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Flexible demand in the GB domestic electricity sector in 2030

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HIGHLIGHTS

- Annual domestic demand by category and daily flexible load profiles are shown to 2030.
- Valuable flexible demand requires loads to be identifiable, accessible, and useful.
- The extent of flexible demand varies significantly on a diurnal and seasonal basis.
- Barriers to accessing domestic demand include multiple low value loads and apathy.
- Existing market structure a barrier to fully rewarding individual load flexibility.

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ABSTRACT

In order to meet greenhouse gas emissions targets the Great Britain (GB) future electricity supply will include a higher fraction of non-dispatchable generation, increasing opportunities for demand side management to maintain a supply/demand balance. This paper examines the extent of flexible domestic demand (FDD) in GB, its usefulness in system balancing and appropriate incentives to encourage consumers to participate. FDD, classified as electric space and water heating (ESWH), and cold and wet appliances, amounts to 59 TW h in 2012 (113 TW h total domestic demand) and is calculated to increase to 67 TW h in 2030. Summer and winter daily load profiles for flexible loads show significant seasonal and diurnal variations in the total flexible load and between load categories. Low levels of reflective consumer engagement with electricity consumption and a resistance to automation present barriers to effective access to FDD. A value of £1.97/household/year has been calculated for cold appliance loads used for frequency response in 2030, using 2013 market rates. The introduction of smart meters in GB by 2020 will allow access to FDD for system balancing. The low commercial value of individual domestic loads increases the attractiveness of non-financial incentives to fully exploit FDD. It was shown that appliance loads have different characteristics which can contribute to an efficient power system in different ways.
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1. Introduction

1.1. Electricity generation and demand side management (DSM)

Projected changes to the combination of electricity generating technologies in the UK, partly as a result of efforts to meet climate change emissions reduction targets, will result in less dispatchable (controllable) generation plant available in the future for use in maintaining a balance between supply and demand (Fig. 1).

This will create opportunities for demand side management (DSM) to play a more active part in maintaining a balance [5]. Elements of DSM described in [6] are demand response (flexibility), demand management (efficiency/reduction), and distributed generation.

The effective exploitation of flexible demand requires loads to be identifiable and accessible, appropriate for the service being called upon i.e. of sufficient size, speed of response and duration, and changes to the loads e.g. load shedding/shifting, must be acceptable to consumers i.e. consumers need to have appropriate incentives to participate.

1.2. Domestic electricity demand in 2012

Electricity consumption in the UK in 2012 amounted to 318 TW h, not including electricity used by the power industry and network losses [7], with domestic consumption amounting to approximately 36% of the total. Scenarios of future demand, including [8,9], indicate changes in overall demand levels. The

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Nomenclature

Abbreviation

CCC	Committee on Climate Change
COP	coefficient of performance
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DSM	demand side management
ECUK	energy consumption in the UK [1]
ESB	energy saving light bulb
EST	energy saving trust
ESWH	electric space and water heating
FDD	flexible domestic demand
GB	Great Britain
HES	Household Electricity Survey [2]
SLB	standard light bulb
UK	United Kingdom

relative size of the domestic sector, however, remains broadly in line with current consumption (34% in 2030 [9] and 36% in 2012 [7]), as shown in Fig. 2.

UK domestic electricity consumption in 2012 amounted to 116.1 TW h [10] divided between lighting and appliances (72%), space heating (21%) and water heating (7%), as shown in Fig. 3.

The majority of domestic consumption in 2012 was in lighting and appliances (72%). The allocation of demand in 2012 between the different lighting and appliances categories is shown in Fig. 4.

Lighting and appliances are further divided into sub-categories, as shown in Table 1.

Characteristics of demand vary between the different categories and are related to the spatial and temporal proximity to consumer engagement. Categories, such as lighting and consumer electronics, have an immediate relationship with the consumer whereas other categories, such as wet and cold appliances, can operate with a degree of independence from consumer engagement [12].

1.3. Flexible domestic electricity demand

Flexible demand is useful in current and future balancing markets. Current markets include frequency response and short term reserves. Potential future markets include the capacity market [13], and services supporting distribution networks.

The degree of flexibility, i.e. the ability of a load to vary in response to an external signal with minimal disruption to consumer utility, varies between load categories. Appliances that can operate independently from consumers, such as fridges and washing machines, can be more flexible without loss of utility to the consumer [14]. Other appliances, such as televisions and lighting, are less flexible as they are required to be on when the consumer engages with their function. Electric space and water heating (ESWH) and cold appliances have thermal storage properties which allow load to be curtailed, reduced or postponed [15].

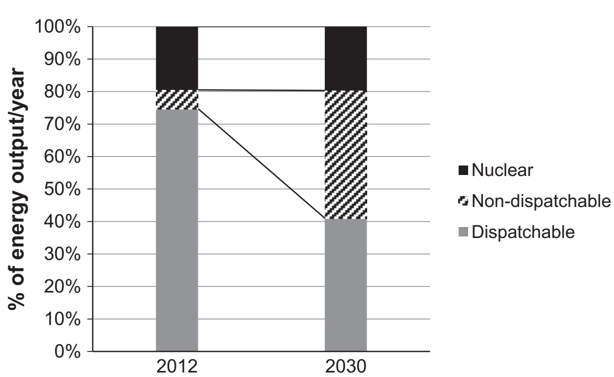

Fig. 1. Energy output from generating technology categories in 2012 and 2030 [3,4].

