A Climate Change Report Card for Infrastructure

Working Technical Paper

Energy Demand

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Key findings

1. The main impact of climate change on energy demand highlighted in the UK Climate Change Risk Assessment (CCRA) relate to future heat and cooling demand. While there have been no significant new studies that quantify the size of the impact on total UK energy demand for comfort cooling or heating since the CCRA was published, a number of studies help understand the influence of location, building fabric, and retrofitting options on embodied and operational energy demand – in particular investigating the tradeoffs between insulation measures and heat and cooling demand. Studies that have assessed both impacts of climate change on heating and cooling energy demand highlight how building design, user behavior and technology determine whether annual increases in energy demand for comfort cooling may be outweighed by reductions in heat demand – with results varying between case studies.

2. It is not possible to give definitive conclusions about the net effect of climate change on aggregate annual UK energy demand, as responses to climate change impacts will interact with a wide range of other non-climate influences.

   However, of particular significance to energy infrastructures are:

   i) the likely impacts on temporal (seasonal and daily) patterns of energy demand, as exemplified by an increase in demand for comfort cooling during warmer periods, particularly when this occurs overnight. This may compound physical impacts on electricity network ratings of high temperatures and reduce the lifetime of components such as power transmission insulators.

   ii) the spatial patterns of impacts, following the distribution of climate impacts across the UK. More pronounced changes are anticipated in the South compared to the North, with additional impacts in urban areas due to the contribution of the urban heat island effect. This spatial distribution exacerbates the challenges facing the electricity networks, due to growing demand in the South East with generation concentrated elsewhere.

3. External temperatures, humidity and, to an extent, wind speed also correlate with energy requirements for heating and cooling and the maintenance of controlled environments in other situations not just households and offices. This includes the transport of passengers and perishable goods, storage and processing of perishable goods and industrial processes. These relationships warrant further research. We have found no studies assessing UKCP09 scenarios in this context. However, given the existing relationship between weather and demand it is likely there will be an impact; the size of which remains to be determined.

4. The impacts of energy demand in the agricultural industry warrant further investigation. Although the sector uses a small proportion of total UK energy demand, the relatively large influence of climate induced energy demand is potentially significant to the sector in terms of costs. Future levels and patterns of precipitation and temperature will potentially induce additional energy demand for

irrigation during dry spells, and for pumping, crop drying and sheltering livestock during prolonged wet spells. For 'housed' animals, cooling in the summer months will also likely be required.

5. Proactive responses to future climate impacts will also have an impact on energy demand. The operation of desalination or geoengineering technologies would lead to new large point sources of electricity demand, furthermore the embodied energy in new technologies that are used to help us adapt to the impacts will lead to changes in energy demand in their supply chain. However, the size of demand increases in this regard remains indeterminate (limited information available). Challenges for energy infrastructure include the emergence of large new point sources of energy demand, potentially requiring very large quantities of energy during and after extreme events.

6. There is limited existing literature exploring the knock-on effects of more extreme weather events such as storms or flooding on the energy requirements to respond reactively to these events. Demand may be shifted to alternative energy sources through the use of back-up generators in the event of a storm induced power cut for example –changing demand for different forms of energy, rather than total demand. Energy will likely be needed to respond to the extreme weather itself such as for water pumping equipment or dehumidifiers. In addition, meeting some of this demand is likely to require mobile energy vectors – currently dominated by diesel and petrol. If large scale adoption of electric transport is achieved by the late 2050s, the ready accessibility of these fuels may be reduced this could be an issue if alternatives have not been developed in that time.

1. Introduction

Future climate and the weather it brings will impact on energy demand in two key dimensions, namely a) energy service demand and b) energy service delivery. For example, heating energy demand will vary with weather according to a) user demand for heating, and b) the performance under different weather conditions of the technology that provides heating services. Changes in both dimensions are determined by interactions between infrastructure (e.g. thermal performance of building), technology (e.g. the heating technology installed) and human factors (e.g. perceptions of thermal comfort). This report identifies the existing weather dependent components of energy demand and explores how this relationship may change with projected climate impacts. In addition, it reviews the available literature on the influence of weather on energy demand associated with measures to either mitigate or adapt to climate change.

Energy supply infrastructure will be affected by climate and weather impacts on energy demand at a range of scales and levels, at which different suites of measures are appropriate to mitigate impacts. Specifically, infrastructure will be affected by changes in:

(i) aggregate UK energy demand;

(ii) energy demand from individual sectors or end-uses;
(iii) spatial distributions of demand across the UK; and
(iv) seasonal and daily patterns of energy demand.

At the level of aggregate UK energy demand, distinct climate impacts may be difficult to distinguish from wider socio-economic changes, whereas the effects of climate change are likely to be more pronounced for particular sectors and end-uses and in patterns of spatial and temporal demand. This report considers the impacts of climate change not only on sectoral and end-use energy demand, but also on the spatial and temporal profiles of demand.

The report is structured as follows: Section 2 provides background information on historic trends of energy demand; Section 3 discusses each key energy demand sector, providing an overview of current end use patterns of the sector, non-climate factors that affect demand and how climate impacts could influence future demand. Section 4 discusses how the influences of climate change on energy demand in each sector may be mitigated or confounded by broader socio-technical changes; Section 5 discusses the energy associated with some of the large scale potential adaptation options Section 6 presents the confidence of the main conclusions and Section 7 includes a summary of gaps in the literature at present and potential research avenues in this area.

2. Background

This section outlines the historic trends in energy consumption in the UK and some of the wider factors that will influence future UK energy demand - many of which are independent of climate change.

2. 1 Existing relationships between climate and UK energy consumption

On aggregate, the main observable relationship between weather and energy demand in the UK is related to temperature. Temperature has a demonstrable effect on annual total UK energy consumption and seasonal fluctuations, particularly for natural gas use, the dominant energy source for heating. Historically, energy demand tends to increase during colder weather and decrease during warmer weather. This effect is most noticeable during autumn and spring; whilst in summer a $1^{o}C$ decrease in temperature compared to the threshold temperature is unlikely to lead to heating being used, during autumn and spring this change could be sufficient to lead to heating being turned on or off (DECC, 2013, 1.1.16). Figure 1 demonstrates this relationship during the last decade, the cooler years 2001, 2008 and 2010 correlate to peaks in energy demand compared to temperature corrected figures. Of significance is the magnitude of the weather influence compared to wider socio-economic changes influencing the UK's energy demand.

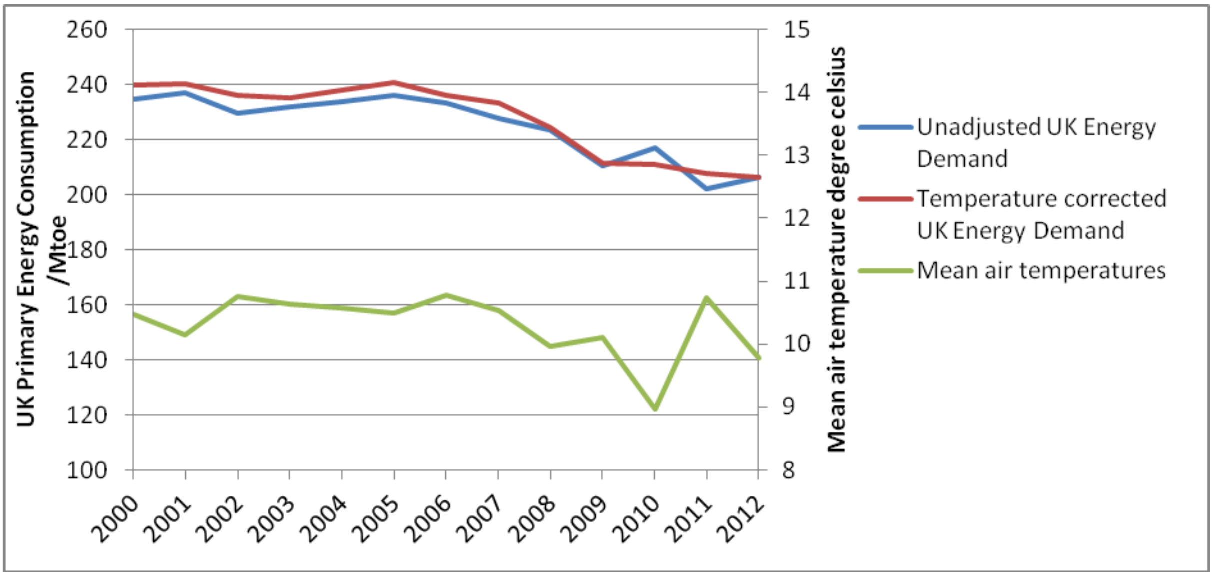

Figure 1: Existing relationship between total UK energy consumption and mean annual air temperature (Source: DECC, 2013, Table 1.01)[i]

2.2 Other factors influencing future energy demand

One of the challenges in discerning the extent of climate impacts on aggregate UK energy demand is discerning an impact over and above wider socio-economic factors, thus considering sectoral end-use energy demand is a more helpful scale of analysis. Other, non-climate, factors will affect future UK energy demand, some of which may strengthen the interdependence between climate and demand, while others may weaken the relationship. Non-climate factors include: changes in the structure of the UK economy; current and future UK energy policy; technological innovation and changes in social norms and behaviours. Distinguishing future climate from non-climate influences on demand can be challenging, particularly when they are inter-related, this section outlines the dominant non-climate influences over UK energy demand to date to highlight their significance in shaping future UK energy demand.

Considering the long term trend of energy demand in the UK since 1970 (Figure 2), there is a noticeable decline in energy demand during the last 10 years. Disaggregating the observed change to core sectors highlights a clear downward trend in the energy consumption of industry coupled with an increase in demand for energy from the transport sector.

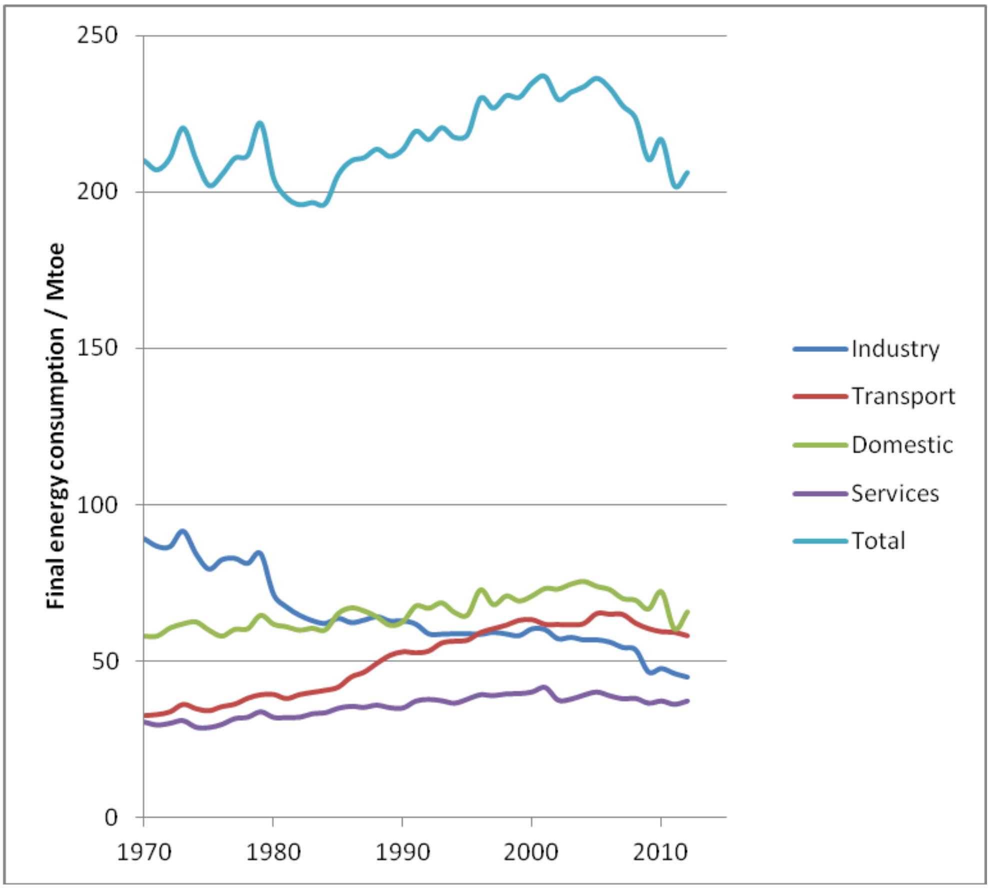

Figure 2: Long term trends in UK final energy consumption 1970-2012 (Source: DECC 2013, Table 1.02)

Changes in demand in each sector can be attributed to various combinations of changes in output (or growth of the sector) and changes in sectoral energy intensity. Table 1 demonstrates the change in UK energy consumption by different demand sectors between 1990 and 2011 and provides estimates of the contribution to this change of sector output (measured in GVA, passenger / freight km or number of households, as applicable) and improvements in efficiency. An overall reduction in UK energy demand, predominantly delivered by industry has been partially offset by growth in transport energy demand. Improvements in the energy intensity of both the service and domestic sectors are noticeably offset by increased output.

