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A clean healthy future for Frome.

How we get there.

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Date: 1st draft 26th July 2016, revised 5th September 2016.

Proposal ref: A clean healthy future for Frome - final report

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Introduction

In April 2016 Climate Works Ltd (CWL) produced 'Fossil Free Frome' a discussion document considering how Frome might respond to the Paris Agreement and the call to limit the average rise in global temperature to 2 deg C, and preferably 1.5 deg C.

The report proposed that Frome should be 'fossil free' within 30 years, by 2046, and set out the case for why such a transition is needed and what, in board terms, that meant.

This report considers in more detail how Frome could shape a clean healthy future, meeting its daily requirement for power and heat without drawing on fossil fuels.

It reviews Frome's current energy needs and how these could be met through a combination of energy efficiency measures and the generation of renewable heat and power.

To help understand what this means energy demand and renewable energy potential are expressed as daily averages per person and per household using population data from the 2011 census.

Beyond emphasising the importance of energy efficiency the report does not set out to be prescriptive about what combination of renewable energy measures should be put in place. Rather it considers the relative contribution of different technologies and the implications in terms of capacity, land area and scale.

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Section 1 - baseline energy consumption

How much energy does Frome require?

To estimate how much energy Frome uses to heat and power domestic buildings we have used Energy Map[1] - a free, on-line mapping tool which utilises a range of publicly available data on domestic energy consumption (which are described in Annex 1).

Energy Map defines this data by Local Authority Area (LA), and two statistical boundaries, Middle Layer Super Output Area, and Lower Layer Super Output Area. Whilst these don't match the ward boundaries in Frome exactly, the fit is sufficiently close to provide an approximation of energy use in the town.

Energy Map uses energy consumption data for 2012, and population data provided by the Office of National Statistics from the 2011 census. The population of Frome is given as 26,203 women, men and children. Whilst both datasets are now 4-5 years old our view is that they give a useful indicator of the average level of energy demand within Frome, albeit one what may have changed in the last five years.

We have used the kilowatt hour (kWh) as the unit of energy in this report as it is the one that most people are likely to be familiar with from their energy bills. As this produces large numbers for quantities such as total estimated gas and electricity consumption in Frome, we have converted these into energy use per day per person (kWh per day per person) and per household.

Other baseline data, such as the energy used for transportation has been extrapolated from government statistics. As these are estimates, where available, we have used more than one approach to compare and check energy consumption figures.

It should be noted that the estimate of Frome's current energy demand has some omissions. We have not for example included heat generated from oil boilers or solid fuel boilers, including wood stoves and stoves burning coal or anthracite. Clearly, for Frome to become 'fossil free', with the possible exception of wood fuel produced from sustainable sources (which are discussed in the report) there are no free passes and all energy use needs to be considered. The reason they are not included here is that usage data is not collected in the same way as gas and electricity consumption and reliable data is much less readily available. With further research the 'baseline' could be extended to include all fuels.

[1] http://energymap.theconvergingworld.org/energymap/main

Domestic gas consumption

Energy Map estimates the total annual consumption of gas in Frome as **127,534,167kWh**.

Expressed as average consumption the figures are as follows:

- **Average gas consumption per household per year:** 11,108kWh
- **Average gas consumption per day per household:** 31kWh
- **Average gas consumption per day per person:** 13kWh

About gas consumption in Frome

These figures are averages based on the number of households and the population of Frome. The daily figures are intended to make the numbers more manageable and to give a better indication of how much energy we need to generate from non-fossil fuel sources. But they also mask the fact that gas consumption is 'lumpy' throughout the year and across households.

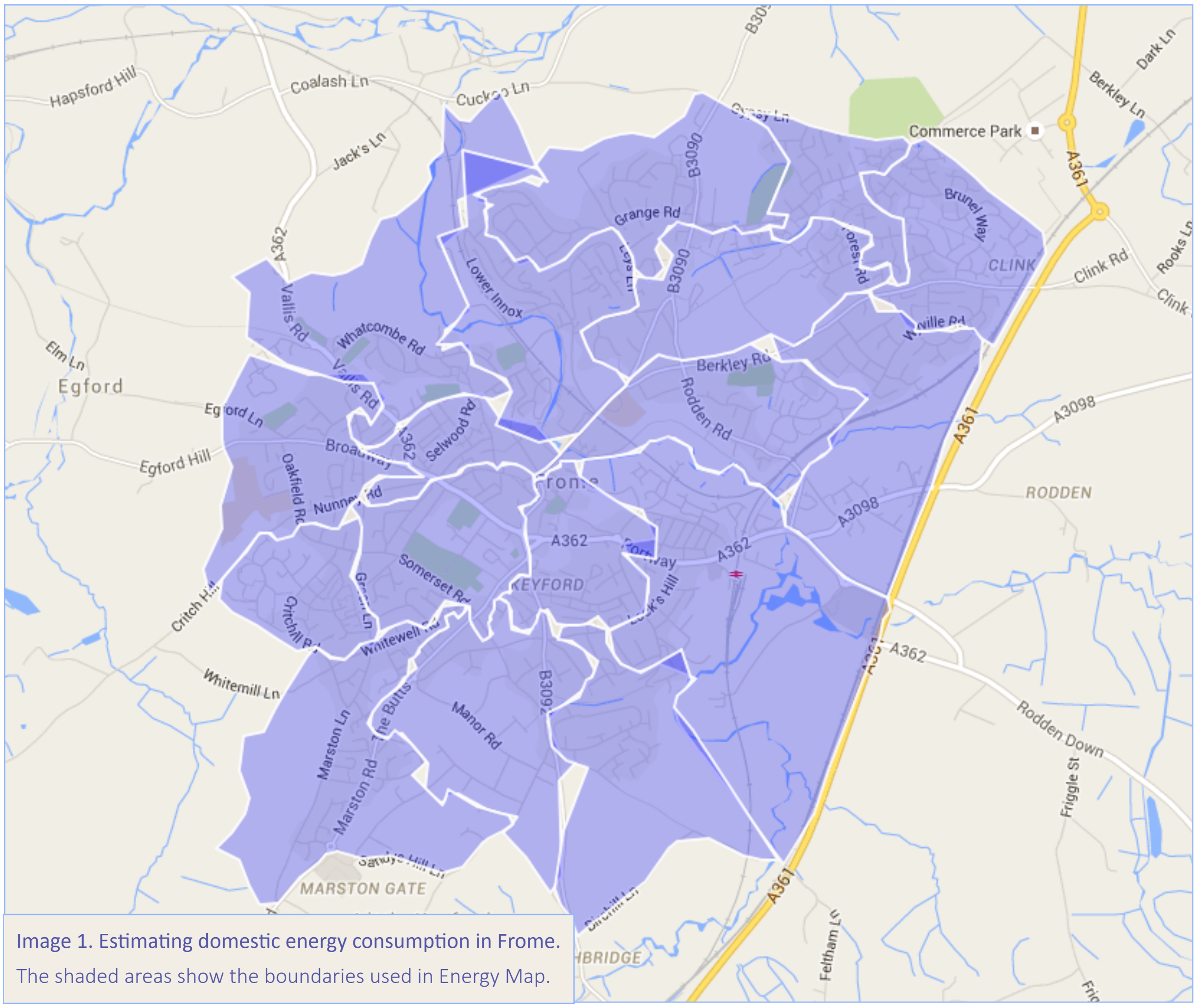

Image 1. Estimating domestic energy consumption in Frome.
The shaded areas show the boundaries used in Energy Map.

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In households heated by gas, most of their usage will be during the heating season. In households that have other forms of heating and only use gas for cooking their consumption will be fairly consistent around the year. And there will be households that don't use gas at all.