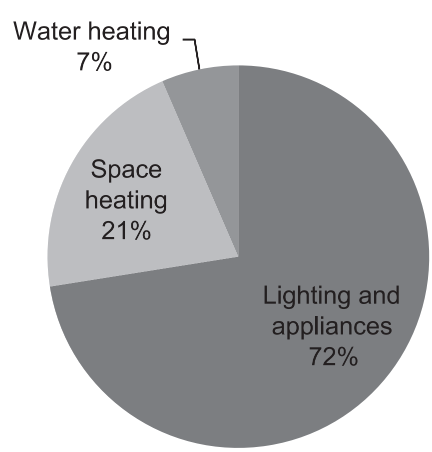

Fig. 3. UK annual domestic electricity consumption in 2012 [10].

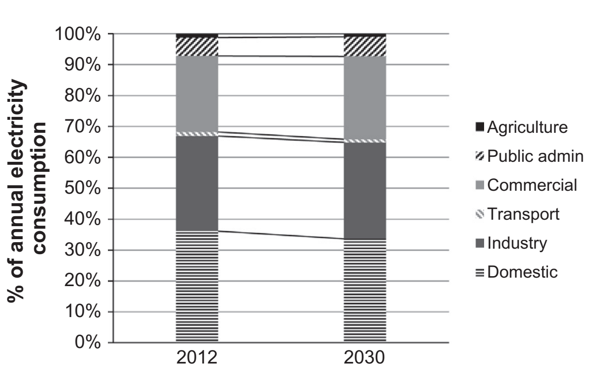

Fig. 2. UK electricity consumption by sector (2012 and 2030) [7,9].

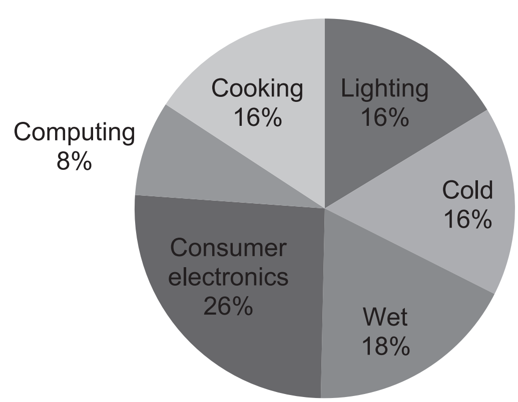

Fig. 4. UK domestic electricity consumption – lighting and appliances in 2012 [11].

Table 1
Lighting and appliance categories and sub-categories.

Category	Sub-category				
Lighting	Standard light bulb (SLB)	Halogen	Fluorescent strip lighting	Energy saving light bulb (ESB)	LED
Cold appliances	Chest freezer	Fridge-freezer	Refrigerator	Upright freezer	
Wet appliances	Washing machine	Washer dryer	Dishwasher	Tumble dryer	
Consumer electronics	TV	Set top box	DVD/VCR	Games consoles	Power supply units
Home computing	Desktops	Laptops	Monitors	Printers	Multi function devices
Cooking	Electric oven	Electric hob	Microwave	Kettle	

This study projects annual household electricity consumption from 2012 to 2030 and details daily load profiles for flexible loads, defined in this study as ESWH and cold and wet appliances, for typical summer and winter days in 2030. The projected annual load indicates the total electrical energy consumed by the GB domestic sector per year, and the electrical power load profiles indicate the maximum flexible domestic load from ESWH and cold and wet appliances which may be available for system balancing and other purposes such as peak shifting.

2. Methodology

2.1. Great Britain (GB) and United Kingdom (UK)

The transmission network in GB is operated independently of the network in Northern Ireland, which is part of the all island Irish network, including the Republic of Ireland. However, the primary source of historic appliance consumption data (ECUK) [1] used in this study is expressed in UK terms i.e. GB and Northern Ireland. In order to examine how domestic loads contribute to balancing the GB network, annual consumption per appliance is converted to GB terms at the final stage of analysis.

The total number of households in GB in 2012 was 26.1 m which was 97.4% of the total number of UK households [16]. When this is applied on a pro-rata basis to consumption, GB domestic electricity consumption in 2012 was 113.1 TW h. Minor differences in demographics forecast by the UK Government's Office for National Statistics [17] show that the number of GB households relative to UK households drops marginally from approximately 97.4% in 2012 to approximately 97.3% in 2030 (32.1 m UK households and 31.3 m GB households).

2.2. Appliance annual electricity consumption

The primary data source used for household appliance consumption is Energy Consumption in the UK (ECUK) [1] tables published by the UK Government's Office for National Statistics. This data allows the calculation of total domestic energy consumption, consumption by fuel type and electricity consumption by appliance type. The July 2013 issue of ECUK gives consumption data in the UK from 1970 to 2012 and, from this data, projections are made to show possible annual consumption figures by appliance type to 2030.

Selected data from Tables 3.05 [18] and 3.10 [13] of the July 2013 issue of ECUK [1] are used in this study to calculate the total annual consumption of electricity for each appliance category and sub-category. Total consumption for each appliance category and sub-category is calculated by multiplying the number of appliances with the annual consumption per appliance. The number of appliances is the number of households multiplied by the number of appliances per household, and the consumption per appliance is appliance efficiency multiplied by usage rates.

Projections of electricity consumption to 2030 for domestic ESWH are based on the Committee of Climate Change, Decarbonising Heat Report [19]. The number of households projection is sourced from the Department for Communities and Local Government Household Projections, United Kingdom, 1961–2033 [16] and is used across all appliance categories in this study. The number of appliances per household and the consumption per appliance projections are calculated using extrapolation of the last 10 years of data from ECUK [1]. Flexible demand categories i.e. cold and wet appliances, and cooking appliance projections are calculated with the MS Excel TREND function, using exponential extrapolation of the previous 10 years of data, and assume existing trends will continue with no major technological or behavioural disruptions. Where such disruptions are anticipated, such as in consumer electronics, computing and lighting categories, projections are damped to reduce the risk of large errors [20].

