanded for the service it provides rather than the actual energy itself. Improving energy efficiency would allow for the same services to be provided but with fewer units of energy required. Heating functions (space and water heating) account for approximately 80% of energy demand in housing, with space heating alone accounting for 60% of the overall figure (BERR[6] 2008). Electrical appliance use represents a smaller, but growing proportion of energy use. The main determinants of domestic sector energy consumption can be broken down by: demographics, economics, built form, and climate. The rebound effect should also be taken into account.

Demographics: Over the past two hundred years the population of England has grown from 8 million to 48 million while over the same period average household size has fallen from 7 to less than 3 (Lowe 2007), leading to an increase in housing from 1.2 million to 26 million (Boardman 2010). Over the past 30 years this trend has been accelerated by a growing proportion of single person households, doubling from 17% in 1971 to 32% in 2000. Living alone increases energy demands compared with multiple occupancy where services can be shared, as in ‘heat sharing’ (Druckman and Jackson 2008).

Economics: Household income and relative energy prices influence domestic energy consumption. Economic theory suggests that an increase in the price of a good would lead to a corresponding decrease in its consumption. If we translate this theory into energy use, work carried out by Summerfield *et al* (2010a) suggests that energy price elasticity in the domestic sector is -0.2, indicating a 50% increase in energy prices would correspond to an approximate 10% reduction in energy demand. Income has also been shown to dictate the affordability of energy, as well as influencing: (1) the purchase and use of energy consuming goods, and (2) the ability to meet the costs of achieving higher internal temperatures, enjoying longer heating periods and affording larger houses (which are more energy demanding). Of note here is the Summerfield *et al* (2010b) study of 36 low-energy houses in Milton Keynes which recorded that the top 30% of households by income used more energy than the remaining 70% of households combined.

[6] Department for Business, Enterprise and Regulatory Reform (2007-2009). Now the Department for Business, Innovation and Skills

Built Form: The shape, size and construction of a dwelling has a major impact on the amount of energy demanded, especially in relation to space heating. The age of construction, which influences the insulation levels of a dwelling has an influence on the amount of energy required to maintain a thermally comfortable interior (defined by BERR (2008) as 18°C). Housing built before 1919 is the most thermally inefficient, while housing built since 1990 is 40-50% more efficient than the national average (Lowe 2007). This is a result of technical advances, improved construction techniques and stricter building regulations. In terms of house type, detached housing is considered to have the highest energy demands due to lack of shared walls and relatively large floor areas, while inner city blocks of flats are generally more efficient since they allow for heat sharing with neighbouring residents and have relatively small floor areas (Utley and Shorrock 2008). This information is important for Local Authorities as the composition of their housing stock is a key factor in determining feasible energy reduction targets. Local Authorities only have control over their own housing in terms of carrying out efficiency improvements. However this comprises only 20% of the national stock (DECC 2010a) and so encouraging private landlords and owner occupiers to carry out refurbishment will be essential to reaching their targets.

Climate: External air temperature is a key determinant of demand for space heating and cooling energy (Utley and Shorrock 2008). In their study of British homes, Summerfield *et al* (2010a) model the impact of average heating season air temperature on heating energy. Their results suggest that a 1°C increase in air temperature leads to an approximate 5% decrease in energy demands. The work of Firth and Lomas (2010), using a bottom up stock model, produced a figure of around 6.2% decrease per 1°C temperature rise (Lomas 2010). Consideration of how fluctuations in air temperature influence the demand for space heating is therefore important when monitoring progress towards targets. In this way energy consumption reduction can be attributed to political intervention, not global warming, and is especially important when comparing Local Authorities from areas of the country with different climates.

Rebound: A major factor in the effectiveness of energy efficiency interventions is the rebound effect, where increased efficiency reduces the effective cost of energy services and therefore energy demand increases. This results in energy efficiency installations producing less than expected savings (Sorrell 2007). The European Energy Agency (EEA) noted that the level of internal thermal comfort (represented by temperature and time period of heating) in homes has increased over time, negating some of the insulation measures installed and the resultant efficiency gains (EEA 2008). Some suggest that internal room temperatures have risen from 13°C in 1970 to almost 19°C in 2001 (Lowe 2007). For Local Authorities, strategies to reduce fuel poverty (where a household would spend more than 10% of their income on fuel to be adequately heated) through improved energy efficiency is unlikely to reduce consumption in areas of fuel poverty where homes are not being adequately heated.