Domestic electricity consumption

Energy Map separates electricity consumption into electricity bought using an Economy 7 tariff and all other tariffs.

The figures are as follows:

- **Estimated domestic electricity consumption:** 46,697,583kWh
- **Estimated domestic electricity consumption (Economy 7):** 8,877,064kWh
- **Estimated total domestic electricity consumption:** 55,574,647kWh

As with gas consumption we can break this down into average daily consumption per households and per person.

- **Estimated annual average electricity consumption per year per household:** 4840kWh
- **Estimated average electricity consumption per day per household:** 13kWh
- **Estimated average electricity consumption per day per person:** 6kWh

Another way of thinking about the average amount of electrical energy used in a day by each person is that this equivalent to an average power consumption of 250 Watts[2]. In other words, the same amount of energy that would be needed to run a 250W appliance continuously, 24 hours a day.

Energy for transport

Whereas domestic energy consumption is physically linked to a specific address and metered, by definition the energy used to move people and goods in and around Frome is not, so we have to make a 'best guess' from the data available.

The average, daily, domestic electrical power consumption per person in Frome, is approximately 250W. The Oster Ironman Fitness Blender also has a power consumption of 250W. Running the blender continuously for 24 hours consumes 6kWh of electrical energy, as does the average person in Frome.

[2] Energy consumption (kWh) = Power (kW) X time (hours) = 0.25 x 24 = 6kWh. Details of Oster blender https://www.amazon.com/dp/B008PQR22K/?tag=ecosia-20

The Department of Energy and Climate Change (DECC) estimate[3] that in 2012 the energy needed for personal transportation in Mendip was equivalent to 48,188 tonnes of oil equivalent. The energy content of one tonne of oil equivalent is 11,630kWh so this equates to 560,426,440kWh of energy.

The 2011 Census estimated there were 46,157 households in Mendip. If vehicle ownership and travel patterns for households Frome are similar to those across Mendip as a whole then the estimated energy needed for personal transportation in Frome would be:

(11198/46157) x 560,426,440 = 135,963,240kWh[4]

As with domestic energy we can consider this on a daily basis for households and individuals.

Estimated energy for personal transport per household: 12,142kWh

Estimated energy for personal transport per day per household: 33kWh

Estimated energy for personal transport per day per person: 14kWh

This estimate is lower than some based on national figures so it's useful to consider another way of reaching average consumption per person and household.

The Department for Transport Statistics estimate that in England in 2012 the average person travelled 5,540 miles (8916km) a year allowing for all forms of road transport, excluding walking, and cycling[5]. If residents of Frome follow the national trend then on average each person travels 15 miles (24km) a day which requires 20kWh of energy[6] (approximately 47kWh per day per household). For the purposes of this exercise[7] we have used the higher of the two figures - 20kWh per day per person.

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[3] Source: Department of Energy and Climate Change (DECC): Sub-national Road Transport Fuel Consumption 2005-2013

[4] The population of Frome is taken to be 26,203, and the number of households 11,198. Both figures taken from Energy Map.

[5] The following modes of transport are ***included*** in this total: car/van driver, car/van passenger, motorcycle, other private transport (mostly private hire bus), other local buses, and taxis and mini-cabs. Source: Dept for Travel Statistics, National Travel Survey. Data for 2012.

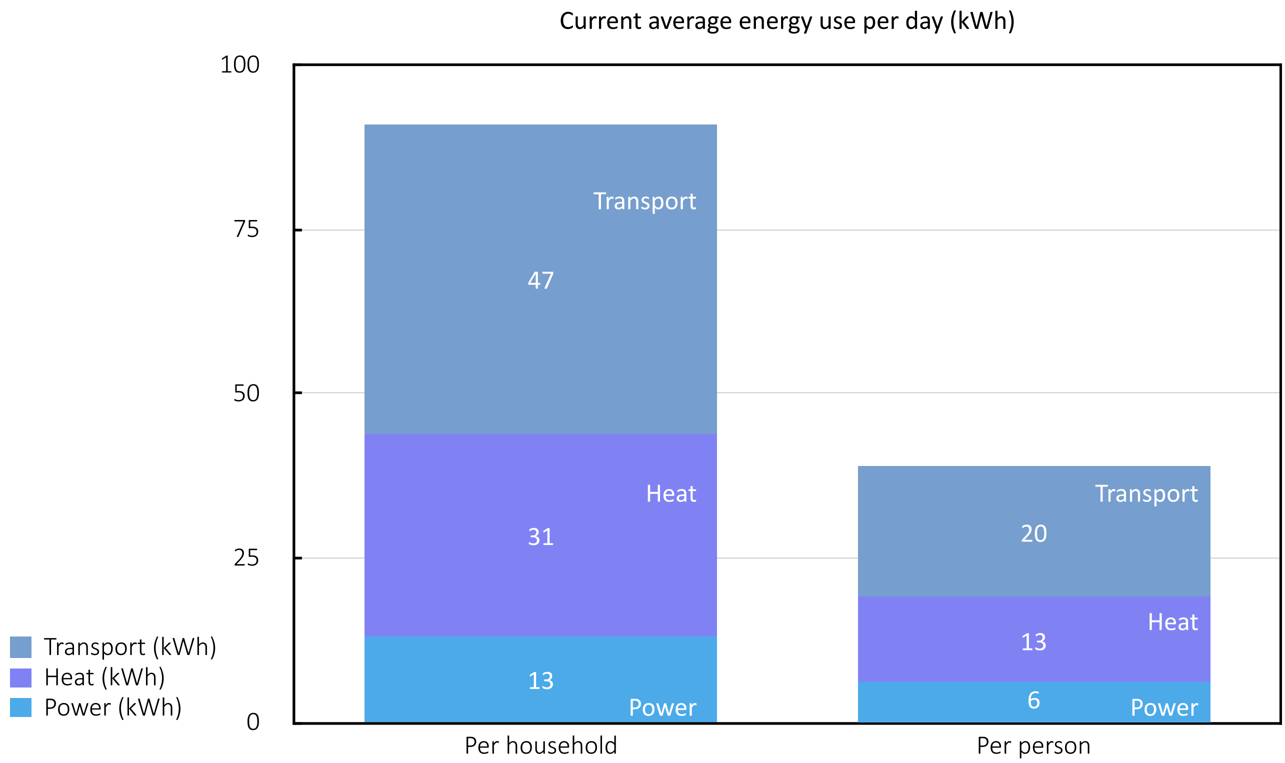
[6] Energy per day = (Distance travelled per day/Distance per unit of fuel) x Energy per unit of fuel. Distance travelled per day derived from the data in the text. Source for Distance per unit of fuel and Energy per unit of fuel: Sustainable Energy without the Hot Air, David JC MacKay. For the purposes of this estimate we have assumed that the useful energy content of petrol and diesel are roughly the same.

[7] As a further comparison in his book Sustainable Energy Without The Hot Air, David JC MacKay calculates daily energy use for transport to be 40kWh per day per person. His figure is based on a Dept of Transport estimate for 2008, that the average person drove 30km per day. He then ups this figure to 50km per day (11,000 miles per annum) to reflect the consumption of a "typically moderately-affluent person". Daily travel distances fell following the financial crash in 2008 which may explain in part the reduction from 30 to 24km per day.

Summary of current energy demand in Frome

Based on the estimates above we can summarise current energy consumption as follows:

Average use per day	Per household	Per person
Power (kWh)	13	6
Heat (kWh)	31	13
Transport (kWh)	47	20
Estimated total (kWh)	91	39



And carbon dioxide?

How much carbon dioxide is emitted as a result of personal and household energy use? The table below gives daily and annual figures for domestic consumption[8] excluding transport.