2.3. Daily load profiles

Whilst an appreciation of annual appliance demand is useful in understanding the total amount of energy consumed each year by each category, this does not take account of the relationship between instantaneous power demands on generation and network capacity on an ongoing basis.

In order to consider the extent of flexible demand available on an ongoing basis, this study produces typical summer and winter daily demand profiles for ESWH and cold and wet appliances in 2030. The profiles are derived from hourly data from the Household Electricity Survey (HES) [2] and adjusted for changes in household numbers, household composition and changes in annual electricity consumption per appliance. The HES, jointly funded by Defra, DECC and EST, comprised a survey of 251 households in England between May 2010 and July 2011. 26 households were monitored for 1 year and the remainder for periods of 1 month throughout the year [2]. Space heating profiles are based on data for electric central heating (6 no. appliances monitored), circulation pumps (2 no. appliances monitored) and individual heaters (46 no. appliances monitored) [21]. Water heating profiles are based on data for immersion heaters (22 no. appliances monitored) and electric showers (92 no. appliances monitored) [22]. Both space heating and water heating profiles were adjusted for seasonal factors [23].

3. Results

3.1. Projected annual domestic electricity demand in 2030

Results for GB domestic electricity demand in 2030 show an increase in overall demand from 113.1 TW h in 2012, to 124.6 TW h in 2030, as shown in Fig. 5.

The main increases are found in space heating and water heating (ESWH) and the wet and consumer electronics categories, and the main reductions in the cold, computing and lighting categories.

3.2. Analysis of annual domestic electricity demand

Trends for individual appliance category consumption vary according to use, household numbers and composition, and tech-

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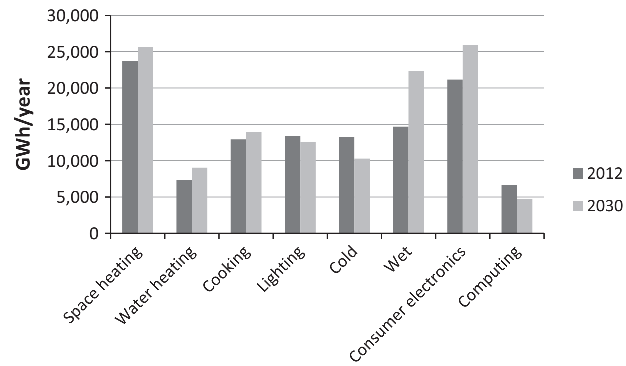

Fig. 5. GB domestic electricity demand 2012 and 2030.

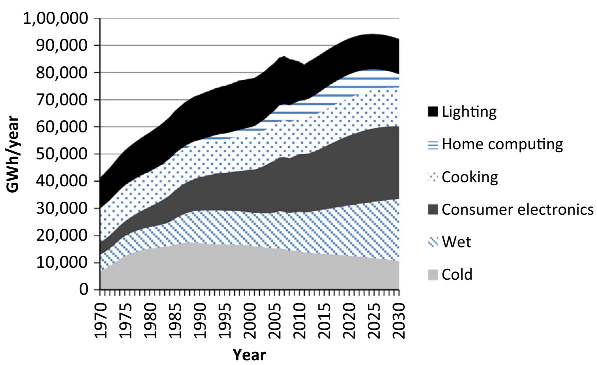

Fig. 6. UK annual domestic appliance electricity demand 1970–2030.

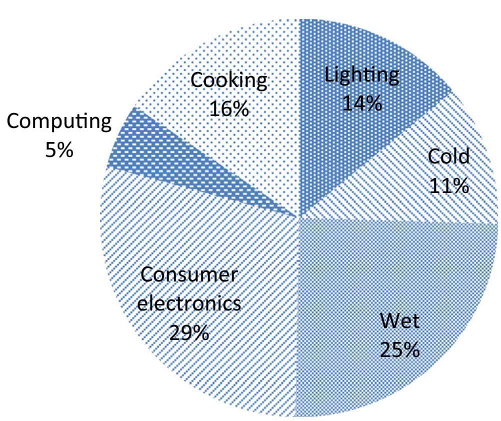

Fig. 7. UK annual domestic electricity demand – lighting and appliances in 2030.

nological changes, including improved levels of efficiency. Long term UK trends for each appliance category are shown in Fig. 6 and the percentage allocation of demand between different categories of lighting and appliance in Fig. 7. Results from 1970 to 2012 are sourced from ECUK data [1].

3.2.1. Electric space and water heating (ESWH)

Annual electricity demand for ESWH is projected to increase from 31,114 GW h in 2012 to 34,684 GW h in 2030. Calculations are based on assumptions from CCC Decarbonising heat report (2010) [19] which indicate a reduction of 8.6% in overall heat demand by 2030, but with a higher proportion of heat from electric power.

Current demand, mainly met through gas, is 401.3 TW h which reduces to 366.8 TW h in 2030. The ratio of space heating demand and water heating demand in 2012 is 79.9:20.1 [10]. The CCC "Decarbonising heat: Low-carbon heat scenarios for the 2020's" report [19] forecasts 28% of space heating being supplied from heat pumps by 2030. This study assumes all electric heating in 2030, i.e. 89,779 GW h, is delivered by heat pumps, which, with a heat pump coefficient of performance (COP) of 3.5 results in 25,651 GW h electricity required. This study also assumes that 28% of water heating in 2030, i.e. 22,583 GW h, is delivered by heat pumps, which, with a heat pump COP of 2.5 (lower efficiency than space heating due to higher temperature requirements) results in 9033 GW h electricity required.