4 Research Methodology

The aim of this work is to develop a tool to that will help Local Authorities to set and monitor the relative successes of their domestic sector CO_2 emission reduction policies. This will be achieved by accounting for those local variations in energy consumption that are dependent on the demographic, economic, built form and climatic factors described above. It will allow for the development of a benchmark, to guide the setting of targets, and identify areas of relatively low energy consumption that may serve as exemplars as well as highlighting areas with above average consumption.

Analysis has been carried out at LSOA level as this is the smallest sized area for which nationally available data is widely available. Analysis at this level has proved to give significantly stronger correlations than using data at Local Authority level. Data were obtained from a number of sources, as shown in Table 4.1. These include official statistics from DECC and Office for National Statistics (ONS); commercial data from Experian; and research data from the Environmental Change Institute (ECI). In the first stage of work, descriptive statistics and histograms were generated for each of the LSOA variables, to better understand their distribution. The results for total CO_2 emissions from gas and electricity are presented in section 4.

Table 4.1 Data Sources for Statistical Analysis (All data for 2008)

Source	Variables	Driver Type
DECC (2010c)	CO_2 Emissions Number of Gas Meters Number of Electricity Meters	Demographic
DECC (2010d)	Per Unit Cost of Gas[7] Per Unit Cost of Electricity	Economic
Experian (2011)	Median Household Income	Economic
Experian (2011)	Total Number of Households Household Density (people per km^2) People Per House (people per km^2)	Demographic
EDINA (2011)	Area of LSOA (km)	
ONS(2010b)	People per House Population Density	Demographic
ECI (2011)	Number of Heating Degree Days[8]	Climatic

Correlation and regression statistics were calculated to assess the strength of association between each variable and domestic CO_2 emissions. From these results, a stepwise multiple regression model was constructed. The results are given in the next section. Using the stepwise method for constructing the regression model allowed for a balance between increasing complexity of the model and a higher r^2

[7] For energy costs and heating degree days, all LSOAs within individual data regions are assigned the regional figure

[8] Heating Degree Days obtained from 43 England-wide regional weather stations and assigned to Local Authorities using GIS

value. The model is an attempt to simplify reality, while maximising the r^2 value. Stepwise regression allowed those variables which introduced ‘significant’ change to the r^2 value to be included, while those variables which have little effect on r^2 are excluded: this was been defined as causing a change in r^2 of less than 0.01.

5 Results and Discussion

These results were derived from 2008 gas and electricity consumption figures for LSOAs in England. Descriptive statistics for CO_2 emissions are given in Table 5.1 and the distribution of CO_2 emissions is shown in the histogram in Figure 5.1. Figure 5.1 show that the distribution of LSOA domestic CO_2 emissions is skewed with a long tail above the mean. The maximum value in (Swindon 002B) is 21 standard deviations from the mean, while the lowest value (Greenwich 024B) is within 4 standard deviations from the mean. Analysis of the distribution shows that 98.8 of LSOAs have CO_2 emissions within 3 standard deviations from the mean (32252 of 32612, with 3 areas more than 3 standard deviations below the mean and 353 more than 3 standard deviations above the mean). This distribution has a relatively high skew value of 2.21. Understanding the reasons for the skew in the distribution is of high importance for: (1) Local Authorities with areas located in this tail, and (2) identifying whether this distribution is an accurate reflection of reality or due to systematic errors in the data.