Average emissions per day (kg CO_2)	Per household	Per person
Power	6kg per day, 2.2 tonnes per annum	3kg per day, 1.1. tonnes per annum
Heat	6kg per day, 2.2. tonnes per annum	2kg per day, 0.7 tonnes per annum
Total excluding transport	12kg per day, 4.4 tonnes per annum	5kg per day, 1.8 tonnes per annum

[8] Carbon factors for gas and electricity taken from Energy Map, based on data provided by UK Government at the time. Gas: 0.18404kg CO_2 per kWh. Electricity: 0.44548kg CO_2 per kWh. N.B figures vary annual depending on the generating and fuel mix.

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Section 2 - energy efficiency

Cutting energy demand through efficiency

The quickest, most effective and cheapest way to reduce reliance on fossil fuels is to reduce demand by using energy more efficiently. This is either by changing behaviour or by switching to appliances and technology which require less energy to delivery the same output or service.

Behaviour

Behavioural change can produce rapid reductions in energy use at little or no cost. The impact of behavioural measures and how to elicit these has been researched in detail over the last 20 years. For example we know that informing households that their energy consumption is being monitored will produce a small but measurable reduction energy use, even without any further intervention.

Studies in the US have shown that providing information for householders that compares their energy consumption with that of their neighbours can produce longterm reductions in energy use of 2%[9]. Energy retailers already provide customers with a comparison between their current consumption and what they use in the same period last year. Further comparisons may be possible at relatively low cost.

We also know that modest changes can have a significant impact. Turning down a domestic heating thermostat by 1 deg C, for example, can reduce energy consumption from heating by 10%. However, we also know that a proportion of homes will be under heated and the occupants in 'fuel poverty', meaning that the average temperature of their homes needs to rise.

For the purposes of this exercise we have assumed that behavioural measures would form part of a package of energy efficiency measures cutting energy demand in Frome. Reductions of 2% in electricity use and 5% in gas consumption ought to be achievable.

Technical energy efficiency measures

The effectiveness of energy efficiency measures to cut usage has been demonstrated beyond doubt. Measures such as roof, floor and wall insulation, draught-proofing, and energy efficient appliances are key to reducing energy demand locally and nationally.

[9] Source: Evidence from Two Large Field Experiments that Peer Comparison Feedback Can Reduce Residential Energy Usage. Ian Ayres et al. http://jleo.oxfordjournals.org/content/early/2012/08/18/jleo.ews020.abstract

The Committee on Climate Change regards energy efficiency as an essential part of the package of measures needed to cut carbon pollution by 80% by 2050. Critically, the less efficient our use of energy is the more renewable energy generation capacity is required to eliminate our use of fossil fuels.

So by how much could energy demand in Frome be cut through energy efficiency? 'The power to transform the South West: *How to meet the region's energy needs through renewable energy generation*'[10] published in 2015 concluded that energy demand could be reduced by 40% in the South West through energy efficiency measures.

For comparison 'Zero Carbon Britain: Rethinking the Future' proposed that energy demand in buildings and industry could be reduced by 52% (from 1050TWh to 510TWh) through a combination of energy efficiency measures. And 'The 40% House'[11] considered what measures would be needed to reduce carbon emissions from housing by 60% in line with what the national carbon reduction target in 2005.

For the purposes of this exercise we have assumed that it is feasible to reduce energy demand in Frome by 40% by 2046 through the concerted application of energy efficiency measures and behaviour change.

What does this mean?

As discussed in our previous report, achieving a 40% cut in baseline energy demand means that every home in Frome needs to be made as energy efficient as technical measures allow.

In addition to 'standard' measures such as loft and cavity wall insulation and draught-proofing, homes with solid walls will need to be insulated with external or internal wall insulation.

A study by the Centre for Sustainable Energy[12] estimated that 35% of homes in Mendip have solid walls. If the distribution of property types is similar in Frome, just under 4000 homes will require solid wall insulation. The Energy Saving Trust estimate external wall insulation to cost between £8,000 to £22,000, and internal wall insulation between £3,500 to £14,000[13]. They point out

External wall installation in progress. Image courtesy Centre for Sustainable Energy. https://www.cse.org.uk/news/view/1611

[10] Researched and written by The Resilience Centre Commissioned by Molly Scott Cato MEP Funded by the Green/EFA group in the European Parliament

[11] Dr Brenda Boardman et al, 2005. Published by Environmental Change Institute, University of Oxford.

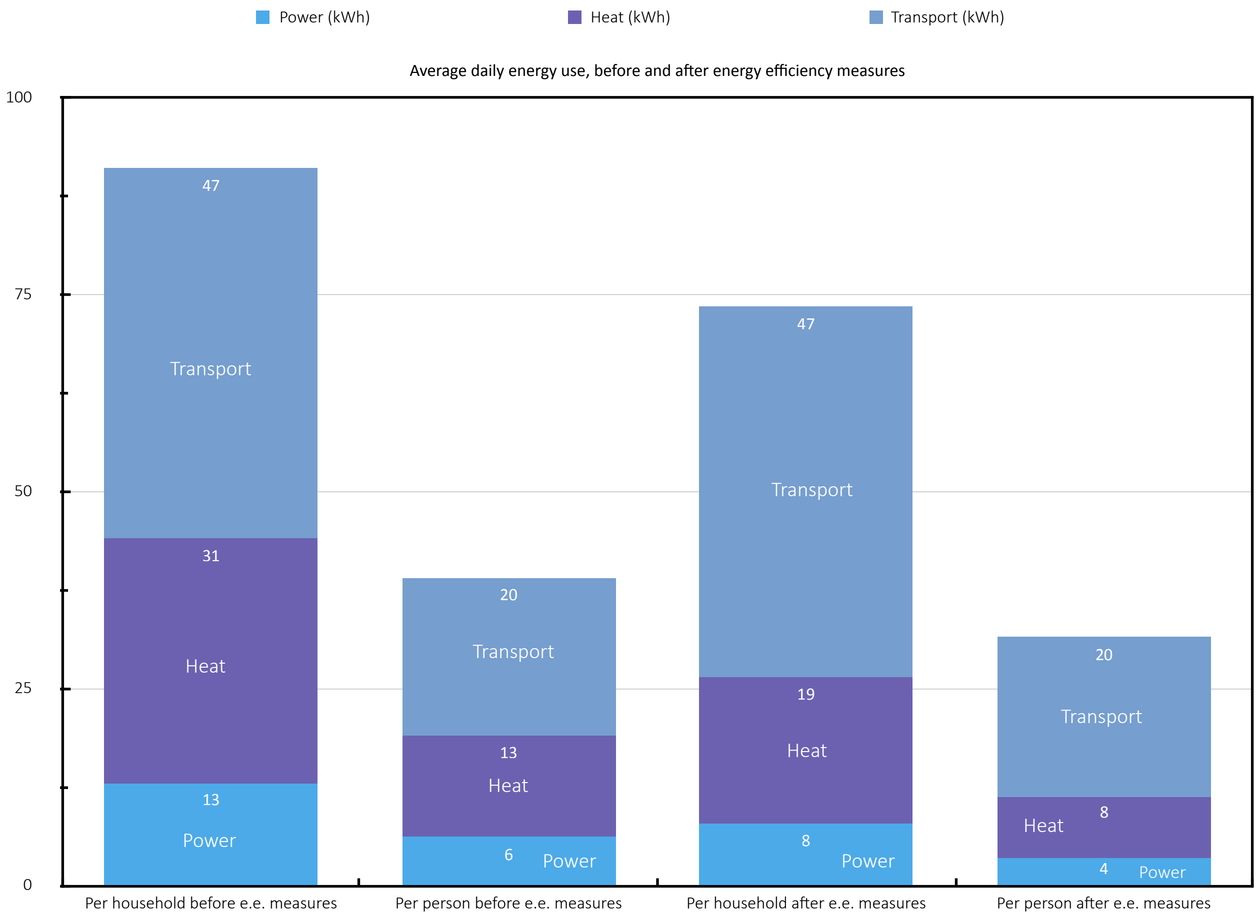
[12] Somerset Fuel Poverty Gap Analysis. Centre for Sustainable Energy for Somerset County Council. 2008. https://www.southsomerset.gov.uk/media/210987/somerset%20fuel%20poverty%20gap%20analysis.pdf

[13] http://www.energysavingtrust.org.uk/home-insulation/solid-wall

that the actual cost depends on the house type, (flat, terraced, semi-detached house etc), and factors such as access, and the detailed design of the property. Nonetheless, improving the energy efficiency of existing homes in Frome remains one of if not *the* major challenge to Frome becoming 'fossil free'.