		Of which estimated to be due to change in	
	Change in demand (Mtoe)	**Output (Mtoe)**	**Intensity (Mtoe)**
Industry	-12.8	1.1	-13.9
Transport	5.4	8.5	-3.2
Domestic	-1.9	6.8	-8.7
Services	-0.7	11.2	-11.9
Total	**-9.9**	**27.7**	**-37.6**

Table 1: Output and intensity factors affecting the change in final energy consumption between 1990 and 2011 (Source: DECC, 2013 Table 1.11)

The relative influence of weather and climate on aggregate UK energy demand will to an extent be determined by changes in the composition of the UK economy over time. The most energy intensive industries tend also to be related to the processing of fossil fuels; for example, manufacturers of coke oven and refined petroleum products (402 TJ/m£, 92TJ/m£) and the manufacture of petrochemicals (90 TJ/m£). Meeting global climate mitigation objectives will require a reduction in output from these fossil fuel industries. However the delivery of such objectives is by no means certain, and future similarly energy intensive sectors could emerge in time (e.g. desalination or H_2 production plant). Other intensive sectors include the manufacture of basic iron and steel (101 TJ/m£), a prerequisite material for many alternative energy supply options, and air transport services (92TJ/m£). In contrast, many commercial and service industries such as the motion picture and music publishing industry and public administration have energy intensities as low as 0.5TJ/m£ (ONS, 2012 – data cited for 2010).

Future energy demand will also be affected by current and future energy policy. Current energy policy incentivises improvements in the carbon intensity of energy supply, energy efficiency and energy security for example through the Feed in Tariff and Carbon Reduction Commitment. Incentives may lead to the adoption of new technologies as well as behavioural practices such as the use of heat pumps and ‘smart’ technologies. Reductions in the carbon intensity of the UK’s energy supply can shift demand between energy sources, for example the electrification of services currently provided by fossil fuels such as road transport or heating. Switching between energy sources changes the relative demand from each and in some cases can alter the relationship between end use energy demand and climate. For example as will be discussed in Section 3.4, the battery performance of electric vehicles is dependent on temperature, a relationship not previously observed between the performance of petrol cars and weather. Other societal trends and technological innovations are to a large extent unpredictable, the dramatic increase in the use of ICT observed over the last decade, could not have been predicted 25 years ago – the relationship of the energy demand and weather associated with such changes cannot be predicted.

3. Sectoral analysis of energy & climate

3.1 Domestic (Residential / Household) Energy Demand

A number of studies assess the implications of UKCIP02 and UKCP09 climate scenarios on samples of the UK housing stock’s heat and cooling demand. In general, total heating demand decreases whereas cooling demand increases as observed in the CCRA 2012. Increases in cooling demand and decreases in heating demand, will likely follow the distribution of climate impacts on temperatures across the UK, i.e. with the South experiencing greater demand for cooling in the summer than the North. Currently, heating demand occurs during mornings and evenings in winter – extending to spring and autumn depending on weather. Comfort cooling demand is likely to become significant in latter decades occur during summer afternoons and evenings and if met by current methods of mechanical cooling (air conditioning units) demand for electricity is likely to occur during what are the current periods of daily peak electricity demand. Furthermore, Peakcock et al (2010) suggest overnight cooling load may be required in cities – again, if met by traditional air conditioning units, placing an additional load on the electricity network overnight.

The analyses to date are mainly scenario based, exploring various modelled housing types and adaptation methods and their ramifications on future total energy demand (not daily profiles). Given the large range of thermal performance in the existing housing stock, different thermal comfort expectations and occupancy profiles coupled with future spatially differing trends affecting these factors it would be inappropriate to draw conclusions regarding a single figure of absolute change in energy demand for the UK's domestic housing stock due to climate change. DECC (2010) estimate that future domestic heating demand could range from 90-525TWh per year and domestic mechanical cooling demand could range from 0-50TWh per year by 2050 depending on the uptake rate of efficiency measures, mechanical cooling technology and household numbers – however it is unclear how they have taken future climate into account in these estimates. There is discussion in the literature whether passive cooling measures would be sufficient to alleviate all expected cooling demand and so ensure a net reduction in household energy demand for heating and cooling in the future, however whether this is technically possible or not neglects the role of the occupants.

3.1.1 Historic Trends in Domestic Energy Demand

Historic trends in energy demand provide the context within which future climate impacts should be seen. In particular they demonstrate the significance of other factors in determining demand and highlight the relative contribution of weather dependent end uses to overall demand from the sector. Figure 3 illustrates changes in the total energy use in the residential sector since 1990. Using an index of 1990, the figure shows service demand per household increasing over time - taking into account changes in demand for individual energy services such as the level of household thermal comfort or hot water use. The energy consumption per household curve mirrors service demand but decreases over time as a result of the increased efficiency with which service energy demand is met. The difference between total energy consumption and per household consumption highlights the increasing number of households in the UK. These three indicators are dominated by space heating and influenced by fluctuations in temperature. Specific energy consumption is a modelled variable, illustrating the improvements in efficiency of providing energy services over time, independent of fluctuations in temperature, taking into account improvements in boiler efficiencies and insulation levels.

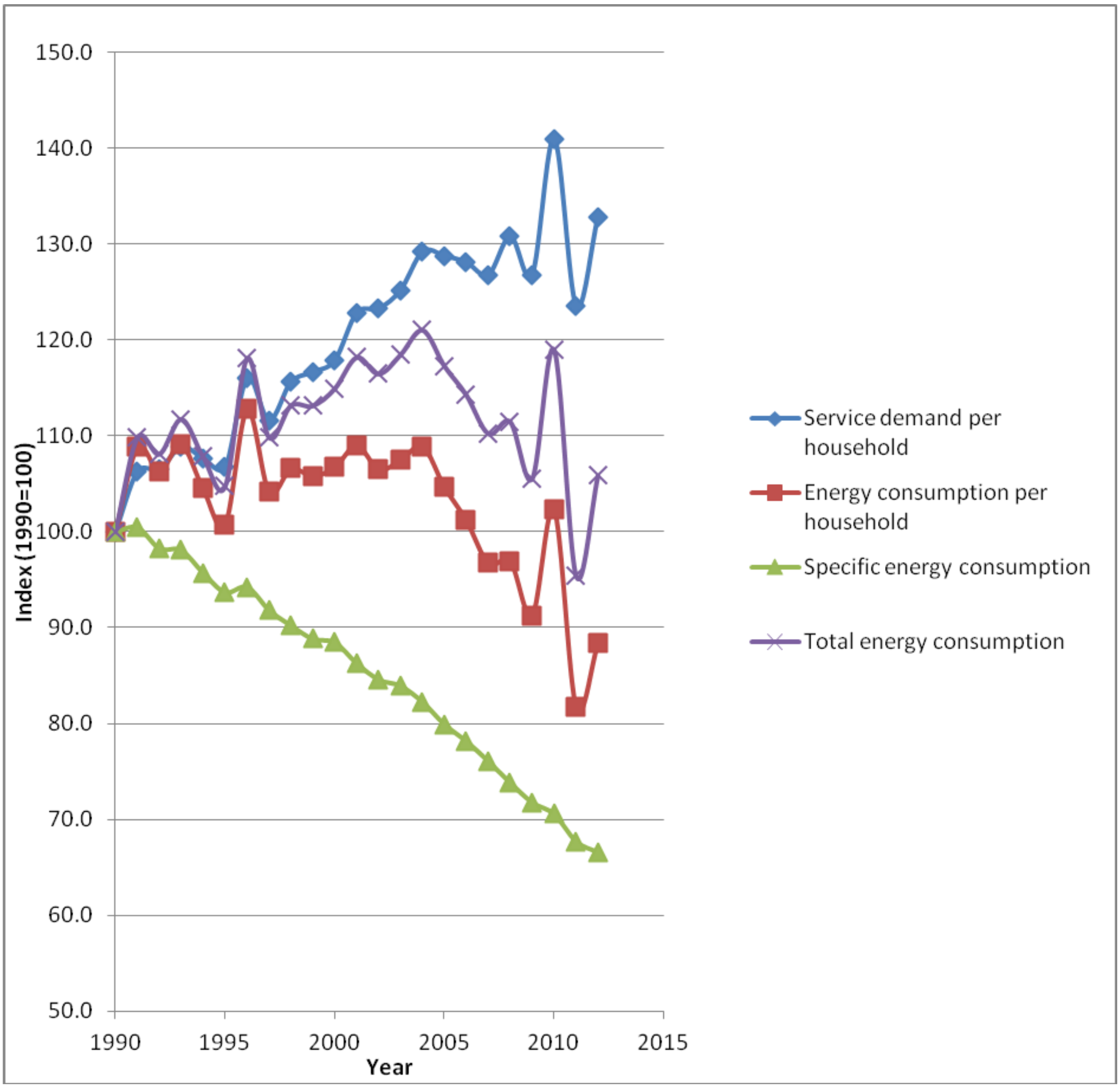

Figure 3. Change in energy & service demand indexed to 1990 (Source: Table 3.36 DECC, 2013)

Domestic energy demand can be disaggregated into eight main end uses; space heating, hot water, lighting, wet appliances (e.g. washing machines), cold appliances, computing and consumer electronics and cooking. Air conditioning does not currently feature in published analyses of residential demand, however is a potential future source of energy demand in this sector.

ktoe/year	**1990**	**2000**	**2011**
Space heating	24,618	31,094	24,043
Hot water	9,164	8230	7138
Cooking	1,509	1,320	1,113
Lighting & appliances	5,465	6,206	6,598
Total	**40,756**	**46,851**	**38,893**

Table 2. End use energy demand from the residential sector (Source: Table 3.05 DECC, 2013)

In terms of the amount of consumption in the UK and published studies the main weather dependent energy uses from the domestic sector at present are space heating demand, refrigeration and lighting. Energy demand for the former two sources relate to external temperatures and the latter to cloud cover, solar variance. Typically heating demand increases with colder weather; the elasticity of this relationship dependent on the building performance and levels of thermal comfort expected by household occupants. Refrigeration demand increases in warmer temperatures, however, the effect is minimal when compared to other factors such as the frequency with which the fridge or freezer door is opened. Lighting demand typically follows day light hours but can increase during the day time when there is extensive cloud cover.