3.2.2. Cold appliances

The 2012 annual electricity consumption for domestic cold appliances in the UK was 13,595 GW h, made up of 1256 GW h chest freezers, 7920 GW h fridge freezers, 1931 GW h refrigerators and 2489 GW h upright freezers. Cold appliance electricity demand is projected to decline from 13,595 GW h in 2012 to 10,585 GW h in 2030, as shown in Fig. 8.

Increased efficiency levels offset the increase in numbers of households resulting in an overall decline in demand.

3.2.3. Wet appliances

The 2012 annual electricity consumption by wet appliances in the UK was 15,073 GW h, made up of 4582 GW h washing machine, 2431 GW h washer dryer, 3338 GW h dishwasher and 4722 GW h tumble dryer. Wet appliance electricity demand is projected to increase from 15,073 GW h in 2012 to 22,938 GW h in 2030, as shown in Fig. 9.

The main factors affecting consumption, by sub-category, are improved efficiency reducing the effect of increased ownership levels and household numbers of all appliances, though tumble dryer demand more than doubles (from 4722 GW h to 9533 GW h) reflecting changes in types of households and drying practices.

3.2.4. Lighting

The 2012 annual electricity consumption by domestic lighting in the UK was 13,747 GW h, made up of 1651 GW h standard light bulb (SLB), 6908 GW h halogen, 1221 GW h fluorescent strip lighting, 3861 GW h energy saving light bulb (ESB) and 105 GW h LED. Lighting electricity demand is projected to decline from 13,747 GW h in 2012 to 12,949 GW h in 2030, as shown in Fig. 10.

Standard light bulbs are substantially replaced by energy saving light bulbs by 2020 which contributes the main reduction in demand. The recent increase in the use of halogens slows and fluorescent strip lighting continues to decline in usage.

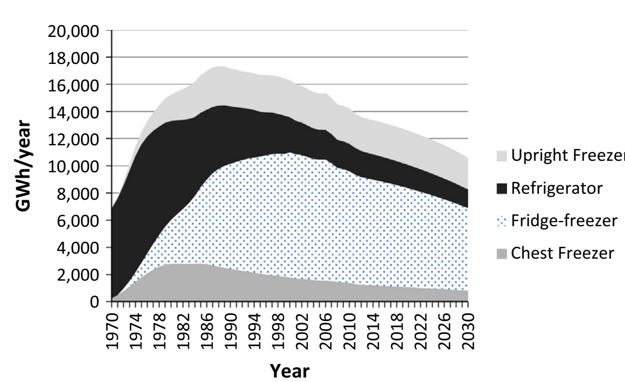

Fig. 8. UK annual domestic electricity demand by cold appliances 1970–2030.

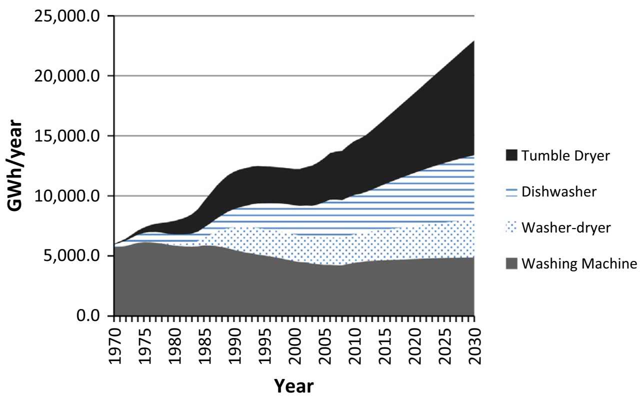

Fig. 9. UK annual domestic electricity demand by wet appliances 1970–2030.

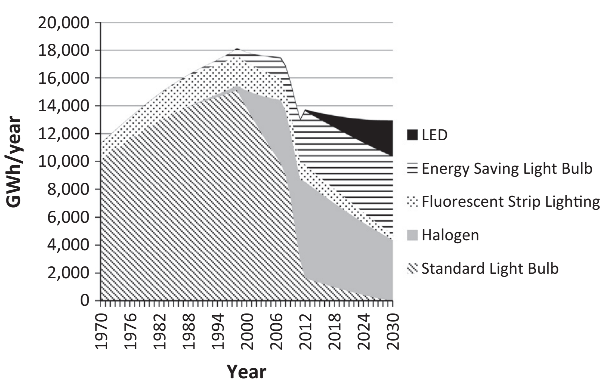

Fig. 10. UK annual domestic electricity demand by lighting 1970–2030.

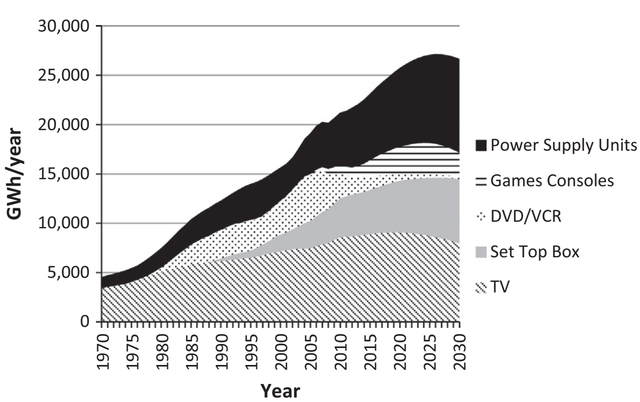

Fig. 11. UK annual domestic electricity demand by consumer electronic appliances 1970–2030.