Summary - the impact of energy efficiency on energy demand

The bar chart below shows the impact of a 40% reduction in energy demand through a combination of behavioural and technical energy efficiency measures.



Transport - more energy efficient ways of moving people and goods in and around Frome

Above we estimated the average energy needed to move people in and around Frome as about 20kWh per day per person.

To compare different modes of transport we use the 'passenger-kilometer' (p-km). A car carrying one person a 100km, delivers 100 p-km of transportation, and if it carries four people the same distance it delivers 400 p-km of transportation.

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To compare the energy required for different modes of transportation we use kWh per 100 'passenger-kilometers'. Unlike 'miles per gallon' the lower the energy per 100 passenger-kilometers the better.

The graphic in Annex 2 shows the energy requirement for different forms of passenger transport including aviation. The table below pulls out key figures of interest in Frome.

Mode of transport	Approximate energy requirement (kWh per 100 p-km)
Cycling	1
Walking	3.6
Electric scooter	4
Electric car (full - 5 people)	3-4
Coach (full)	6
Diesel high speed train	9
Average electric car	15-20
Average car (full)	16-23
Bus	32
Average UK car	80-114

Source: David JC MacKay 'Sustainable Energy Without the Hot Air'. http://www.withouthotair.com/c20/page_128.shtml

These figures are approximate. Actual figures will be subject to the age, make and model of the vehicle and especially to driving style, as well as the number of people being transported.

Even allowing for these variations we can draw conclusions on how to reduce the transport energy demand in Frome:

- The easiest way of improving the 'per person' energy efficiency of vehicle transport is to fill the vehicle. Reducing the number of vehicles on the road brings the added benefits of reducing congestion as well as local air pollution.
- For short journeys encouraging people to cycle, walk or use electric bikes/scooters instead of driving produces a huge boost in efficiency. A bike is 80 to 100 times more energy efficient than a car per passenger km.
- For longer journeys there is a similar lift in efficiency from switching from cars to public transport.

Norway - accelerating the transition to electric vehicles

Based on reports in the Norwegian newspaper Dagens Nearingsliv, it has been widely reported that Norway intends to ban the sale of all petrol and diesel cars by 2025.

The policy follows what is possibly the most generous packages of support for electric vehicles anywhere in the world. Norwegians are eligible for tax breaks, grants, reduced fees for parking and bridge tolls for EV's, all of which are intended to reduce the cost of running an electric car relative to petrol and diesel alternatives.

Norway leads the table for the proportion of EV's on the road. Currently, 24% of its vehicles run on electricity.

- In terms of cars, electric cars are about five times more energy efficient than the average fossil fuel (petrol/diesel) car.

Taking our figure of 20kWh per day per person for personal transportation in Frome, switching to electric vehicles could reduce this figure to approximately 4kWh per day per person[14].

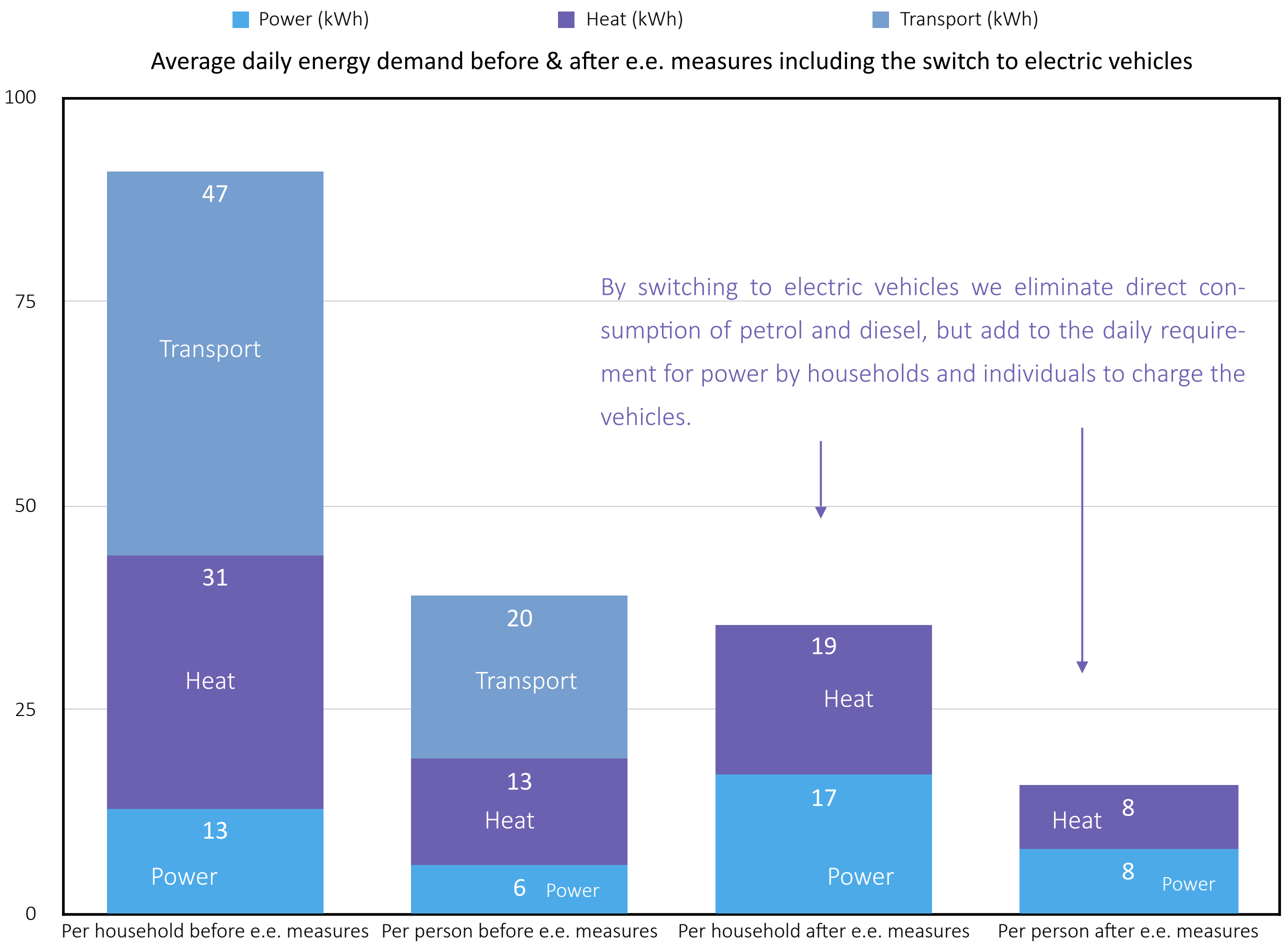
Increasing the number of journeys on foot and bike would reduce this figure and car sharing could make a significant further reduction.

