ZERO CARBON BRITAIN

Methodology for Power Down

Contents

1 Introduction

The following describes how the annual final energy use in the Zero Carbon Britain scenario was derived. Baselines of either 2007 or 2010 were used. Appropriate reductions in energy use were arrived at using a range of existing studies and some primary research.

2 Population assumptions

UK Population:
2007 - 61 million
2030 - 71 million
The 2007 and projected 2030 figures are both taken from [1].

Average number of occupants per household: stable at 2.34.
Number of households:
2007 - 26.0 million
2030 - 30.1 million
The 2007 figure is from [1]; it is an assumption of the ZCB scenario that average occupants per household remains the same to 2030.

3 Space heating

It is necessary to determine a baseline for space heating demand in terms of the heat loss of the UK's buildings (measured in GW/°C). This can then be adjusted for the ZCB scenario based on our assumptions about the extent to which buildings are improved by insulation, airtightness, better glazing and doors etc. It is also necessary to derive a 'base temperature' for ZCB - this is the temperature to which buildings must be heated, after which internal and solar gains are sufficient to bring the building to the required temperature. To calculate this requires the building heat loss but also the average internal temperature and the average internal gains and solar gains. Using the building heat loss and the base temperature we can then determine a predicted space heating energy demand in ZCB by applying hourly or average seasonal temperatures.

3.1 Domestic space heating

DECC 2050 Pathways estimates for 2007 that the average heat loss per domestic building is 247 W/°C, average internal temperatures are 17.5°C, and average internal and solar gains are 1,030 W [1].

In DECC 2050 Pathways level 4, the average heat loss coefficient reduces just over 50% from 247 W/°C to 119 W/°C [1]. This is achieved by the retrofit measures, applied to the stated proportion of dwellings, shown in figure 1 below (they are only applied to 96% of the 2007 potential but this is essentially all dwellings as the 4% are demolished) [5]. All new dwellings are assumed to be Passivhaus standard [5].

Figure 1. Retrofit measures for housing stock in DECC 2050 Pathways level 4 [5].

Measure[135]	Assumed average U-value (W/m².°C) before measure	Assumed average U-value (W/m².°C) after measure
Solid wall insulation	2.20	0.35
Cavity wall insulation	1.60	0.35
Floor insulation	0.60	0.16
Triple-glazing or equivalent	2.20	1.00
Loft insulation[136]	0.29	0.16

Measure	Assumed average air permeability (m³/m². hr@50Pa) before measure	Assumed average air permeability (m³/m². hr@50Pa) after measure
Draught-proofing[137]	15	5

Measure	Number of UK households receiving measures	Year installations complete	Fraction of 2007 potential addressed on completion of roll out
Solid wall insulation (internal or external)	7,659,250	2040	96%
Cavity wall insulation	8,755,936	2030	96%
Floor insulation	11,387,501	2050	96%
Triple glazing equivalent	22,641,032	2050	96%
Loft insulation	21,439,968	2040	96%
Improved air-tightness	24,050,381	2020	96%

We assume for ZCB that the average heat loss per dwelling is reduced to 119W/°C. It may not be exactly fair to use the DECC 2050 Pathways derived average heat loss per dwelling because in ZCB we assume a lower number of dwellings. However, we can assume that a higher demolition rate occurs, meaning the proportion of retrofitted and 'Passivhaus standard' new builds is the same, giving the same average heat loss per dwelling. Multiplying the per dwelling heat loss by the total number of dwellings in the ZCB scenario gives us a total domestic building heat loss of 3.57 GW/°C.

Our assumptions about how average internal and solar gains change is also important. The methodology used by DECC 2050 Pathways [1] is to fix total gains at the same proportion of losses as 2007 - thus gains are reduced by around 60% (50% reduction in heat loss per dwelling plus slightly warmer temperatures reducing losses). In reality what should the reduction in gains be? Solar gains and internal gains from people should be about the same; gains from lighting and appliances should reduce by around 60% in our scenario in line with improved lighting and appliance efficiency; and gains from hot water can be expected to reduce because of better tank insulation but there will also be more hot water storage. The gains from hot water may be crucial to whether the 60% reduction is a good assumption.

The average internal temperature used for ZCB is 16°C, as per DECC 2050 Pathways level 4 [1]. This assumes better controls and some behavioural change.