Table 5.1 Descriptive Statistics for CO_2 Emissions ($KtCO_2$)

Mean	3458937
Median	3353203
Standard Deviation	832589
Kurtosis	22.43
Skewness	2.21
Minimum	655636 (Greenwich 024B)
Maximum	20786503 (Swindon 002B)

One potential reason for the long tail above the mean is that these figures deal with absolute CO_2 emissions in LSOAs and do not take into account the relative population sizes. While LSOAs are intended to be of approximately constant population size, the boundaries were fixed on the 2001 Census and significant house building may have occurred in the intervening years. Another issue that is being investigated is the accuracy of the energy consumption figures that underlie the CO_2 emission values. Both electricity and gas consumptions use arbitrary cut off values to differentiate between domestic and small commercial customers (73 000 kilowatt hours (kWh) per year of gas consumption, and 100000 kWh per year of electricity consumption). As a result, approximately 2 million small businesses have been incorrectly classified as domestic properties (DECC 2010b). Also, these data are based on the bills that energy suppliers produce for their customers and may include estimated meter readings.

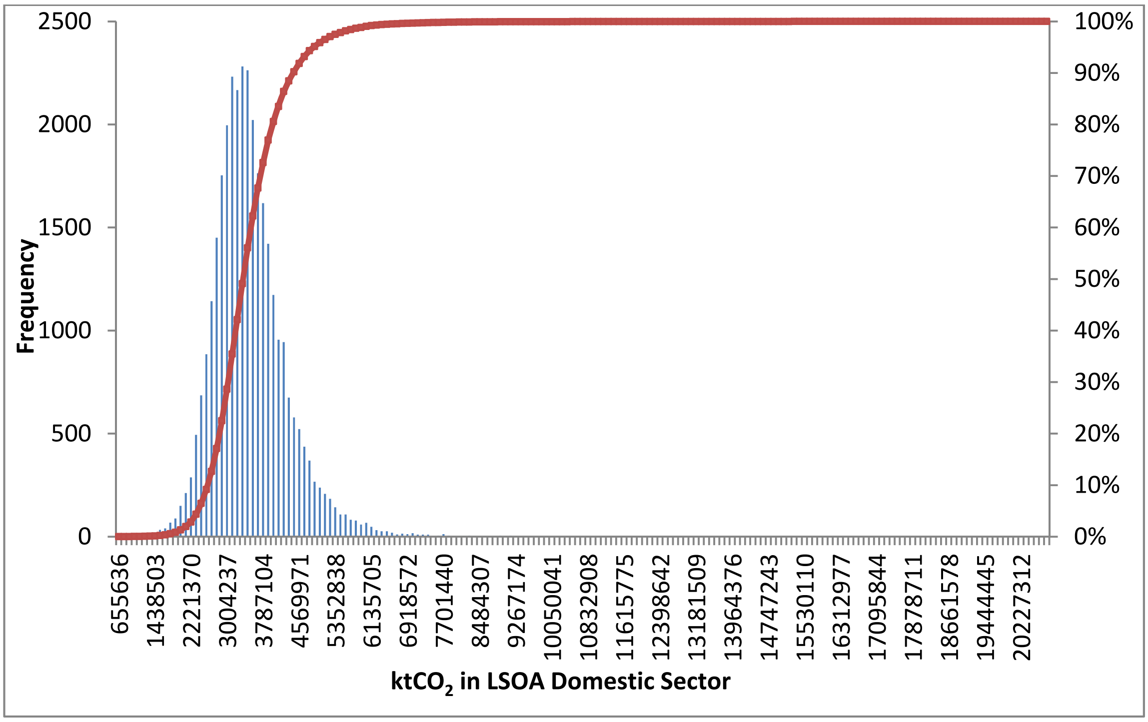

Figure 5.1 Histogram of England LSOA CO_2 Emissions

Results of the correlation analysis are presented in Table 5.2, which shows the strength of correlation between each of the variables and CO_2 emissions. From this analysis, it can be seen that the variables with the largest impact on CO_2 emissions are associated with demographic factors. Clearly emissions would be expected to increase with the number of households (or meters) and the number of people. The positive relationship with median income is also expected; those with higher incomes are more likely to have larger houses (with greater space heating requirements), perhaps more electrical appliances and a greater ability to pay for electricity and gas. Conversely, those on higher incomes are also more able to invest in energy efficiency measures. Housing density has a negative relationship with domestic CO_2 emissions, which may be as a result of heat sharing in flats and dense housing estates. Low housing density may also be associated with rural areas, which are often characterised by large, older housing that may not be connected to the gas grid. This is supported by the negative correlation between area and % of gas meters to electricity meters, with lower proportions of gas meters occurring in larger LSOAs (by area). The cost of energy and number of heating degree days appear to have little relationship with overall CO_2 emissions, although this may be partly as a result of the regional way in which these data are reported (as opposed to being at LSOA).