The energy use for heating has increased slowly over time as a result of a number of factors. The number of households with central heating has increased significantly since the 1970s and by an annual average of 1.9% between 2000 and 2011 (DECC, 2013). This is a combination of increasing number of households and central heating being fitted to homes that didn't have it previously. Accompanying the trend in central heating have been that long term efforts to reduce heat energy demand have led to improvements in domestic boilers – as older boilers are replaced average efficiency is improving. For the period 2008-2011 average annual efficiency improved by 1.12% (2008-9), 2.22% (2009-10), and 0.18% (2010-11) (DECC, 2013). This trend is expected to continue over the next decade as more households replace older back boilers with newer efficient models. There are also incentives for householders to move to alternative heating provision such as heat pumps or biomass boilers through the 'Green Deal' and which will influence the ultimate form of energy required for domestic households and potentially the amount of energy. Another important factor is improvements in the thermal performance of UK homes. The SAP rating – the standard way of estimating the energy efficiency of homes in terms of levels of insulation, air tightness etc – is reported annually and, by 2011, had increased three times over 1970 values (DECC 2013). This increase continues and since 2000 the average SAP rating for UK homes has improved by an average of 2% per annum. However, the comfort levels that people expect, highlighted by the internal temperature to which homes are heated, has been a counter driver to the improved efficiency of boilers and homes. Since the 1970s there has been a substantial increase in the average internal temperature maintained in homes (from 12^{o}C in 1970 to 17.6^{o}C in 2011) although over the last decade that trend appears to have halted (DECC, 2013).

3.1.2 Interactions between weather and climate and end use energy demand for the domestic sector

Subsector	**Currently weather dependent?**	**Potentially affected by future weather & climate?**	**Other factors affecting the impact**	**Spatial or temporal variation**
Heating: demand	Yes	Yes, annual demand for heating predicted to decrease.	Changes in standards of thermal comfort and increase in household numbers could lead to increase in heating demand and compensate reductions in heat demand associated with climate change.	Reductions across autumn, winter and spring during times of current daily peak energy demand. In general appear to be larger reductions in HDD in northern latitudes compared to Southern, thus greater reductions in energy demand in Northern latitudes compared to Southern during winter.
Heating: supply - boiler efficiency / CoP	Yes	Yes, provision of heat can be affected by external temperatures. Heat pump performance declines with a decrease in temperature. Lower building heating demand due to increased winter temperatures can mean heating systems designed to meet the current climate become oversized and less efficient in time	The rate of uptake of different heating technologies and future technological developments that improve their performance at low temperatures will influence the scale of this challenge. Impact may be particularly	

		unless replaced periodically using new climate data to predict demand.	significant for ‘peak’ demand days. Appropriate boiler / heating system sizing that takes into account climate impacts can avoid inefficiencies.	
Hot water demand	No (while there is seasonal variation there does not seem to be any particular weather dependence)	No		
Hot water: supply - boiler efficiency / CoP	Yes	Yes, as above for heating provision.		
Comfort cooling demand	Yes	Yes, warmer temperatures, both average and peak summer days lead to annual increase in cooling demand and peak day cooling demand.	Energy demand for cooling is dependent on the success of measures to improve the natural ventilation and cooling of households and householders’ perception of thermal comfort in warmer weather. In addition the technology chosen to provide cooling demand influences its energy demand.	Any demand increase would be most evident in summer months, particularly in the south and urban areas affected by the urban heat island effect. Demand is likely to occur during existing times of peak electricity demand, if cooling demand is met by electricity this will have implications for

				the network. In addition when overnight temperatures are also high, cooling demand may extend to overnight.
Comfort cooling supply	Yes	Yes, the efficiency of performance of certain air conditioning technologies vary with temperatures, tending to decrease in efficiency with hotter temperatures.	The future technology mix and technological development to enhance performance at hotter temperatures will determine the significance of this impact.	
Lighting	Yes	Yes, daytime lighting demand is influenced by cloud cover, any increase (or decrease) in cloud cover will influence lighting demand during the daytime.	The effect on energy demand will be influenced by the efficiency of lighting technologies, reliance of householders on natural light during the daytime, household occupancy patterns.	
Wet appliances	No direct relationship	No evidence to support any change available.		
Cold appliances	Yes	Yes, warmer temperatures increase cooling demand for refrigeration.	The scale of the influence is dependent on the future performance of cold appliances in the home and the patterns of their use by householders. Currently use patterns outweigh the impacts of temperature on energy	

			demand for refrigeration.	
Computing	No	No		
Consumer Electronics	No	No		
Cooking	No explicit analyses on this found.	No		

Table 3. Influence of weather and future climate on domestic end use energy demand

Heating demand

Heating demand is higher during colder weather, so as long term average temperatures increase, annual energy demand for heating is likely to decrease. However analysis by Du et al 2011 suggests that the size of peak winter day heat demand may not change in the future. Heat demand is directly related to thermal performance of a house, thermal comfort standards of occupants, and the external temperature in relation to a baseline threshold below which it is assumed heating is required. This is measured in heating degree days (CIBSE, 2006). Projections of future heating degree days (HDDs) and associated heating demand outlined in the CCRA 2012 demonstrate an almost linear decline in heat demand out to the 2080s under each climate scenario. Reductions in HDD in London are predicted to be between -360 to -1214 under the different emission scenarios and a 15.5°C threshold by the 2080s and in the North of Scotland between -437- 1584 (Capon and Oakley, 2012 Appendix 5). This corresponds under median population projections and no assumed improvements in efficiency to between an increase in 20% to a decrease in -50% GWh per annum in London and between 0-60% reduction in GWh for heating in the North of Scotland (ibid). These figures are for total UK heating demand and assume no improvements in the thermal performance of buildings or efficiency of the heat supply. It can be assumed that domestic housing will follow similar trends, but there is potential to achieve lower heating demand if efficiency gains and insulation measures continue as planned (discussed further in section 3.1). Subsequent analyses provide additional information on case study buildings demonstrating the characteristics of how the building stock affect the magnitude of this reduction and the additional reductions associated with increase thermal performance and energy efficiency. This area of research tends to focus on both heating and cooling demand and is discussed in the cooling demand section below.

Heating provision

Boiler efficiency and the coefficient of performance (CoP) of heat pumps are affected by temperature. In colder weather the efficiency with which heat is produced is reduced. For gas boilers the size of the effect appears to be limited and any influence would be reduced as many are sited inside a house. However, for heat pumps it can be significant as the system is interacting with cold air or earth. For an air source heat pump, a change in temperature from +7°C to -7°C can see the CoP drop by 28% (Dunbabin et al, 2013, p.15) For ground source heat pumps the CoP will decline with ground temperature and will therefore be influenced by the length of cold spells. Technology improvements may reduce the effect of temperature on CoP but if more heat pumps are installed then the overall combined effect may be greater. Higher average winter temperatures would suggest that the average impact on CoP across a winter will be reduced.

Heating systems generally run at maximum efficiency when at close to full output. Warmer winter average temperatures should result in a requirement for lower capacity heating systems than currently installed (Sharples and Lee, 2009). When retrofitting new systems, appropriate weather data is needed to ensure the correct sizing and minimise inefficiencies through over sizing (Sharples and Lee, 2009).

Comfort Cooling demand

Higher summer temperatures will likely result in greater demand for comfort cooling. Where mechanical cooling is installed its use will be closely linked to temperature. The exact relationship is dependent on numerous factors (not least comfort expectations of building occupants) for a given standard of comfort as the temperature exceeds a baseline threshold and the number of cooling degree days increase, so will the use of cooling systems, mechanical or other. Hotter temperatures, with increased number of cooling degree days, are more prevalent in southerly latitudes. Projections of future Cooling Degree Days (CDDs) outlined in the CCRA (McColl et al 2012 Figure 5.1), provides the basis for assessing the size and spatial distribution of cooling load across the UK. The average CDD over southern England for the 1961-1990 ensemble mean are simulated to be approximately 25 – 50, whereas by the 2080s they have increased by 125 – 175 based on a threshold temperature of 22^{o}C (McColl et al 2012). The projected increase in CDD is reduced with increasing latitude, such that the increases over northern England and Scotland are much smaller (25 – 50). This will be further exacerbated in urban areas due to the urban heat island (UHI) effect. For example, central London can see temperatures 7^{o}C warmer than those experienced in rural areas 20km away (Watkins et al, 2007, p. 85).

The increase in temperatures seen in the UKCP09 scenarios suggests that comfort cooling demand will increase over time. Comfort cooling demand is currently mainly limited to the summer months and peak demand is during late afternoon on hot days. As average and extreme temperatures increase, households that have mechanical cooling will use it more frequently. However, given the low number of domestic properties that currently have mechanical cooling, the biggest impact on overall energy demand in the domestic sector will be the uptake rate. This is likely to be influenced by many factors. Events such as heat waves are a spur to the adoption of air conditioning, while general temperature increases will also be important. With respect to heat waves, analysis by Patidar et al (2014) suggests that the amount of time where average bedroom temperatures exceed 28^{o}C for 5 days or more will increase over time as the climate changes. Taking a bedroom comfort temperature of 23.9^{o}C, Peacock et al (2010) find that number of 'cooling nights' (when the comfort temperature is exceeded at 11pm) in London increase between 2005 and 2030 by up to 47% to a maximum of 105-121 cooling night/year depending on the type of construction.

An increase in cooling nights has significant implications for both the health and wellbeing of building occupants – particularly vulnerable populations and the electricity network (if cooling is provided by electricity). Overnight cooling provides individuals with a chance to recover physiologically from hot weather, prolonged exposure to high temperatures is associated with excess mortality in vulnerable populations. Demand for electricity to provide cooling overnight to avoid these impacts, can lead to increased electricity demand overnight, a time when traditionally network cables and equipment cool down – prolonged operation at high temperatures (through external temperatures as well as high load) reduces the lifespan of equipment.

Delivering cooling demand

The coefficient of performance (CoP) of air conditioning units reduces as the temperature increases. Between 26°C and 30°C the CoP of an air conditioning unit can drop by over 10% (Izham and Mahlia (2010). Similarly trigeneration air sourced heat pumps see a decline in cooling efficiency at higher temperatures. CoP will be lowest when temperatures are highest and demand is greatest, compounding the effect of hotter temperatures on energy demand (Izham and Mahlia, 2010). The efficiency of air conditioners should improve over time, but the impact of this on the relationship between temperature and energy demand is unclear. In Australia a move towards larger capacity air conditioning units has been outstripping efficiency improvements so energy savings are not being realised (Strengers 2008).

Lighting

Increased cloudiness leads to a higher requirement for lighting and, though the overall effect on annual energy demand is relatively small, it could enhance daytime electricity loads. This is unlikely to have much impact on winter peak demand which occurs when it is already dark. The largest influence would be during the day in winter and also morning and early evening in the summer.

Cold appliances

The efficiency of cold appliances can be reduced in hot weather, however the size of this influence is likely to be limited. Although ambient temperature will have an effect on energy demand for refrigeration it is one among many factors. These include: how often the door is opened; what the internal temperature is set to; whether the appliance is built in; where the appliance is located etc (Lagueere et al 2002). As temperatures increase the impact will increase although this may be offset by more efficient appliances with better insulation.

3.2 Service sector - Non-domestic buildings

The main energy use in this sector is associated with buildings, encompassing a range of types and uses, including office space, government (public admin) and commercial as well as retail space and warehouses. There is an emerging literature assessing the impacts of climate change on building energy demand – primarily for heating and cooling (eg. Chow and Levermore, 2010; Patidar et al 2014; Lomas and Ji, 2009; Short et al 2012; Du et al 2012; Jentsch et al 2008). There are also efforts to produce ‘test reference’ and design summer years that encompass future climate impacts for use in building performance simulation packages (Jentsch et al 2008; Du et al 2012; PROMETHEUS, 2011). The studies collectively show a reduced demand for winter heating and an increase in summer cooling, whether energy demand reductions from winter heating outweigh increases in cooling demand depend on the case study building designs used and the emission scenarios chosen – with results including summer energy demand for cooling outweighing savings in heating demand. The studies illustrate that how the changes in heating and cooling load translate into changes in eventual energy demand is dependent on a) the performance of the building stock b) thermal comfort perceptions or needs of building users and occupants and c) the type of systems installed to provide heating and cooling. These factors are discussed further in Section 3.3.

3.2.1 Historic trends in the service sector demand

Over the last twenty years energy demand from the service sector has reduced by 2%; reductions in the energy intensity of the sector have been offset by growth in output (measured as GVA in 2010 prices) as illustrated by Table 4.