3.2.5. Consumer electronics

The 2012 annual electricity consumption by consumer electronics in the UK was 21,725 GW h, made up of 8676 GW h TV, 4233 GW h set top box, 1803 GW h DVD/VCR, 942 GW h games console and 6071 GW h power supply. Consumer electronics demand increases from 21,725 GW h in 2012 to 26,656 GW h in 2030, as shown in Fig. 11.

Ownership levels of TVs, set top boxes and games consoles increase whilst the popularity of DVD/VCRs continues to decline as alternative media sources become more widespread. Increased levels of ownership are partially offset by improved levels of appliance efficiency.

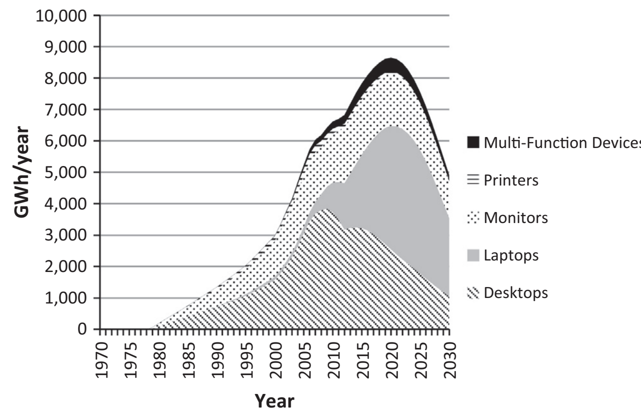

Fig. 12. UK annual domestic electricity demand by home computing appliances 1970–2030.

3.2.6. Home computing

The 2012 annual electricity consumption by home computing in the UK was 6827 GW h, made up of 3175 GW h desktop, 1489 GW h laptop, 1768 GW h monitor, 116 GW h printer and 279 GW h multi-function device. Home computing demand declines from 6827 GW h in 2012 to 4909 GW h in 2030, as shown in Fig. 12.

Reductions in energy consumption of desktops and monitors outweigh increases in laptops and multi-function devices.

3.2.7. Cooking

The 2012 annual electricity consumption by cooking appliances in the UK was 13,270 GW h, made up of 3117 GW h electric oven, 3140 GW h electric hob, 2524 GW h microwave and 4489 GW h kettle. Cooking demand increases from 13,270 GW h in 2012 to 14,337 GW h in 2030, as shown in Fig. 13.

Increases in household numbers and use patterns result in increased demand from microwaves and kettles, whereas improved appliance efficiency and changes in cooking practices result in a decline in demand from electric ovens and hobs.

3.3. Flexible domestic electricity demand in 2012 and 2030

The total annual electricity demand by ESWH, cold and wet appliances is projected to increase from 59,024 GW h in 2012 to 66,159 GW h in 2030, with changes to flexible demand categories shown in Fig. 14.

Increases in the amount of space heating and water heating (ESWH), due to a greater penetration of heat pumps, and wet appliance demand, due to changes in appliance usage rates, are partially offset by reductions in cold appliance demand due to improved appliance efficiency.

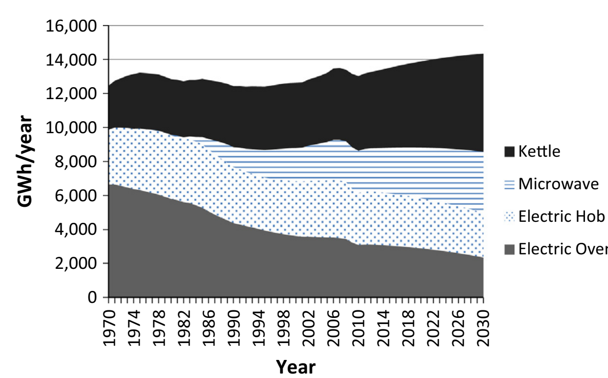

Fig. 13. UK annual domestic electricity demand by cooking appliances 1970–2030.

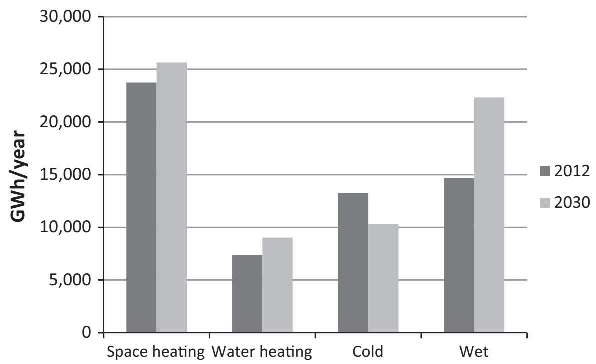

Fig. 14. Flexible domestic electricity demand in 2012 and 2030.

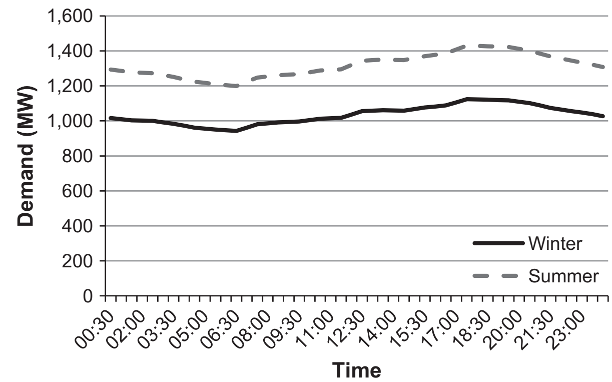

Fig. 17. Cold appliance daily load profile in winter and summer 2030.