In the model for the total domestic CO_2 emissions in England LSOAs, the number of electricity meters was entered first, and explained about 45% of the variation. Median income was entered second and explained a further 20% of the variation. The number of gas meters was entered third and explained a further 8% of the variation. Housing density of the LSOA was entered fourth and explained a further 5% of the variation. Housing density was the last variable to increase r^2 by at least a percentage point. Where two independent variables are strongly correlated, the stepwise regression technique will select the variable which has the greatest impact on the dependent variable and discard the alternative. In this instance there was a very strong correlation between housing density and population density and therefore population density has not been considered in the model as it had less impact (see Table 5.3). This highlights why some variables which initially appeared to have a relatively strong relationship with CO_2 emissions appear to have relatively weak effects in the regression analysis.

Table 5.2 Correlations between Independent Variables and CO_2 Emissions

Variable	Correlation with CO_2 Emissions
Number of Electricity Meters	0.669
Total Households	0.602
Total Population	0.564
Number of Gas Meters	0.540
Median Income	0.401
Gas Cost	0.040
Area of LSOA	0.032
Number of Heating Degree Days	0.024
% of Gas Meters to Electricity Meters	0.011
Electricity Cost	-0.054
Number of People Per House	-0.127
Housing Density	-0.222

Table 5.3 Correlations between Independent Variables

Variable 1	Variable 2	Correlation
Population Density	Housing Density	0.991
Total Households	Number of Electricity Meters	0.875
Total Households	Total Population	0.689
Total Population	Number of Electricity Meters	0.657
Total Households	Number of Gas Meters	0.605
Number of Gas Meters	Number of Electricity Meters	0.538
Number of Gas Meters	% of Gas Meters to Electricity Meters	0.524
Total Households	People Per House	-0.457
Area of LSOA	% of Gas Meters to Electricity Meters	-0.508

The four variables model gives a regression equation of:

$$ktCO_2\ \text{Emissions} = -375432 + 2390a + 41b + 1920c - 100175d$$

Where: a = Number of Electricity Meters, b = Median Income, c = Number of Gas Meters, d = Housing Density

The regression model has an r^2 value of 0.783, explaining almost 80% of the spatial variation in CO_2 emissions across England LSOAs. A plot of predicted values against actual is shown in Figure 5.2. This is impressive considering that the model does not yet contain any information that reflects the built form and energy efficiency of the hoses (e.g. the age of construction, size of the house, level of insulation).