There are two added benefits of switching to electric vehicles. Firstly, it eliminates exhaust pipe emissions which would significantly improve local air pollution. Secondly, it provides electrical energy storage, (the cars' batteries) which could help to smooth out peaks and troughs in energy demand and maximise the energy generated from renewable sources (discussed below). A further benefit is noise reduction. Electric vehicles are much quieter than their petrol and diesel equivalents, so Frome would be a quieter place in which to live and work.

Whilst electric vehicles are much more efficient than fossil fuel cars we still have to generate the electricity to charge them; in this case about 4kWh to the daily electrical energy requirement for the average person in Frome.

Updating the summary of energy demand in Frome we illustrate the transition to electric vehicles in two ways in the bar chart below. Firstly, the energy required for transport from burning petrol and diesel falls to zero. Secondly, the electrical energy required to charge the vehicles is added to the power 'stack' of the graph.

[14] For simplicity we have ignored the contribution to the figure of 20kWh per day per person from public transport, and the added reduction that could be made by increasing the number of journeys made by bike or on foot.


Power (kWh)
Heat (kWh)
Transport (kWh)
Average daily energy demand before & after e.e. measures including the switch to electric vehicles
100
75
50
25
0
47
Transport
31
Heat
13
Power
20
Transport
13
Heat
6 Power
19
Heat
17
Power
Heat 8
8 Power
By switching to electric vehicles we eliminate direct consumption of petrol and diesel, but add to the daily requirement for power by households and individuals to charge the vehicles.
Per household before e.e. measures
Per person before e.e. measures
Per household after e.e. measures
Per person after e.e. measures

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Section 3 - renewable power

Having reduced the demand for power in Frome through better energy efficiency, how can we generate the remaining energy we need renewably? 'The Power to Transform the South West' considered Somerset as a whole. Here we start by considering how much energy could be generated within Frome.

Solar PV

Solar photo-voltaic panels generate electricity from sunlight. The output of the panels is directly related to the intensity of the sunlight, which is in turn governed by latitude, the tilt and orientation of the panels, the time of day, time of year and cloud cover.

A simple way of estimating how much energy could be generated from solar PV is from the average roof area per person. For each person living in England, approximately 48m^2 of land is covered by buildings. If we assume that roughly a quarter of this is south facing and increase the area by 40% to allow for roof tilt the average area per person is 16m^2.

Because PV panels are rectangular we lose some of the available roof area, so assume this drops to 10m^2 per person. What area of solar panels would this give in Frome?

10m^2 x 26203 $_{\text{(the population of Frome)}}$ = 262,030m^2

The average power of sunshine per square meter of south facing roof in the UK is approximately 110W/m^2. If we take the average efficiency of PV panels to be 20% the average power delivered by south-facing PV panels in Frome would be:

20% x 110W/m^2=22W/m^2

So the average power from PV roofs in Frome would be:

22W/m^2 x 262030m^2 = 5,765kW

In an average day this would generate 5765kW x 24 hours = 136,200kWh of energy.

This is equivalent to just over 5kWh per day per person.

Solar limitations

On paper solar PV would provide just over 60% of the daily per person requirement for power in Frome which was 8kWh (allowing for the reduction from energy efficiency and the switch to electric vehicles).

However, the calculation above uses the *average* power of the sunshine on a south facing roof. The energy actually generated comes mainly during the summer months and only during daylight hours, with most of that coming in the middle part of the day. So whilst roof mounted PV could generate a lot of energy in total, to get the full benefit of this we need some way of storing the electricity generated in the day for use at night plus other forms of power generation during the winter months when the solar resource is much smaller. We discuss the role of electrical energy storage below.

Field scale solar PV

Field scale, or ground-mounted PV is an alternative to fixing PV onto buildings.

What contribution could field scale PV make to the annual power requirements in Frome? The area needed depends on the number of panels per square meter of field space, as well as the efficiency of the panels and intensity of solar radiation at the site in question.

The Wheal Jane solar PV farm in Cornwall covers an area of 3.88ha including the inverters, substation and security fencing, and has a peak output of 1.55MW.

A 2.34MW solar array at Wilmington Farm, installed by Bath and West Community Energy. Photo: Bath and West Community Energy.http://www.bwce.coop/projects/wilmington-farm/

This equates to a peak output of 0.04kW per m^2. Using an average figure of 850kWh for the energy generated in a year for each kilowatt peak of installed PV one square meter of field scale PV would generate 34kWh a year[15].

The estimated daily electrical energy consumption per person in Frome is 8kWh[16], which is 2922kWh per year. So to meet the annual requirement *per person* from field scale solar would require about 86m^2 of field mounted PV.

In reality substituting fossil fuels in Frome would most likely be achieved using a combination of renewable technologies. But if field scale PV was the only option available meeting the power requirements of everyone in Frome would require 2,253,458m^2 (86 x 26,203) of ground mounted PV. That's about 209 football pitches[17].

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[15] An areas of 3.88ha has a peak output of 1.55MW. So an area of 1ha would have a peak output of 0.40MW, or 400kW. 1ha is 10,000 sq meters, so 1 sq. meter has a peak capacity of 0.04kW.

[16] Allowing for reductions due to energy efficiency, and the extra energy required for electric vehicles.

[17] Assuming the smallest Fifa approved football pitch which is of 90 X 120m in size. The population of Frome is taken as 26,203 people.

An important difference between ground and roof mounted PV is that the energy density of roof mounted PV is higher because the panels can be mounted closer together and roof space doesn't need to be allocated for security fencing, access paths and inverters etc.

A further issue is that land given over to ground-mounted PV is less available for food production, such as arable crops, (though the guidance has been amended so that only lower grade agricultural land can be used for PV). However, it is possible to design ground mounted systems such that cattle and sheep can graze around the panels. The long life of ground mounted PV systems, expected to be 20 years plus, coupled with the relative lack of disturbance during this time, also means that they can be designed to be diverse habitats with good ecological value.

Wind

On-shore wind

On-shore wind is a 'mature' technology, meaning it is well established, and has been installed and tested in the UK for over 30 years. According to RenewableUK there are 5,392 on-shore wind turbines in the UK with an operational capacity of 8841MW (8,841,000kW).

On 1st April 2016 the UK government ended public subsidies for onshore wind farms by closing the Renewables Obligation. The Government has also amended the planning regulations to give local communities the final say over wind farms. As a result the cumulative capacity of on-shore wind is expected to peak around 2020, with little additional capacity being added thereafter, despite the fact that (per unit of installed capacity) it is the cheapest form of renewable energy and is, in some locations, cheaper than gas[18].

Leaving aside government policy, *theoretically* what contribution could onshore wind make to power demand in Frome? The power in the wind is proportional to the cube of the wind speed[19] and the square of the rotor diameter. So the energy which could be generated depends on the annual average windspeed at the location in question, and the (tower) height and rotor diameter of the turbine.

Average windspeed increases with height above sea level. It is also reduced by buildings and natural obstructions such as trees and hedges. So to know how much energy could be generated we would need to know exactly where a turbine was located and the characteristics of the windspeed in that location over the course of a year. The turbine would then be specified to match the characteristics of the wind at that location, in order the maximise the amount of energy which could be generated.

[18] http://about.bnef.com/press-releases/wind-solar-boost-cost-competitiveness-versus-fossil-fuels/

[19] This means that doubling the windspeed increases the power 8 times (2 x 2 x 2).

However, we can estimate what wind turbines could contribute using more generic figures. The European Wind Energy Association estimate that on average a turbine with a rated output[20] of 2.5 to 3MW would produce about 6 million kWh per year, or 16,427kWh per day.