3.2 Services and industry space heating

DECC 2050 Pathways level 4 assumes a 40% reduction in the space heating demand per building for commercial buildings [5]. To derive a heat loss of the services sector building stock for ZCB, we apply a 40% reduction to the heat loss in GW/°C for 2007, taken from DECC 2050 Pathways (which is 1 GW/°C) [1]. We assume the same number of commercial buildings in ZCB as today. This gives us a heat loss of 0.6 GW/°C.

For industrial space heating, the current heat loss is derived by multiplying the services heat loss by the ratio of industry space heating energy use to services space heating energy use. A 40% reduction is then applied to this value giving us an industrial building heat loss of 0.2 GW/°C.

3.3 Total space heating

We thus derive a total building heat loss of 4.4 GW/°C.

This is used in the hourly model with a base temperature. This base temperature is calculated as below:

base temperature = average internal temperature (°C) - (Gains (W) / Losses (W/°C))

The average internal temperature, gains and losses are those for the domestic houses from [1]. This base temperature is used for the whole building stock. This calculation gives us a base temperature for the ZCB scenario of 12.8°C.

In the hourly model we can then calculate at each hour:

Space heating energy demand = (base temperature - external temperature) x total building heat loss

4 Hot water

Domestic hot water energy use was 89 TWh in 2007 and 82 TWh in 2010 [2, table 3.7]. For ZCB this energy use is converted to hot water energy demand by multiplying by 80% for inefficiency losses. For ZCB, hot water energy demand is assumed to remain static per person but increase due to population increase to 2030.

Services hot water energy use was 19 TWh in 2007 [1, table 1.14] and 18 TWh in 2010 [2, table 1.14]. The hot water energy demand is taken from DECC 2050 Pathways [1] (14 TWh) - this remains the same in ZCB as we assume the number of commercial buildings is static.

5 Cooking, lighting and appliances, and cooling

5.1 Cooking

Domestic cooking used 15 TWh in 2007 [1, table 1.14] and 13 TWh in 2010 [2]. Non-domestic cooking used 15 TWh in 2007 [1, table 1.14] and 13 TWh in 2010 [2].

For ZCB, the 2007 domestic cooking energy use figure is reduced 40% per household - 32% including the increase in number of households. Non-domestic cooking is reduced 25% from the 2007 level. These reductions are as per DECC 2050 Pathways level 2-4 and 4, respectively [5]. Cooking is assumed to become fully electric.

5.2 Lighting and appliances

Domestic lighting and appliances used 86 TWh in 2007 [2, table 3.7] and 86 TWh in 2010 [2]. Non-domestic lighting and appliances used 57 TWh in 2007 [1, table 1.14] and 58 TWh in 2010 [2].

For ZCB, the 2007 domestic lighting and appliances energy use figure is reduced 61% per household - 55% in total including population growth. The reduction per household is as per DECC 2050 Pathways Level 3 (Level 4 is not used as it assumes technology breakthroughs) (see the relevant info sheet on [6]).

The 2007 non-domestic lighting and appliances energy use figure is reduced by 30%, as per DECC 2050 Pathways Level 4 [5], although this is slightly less ambitious than DECC because we assume no growth in the number of non-domestic buildings.

5.3 Cooling

Non-domestic cooling energy use was 9 TWh in 2007 [1, table 1.14] and 9 TWh in 2010 [2]. Cooling energy demand (the thermal energy removed) was 27 TWh in 2007 according to DECC 2050 Pathways [1].

In ZCB, despite increased temperatures due to climate change, cooling demand is assumed to be kept stable by better insulation, shading and ventilation of buildings. This is roughly consistent with cooling demand in DECC 2050 Pathways level 3 [1]. The efficiency of air conditioning systems is expected to increase to 600%, as per DECC 2050 Pathways [1].

It is assumed that no significant demand for domestic cooling emerges. This may be a dubious assumption given that climate change is expected to increase mean summer temperatures in the UK by around 1.5°C in the 2020s and 2.5°C by the 2050s (compared to baseline period of 1961–1990) [13]. The mass installation of heat pumps may also make their reverse operation for cooling possible and perhaps likely. That said, the inclusion of a cooling demand in our scenario may not be so important from a system perspective. The energy demand would not be that high - perhaps 10-20 TWh/yr of electricity under DECC 2050 Pathways level 1 scenario [1]. Renewables must already supply much higher heating demands in winter, so cooling may provide a manageable electricity demand in summer, allowing electricity from renewables to be usefully used. That said, storing coolth may be difficult so issues of peak demand would need to be managed.

6 Industry

For industrial energy use, we get numbers of 355 TWh in 2007 and 322 TWh in 2010 [7, table 1.2]. For ZCB, industrial space heating energy use was dealt with in ‘Space heating’, so our baseline is 311 TWh for 2007.