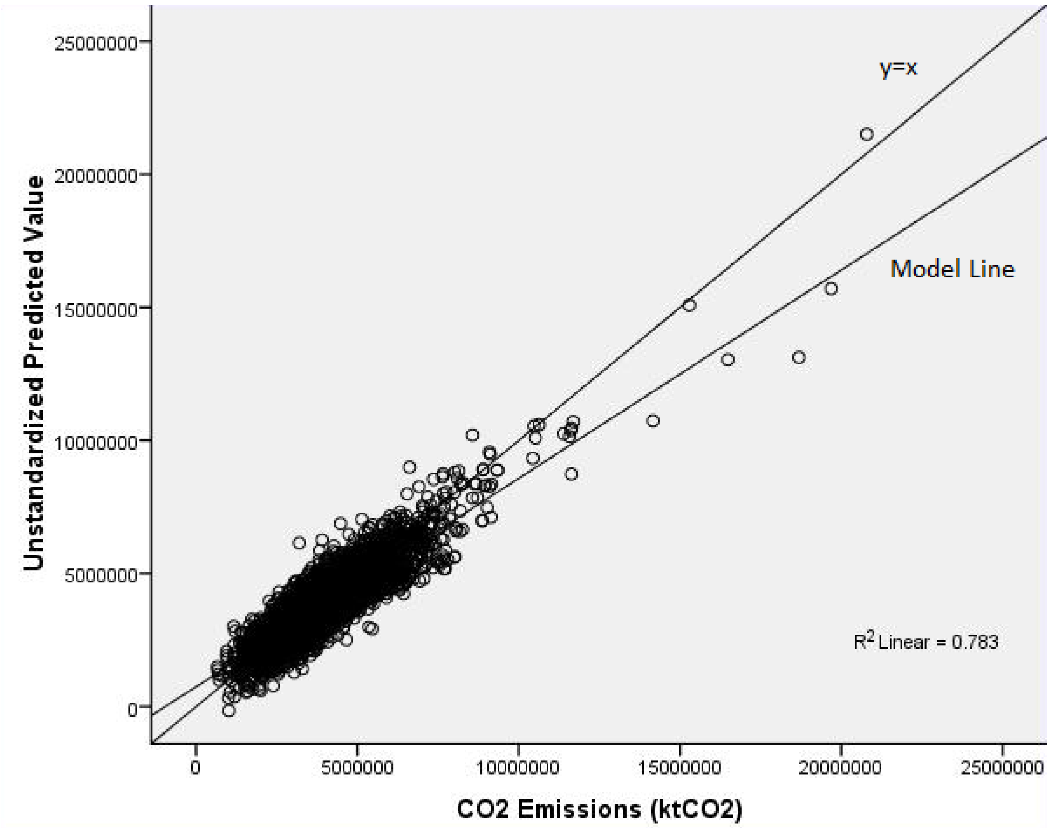

Figure 5.2 Plot of Modelled values v Actual Values

Table 5.4 Stepwise Regression Results for CO_2 Emissions

Variables	r	r^2	Δr^2
Number of Electricity Meters	0.669	0.448	0.448
Number of Electricity Meters, Median Income	0.803	0.645	0.197
Number of Electricity Meters, Median Income, Number of Gas Meters	0.853	0.728	0.083
Number of Electricity Meters, Median Income, Number of Gas Meters, Housing Density	0.885	0.783	0.055

6 Conclusions and Further Study

DECC promote Local Authorities as their preferred route for implementing policies aimed at reducing domestic sector energy consumption and CO_2 emissions. A benchmarking tool would allow Local Authorities to compare their emissions, set reasonable targets, and monitor their progress against those targets, in an equitable way. Such a tool would account for local variations in demographics, economics, built form, and climate as well as considering fuel poverty and the rebound effect.

At LSOA level, CO_2 emissions from houses in England have a skewed distribution with 98.8% of areas lying within 3 standard deviations of the mean with the highest area having recorded CO_2 emissions 32 times greater than of the smallest. However these results do not take into account the relative population sizes of each LSOA. There is also a question of accuracy of these data due to misclassification of small businesses as domestic properties and the use of estimated billing data in the energy consumption data. A stepwise regression model has been developed using data to represent demographic, economic and climatic factors. The results have demonstrated that widely available published figures can be used to describe almost 80% of variation in domestic CO_2 emissions in England with independent variables of: (1) number of electricity meters, (2) median income, (3) number of gas meters and (4) housing density. These preliminary findings confirm that a Local Authority's domestic CO_2 emissions are highly affected by the number of households in their area, and the relative wealth of these residents. However the model does not yet address the standard of the housing stock within their boundaries, which is where Local Authorities might have most influence when conducting domestic energy reduction policies. In this way, 80% of the variation might be considered outside of their control and a benchmarking tool would allow this to be accounted for.

Future work will concentrate on improving the regression model by improving the precision of Heating Degree Day data to a spatial scale below the current regional level, and seeking other statistical data to represent Built Form i.e. condition, age and type of the housing stock. Fuel poverty will also be considered, as higher rebound effects are expected when energy efficiency strategies are carried out in LSOAs with under heating due to affordability issues. Finally, consultation with Local Authorities is on-going to ensure that any future work is applicable to domestic energy policy, that appropriate data sources are being used, and that these results can be applied to National and Local Government targets given the resources available to them.

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