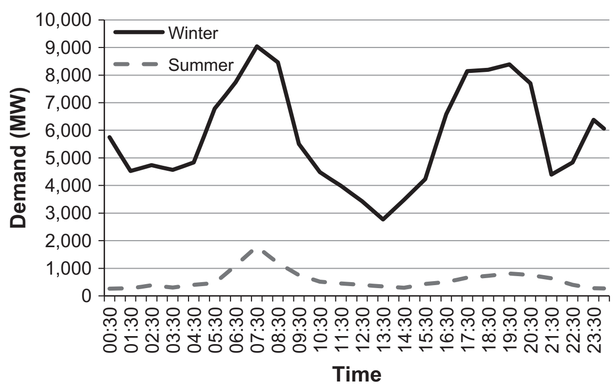

Fig. 15. ESWH daily load profile in winter and summer 2030.

3.4. Daily electricity load profiles

Daily load profiles for ESWH, cold appliances and wet appliances are based on profiles from the Household Electricity Survey (HES) [2]. The magnitude of these profiles has been adjusted to reflect the difference between the projected total UK domestic demand in 2030, from this study, and the annual demand from the smaller dataset of the HES, whilst maintaining the same overall profile.

3.4.1. Electric space and water heating (ESWH) daily load profile

ESWH demand is highly seasonal with a higher demand in winter, due to lower ambient external temperatures, than in summer, when demand for space heating drops significantly, as shown in Fig. 15.

3.4.2. Cold appliances daily load profile

Cold appliance electricity demand is subject to seasonal variations, with summer peak consumption at approximately 1.15 of the annual average and winter low consumption at approximately 0.8 of the annual average, reflecting changes in ambient temperatures [24], as shown in Fig. 16.

There is also a minor fluctuation in daily loads with consumption slightly above average at times of high household occupancy and usage e.g. at meal times [25], as shown in Fig. 17.

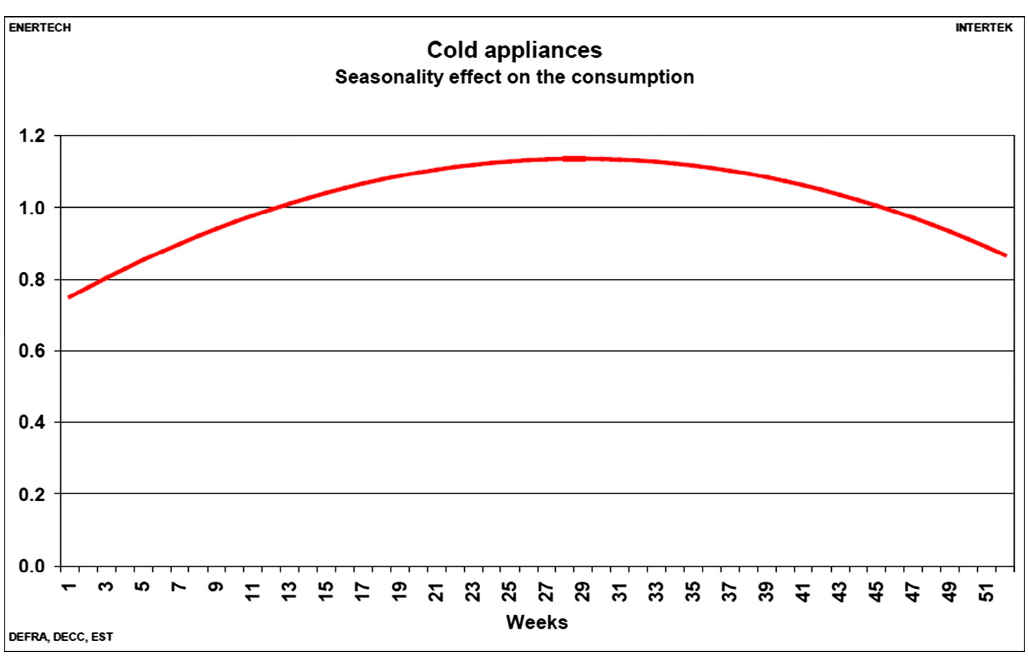

Fig. 16. Cold appliances–seasonality effect [24].

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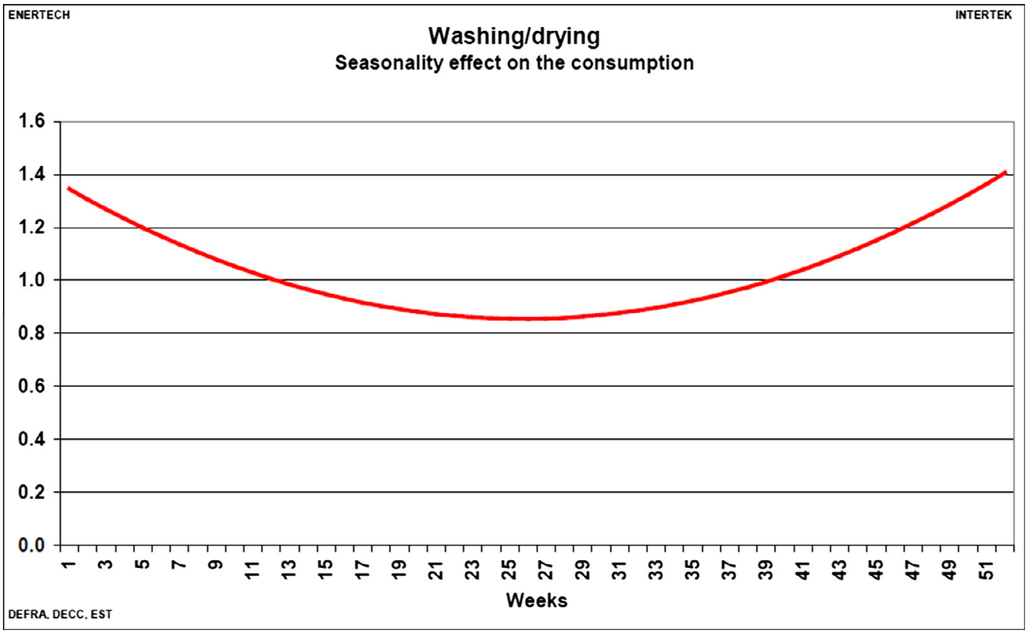

Fig. 18. Wet appliances–seasonality effect [26].