This equates to about 0.6kWh per day per person in Frome. So to meet an average requirement of 8kWh per day would need approximately 13 such turbines.

An alternative way of estimating the number of turbines required is in terms of 'typical' households. The same turbine would supply the power requirements of 1500 average households in Europe. Meeting the power requirements of 11,200 households in Frome would require seven-and-half turbines[21].

Based on these generic figures it would require between 7 and 13 turbines to meet the average power requirements in Frome using wind energy alone. As discussed above this would depend on the characteristics of the specification location in question which is why there is such a broad range here.

Off-shore wind

Frome may lack a coastline, but the 'The Power to Transform the South West' report examined the potential for offshore wind to contribute to the power requirements in Somerset as a whole, and concluded that it could provide 29% of the county's power requirement.

On a per head basis it could be assumed that it might contribute a similar amount to Frome. This would equate to about 2kWh per day per person.

Clearly, it is not suggested that Frome develop its own off-shore wind capacity, rather that it source a proportion of the power it needs from off-shore wind. With this in mind a number of community energy companies are looking at ways of offering members the chance to invest directly in offshore wind projects, as they do now with PV and hydro projects.

Electrical energy storage

Electrical energy storage, in combination with smarter grids (electrical distribution networks) and measures to manage the daily demand for power, is widely regarded as key to accelerating the transition to fossil free power in the UK and around the world.

It has come to the fore in the last five years as a result of developments in battery technology and rapid cost reductions with further developments and price reductions expected in the next 5 to 10 years.

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[20] Rated output, also referred to as capacity. The maximum sustained output of the turbine under optimum conditions and before speed regulation is applied.

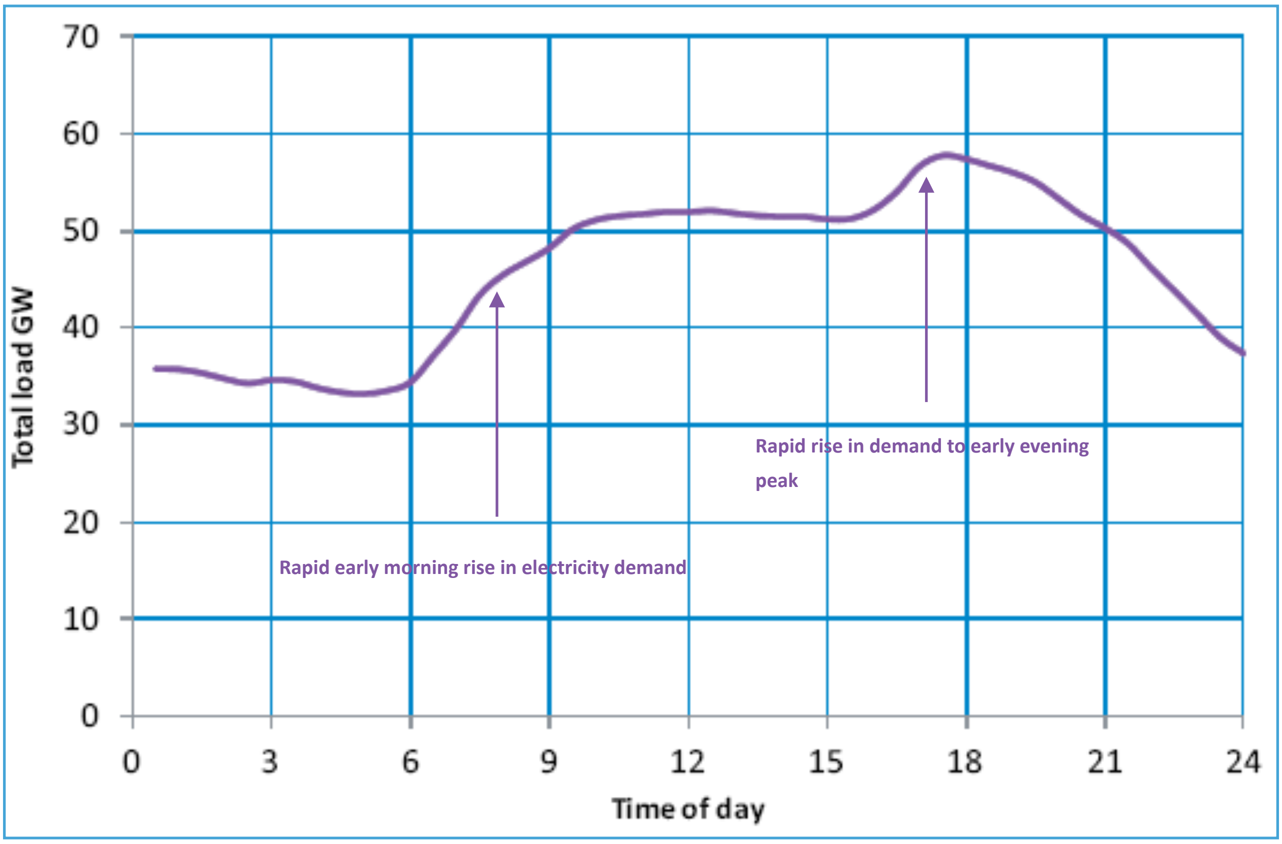
[21] Why are these two estimates different? The answer is because they are somewhat crude estimates of the annual amount of energy generated by a turbine of this size, and in the case of the second estimate, the annual energy consumption of a typical household. The actual energy generated by a wind turbine is specific to location in question. Assessing this requires information on the windspeed characteristics of the specific site.

Electricity storage. The top image shows a utility scale 20MW, frequency response energy storage unit from RES. Bottom left the Tesla Powerwall. Each unit has 6.4kWh energy storage capacity and is intended for home use The graph on the right shows the typical output from a rooftop PV array (yellow) and the typical daily domestic demand for power (blue). Products such as Tesla's power wall are designed to store solar energy during the day for use in the morning and evening. Energy can also be stored when electricity is cheap, for example during the night. Sources: electricitystorage.co.uk and tesla.com

Nationally, the supply of mains electricity has to match demand exactly at all times. To ensure this is always the case generating capacity has to be switched on and off to meet every peak and trough in demand in each 24 hour period, even when these variations last for limited periods, such as the early evening peak illustrated in the graph below.

Much of the electricity generating plant in use today such as coal and nuclear power, was designed and built to run continuously for extended periods and cannot easily be turned on and off in response to changes in supply and demand. In an effort to smooth out daily peaks and troughs, amongst other measures, suppliers

Variation in national demand in for power on 4th January 2010.



Source:http://www.publications.parliament.uk/pa/cm201213/cmselect/cmtran/239/239vw06.htm

and retailers offer customers cheaper energy at night, as an incentive to shift consumption to a time when national demand is lowest.

As discussed above, energy from renewable sources such as solar, adds to the complexity of this picture. The majority of the energy generated during the summer months from a roof top PV system will be during the day. Typically, the weekday demand for power at home will be concentrated in the morning and evening, when the output from the PV system will be lowest. Electrical energy storage is a way of storing the energy generated in the day for use in the evening, morning and night.

Electrical energy storage can be located at the power station, for example a wind farm or PV array, at points on the grid, such as substations or within individual buildings. Electric vehicles also provide mobile electricity storage which could also be used to provide capacity when vehicles are connected to mains electricity supply for charging. As yet it is unclear what the optimum scale and mix of this storage will be, or whether the investment will be met through a levy on fuel bills, taxation or direct investments from businesses and individuals. More work is needed to understand the full potential benefits of electrical energy storage and how these can be realised at a local and regional level[22].

How much storage would be needed in Frome?