Mtoe	**1990**	**2000**	**2011**	**Change between 1990 and 2011 (Mtoe)**	**Of which change estimated to be due to**	
					Output (Mtoe)	**Intensity (Mtoe)**
Public Admin	7.6	8.1	6.3	-1.2	3.2	-4.4
Commercial	10.30	12.2	11.2	0.9	7.9	-6.9
All services (excl agriculture)	**17.9**	**20.3**	**17.6**	**-0.3**	**11.1**	**-11.4**

Table 4 Output and intensity factors affecting service sector energy demand between 1990 and 2011 (Source: Table 5.17 DECC 2013).

Table 5 provides a breakdown of the main energy end use by groups in 2012. It shows the current dominance of space heating and the relatively small contribution of cooling to total energy demand. To assess the current and potential future impacts of weather and climate change this section focuses on those uses of energy demand that are directly influenced by weather.

Ktoe	**Catering**	**Computing**	**Cooling & Ventilation**	**Hot Water**	**Heating**	**Lighting**	**Other**	**Total (ktoe)**
Commercial Offices	41	116	167	83	787	252	48	1,493
Communication and Transport	34	8	29	25	110	205	86	497
Education	265	91	12	386	1694	381	134	2,963
Government	129	91	39	154	1261	137	89	1,901
Health	64	15	1	201	1170	223	31	1,707
Hotel & Catering	572	6	103	364	726	309	106	2,186
Other	40	14	18	79	473	136	70	831
Retail	461	118	295	158	1074	1,190	280	3,576
Sport & Leisure	71	11	45	116	302	148	144	838
Warehouses	152	35	54	93	1104	424	259	2,120

Total	**1,831 (10%)**	**505 (3%)**	**764 (4%)**	**1,659 (9%)**	**8702 (48%)**	**3,405 (19%)**	**1,247(7%)**	**18,113**

Table 5. Breakdown of service sector final energy consumption by end use 2012 (Source: Table 5.07 DECC, 2013)

3.2.2 Impacts of climate change on future energy demand in service sector buildings

Subsector	Direct relationship with weather?	Potential impact of climate change on overall demand	Other factors affecting the impact	Spatial or Temporal variations
Catering	No, there may be seasonal variations however weather is only part of correlation which includes changes in lifestyles between seasons.	None		
Computing equipment	Current equipment generates heat adding to cooling demand of buildings on already hot days and reducing demand for heating on colder days	The heat generated by computing equipment may affect the relationship between heating and cooling demand and external temperatures. The exact relationship is likely to depend on specific circumstances and an influence may not be apparent on aggregate.	Technology improvements reducing heat output of computing equipment. Increased use of computing equipment in buildings.	Heat gains from computing equipment are useful in winter, reducing demand, but can increase cooling demand in summer months.
Comfort cooling	Proportional to air temperatures above a threshold	Cooling demand likely to increase	Thermal performance of building stock, perceptions of thermal comfort and norms around office working, provision of cooling by natural ventilation / shading alter cooling demand. Changes to buildings that reduce air flow can increase cooling demand. The balance between passive cooling and mechanical	Impact during summer months likely to be during times of peak demand. Cooling demand is greater in Southern latitudes than Northern and is amplified in areas suffering from urban heat island effect.

			cooling determines the energy needed to provide resulting cooling.	
Hot water	No, there may be seasonal variations however weather is only part of correlation which includes changes in lifestyles between seasons.			
Heating	Indirectly proportional to air temperature below a threshold	Heating demand likely to decrease	Thermal performance of building stock, expectations of thermal comfort, choice of technology.	Reductions in demand during peak times during winter months. In general appear to be larger reductions in HDD in northern latitudes compared to Southern.
Lighting	Related to cloud cover	Impact of climate change on cloud cover uncertain.	Building design to increase natural light	

Table 5. Influence of weather and future climate on service sector end use energy demand

Heating and cooling – service demand

As in the residential sector, studies suggest a decrease in annual energy demand for heating, and an increased demand for cooling in the service sector under future climate projections. Projections of future heating degree days and associated heating demand outlined in the CCRA demonstrate an almost linear decline in heat demand out to the 2080s under each climate scenario as detailed in Section 2.1. DECC's (2010) analysis on future heating and cooling from buildings provides an envelope of possible energy demand associated with cooling in the future. Research published subsequently, does not update this UK wide figure however, through the use of case studies the literature quantifies the impact of different methods of adapting both domestic and non-domestic buildings to reduce both heating and / or mechanical cooling load. The studies tend to examine a particular type of facility or building scenario, making it difficult to extrapolate results to the whole UK service sector building stock. Moreover studies seldom cover the range of the UKCP09 emission scenarios or include additional ramifications of the urban heat island effect.

Chow and Levermore (2010) assess the future heating and cooling demand for a model office building based on future temperatures under the UKCIP 2002 A2 emissions scenario. Their results suggest that the reduction in heat energy demand is approximately equal to the rise in cooling demand (assumed cooling CoP of 3.5) as a result of climate change up to the 2080s. They also note that natural ventilation alone would be unable to provide sufficient summer cooling in the UK in the near future. Du et al (2012) assess the impacts of the 85% & 99% percentile warmest summer months and coldest winter months from the UKCP09 scenarios on heating and cooling loads in a multi-cellular office building built to 2006 Building Regulations. As in a previously published study (Du et al 2011), their results indicate a decline in annual heating demand over time and according to emissions scenario, but no decline in peak heating demand. Du's analysis also demonstrates an increasing demand for cooling over time, depending on emission scenario. The extent to which cooling load translates into energy demand depends on the uptake and use profile of specific cooling technologies, availability of natural ventilation and adoption of remediation measures such as solar-shading and augmenting the thermal mass of the building (Du et al 2012).

Jenkins et al (2013) assess electrical cooling demand under UKCP09 low, medium and high emissions scenarios for a case study office building. Their results demonstrate a 45% increase in electricity consumption for cooling between the baseline year and 2080s under the medium scenario. Adapted buildings show a reduction in cooling demand compared to unadapted facilities, but a significant *increase* in cooling demand compared to the baseline year. For example, their simulations for London show baseline consumption in unadapted buildings of 46MWh/yr rising to 71.9MWh/yr under a high emissions scenario in 2080, compared to an adapted building baseline of 25.2MWh/yr increasing to 29.5MWh/yr. Results for Edinburgh are in similar proportion, albeit approximately a third lower in total compared to London. The study highlights the significant contribution to reducing future office cooling demand from adaptation measures such as horizontal external shading on south facing glass and limiting heat gains from IT and lighting.

Tian and de Wilde (2011) use UKCP09 scenarios to estimate the impacts on heating and cooling load of an air conditioned university building. By the 2050s under a medium emissions scenarios the mean annual cooling energy increases by 122% and the mean annual heating energy decreases by 40% relative to the 1961–1990 baseline. Their results suggest that by 2050 cooling demand (measured in Kwh/m^2) is similar to heating demand in a low emissions scenario and is higher for both medium and high scenarios. Both Tian and de Wilde (2011) and Jenkins et al (2013) stress the significance of assumptions regarding internal gains and the thermal characteristics of building materials.

The studies highlighted so far do not include the added effects of the urban heat island effect. Kolokotroni et al (2012) assess both future climate impacts and the urban heat island effect on the heating and cooling loads of an office in London. Climate impacts were represented by morphing baseline temperature measurements according to the 2050s medium-high emissions UKCIP02 scenario. An increase in electricity consumption for cooling (in kWh/m^2/year) of 23% to 30% was found for all building scenarios. Heating demand reduces by between 45% and 35% in 2050, with gas demand reducing by approximately 45% for all building scenarios.

The scale of potential impacts is spatially specific, with Southeast England seeing an increase in cooling degree hours earlier in the century than Scotland. The urban heat island effect will likely compound impacts in built up areas, leading to higher cooling demand than predicted solely on the basis of climate change scenarios.

While in all the studies cited there is a clear trend indicating a decline in annual heating demand and an increase in cooling demand throughout the century, the extent of these changes depends on assumptions about buildings, adaptation measures and the type and efficiency of cooling systems. There is evidence, discussed in more detail in Section 4.2 that building adaptation measures and changes in behaviour by occupants (e.g. closing windows when air outside is hotter than that inside; starting the working day earlier; wearing clothes in the office suitable for the external temperature) can reduce cooling demand from mechanical means (Coley et al 2012; Jenkins et al 2013). Useful further research in this area includes running different adaptation and cooling scenarios using a combination of probabilistic climate projections for all the UKCP09 scenarios for a wider range of building models and incorporating future urban heat island effects.

Heating and cooling – service provision

As discussed in section 2.1, some heating and cooling technologies such as air source heat pumps or air conditioning units are influenced by ambient temperature, reducing performance during either very cold or very hot weather. However, Hanby and Smith (2011) demonstrate that evaporative cooling methods may have enhanced potential in the UK under the medium UKCP09 scenario, based on a case study office building in the South East. The passive techniques they consider could provide low-energy cooling demand when retrofitted to other commercial buildings, depending on their configuration and use. The service provision and retrospective changes to the building solutions chosen can shift the balance of energy used over the lifetime of a building, between embodied and operational energy – with relevance to the timing and end-use sector of energy demand (see for example Yohanis & Norton (2002) and Williams et al (2012)).

3.3 Transport

There are limited published case studies assessing the impacts of the UKCP09 scenarios on UK transport energy demand. However, research on the impacts of climate change on European aviation is emerging, suggesting a likely increase in energy demand from this sector in response to climate change. The review presented below uses information on the current weather dependency of transport demand to draw conclusions as to the likely direction of change in energy demand induced by future climate impacts. Future demand for cooling on transport systems is a particular area of future energy demand, as with the domestic and service sectors, the implications for the size of associated energy demand are dependent on both standards of thermal comfort and how cooling is provided.

3.3.1 Historical Trends in Transport Energy Demand

Table6 illustrates trends in transport energy demand between 1990 and 2011, attributing changes in energy demand to either change in output (measured as passenger or freight km) or changes in the energy intensity per passenger or freight km. In road transport, the dominant sector responsible for the increase in energy demand from this sector is attributed to light good vehicles, with car energy use declining (DECC 2013, table 2.02) Aggregate energy demand from LGV use has shown steady growth (+66% since 1990, ibid.), unlike other forms of road transport improved efficiency has essentially offset increased user demand leading to slightly declining aggregate energy demand. LGV energy use represents ~14% of total road transport energy at around 5Mtoe (DfT 2013b, TSGB0101). Aggregate energy demand from HGVs has remained fairly stable over the last decade at around 7Mtoe, peaking at 7.7Mtoe in 2007 (ibid.).

	1990	2011	Change in energy consumption between 1990-2011 (Mtoe)	Of which are estimated to be due to changes in	
				Output (Mtoe)	Intensity (Mtoe)
Road transport	27	25.8	-1.2	3.1	-4.3
Road freight	11.8	14.0	2.2	2.0	0.2
Rail	1.1	1.1	-0.1	0.6	-0.7
Air (domestic & international)	7.3	12.8	5.5	3.5	1.9
National navigation	1.4	0.4	-1.0	-0.3	-0.7
All transport	**48.6**	**54.0**	**5.4**	**8.5**	**-3.2**

Table 6: Change in energy demand from UK transport allocated to either change in output or intensity. (Source: DECC 2013, table 2.1)

The energy intensity of all road freight lifted by HGVs and LGVs combined increased by 9% between 2000 & 2011 from 0.079Mtoe/btkm to 0.085 Mtoe/btkm (DECC 2013, table 2.11). Aggregate energy use by buses increased by approximately 7% between 2000 & 2011, from 1.27Mtoe to 1.36Mtoe (DECC 2013, table 2.02) due to growth in vehicle km despite fuel efficiency improvements.

3.3.2 Interactions between weather and climate and energy demand for transport

The main influences of weather on energy transport demand relate to the effect of ambient temperature on a) the performance of propulsion technology b) demand for passenger thermal comfort. Influences of weather on travel demand per se and mode of travel (e.g. bicycle, car or bus) are also plausible, indeed anecdotal evidence also suggests a relationship between UK summer temperatures and the numbers of flights for holidays or 'staycations' – however, we have not found evidence to support this. The relationship between external temperature and internal combustion engine and electric vehicle performance is discussed below. The impact of external temperatures on passenger demand for heating or air conditioning creates additional energy demand in colder and hotter temperatures respectively, hence additional engine (or battery) load. Ambient temperature also affects the freight energy load associated with the refrigeration of certain perishable goods.