3.4.3. Wet appliances daily load profile

Wet appliance electricity demand is subject to seasonal variations, with winter peak consumption at approximately 1.35 of the annual average and summer low consumption at approximately 0.85 of the annual average, reflecting greater heating requirements and requirements to dry clothes with dryers rather than on clothes lines in winter [26], as shown in Fig. 18.

Electricity demand by wet appliances varies significantly throughout an average day. The profiles shown in Fig. 19 reflect links between appliance use and other activities, e.g. dishwasher use following mealtimes, dryer use following washing machine usage and household occupancy, and washing machines and washer dryers being activated after breakfast. Wet appliance use is lowest between 00:00 and 07:30 reflecting the sleep patterns of household occupants. This may be because occupants are not present to initiate wet appliance operations or because there is a reluctance to have noisy appliances running during the night with the potential to cause disturbance.

3.4.4. Flexible domestic daily load profile

The combination of ESWH and cold and wet appliances load profiles, is shown in Fig. 20.

4. Discussion

The effective exploitation of FDD requires the load to be identifiable and accessible, useful, and to have a value which can be passed to the owner of the load to incentivise demand response behaviour.

4.1. Identifiable and accessible demand

Annual domestic electricity consumption is projected in this study to increase from 113.1 TW h in 2012 to 124.6 TW h in 2030, accounting for approx 34% of GB's total electricity demand in 2030.

The extent of flexibility is determined by load interruptibility, time of use flexibility and the willingness of consumers to cede control over their appliances [27]. Load categories, such as ESWH and cold and wet appliances, with characteristics allowing temporal distance between the power demand and service delivery [27] are more able to provide flexibility than loads such as lighting and consumer electronics. The flexibility of different load categories, in the context of participation in the GB balancing market, is shown in Table 2.

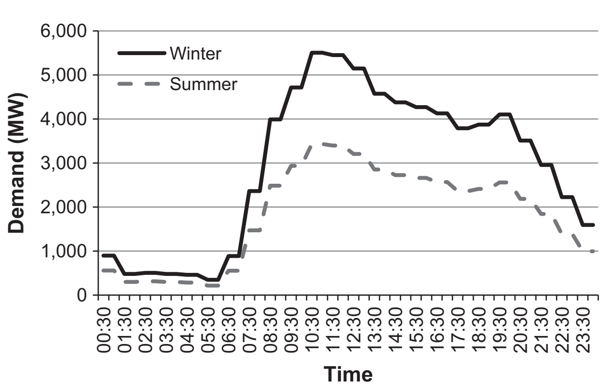

Fig. 19. Wet appliance daily load profile in winter and summer 2030.

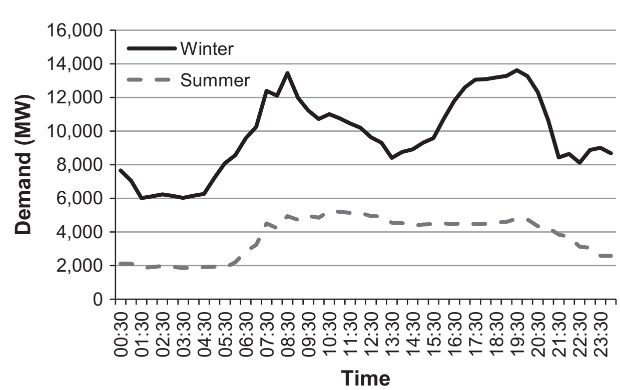

Fig. 20. Flexible domestic daily load profile in winter and summer 2030.

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The amount of FDD in GB is projected in this study to increase from 59.0 TW h in 2012 to 68.2 TW h in 2030, though the amount available at any one time varies significantly on a diurnal, weekly and seasonal basis. Additionally, the amount of practically available FDD is less than the total FDD and is dependent on permissions being granted to access load, duration of access [28] and how recent previous interventions have been made. The maximum available FDD in 2030, available at different time points during two sample days (winter and summer), are shown in Tables 3 and 4. The 2012 total GB system demand on comparable days, are also shown for reference.

Access to domestic loads will become more technically feasible following the roll out of smart meters to domestic properties and a number of small businesses, by 2020 [29], though it will be beneficial for individual loads to be aggregated in order to participate in the balancing market. In 2012, domestic loads accounted for 36% of the total GB electricity consumption but were spread across 92% of the total number of metered consumers (27.3 m out of 29.7 m in total) [30]. This raises practical difficulties in accessing the full potential of FDD. Other barriers to accessing FDD include social barriers, such as concerns over appliance controls, data security, and the cost of implementing technological enablers [31].

Access to FDD is dependent on demand responding to an external signal. This can be automated, so that the appliance load varies without requiring the consumer to intervene, or by the consumer taking a specific action in response to a signal. A major qualitative and quantitative study examining public attitudes to future energy systems in the UK [32], has indicated that levels of public acceptability of automatic controls being applied to domestic appliances are not high, and that levels of reflective consumer engagement with electricity consumption are also not high. This presents a barrier to effective access to FDD.