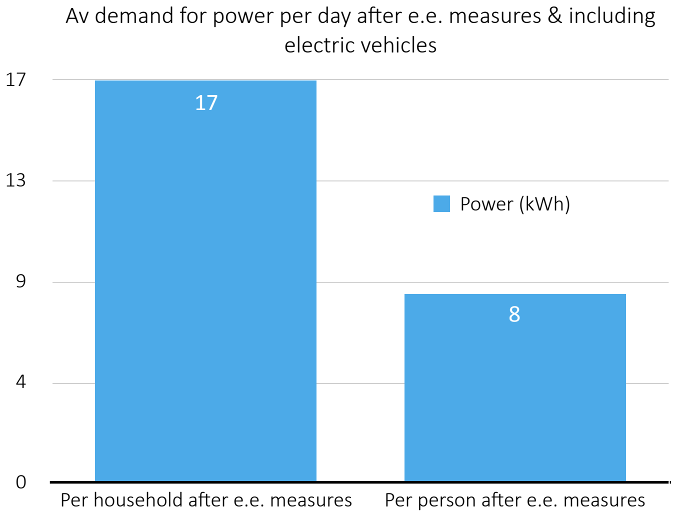
'The Power to Transform' estimate that to become fossil free Somerset would require storage with a capacity of 2,176MW.

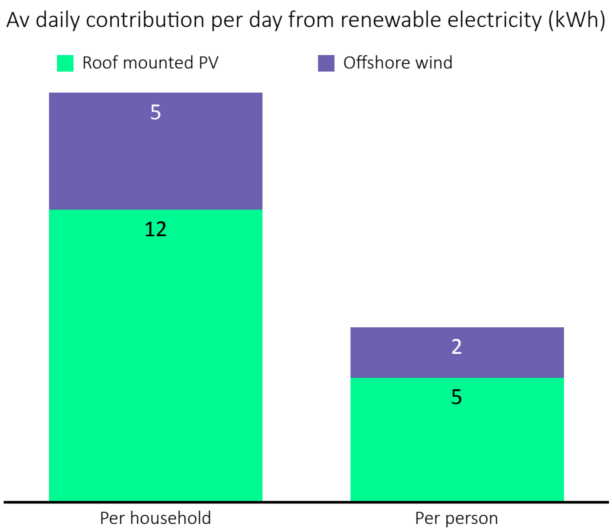
On a per capita basis that would equate to 105.96MW (105,960kW) for Frome or approximately 4kW per person[23]. For comparison the Tesla Powerwall provides 6.4kWh of electrical energy storage. We have included storage within our model as a measure in combination with solar PV and part of the energy efficiency demand reductions.

The contribution from renewable electricity - summary

Allowing for reduced demand through energy efficiency and the increased need for energy to power electric vehicles, what contribution could roof mounted PV (plus storage) and offshore wind make to the daily demand of power in Frome?

The graphs below suggest that in average terms, wind and solar could come close to matching the energy required daily by each person in Frome. However, it's important to note that these are *average* figures in which annual demand for and supply of electricity is assumed to be spread evenly across the year; in reality both vary throughout the day and seasonally.





[22] There are three main types of energy storage: bulk storage such as pumped hydro and compressed air, distributed storage such as lithium ion batteries, liquid air storage and pumped heat storage, and fast/instantaneous storage. The last of these includes flywheels and super capacitors. A current policy question is what mix of these technologies will deliver greatest environmental and financial benefit locally, regionally and nationally in the UK.

[23] Population of Somerset from 2011 census 538,104.

The inclusion of electrical energy storage helps to make full use of the energy generated from intermittent renewables such as roof top solar. But we still need to fill in the gaps when solar output is low (mid-winter for example) and when wind-speeds are low, and at times when the output from both is lower than required to meet demand.

This additional capacity could be provided in a number of ways. For example by installing more renewables at other locations, and of different types, hydro for example, to diversify the mix. Adding more storage, and storage of different types, in combination with measures to manage demand, by controlling for example when appliances turn on and off are also likely to form part of the solution. So too is greater connectivity with other parts of Europe meaning that nationally we can shed and sell excess energy when supply exceeds demand, and buy additional energy when the opposite applies. And forms of renewable electricity generation such as 'green gas[24]' which can be turned on and off quickly and on demand may form part of the solution.

Research on just how much additional capacity will be needed to supplement renewable power plus storage, in combination with a 'smart grid' is on-going.

[24] 'Green gas' usually refers to methane produced as a bi-product of processing food waste, or energy crops. The gas is burned in a conventional power station to generate electricity or processed in a fuel-cell. Companies such as Ecotricity are also exploring the production of methane from growing grass (as opposed to energy crops).https://www.ecotricity.co.uk/for-your-home/britain-s-greenest-energy

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Section 4 - renewable heat

Solar thermal

Solar thermal or solar water heating is a very well established technology which has been available commercially in the UK for over 40 years. A good quality solar system will, over the course of a year, generate about 50% of the energy needed for domestic hot water.

Solar thermal panels are about 50% efficient at turning sunlight into hot water. Using the estimate of available south facing roof space in Frome (see above) we can estimate how much hot water could be generated in Frome if this space was covered with solar thermal panels.

Estimated area of south facing roof: 262,030m^2

Average power of sunshine per square meter of south facing roof in the UK: 110W/m^2.

Allowing for efficiency of solar thermal panels (50%) this is reduced to: 50% x 110W/m^2 = 55W/m^2

So if all south facing roofs in Frome had solar thermal the average power would be:

55W/m^2 x 262030m^2 = 14,412kW

In an average day this would generate 14412kW x 24 hours = 345,880kWh of energy (heat)[25].

This is equivalent to just over 13kWh per day per person.

Solar thermal limitations

Thirteen kilowatt hours per day per person matches the current daily average for the heat required per person by burning gas (also 13kWh/day/person), before applying energy efficiency measures. And it's 5kWh per day more than the requirement after energy efficiency measures have been applied. But as with solar PV there are limitations.

- To compare the potential contribution from solar thermal to other forms of renewable energy we have used average figures. The major share of the energy generated by solar thermal is during the summer

[25] As before these are ***average*** figures to allow comparison with average energy consumption and between different forms of renewable generation. This approach assumes that the total amount of radiant heat from the sun is received evenly throughout each hour of each year. The reality is that solar energy from direct sunlight is only available during the day and mainly in the summer months.

months. Only a small fraction is produced in the winter which is when the demand for energy to heat the interior of buildings is required.

- Covering all the south facing roofs with solar thermal would produce much more hot water than is actually needed during the summer months and result in a lot of wasted heat.
- By opting for solar thermal we take roof space which could be allocated for PV panels[26].
- The heat produced by solar thermal systems is 'low grade' energy, and needs to be distinguished from higher temperature heat which can be used for other applications such as space heating. It is not as valuable or useful as high grade electrical energy.

Solar thermal could make a significant contribution to the heat required for hot water in Frome. However, as south facing roof space is at a premium and could also be used to generate electricity with solar PV it is likely that only a small proportion of the available space would be given over to solar thermal across the town as a whole.

Biomass

'Biomass' is often used interchangeably with 'bioenergy'. In this case we use it to refer to heat generated by burning wood in the form of logs, chip or pellets to generate heat for space heating and hot water.

Wood heating is used extensively in Scandinavia, Germany and Austria, in urban as well as rural areas. The use of wood in this way is treated as a form of renewable energy, because burning wood replicates part of the naturally occurring 'carbon cycle'. The proviso to this is that the wood must come from a managed source and be continuously replenished by new planting[27].