Sub-sector	Comprising	Direct relationship with weather?	Potential impact of climate change on overall demand	Other factors affecting the impact	Temporal or spatial influences
Road	Cars	Ambient air temperature affects engine efficiency and demand associated with thermal comfort	Yes – increase in air conditioning demand with increasing ambient air temperatures. Battery performance optimal between certain operating temperatures.	Depends on the fuel mix of the future car fleet. Energy requirements for heating and cooling depend on passenger expectations of thermal comfort and measures to provide natural ventilation / cooling. Passive cooling measures, e.g. retrofitting buses with white roofs and automatic ventilation systems (TfL, 2014).	Patterns in future temperature distribution will affect the spatial variation of changes in energy demand. Warmer temperatures likely to be more common in urban areas and lower latitudes. Colder temperatures more prevalent in northerly latitudes and rural areas.
	LGVs				
	HGVs				
	Buses				
Rail	Passenger	Ambient air temperature associated with energy demand for passenger's thermal comfort	Yes potentially depending on how increases in summer cooling demand are met	Natural ventilation and changing expectations / acceptability of warmer temperatures could reduce cooling energy demand.	
	Freight	No – unless used for refrigerated goods	No		
Aviation	Domestic	Adverse weather events can cause diversions leading to increased fuel burn. Climate currently influences sun and winter sports holiday	Yes, higher frequency of convective weather can lead to rerouting and the need for additional fuel to be carried. Increased temperatures can reduce climb efficiency increasing energy demand during	Plans by the aviation industry to improve the efficiency of flights could offset some of the potential increase in energy demand caused by climate impacts.	Increase in fuel for take-off mainly in summer months. Impacts of convective weather, depend on distribution throughout the year.
	International				
Shipping	Domestic	No	No		

	International	No	Opening up of the Arctic passageway provides a shorter route for ships between NE Europe and the Far East compared with the Suez Canal.	Dependent on the uptake of this route by ship operators and any international legislation governing its use.	

Table 7: Summary of interactions of weather and climate with demand for energy in the transport sector

Effects of ambient temperature on propulsion systems

Internal combustion engines (ICE) operate more efficiently at higher ambient air temperatures, thereby reducing energy required per kilometre (Mock *et al.* 2012). In test conditions, an average 0.161% reduction in CO_2 emitted (hence fuel consumed) was observed for each 1°C rise in ambient air temperature over the standard European test cycle (Kadijk *et al.* 2012). Increased mean and extreme temperatures associated with climate change are likely to result in a relatively small reduction in energy demand from ICEs, with the overall impact dependent on the growth rate in vehicle kilometres driven by ICE vehicles.

Electric vehicle battery performance is also affected by external temperatures. Colder air temperatures impair battery performance in electric vehicles, effectively increasing electricity demand per kilometre of travel. The extent of reduction in battery performance varies with battery chemistry and with severity of low temperature. Lead acid and nickel metal hydride (NiMH) batteries have a narrower range of performance than lithium ion batteries, requiring energy for cooling and heating of the battery unit to achieve acceptable operating temperature (Pesaran *et al.* 2003). NiMH batteries show a reduction in maximum discharge power between 20°C and 0°C of around 50% (ibid.). Modern lithium ion batteries have proved more resilient to cold temperatures than lead acid and NiMH, maintaining 90% of their 25°C discharge capacity at -5°C (Horiba *et al.* 2005).The effect of reduction in battery discharge capacity is potentially more problematic for extra-urban areas where charging points are fewer and further between. The overall effect of future climate change is not expected to change an electric vehicle's energy demand markedly in future as winter mean temperatures are forecast to rise, but extreme cold weather events will remain problematic for users during these events.

Warmer air temperatures (especially in urban areas) are associated with increased use of mobile air conditioning (AC), increasing the electrical load on the battery and more rapidly depleting charge (Devie *et al.* 2012). The scale of demand change is indeterminate given the elective nature of AC use. However, AC is by far the greatest auxiliary load on a vehicle's battery. Reduction in hybrid and electric vehicle fuel economy / range due to AC use is estimated to be up to 40% – hence 40% increase in charging energy to travel same distance (Farrington and Rugh 2000). Energy demand for transport air conditioning could potentially significantly increase as mean and peak summer temperatures rise as a result of climate change.

Whereas the CCRA notes "widespread agreement that when used during high speed travel, the increase in fuel consumption attributable to use of air conditioning in vehicles is relatively small – in the region of one per cent or so", this applies only to conventional ICE vehicles where the AC compressor is powered by a drivebelt from the engine. The CCRA goes on to note that "the frequency of usage of air conditioning will increase with a warming climate" – therefore understanding the effects of increased mean and peak temperatures on the energy demand for mobile air conditioning will be a key consideration for an electrified fleet.

It is likely that increases in mean and extreme summer temperatures will also lead to an increase in cooling demand for other forms of surface transport including buses and trains.

The requisite information to determine the significance of this load is not currently available to provide an indication of the relative scale of change associated with climate impacts. However, the demand for cooling on public transport has been noted, with London Transport undertaking a retrofitting exercise to install automatic ventilation systems and paint the roofs of buses white to improve the thermal comfort of passengers during hot weather (TfL 2014). Similarly the London Underground is undertaking a series of measures, including the installation of pumps and fans and of air conditioning units on the trains on some lines, which incur energy costs to provide cooling to the underground network in hot weather (GLA 2005; GLA 2011). Demand for cooling on the London Underground is likely to increase under all climate scenarios.

In the aviation sector, a potentially significant impact on energy demand arises from the potential increase in larger and more intense convective systems within the atmosphere. Avoiding these systems typically adds to journey length, requiring additional fuel. An increase in temperature also affects climb performance of aircraft, increasing the fuel demand during take-off (Eurocontrol 2013).

3.4 Industrial Energy Demand

There is minimal publishes information discussing the impacts of climate on energy demand by industry. A collection of studies highlighting the significance of weather on various industrial processes are presented, it is assumed that these are sensitive to climate impacts however there is no quantification of the scale of change that climate impacts may cause. Main processes affected include those operating in controlled environments such as the food and biotechnology sectors; steam production; general heating and cooling and water pumping.

3.4.1 Historical Trends in Industrial Energy Demand

UK industry has demonstrated a significant reduction in the energy intensity of manufacturing over the last 40 years. The industrial sector has grown by an average of 1% annually in gross value added terms, whilst reducing total energy consumption by 44% since 1970 and by 9% since 1990 (DECC 2012). The main efficiency gains were in the iron and steel and chemical sectors, which in 2011 had reduced their energy intensities by 70% and 50% compared to their respective 1990 levels (DECC 2013d, chapter 4). Table 8 outlines the contributions of different parts of the industrial sector to its total energy demand and their relative improvements in energy intensity over time. While most sectors have demonstrated an improvement in energy intensity, only the iron and steel industry has made significant absolute reductions in energy demand between 1990 and 2011, the chemical industry’s significant improvements in energy intensity are outweighed by growth in output.

	1990 (Mtoe)	2000 (Mtoe)	2011 (Mtoe)	Change in energy	Of which are estimated to be due

				consumption 1990 – 2011 (Mtoe)	**to changes in**	
					Output (Mtoe)	**Intensity (Mtoe)**
Iron, steel & non-ferrous metals	8.2	3.4	2.1	-6.2	-1.5	-4.7
Chemicals	5.9	7.6	4.1	-1.7	2.4	-4.1
Mechanical, electrical & instrument engineering	3.6	3.0	2.0	-1.6	0	-1.5
Vehicles	1.8	1.7	1.4	-0.3	0.8	-1.1
Food, drink & tobacco	4.2	3.8	3.5	-0.7	0.6	-1.3
Textiles, leather, clothing	1.2	1.2	0.9	-0.4	-0.6	0.3
Paper, printing, publishing	2.4	2.6	2.2	-0.2	-0.5	0.3
Construction	1.1	0.9	0.4	-0.7	0.2	-0.9
Other industries	8.7	8.1	5.7	-3	-0.3	-2.8
Unclassified	1.5	3.1	3.6	2.1	0.1	2.0
Total	38.7	35.5	25.9	-12.8	1.1	-13.9

Table 8 Change in energy demand from UK transport allocated to either change in output or intensity. (Source: DECC 2013b, table 4.15)

The end uses of industrial energy provide an indication on those likely to be affected by climate change. Table 9 provides a summary of the size of the industries' major end uses over the last two decades. Space heating accounts for 13% of industrial energy demand and will likely follow a similar decline to those projected for buildings in the service sector. Process use dominates energy end use, while the exact use is specific to the industry in question this figure includes the production of high grade heat or steam.

	End use demand (Mtoe) 2012	% of total demand
Space heating	3.2	13%
Lighting	0.2	1%
Process use	10.0	40%
Motors / drivers	2.8	11%
Drying / separation	2.2	9%
Other non transport*	6.7	27%

Table 9. Industrial energy demand by end use 2012 (Source: DECC 2013; table 1.04)* Includes construction and unclassified energy use in the Industrial column but excludes energy used in the manufacture of coke, refined petroleum products and nuclear fuel (SIC2003 class23; SIC2007 class19).

<u>3.4.2 Interactions between weather and climate and the energy demand for industry</u>

There are few studies examining the effects of climate change on industrial energy demand, none that we could find using UKCP09 projections. The literature presented here highlights potential impacts on types of industrial energy use as described in particular case studies – the direction of the impact will likely be applicable to other industrial processes that operate in a similar way.

Food production / pharmaceutical / biotech sectors

Industrial sectors that rely upon controlled environments for production such as the food, pharmaceutical and biotech sectors are likely to be affected by changes to the climate. An example from the food manufacturing sector highlights the ramifications of external temperatures on the energy required to maintain a controlled environment for biological processes. The production of single cell protein (SCP) from cheese whey using the yeast *K. fragilis* is an exothermic process requiring a cooling system (at an ambient temperature of 22°C, approximately 20% of heat generated in the reaction vessel is dissipated by means of a coolant). An increase in ambient temperature associated with climatic variability would increase the cooling load and associated energy demands, depending on the type of cooling system employed. The cooling demand necessary to maintain suitable growth conditions increases by two orders of magnitude (from 3 to 281kJ/h) when room temperature increases from 16 to 30°C. Conversely, if room temperature falls below 16°C, heating is required to maintain the optimum growth temperature of the medium (Ghaly and Mahmoud 2002).

Energy for steam use at an industrial chemical production facility

In addition to increased space heating demand, at lower outside temperatures steam is released to prevent freezing of pipes, resulting in greater energy demand for raising steam. Intensity of steam consumption is temperature dependent: a reduction in outside temperature from 15 to -30 °C increases the rate of steam consumption from 0.25 to 3 tonnes/m^3 flow (Leksell and Pärsdotter 2013).With an increase in average temperatures during winter, energy demand for raising steam for this purpose is likely to reduce. During periods of warmer temperature, demand for cooling water increases, in turn increasing the proportion of non-condensing gas requiring removal by energy-consuming steam extractor fans (*ibid*).

Industry demand for water pumping

Coastal inundation associated with extreme weather events poses a threat to high value industrial installations sited in coastal areas. While disruptions to industrial production may temporarily reduce energy demand due to lower productivity, onsite energy demands associated with pumping of flood water may increase. Reduction in industrial productivity may have to be recouped at a later stage, increasing energy demands. Extreme weather events may cause disruptions to normal grid operation; while outages or blackouts may reduce wider energy demands, diesel consumption may rise if firms self-generate in response to shortages especially where smaller, less efficient generators are used (Fisher-Vanden *et al.* 2013).