More passive measures, such as improved appliance efficiency and improved thermal efficiency within the built environment, may deliver greater benefits to the electricity system than forced consumer participation.

Table 2
Domestic load suitability to participate in GB balancing market.

	Primary frequency response	Secondary frequency response	Frequency control by demand management	Fast reserve
ESWH	PS	PS	PS	PS
Cooking	N	N	N	N
Lighting	N	N	N	N
Cold	Y	Y	Y	P
Wet	N	P	P	Y
Consumer electronics	N	N	N	N
Home computing	N	N	N	N

Y = yes, N = no, P = partly, PS = partly seasonal.

4.2. Uses of flexible domestic demand

Bradley et al. [33] identify a number of benefits of demand response and uses for flexible demand. These include reduction in electricity demand, peak shifting (marginal cost savings and avoidance of generation and network infrastructure costs), reserve capability (emergency and standby reserve), balancing for increased penetrations of distributed generation, and improving network efficiency.

One of the most established markets in GB for flexible demand is the balancing market, managed by the System Operator (National Grid). Market arrangements specify the type and nature of load which is required to participate in the market, as shown in Table 5.

4.3. Value of flexible demand and consumer incentives

The value of FDD can be established by using the market model and the avoided cost and asset utilisation model. The market model takes account of existing GB market arrangements, such as the balancing market, and future opportunities, such as with suppliers in the wholesale market in competition with higher cost generation [35]. The avoided cost and asset utilisation model takes account of total system costs and the potential for DSM to improve system efficiency to improve generation and network utilisation rates and avoid infrastructure investment.

Table 3
Maximum flexible domestic demand in 2030 (winter).

Winter (time)	System demand (MW) (21/12/12)	Theoretical maximum FDD (MW) (2030)	Cold (MW)	Wet (MW)	Space heating (MW)	Water heating (MW)
05:00	31,292	7228	956	461	5165	646
08:00	43,214	12,100	986	2361	6516	2237
17:30	49,936	13,058	1124	3788	7152	994

Table 4
Maximum flexible domestic demand in 2030 (summer).

Summer (time)	System demand (MW) (21/06/12)	Theoretical maximum FDD (MW) (2030)	Cold (MW)	Wet (MW)	Space heating (MW)	Water heating (MW)
05:00	25,202	1935	1217	287	0	431
08:00	37,507	4217	1254	1471	0	1492
17:30	41,299	4454	1430	2361	0	663

Table 5
Requirements to participate in 2013 GB balancing market [34].

	Primary frequency response	Secondary frequency response	FCDM (frequency control by demand management)	Fast reserve
Speed of response	From 0 to 10 s	Full availability within 30 s	$\leqslant$2 s	Within 2 min at a delivery rate > 25 MW/min
Duration of intervention	Further 20 s	Further 30 min	$\geqslant$30 min	$\geqslant$15 min
Amount of power	$\geqslant$10 MW	$\geqslant$10 MW	$\geqslant$3 MW	$\geqslant$50 MW

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The market model is based on a centralised, dispatchable power system which does not reflect a future structure with higher levels of supply side instability. It also does not reflect total system costs of underutilised generation and network assets or the benefits of avoided infrastructure investment costs. The avoided cost and asset utilisation model does not take account of the design of the existing market and the difficulty of apportioning socialised infrastructure investment costs to individual consumer actions. It also does not take account of the step-change nature of infrastructure investment and asset lifetime, or potential conflicts between different elements of supply chain (e.g. generators may want additional demand for excess supply whereas networks may be capacity constrained).

The method of calculation used can lead to substantial differences between values for domestic flexible demand. For example, the value of flexible demand from cold appliances varies between £1.97/household/year (1.12 GW $\times$ £55 m $\div$ 31.251 m households) [35] to £80 – £200/fridge/year [36].

Given the low financial value to individual households using the market model, and the structural difficulty in linking the benefits of avoided costs and improved asset utilisation to individual consumer actions, using the avoided cost and asset utilisation model, consideration is given to alternative, non-financial, incentives. These include providing access to accurate and real-time feedback [37,38], encouragement of pro-environmental behaviour through social marketing and descriptive norms [39], recognising and encouraging individual actions which benefit the wider community even if not following the classical economic theory of individual utility maximisation [40], increased appliance automation [41], and the development of electricity storage technologies [42].

5. Conclusions

The GB domestic sector is projected to account for 124.6 TW h annual electricity demand in 2030. The extent to which this demand is flexible, and thus useful for demand side management, varies between different categories of appliance. GB domestic flexible demand, defined as electric space and water heating, cold appliances and wet appliances, is projected to account for 68.2 TW h of annual demand in 2030 though the amount that is apparent at any point in time varies significantly on a diurnal, weekly and seasonal basis. This is due to links between household occupancy patterns and habitual appliance use, such as the use of dishwashers after meal times.

The amount of flexible demand which could be practically available at any point in time is also subject to permissions being granted by domestic electricity consumers to allow access to the loads. The amount of practically available domestic flexible demand in 2030 on two sample days (mid summer and mid winter) at three sample time points (05:00, 08:00 and 17:30) varies between 838 MW at 05:00 in mid summer to 6150 MW at 17:30 in mid winter.

The use of flexible domestic demand to balance a future electricity system would result in significant benefits. The current market structure creates barriers to rewarding individual household flexibility as savings in infrastructure costs would be socialised. Other, non-financial, incentives and increased appliance automation is necessary to realise the potential of flexible domestic demand.

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