For ZCB, we assume that industrial output returns to 2007 levels per person in the UK, therefore increasing by 16% from 2007 levels as per population increase. However, industrial energy intensity is expected to decrease by 25% - as per DECC 2050 Pathways lowest or medium energy intensity levels [5, p90-93]. Therefore, industrial energy use is (1.16x0.75) 87% of 2007 levels. We do not study the actual make-up of the industrial output but assume it to be quite different from that in 2007. Output of materials and equipment for the energy system will increase, other products will decrease.

The above does not address non-energy fuel use i.e. where fuels such as oil and gas are used to produce materials and chemicals. This was 113 TWh in 2007 and 105 TWh in 2010 [2, table 1.4]. To some extent this is only important in ZCB if use of this fuel liberates GHGs. If oil or natural gas were used in a way that didn’t release GHGs, for example as a material in plastic or in roads, then it would not be problematic from an emissions perspective. However, where the non energy use of fuel liberates CO2 this process should be changed or must use biogas or biofuel. These non-energy uses of fuels need looking at in more detail.

The current fuel mix for energy in industry is roughly 35-40% gas; 30% electricity; 15% solid fuel; and 15-20% oil [7]. In ZCB, the proposed change in industrial fuel mix aims to increase the proportion met by electricity. However, it was identified that some industrial energy uses may be very difficult to meet using electricity. AEA/NERA identifies “50 TWh of industrial process heat not easily served by the combustion of solid biomass. Biogas may be the option facing the least obstacles for these and other hard-to-reach heat demands” [12].

In ZCB we state that biogas meets all the ‘high temperature heat’ demand except for that currently electrified; ‘low temperature process’ heat and ‘drying and separation’ heat is met by two-thirds electricity and one third biomass derived fuels (of this one third is biogas and two thirds is solid biomass); for the non-heat fuel use, 50% of the proportion that was not electricity in 2007 is switched to electricity, the remainder is met by half biofuel and half biogas. This gives us a fuel mix with more electricity (171 TWh), 61 TWh of biogas, some solid biomass (26 TWh), and a small amount of biofuel (12 TWh). The fuel mix is similar in percentage terms to the DECC 2050 Pathways ‘high electrification’ scenario fuel mix in 2050 [1, table XI.a], however, there is less liquid hydrocarbon and more methane (see below).

Table 1. Comparison of industrial fuel mix in DECC 2050 Pathways ‘high electrification’ scenario [1] and ZCB.

Description	DECC 2050 Pathways ‘high electrification’	ZCB
Electricity	66%	64%
Solid hydrocarbons	9%	9%
Liquid hydrocarbons	16%	4%
Gaseous hydrocarbons	8%	22%
Heat transport	2%	-

7 Transport

UK transport energy use was 695 TWh in 2007 and 641 TWh in 2010 [2, table 2.1]. This breaks down for 2010 as:
Rail - 12 TWh
Road - 470 TWh
Water - 17 TWh
Air - 143 TWh

However, the above ‘Water’ figure (and hence the total) doesn’t include international shipping. Referring to [8, table env0102] we get a figure of 43 TWh for shipping in 2010 (48 TWh in 2007) - “These figures include international and military aviation/shipping and thus marine bunkers”. Thus international and military shipping can be deduced to be 26 TWh for 2010 and 29 TWh in 2007. However, DECC 2050 Pathways [1, table XII.e] gives international shipping in 2007 as 54 TWh based on the UK share of marine bunkers as calculated by the IEA [5]. We use the 54 TWh figure as our baseline for international shipping in ZCB. This gives us a total transport energy use of 749 TWh in 2007 and 695 TWh in 2010.

In the analysis for this ZCB scenario, we use distance based baselines for domestic passenger transport (we also include vans in this - only HGVs are included in ‘road freight’). Distances travelled are taken from DECC 2050 Pathways [1, table XII.a] for 2007 and Department for Transport [8, tables TSGB0101 and TSGB0103] for 2010. The DfT data is for Great Britain so we increase it for the UK population by the ratio of UK to GB population in 2010 (62.3 million/60.5 million).

7.1 Domestic passenger transport

To change from the 2007 domestic transport mode mix to the ZCB domestic transport mode mix we firstly apply a 20% reduction in distance travelled per person. This implies greater use of communication technologies such as video conferencing making journeys unnecessary. It is also expected that on average people live closer to where they work and socialise.