Industrial process cooling and heating

While no specific details can be found for climate impacts on UK industrial process cooling and heating demand, studies from the USA show that temperature dependencies of US industrial energy demand are more sensitive to changes in heating demand than cooling demand (USGCRP 2009). Thus US industrial energy demand is expected to decrease by up to 20%, based on aggregate energy demand elasticities (Considine 2000) and the anticipated changes in US cooling and heating degree days by the end of the century under a high emissions scenario (USGCRP 2009).

US city regions where the projected reduction in heating degree days exceeds the increase in cooling degree days are expected to see the greatest reduction in industrial energy demands (15-20%). Regions where cooling demand is projected to increase more than heating demand reduces would experience smaller reductions (below 5%) in industrial energy demand (based on data in USGCRP 2009).

3.5 Agriculture

Weather and climate have a significant impact on the agricultural industry. The UK agricultural industry is shaped by the UK's climate, determining what is farmed, when and how. One of the challenges faced by the sector is weather events that are not usually experienced during a particular time of year. The prolonged wet period in 2012 causing extensive flooding affected both the 2012 harvest and the planting and establishment of the 2013 crops (Defra et al 2012). Agricultural inputs such as pesticide use (and hence energy requirements for field operations) vary from year to year depending on the weather and its influence on disease, weed and pest pressures (Defra et al 2012). Although there are a number of studies examining the impacts of climate change on agriculture or adaptation strategies (e.g. Hossell & Hughes, 2008; Farming Futures 2011a & 2011b), a quantification of the impacts on energy demand has not been carried out, hence the section below highlights impacts and adaptation strategies identified that are likely to affect energy demand.

3.5.1 Historic Trends in Agricultural Energy Demand

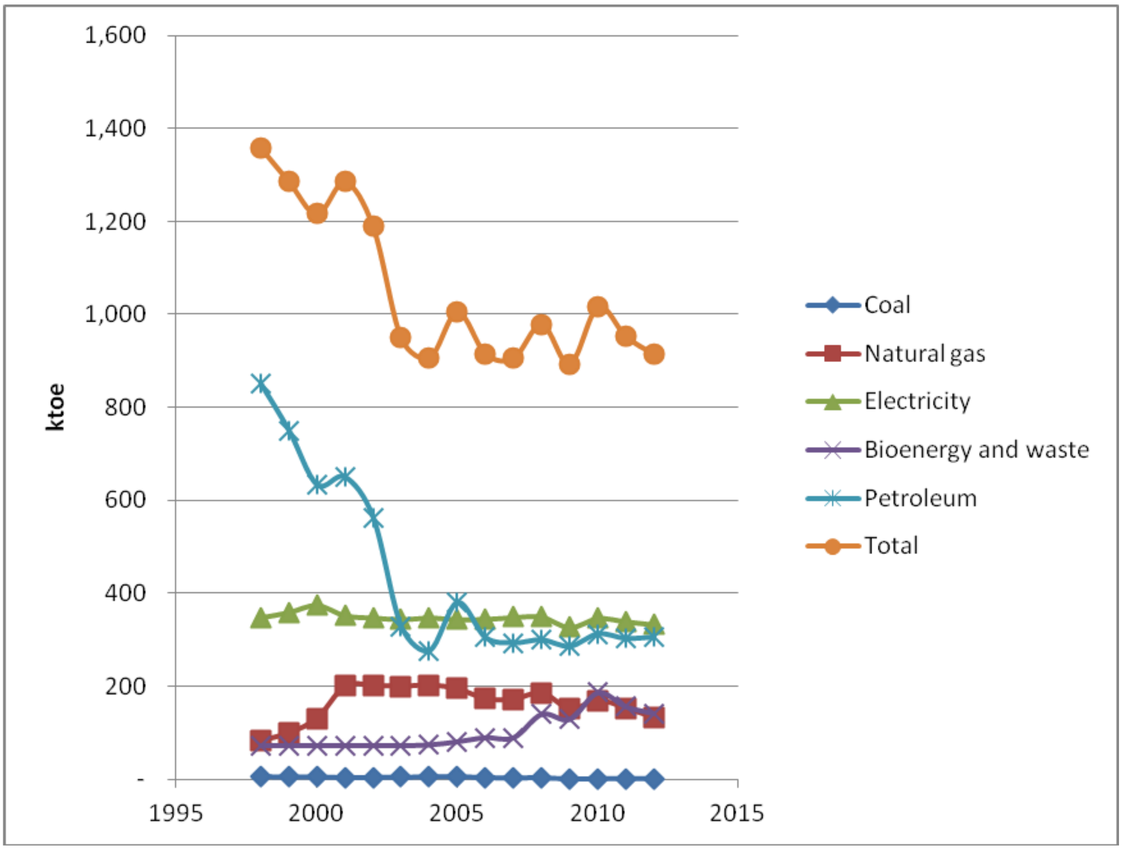

Figure 4. Agricultural energy demand by source 1998-2012 (Source Table 5.08, DECC 2013)

The decline observed in energy demand by the agricultural sector is dominated by reductions in petroleum use. Analysis by Defra in 2008 concluded that the reduction was due to a combination of more efficient machinery and equipment, more efficient farming practices (e.g. minimum tillage, precision farming) and switching to more efficient sources of energy. Defra's analysis demonstrated that between 1985 and 2006 energy use declined by 30% with little change in the volume of agricultural output thus the reductions were due to efficiencies within the sector. To continue the reduction in energy use, additional efficiencies would be required in equipment, practices and overall productivity improvements. The latter is weather dependent (Defra, 2008).

Agricultural energy use represents a small fraction of overall UK energy demand (approximately 0.6% in 2012), thus annual reports of the end use purposes of agricultural energy are not published. A bottom up analysis undertaken by Warwick HRI in 2005 provides a useful picture of the composition of energy use in the sector at present and a baseline from which to assess the potential impacts of climate change.

Energy end-use	**GWh**	**% 2005 direct energy demand**
Field operations	7231	36
Heating excl CHP	6598	32
Ventilation	2783	14

Refrigeration	1148	6
Motive power	834	4
Lighting	888	4
Heating CHP	899	4

Table 10. Direct energy use in agriculture in 2005 by end use (Source: Warwick HRI, 2007)

Warwick's analysis highlights that 37% of direct energy use by the sector is associated with heating, of which 61% is used to heat greenhouses and control humidity in the protected crops sector, 24% provides heating for rearing chicks and piglets, 9% provides hot water for hygiene purposes in the dairy sector and 9% is used for the drying, conditioning and storage of grain and other agricultural products. With the exception of hot water provision each of these end uses will likely be affected by future climate impacts. In addition, ventilation and refrigeration together account for 19% of agricultural energy use, with 44% of the energy used for ventilation associated with grain drying and storage (Warwick HRI, 2007).

3.5.2 Interactions between weather and climate and the energy demand for agriculture

End use demand	Direct relationship with weather?	Potential impact of climate change on overall demand	Other factors affecting the impact	Temporal or spatial differences
Field operations	Demand in response to daily weather patterns.	Increased demand for weed control due to warmer temperatures could increase energy required for field operations	Alternative farming practices could be used to reduce the size of any increased need for pesticides.	
Heating	Yes, colder temperatures require more energy for heating	Annual heating demand likely to reduce	Savings from milder winters could be offset if adverse weather (e.g. floods) requires livestock to be housed for a greater length of time.	Potential reductions during winter months.
Ventilation	Yes, increased ventilation needed during warmer weather	An increase in demand for cooling during warmer weather likely to increase energy demand Wetter weather increases demand for energy to dry grains prior to storage.	Installation of natural ventilation, mixed mode cooling provision can reduce the size of the impacts of climate change on energy demand for cooling. Increases in the housing of livestock either in response to climate impacts or as a general trend would confound this relationship.	Potential demand increase mainly in summer months
Refrigeration	Yes, demand increases in warmer weather	Refrigeration demand likely to increase	Improvements in refrigeration technology could offset this increase.	Potential increase during summer months
Motive power	No direct relationship			
Lighting	Some association with cloud cover, but agricultural			

	buildings tend not to rely on natural lighting.			

Table 11: Summary of interactions of weather and climate with demand for energy in the agricultural sector

Impacts of precipitation

Assuming no significant restructuring of the agricultural sector in response to climate change, many of the potential impacts of future climate impacts depend on the timing, severity and duration of weather events. For example, prolonged spells of precipitation during the grain growing season, particularly at harvest, require more drying (thus energy) to avoid spoilage (HGCA, 2011). If there is increased precipitation leading to flooding on agricultural land, energy is required for pumping and drainage to restore land; in addition if grazing land is flooded, then livestock need to be housed indoors, creating additional demand for heating and lighting as well as indirectly for feed (Hossell and Hughes, 2008). Conversely, a decrease in precipitation in summer or during the growing season increases energy demands associated with crop irrigation s (Hossell and Hughes, 2008).

Impacts of temperature

For livestock being housed either temporarily or permanently, temperature affects heating and cooling demand. Beyond certain temperatures animals experience observable heat stress, requiring cooling in hot weather; this demand will increase with climate change (Farming Futures, 2011b). One response to hotter temperatures due to climate change is to house livestock during extreme temperatures, this increases energy requirements associated with ventilation and cooling as well as feed production.

Once dried, crops are stored in controlled temperature and humidity conditions to prevent biodeterioration due to moulds and fungi infections. Storage can last for at several months to a year. The energy demand to maintain these conditions is dependent on external conditions (HGCA, 2008).

Combination of events

Variations to average weather (warmer, wetter) can lead to increases in a variety of pests and weeds. Depending on the timing and duration of weather events and which crops are affected, increased use of pesticides and changes in timing of application may be indicated, along with feedback or side effects for other agricultural processes. Changes in the timing and duration of the growing season itself may require more weed control (mechanical and chemical). These changes incur direct increases in energy demand for field operations, in addition to indirect demand for energy associated with pesticide production (Hossell and Hughes, 2008).

Extreme weather events

Extreme weather events such as storms or flooding reduce the productivity of the agricultural sector, increasing the overall energy intensity of its output. A key adaptation measure by the agricultural industry in response to future climate change is to increase the proportion of crops grown undercover – a measure to protect crops from ‘unseasonable’ weather events (e.g. prolonged rainfall during harvest). This measure could lead to additional energy demand associated with irrigation, temperature and humidity control within the covered areas.

4. Broader drivers and their interactions with climate change risk

4.1 Residential Sector

Broad drivers

Within the residential sectors, current policy drivers encourage energy demand reduction and low carbon energy sources. For new build houses, current policy is that from 2016 they should be zero carbon. The policy covers energy use for heating, along with hot water, cooling and fixed lighting. The approach is to set a minimum fabric energy efficiency standard (through Part L of Building Regulations), ensuring that carbon emissions from heating, hot water and cooling meet a carbon compliance limit, and then, if necessary, bringing it to zero carbon through 'allowable solutions' (which includes off site measures). This will have a significant impact, lowering heat demand in new houses. Although efficiency standards are being tightened there appears to be concern whether this is happening fast enough to reach the 2016 target. The use of LED bulbs with much higher efficiencies than CFLs is expected to grow, however, the impact on energy demand will depend on how they are used. Lighting is covered by the EU Energy labelling directive. The efficiency of new boilers (replacing existing, or in new homes) is set in Building Regulations. Currently the minimum efficiency for a gas boiler is 88%.

For existing houses the current Green Deal, where loans are provided to homeowners to enable them to make energy efficiency improvements, is the main scheme in place to promote energy efficiency. To date uptake has been limited. The Energy Companies Obligation (ECO) sits alongside this, with the larger energy companies required to support domestic improvements in harder to treat homes and for vulnerable customers. Efforts to reduce carbon emissions aim to incentivise a move away from gas as the dominant fuel for domestic heating towards electric and renewable heating sources. The Renewable Heat Incentive, which is due to come into effect for domestic properties in 2014, is designed to facilitate this kind of move. For heat pumps the EU Renewable Energy Sources Directives states that to be considered as a renewable source of energy, heat pumps have to have a minimum SPF (a location-specific measure of performance similar to CoP) of 2.5.

Interactions with climate change risks

The drivers above focusing on heating demand will reduce the elasticity between external temperature and energy demand. If houses were to become much better insulated then the relationship between heat demand and temperature would be lessened. If the trend for increasing internal temperatures were to return then this would reduce the reduction in demand associated with warmer temperatures.