Realistic changes to the percentage of the total distance travelled that is done by different modes of transport is established by a mode change analysis. This uses data from the DfT National Travel Survey

[9]. We use this data to work out the percentage of journeys of different lengths that are travelled by each mode of transport. The following changes to the mode mix are assumed for ZCB:

1. Transfer all domestic air travel to rail.
2. Transfer car journeys less than a mile to walking.
3. Transfer 75% of car journeys of 1 to 2 miles to walking (30%), cycling (30%) and bus (15%).
4. Transfer 60% of car journeys of 2 to 5 miles to walking (10%), cycling (25%), bus (20%) and motorcycle* (5%).
5. Transfer 30% of car journeys of 5 to 10 miles to cycling (3%), bus (15%), rail (5%), and motorcycle* (7%).
6. Transfer 20% of car journeys of 10 to 25 miles to bus (12%), rail (6%), and motorcycle* (2%).
7. Transfer 30% of car journeys over 25 miles to bus (15%) and rail (15%).

*About a fifth of motorcycle is electric bikes/scooters with percentage taken from ZCB2030.

This gives us the following change to the domestic transport mode mix:

Table 2. Domestic passenger transport mode mix by distance travelled in 2007 [1] and ZCB.

Mode	2007	ZCB
Walking	2.17%	4.08%
Pedal cycles	0.51%	4.06%
Motorcycles	0.70%	2.16%
Cars and Vans	82.51%	56.00%
Buses and Coaches	5.96%	18.08%
Railways	7.01%	15.15%
Domestic air travel	1.14%	0.00%
Electric scooter and bikes	0.00%	0.47%
Total	100.00%	100.00%

Applying the new mode mix to the total distance travelled gives use the distance travelled by each mode.

We then apply percentages for different types of vehicle for each mode e.g. for cars and vans: 90% electric cars and vans, 4% hydrogen and 6% biofuel. DfT (2009) shows that around 90% of distance travelled by car is on journeys under 100 miles and therefore achievable in electric vehicles. The split between hydrogen and biofuel for the remainder is somewhat arbitrary but with the rationale that the lack of a widespread hydrogen distribution infrastructure will mean some biofuel vehicles are required.

Applying an average occupancy per vehicle and a fuel specific energy use per vehicle kilometre then gives us the transport energy use by fuel type. Average occupancy is taken from [1, table XII.a] for bus and rail using the 2050 values (18 and 127 passengers/vehicle respectively); for cars and vans we assume occupancy increases to an average of 2. Energy use per vehicle kilometre is taken from [1, table XII.a] using the 2030 values.

7.2 International aviation

International aviation used 153 TWh in 2007 [1, table XII.c]. For ZCB we assume there is a two thirds reduction in distance flown. We do not calculate any energy use for replacements such as rail or coach.

Energy use per passenger km is expected to decrease 1.3% per year to 2030, as per [10, p7] - this gives a 23% reduction in energy use per passenger km. International aviation's energy use is therefore reduced by 73% from the 2007 level.

7.3 Freight

For freight the 2007 baseline from [1] is 54 TWh for international shipping, 19 for national navigation (boats and ships), 88 TWh for road freight in HGVs, and 2 TWh for rail. To establish the changes in vehicle kilometres for freight in ZCB an analysis of freight was conducted using statistics for the amount of freight required for different products from [8, tables TSGB0402 and TSGB0502].

For road and rail, it is assumed fossil fuel freight is no longer required. This eliminates 8% of current road and rail freight (as measured in tonne-kilometres). Around 20% of road freight is switched to rail. It is assumed that 140 million tonnes (100 oven dry tonnes at 30% moisture content) of additional road freight of biomass for energy, wastes for energy, biofuel, materials, and harvested wood products for carbon capture is required to be moved 50 km on average, giving an extra 7 billion tonne-km of freight (this is a rough approximation since we do not know the distance these products would need to travel).

These changes mean rail freight is 216% of the 2010 level, whilst road freight is 80% of the current. The energy use for freight is derived by applying vehicle fuel type percentages and vehicle efficiency figures for 2030 taken from [1,5].

For shipping, a single analysis is done for domestic and international shipping. Since fossil fuel imports are eliminated and food imports are reduced, shipping freight is projected to be reduced by 54%. This is as measured in tonnes of freight and we assume the same reduction for tonne-km. A 33% efficiency improvement is assumed per tonne-kilometre of freight by better engines and logistics. [11, p46] states that 25% efficiency improvements are possible from reduced speeds alone.

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