In current building standards the focus for cooling is on limiting solar heat gains and it is seen as optional as to whether developers wish to exceed regulations to take account of future changes to climate. However, with current heating demand far outstripping air conditioning demand the main focus has been on reducing heating demand. The impact of this on potential internal summer temperatures is not clear. Insulation has two effects, firstly it can reduce and slow down the transmittance of external solar heat gains through the building fabric to the rooms inside, but it can also restrict internal heat gains from escaping the room (Sharples and Lee, 2009). Some analysis shows that measures that reduce heating demand (e.g. curtains / insulated shutters) and internal wall insulation do increase summer cooling demand whereas double glazing and external wall insulation reduces overheating risk in future climates (Gaterell and McEvoy, 2005; Mavrogianni et al 2012; Gupta and Gregg, 2012) . Results on the impacts of loft and cavity wall insulation on future cooling demand are mixed, (Gaterell and McEvoy, 2005; Mavrogianni et al 2012; Gupta and Gregg, 2012). Changes in building techniques, such as moving to lower thermal mass construction, may also impact on summer cooling, although Kendrick et al (2012) suggest that this has a much lower effect on overheating than has been suggested.

The consequences of changes in both heating and cooling demand for the energy supply system differ. Whereas mechanical cooling is mainly provided by electricity, heat provision in the UK is currently dominated by gas. Thus while a reduction in heat demand may reduce a small proportion of the electricity load in winter an increase in cooling demand will likely add additional load in summer, most likely during existing peak times. Warmer temperatures reduce the transmission network capacity, assessing the coupled impacts of increased electricity load for cooling and reduced capacity is the subject of ongoing research by the EPSRC funded RESNET and ARIES projects (ARCC 2014).

The incentivisation of electric heat pumps will also influence energy demand by shifting heat demand from gas to electricity and improving the end-use efficiency with which heat is delivered. The successful roll out of electric heat pumps would increase demand during winter months on the electricity network – however gas fired heat pumps are an alternative technology, and can reduce gas demand compared to traditional boiler systems.

One of the drivers of energy demand for comfort cooling and heating are individual’s expectations around comfort – these are shaped by many factors aside from temperature. People’s exposure to air conditioned environments outside of the home is one of these factors and, already around 70% of the car fleet, 70% of office space (in London) and 65% of London retail space is air conditioned (Peacock et al, 2010). If air conditioned space becomes people’s normal experience outside of the home then the expectation for similar conditions in the home will be affected. These changes can be seen in Australia, where the uptake of air conditioning is much faster than changing temperatures suggesting that “people increase their comfort expectations more rapidly than the climate is changing” (Strengers, 2008, p.383). If the UK follows a similar trajectory to other countries (e.g. US and Australia) then it suggests that people will increasingly demand artificial cooling. The uptake of air conditioning could be very rapid. For example, in the United States in the 45 years from 1960, air conditioning penetration went from 12% of households to 82% of households (Cox, 2010). This scale of change has been seen in the UK with central heating, which was found in 25% of households in 1970 and 90% in 2010 (DECC, 2013b, Table 6a). In the United States, the use of air conditioning changed the nature of peak demand during the 1960s, shifting it from winter evenings to summer days (Nye, 2010), and something similar could be seen in the UK. If the construction of new homes overly focusses on reducing heating demand and they are built with a low thermal mass and include built-in cooling provision through tri-generation air source heat pumps, occupants may be more likely to use it than not increasing cooling energy demand in new homes.

Management of climate change risk

The dominant risk to from residential energy demand on infrastructure arises from comfort cooling demand. Whether people chose to retrofit houses, change behaviour or install air conditioning systems will depend to a large extent on their perceived comfort levels and their vulnerability to hotter temperatures. If rapid increases in comfort cooling demand are to be avoided, then it is important to openly debate how comfort related to hot weather should be defined (Chappells and Shove, 2005). People report feeling comfortable across a wide temperature range (6 to 30^{o}C), suggesting that there is more to comfort than temperature, with cultural factors and convention important contributing factors (Chappells and Shove, 2005). That said, there is a convergence towards the expectation that heating and cooling are provided, with a corresponding impact of energy demand, particularly as mechanical cooling becomes more common in the UK (Ackermann, 2002). Shove (2003) describes how people no longer take steps to maintain comfort, such as by opening windows or wearing warmer or cooler clothes, at the same time becoming less tolerant to a wide range of temperatures. The increased use of mechanical cooling is not irrevocable.

It is possible that people will adapt to higher temperatures, making changes such as closing blinds and curtains, resting during the hottest parts of the day or spending more time outdoors where there is shade. As a society there may be a greater demand for green spaces and trees that can provide relief from the heat. However, while people may adjust their perceived comfort levels, it is important to remember that there are physiological responses to heat. For example, it has been suggested that above 24^{o}C the risk of heart attack and stroke is increased, while above 35^{o}C there is a danger of heat stress (see Gupta and Gregg, 2012, p.27, Table 8). Furthermore, heat stress affects people differently, there are certain sectors of the population particularly the elderly and young infants that are more vulnerable than others both physiologically in their response to heat and in their ability to respond to heat stress. Of particular importance to vulnerable individuals are night time temperatures, and the numbers of 'cooling nights'. Lower temperatures overnight enable buildings (and their occupants) to cool if temperatures are uncomfortable during the day, however climate impacts coupled with urban heat island effects are likely to restrict this the effect of this passive cooling mechanism.

If comfort cooling demand is to be met, further investigation of the trade-offs between insulation and cooling demand are required and retrofit activities that currently focus on heat demand updated accordingly. New building standards include cooling demand, an assessment of the sufficiency of these standards regards future climate is warranted.

4.2 Service sector

Broader drivers

The studies presented in section 2.2 illustrate the significance of building performance; thermal comfort expectations and heat / cooling supply on determining future energy demand. Future building standards will have a significant impact on building fabric and performance. The energy performance of new buildings and in some cases older buildings that have been extended or renovated in England must meet standards set by the Secretary of State under the Building Regulations (2010); similar guidance covers Wales and Scotland. It is expected that the energy performance standards will in future require new non-domestic buildings to have nearly zero energy requirements, though this is unlikely to come into force until at least 2019 (HM Government 2013). Building Regulations also set out requirements for ventilation to limit the effect of internal heat gains during summer months (HM Government 2013).

Efforts to retrofit existing buildings are incentivised with policies including the CRC Energy Efficiency Scheme and the Renewable Heat Incentive. The CRC Energy Efficiency Scheme is a mandatory carbon emissions reporting and pricing scheme to cover all organisations in the UK using more than 6,000MWh per year of electricity. In addition, the non-domestic Renewable Heat Incentive provides financial support for organisations switching to lower-carbon heat sources. While switching does not necessarily lead to a change in overall energy demand, the performance of newly adopted technologies under future weather conditions may differ from that of current heating apparatus. Improvements in the energy performance of both domestic and commercial appliances are incentivised through standards set by the European Union; the minimum energy performance standards being gradually raised over time.

One sector to respond to incentives to reduce CO_2 emissions and in turn energy demand is the British Retail Consortium. Its members reduced the energy related emissions of their stores (in absolute terms) by 8% between 2005-2013 (BRC, 2014), with a further target to reduce energy related emissions from stores by 50% by 2020 (compared to 2005). To deliver this reduction, stores are implementing a range of energy efficiency measures and switching to lower-carbon fuel sources. Some measures adopted are likely to influence the elasticity of the relationship between energy and future climate.

Additional energy savings can be made through changes to buildings' operating temperature – an area under exploited at present, but starting to gain attention. Changes to operating temperature range that are being introduced in some supermarkets extend the range between heating and cooling set points, reducing energy demand by 13–20% per degree at either end of the range (Hill, 2010; Hill 2014 based on a calculation of degree days on the BizEE tool via www.degreedays.net). This involves building operators choosing to accept slightly cooler ambient temperatures on cold days and slightly warmer ambient temperatures on hot days. The extent to which changes in operating temperature ranges are being made in supermarkets is not known. Similar reductions in energy demand could be achieved in other buildings such as offices and non-food retail.

Changes in technology can also reduce future energy demand from refrigeration units, for example in food retail where the installation of doors on cabinets can make large reductions on refrigeration energy demand. Currently stores vary in the proportion of cabinets with doors, with most only having doors on frozen cabinets, while chillers continue to be left open to the store. Fitting cabinet doors also has an impact on the heating demand of retail floorspace: doors on 2/3 of cabinets in a store can save 47% of heating demand (Hill 2010).

Interactions with climate change risk

Actions to reduce energy demand from heating and refrigeration will reduce the elasticity of temperature and heat, further enhancing expected energy demand reductions with generally warmer weather in the UK. However, cooling demand remains a challenge as discussed in section 3.1. Cooling demand represents a much smaller proportion of energy use than heating demand at present, due in part to the low proportion of buildings in the UK with air conditioning systems as well as the current UK climate. In 1994 only 10% of commercial buildings' floorspace was air conditioned, a figure expected to increase to 40% by 2020 (Carbon Trust, 2012). Depending on how current policies affect the thermal performance of the building stock, the size and profile of cooling demand for buildings could present a challenge to the operation of electricity networks.

As is the case for residential buildings, the deployment of new heating technologies may alter the level, daily profile and energy source for heating provision. Technologies currently being installed in buildings include combined heat and power plant (fuelled by gas or other energy source), electric and gas heat pumps and under floor heating. Their potential contribution to energy demand reduction for heat provision is dependent on the building's structure, use pattern, equipment operation profile and the uptake rate of these technologies across the sector. Furthermore the performance of the chosen technology may also be weather dependent; the coefficient of performance of heat pumps is dependent on the temperature of the heat source they extract. While ground- or water-based sources have a relatively stable temperature, air temperatures fluctuate considerably, and the performance of air-source heat pumps will vary between seasons.

Management of climate change risk

To manage the impacts of climate change on energy demand for comfort cooling a three pronged approach is needed firstly to improve the building fabric to reduce levels of cooling demand that may be required; secondly to provide passive cooling methods and other low energy cooling options and thirdly to address perceptions of cooling standards in the workplace. To address the performance of building fabric and installation of passive cooling methods attention is needed regards retrofit policies and building standards.

To address perceptions of cooling standards in the workplace, Chappells and Shove (2005) suggest that we should look beyond standardised ways of maintaining a defined level of comfort. Thus, the adoption of more casual or cooler styles of dress in the summer would allow offices to be warmer, reducing demand for mechanical cooling; or office workers could be informed about outdoor events, encouraging them to leave their offices at lunchtime (Hitching, 2011). Occupants of naturally ventilated buildings are more tolerant of indoor conditions which follow those outside than those of buildings where temperature is mechanically maintained (De Brear and Bragar, 2001), suggesting that people become accustomed or 'addicted to' a controlled indoor environment (Hitching, 2011). To avoid the more extreme demands for electric cooling portrayed by the DECC analysis (DECC, 2010), requires in part an examination of how the trends observed by Shove (2003) can be redirected through changes in both the cultures of working environment (e.g Hitching 2011; CoolBiz, 2014) coupled with design standards that enhance natural ventilation and thus the tolerance of occupants to a wider range temperatures and disrupt existing practices. Cooling demand depends, among other factors, on building users' perceptions and expectations of thermal comfort, in turn influenced by social norms pertaining to office use and attire (as discussed in section 3.2). The temperature at which cooling demand is commonly deemed necessary in the UK is 24^{o}C (Carbon Trust 2012), whereas initiatives in Japan have reportedly raised this threshold to 26^{o}C by proactively targeting the social norms around office attire and behaviours (CoolBiz, 2013). Note that the UKCP09 figures used in the 2012 CCRA apply a threshold of 22^{o}C to assess potential change in cooling demand – this may overestimate future cooling demand (McColl et al 2012; Capon and Oakly 2012).

4.3 Transport

Broader drivers

Efficiency improvements in cars and LGVs are driven by EC regulations that set progressive reductions in the fleet average exhaust emissions for vehicles sold in the EU (EC 2009; EC 2011). While standards are being met largely by improvements in the energy efficiency of conventional internal combustion vehicles, some manufacturers are also selling either all electric or hybrid-electric vehicles. The uptake of electric vehicles is supported by local and national programmes to provide charging points as part of a longer term strategy to promote the electrification of road transport advocated in the *Low Carbon Transport* strategy (DfT 2009) . The potential increase in electric vehicles is expected to alter relative levels of demand between different energy sources. Whereas in general electric vehicles are reported to be more energy efficient than internal combustion vehicles, the upstream efficiency losses associated with electricity generation and distribution in the UK mean that net energy demand reductions will depend on the future UK electricity generation mix and its distribution. The relationship between weather and vehicle energy demand differ between ICEs and battery vehicles. In battery vehicles heating and cooling are provided by the battery, rather than in ICEs where heat is drawn off the engine. Battery vehicles also require cooling for the battery itself.

Energy efficiency improvements in HGVs and buses are incentivised by both the cost of fuel and schemes to reduce the CO_2 emissions. For example, additional subsidies are available under the Bus Services Operators Grant for operators running services on low-carbon emissions buses (emissions 30% less than average diesel bus) or who can demonstrate at least 6% improvement in their fuel efficiency over a two year period (DfT 2012). The net effect on absolute energy demand of incentivising efficiency improvements in HGVs and buses will depend on future trends in vehicle kilometres driven.

Current trends for air travel suggest increased demand for energy in the future. However, the aviation industry plans to improve the fleet average efficiency of aircraft by 1.5% per annum to 2020 (IATA 2014) and the inclusion into the EU Emissions Trading System (EU ETS) of flights into or out of European airports may reverse the current upward trend observed in the energy intensity of UK flights.

Interactions with climate change risk

Incentivisation of electric vehicles potentially increases the weather dependency and thus climate impacts on the energy demand from private road transport; further research is needed to establish the extent of this change for different energy vectors. Increased demand for air travel may compound energy demand increases associated with climate impacts further.

The interaction of the transport system with other infrastructure is significant in terms of its role providing a service and in shaping other energy infrastructure such as fuelling and charging stations. There is a strong interdependency between energy system and the transportation system leading to the following vulnerabilities:

- Replacement of liquid hydrocarbons with electricity will potentially create transport vulnerabilities in case of supply / transmission outages such as extreme weather events associated with future climate change.
- Failure of transport infrastructure can cause break in supply chain of fuel sources to centralised electricity supply, and to supply of liquid hydrocarbons for onsite consumption by generators providing back up electricity supply or pumping etc.

Management of climate change risk

Further research is necessary to establish the risks applicable to this sector and management options.

4.5 Industrial energy demand

Large energy users (thus emitters of CO_2) in the industrial sector are registered under the EU Emissions Trading System (EU ETS). The CRC Energy Efficiency Scheme (or CRC Scheme) is designed to improve energy efficiency within large public and private sector organisations. Applicable to UK emissions not currently covered by the UK Climate Change Agreements (CCAs) and the EU ETS, this scheme encompasses a variety of drivers to incentivise organisations to develop energy measurement management strategies that promote a better understanding of energy usage (DECC 2013a).

Interactions with and management of climate change risk

Further research is necessary to establish any relationship between broader changes in the industrial sector and the impacts of climate change on its energy demand.

4.6 Agriculture

The broader drivers on the agricultural industry include both pressures to reduce greenhouse gas emissions and wider drivers relating to disease control, consumer pressures and new farming methods to increase yields. Two of these farming methods include ‘mega dairies’ and ‘indoor’ or ‘vertical’ farming. In the former, cattle are housing in large indoor areas rather than grazing. This trend could increase energy relationship with climate as cooling demand increases for cattle in hot weather to prevent heat stress. In the latter, crops are grown indoors in closely controlled environments in terms of temperature, humidity and lighting as well as nutrient mix. Increasing the numbers of indoor farming could also increase the energy – climate dependency of the sector. These are very new techniques and require further research to establish their current energy consumption profiles and relationships with weather.

5. Climate adaptation measures and energy demand

High capacity water pumps deployed in response to large scale flood events, such as those observed in the Somerset Levels in February 2014, can be expected to increase local energy demand following extended periods of rainfall. High capacity water pumps in addition, require energy for their production & transport to site. An increase in their use increases energy demand from their supply chain too. Similarly, the embodied energy associated with other adaptation and response measures to climate impacts is likely to be significant when considering the large range in impacts and technical solutions proposed. This includes, but is not limited to, the adoption of air conditioning units and fans to cope with hotter temperatures, the use heat resistant road surfacing materials, new drainage systems required to cope with heavy & prolonged rain.

Population growth and industrialisation increase demands on both surface and ground water reserves. The energy intensity of water provision is likely to increase if uptake of desalination technologies takes off, although this could be potentially offset by behavioural changes that reduce water demand. Sea water desalination using reverse osmosis technology can be achieved at rates of 3kWh (electricity equivalent)/m^3; similar to the energy consumption of fresh water supplies transported over large distances, but significantly higher than the local treatment and supply of fresh water (EPRI 2000). The difference in energy intensity of desalination compared to traditional water supply is more apparent for alternative techniques such as multi-stage flash osmosis and multi-effect distillation, consuming 13.5–25.5 and 6–11 kWh (electricity equivalent)/m^3 respectively. These latter technologies are preferable to reverse osmosis for large scale industrial use (Desware 2014).

Many of the geoengineering options under investigation to either mitigate or temporarily protect areas from climate impacts require energy. The Royal Society's report on geoengineering provides qualitative description on the size of different options, noting several of the methods, or stages involved as having significant energy demand or being energy intensive (Royal Society, 2009). This is an area warranting further research.

6. Confidence

Indisputably climate change will have an impact on future annual energy demand, both in terms of total energy demand and its temporal and spatial profile. The relative size of this impact will be determined both by non-climate influences on demand and socio-technical responses to climate change.

Energy end-use	**Confidence**	**Rationale for confidence rating**
Building heating energy demand – reduction in annual energy demand for heating due to the warmer winters predicted.	Medium evidence; high agreement	Established relationship between weather and heating demand. There are a medium number of studies that assess climate impacts on heat energy demand – they indicate size of change is case specific.
Building comfort cooling energy demand – an increase in energy demand for comfort cooling due to the hotter summer temperatures predicted.	Medium evidence; high agreement	Established relationship between weather and cooling demand. There are a medium number of studies that assess climate impacts on cooling energy demand – they indicate size of change is case specific.
Transport energy demand Electric vehicles and changes in electricity demand associated with internal climate control.	Low evidence	Established relationship between weather and battery performance and its use for internal climate control; no analysis of climate impacts.
Transport energy demand Increase in energy demand during aircraft take-off in hot temperatures & cruise during adverse weather events.	Low evidence; high agreement	Initial studies of the impact of climate change on aviation indicate
Maintenance of controlled environments & heating and cooling demand other than in buildings (e.g. transport)	Low evidence	Established relationship between weather and heating or cooling demand; no analysis of climate impacts on this.
Agricultural energy demand changes in response to climate impacts e.g. cooling for housed livestock.	Low evidence	Theoretical relationship between expected responses to climate impacts.
Industrial energy demand	Low evidence	Established relationships

for process heat changes with climate.		between weather and demand; no analysis of climate impacts on them.

Table 12: Summary of confidence in evidence to date of climate impacts on sectoral energy demand following guidance by Mastrandrea (2010)

7. Research gaps and priorities

1. Domestic and service sector buildings

Much of the research to date examines the temperature impacts on heating and cooling demand. There is scope for further interdisciplinary research exploring a broad range of buildings representative of the UK building stock with the probabilistic climate futures from UKCP09 with and without urban heat island effects with consideration regarding the interactions between the buildings and occupants and the resultant impacts on future heating and cooling demand.

There is evidence that double glazing and external wall cladding can reduce both future heating and cooling demand, and thermal curtains and internal wall insulation can increase future cooling demand. There is mixed evidence related to cavity wall and loft insulation, further research in this area could help inform retrofit policy to ensure buildings are resilient to both temperature extremes.

The current heating and cooling degree days published by UKCP09's weather generator use threshold temperatures of 15.5 and 22^{o}C respectively. Producing these datasets using a range of alternative plausible temperature thresholds can better enable studies to encompass a wider range of levels of thermal acceptance and their impact on future energy demand for heating and cooling.

2. Transport

There is very little analysis, with the exception of the aviation sector, on the impacts of climate change on transport energy demand particularly on electric vehicles, which may be more influenced by weather compared to ICE vehicles. In addition, one area in particular worthy of further research is understanding how weather and future climate influences passengers decisions to travel and their modal choice, for example the impact of weather on cycling or choice of public transport over the car during hot weather.

3. Industry

There is little research regarding the impacts of climate change on industrial energy use. Additional research focussing on the impacts on process and drying energy demand would inform this area together with an assessment of how widespread the use of controlled environments is in the industry and how these may be protected from climate impacts.

4. Agriculture

Agricultural energy use is not considered directly in the CCRA – likely due to its small energy consumption relative to other sectors. However, the twin priorities of food and energy security may intensify future agricultural energy requirements, with increasing demands for land for energy crops (the focus of the agriculture–energy relationship in the CCRA) coinciding with increasing global competition for food stocks.

5. Adaptation options

Many of the actions necessary to respond to climate impacts require energy, in particular pumping equipment and desalination. Their energy demand is likely to be significant. Similarly many of the geoengineering options are likely to have significant point source demand for energy. Further analysis of the energy requirements of these technologies and the levels of deployment in the UK are necessary to fully assess their impacts on energy demand.

6. Assessment of temporal and spatial responses of energy to climate impacts

The timing and profile of demand for energy is important for the operation of energy supply networks. More analysis is needed to understand the ramifications of climate impacts on energy demand according to the time of day and year. Similarly, the spatial location of effects can be significant when balancing supply and demand. Initial assessments of the climate impacts on comfort cooling load for example would suggest increased demand during evenings and potentially overnight as well as greater demand in the South than the North of the UK. There is a need for analyses that consider the temporal and spatial dimensions of climate impacts on energy demand.

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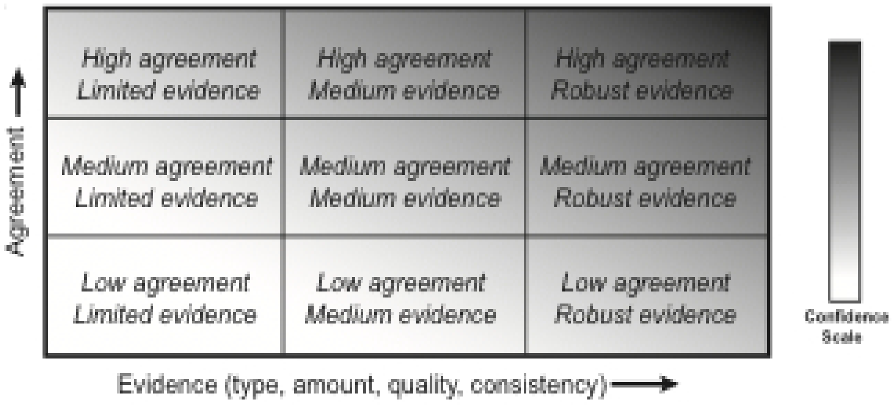
Appendix A.

Matrix used to estimate the confidence ratings used in section 6.



High agreement Limited evidence	High agreement Medium evidence	High agreement Robust evidence
Medium agreement Limited evidence	Medium agreement Medium evidence	Medium agreement Robust evidence
Low agreement Limited evidence	Low agreement Medium evidence	Low agreement Robust evidence

Figure 1: A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence.

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[i] Data taken from the Energy Consumption in the UK (DECC 2013) meets with the UK Statistics Authority's standards for production, however this does not mean the data presented is free from error. The underlying data includes that supplied from surveys and modelled data which is subject to uncertainty – the relative size of which is not reported (DECC, 2013; UK Statistics Authority, 2014).