How much of the current heat demand in Frome could be met by switching from gas to wood? 'The Power To Transform' report estimated that biomass could contribute 15% to the energy requirements in the county. If we apply this percentage to the production of heat from biomass we get the following breakdown:

Current domestic demand for heat from gas[28] in Frome (before energy efficiency measures): 127,534,167kWh per annum

Proportion of gas consumption assumed to be for cooking[29]: 3%

Balance of current demand for heat from gas:123,708,142kWh per annum

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[26] Combined solar thermal and PV collectors are beginning to appear and may become more commercially viable over the next 5 years.

[27] The carbon cycle. Trees convert carbon dioxide into carbon via photosynthesis as they grow. When they die the process is reversed. The carbon breaks down and combines with oxygen in the air to form carbon dioxide. This also happens when wood is burned.

[28] The energy for electric heating, for example from storage heaters, is included within the current demand for power.

[29] Source: United Kingdom Housing Energy Fact File. Department of Energy and Climate Change (2013). Jason Palmer and Ian Cooper.

Proportion of heat to come from biomass: 15%

Heat required from biomass to meet 15% of annual demand: 18,556,221kWh per annum

Assumed efficiency of the wood burner/appliance: 80%[30]

Energy required from biomass allowing for efficiency of wood burners: 23,195,277kWh per annum

Energy content per unit of area for wood[31] (from forestry residues, short rotation wood, thinnings etc): 10.3 MWh/ha.a[32]

Energy content per unit of area for wood (from short rotation willow coppice): 46MWh/ha.a

Area of wood (from forestry) required for heat production: 2252ha roughly 23 square kilometres

Areas of short rotation willow coppice required for heat production: 504 ha roughly 5 square kilometres

These figures are based heat demand in Frome before using energy efficiency to reduce demand. Assuming this can be reduced by 40% the areas required drop to:

Area of wood (from forestry) required for heat production after e.e. measures: 14 square kilometres

Areas of short rotation willow coppice required for heat production after e.e. measures: 3 square kilometres

To put these areas in context 14sq km of woodland is equivalent to a square 3.74km (2.3 miles) on the sides, and 3sq km of short rotation coppice a square 1.73km (1.1 miles) on each side.

The area of willow is smaller than the area of woodland because of the higher energy content. However, as the Biomass Energy Centre points out the crop yield depends on the inputs and may require more intensive production of wood including the use of artificial fertilisers.

Heat pumps - extracting solar energy from the air, ground and water

Almost every household owns at least one heat pump, in their fridge or freezer. Heat pumps in the form of air conditioning, are increasingly being provided as standard fixtures in new cars and some new homes.

Heat pumps use the physical characteristics of a working fluid, also known as a refrigerant, to move heat from one place to another. In the case of a fridge from the inside to the outside of the insulated box.

[30] 80% of the energy produced is useful heat, 20% is wasted including heat lost up the flue.

[31] Source: Biomass Energy Centre. Potential outputs of biofuels per hectare per, annum. These figures are approximate and depend on the geographical location, cultivation inputs and techniques, harvesting and processing etc. The energy content is dependent on the moisture content of the fuel. In both cases it is assumed that this is 30% moisture content.

[32] Per hectare per annum

The same principle can be used to extract solar energy in the form of heat stored in the air, ground or water. Heat pumps can also raise the temperature of the heat energy being transferred or pumped from one place to another. A ground source heat pump extracts ambient heat from the ground at say 11 deg C and can raise the temperature to 30 deg C. Similarly, an air source heat pump extracts heat from the air drawn into the appliance by a fan.

Heat pumps are regarded as a form of renewable energy because for every unit of electrical energy used to operate the appliance 3 to 4 units of heat can be extracted. Because this extracted heat is solar energy in the form of heat stored in the ground, water or air, it is treated as renewable heat.

This ratio of electrical energy 'in' to heat 'out' is known as the Coefficient of Performance (CoP). Another way of thinking about this is that a heat pump is 300-400% efficient. This lift in efficiency means that for each unit of useful heat we need we require 3 to 4 times less energy from a heat pump than from say a gas boiler producing an equivalent amount of useful heat. (Please see footnote for a comparison of CO_2 emissions.[33])

The CoP and efficiency of the system fall as the temperature difference between the heat 'in' and 'out' increases. For this reason heat pumps are best suited to properties which are well insulated and distribute heat using a low temperature distribution system such as low temperature radiators or underfloor heating.

Because heat pumps are best suited for producing and delivering low temperature heat they are not particularly responsive meaning they need to run continuously for long periods unlike say gas heating which can be turned on and off to provide (high temperature) heat on demand.

What could heat pumps contribute in Frome?

For this exercise we assume that 15% of the heat demand in Frome, after energy efficiency measures, comes from biomass, what would be required to meet the residual demand from heat pumps?

Current domestic demand for heat from gas in Frome (before energy efficiency measures): 127,534,167kWh per annum

Proportion of gas consumption assumed to be for cooking: 3%

Balance of current demand for heat from gas:123,708,142kWh per annum

Domestic demand for heat from gas after applying energy efficiency measures: 7,422,488kWh per annum

Proportion of heat generated from biomass (15%): 1,113,373kWh per annum

[33] How do heat pumps compare with gas boilers in terms of CO_2 emissions? The carbon factors used in Energy Map for are 0.18404kg CO_2 per kWh for gas and 0.44548kg CO_2 for electricity. Thus, the carbon factor for electricity is 2.4 times higher per kWh than gas. Provided the Coefficient of Performance of a heat pump is 2.4 or greater, the CO_2 emissions from switching to heat pumps will be equal to or better than a gas boiler. One further point to consider is that the carbon factor for electricity in the UK is set to fall year to year until it is effectively zero. The carbon factor for natural gas is unlikely to fall much below the figure shown, and more recently has risen to around 0.25kg CO_2 per kWh.

Proportion of heat to be generated using heat pumps (85%): 6,309,114kWh per annum

Assumed average Coefficient of Performance (CoP): 3.5

Electrical energy required to run heat pumps to meet residual heat demand: 1,802,604 kWh per annum

Average energy required to run heat pumps per day per household: 0.4kWh

Average energy required to run heat pumps per day per person: 0.2kWh

By combining a big reduction in demand through energy efficiency measures, some biomass heating and heat pumps, the average energy required to heat Frome has reduced from 31 and 13kWh per household and per person per day to 0.4kWh and 0.2kWh respectively. However, there are some caveats.

These are average figures which assume that the annual demand for heat is spread evenly across the year. In fact the major part of this demand will be occur in the heat season (i.e. the winter months). Heat pumps offer a step change in efficiency from 90-95% in the case of an efficient gas boiler to 300-400%. But they only make sense in properties in which a full package of energy efficiency measures including in the case of solid wall properties, internal or external wall insulation.

We also know from field trials of heat pumps that they have to be sized correctly for the property and fitted with appropriate controls. And they have to be used as designed, i.e. run continuously, and not used as you would a gas boiler. Problems in any of these areas will significantly reduce efficiency and increase energy consumption[34].

Nonetheless, even with these caveats it should be possible to keep Frome warm without burning gas, provided properties can be made as efficient as possible.

One further point to note is that we have added a bit more to the daily requirement for power, to provide the electrical energy for the heat pumps which will need to be met from renewable sources.

Cooking

Above we assumed that 3% of the current demand for gas is used for cooking. Over the last 20 years there has been a notable reduction in the energy used for cooking. This reflects changes in lifestyle, the use of appliances, such as greater use of microwave ovens, and some improvements in efficiency. More recently energy for cooking has levelled off, though further improvements in efficiency ought to be achievable.

Breaking this down by household and per person the figures are as follows:

[34] Heat pumps also need to be correctly sized to meet the heat requirement. Undersizing can lead to freezing of the heat exchange in the case of air source heat pumps. Over-sizing will reduce efficiency of the system. For ground source heat pumps the coils used to extract solar energy from the ground have to be buried at an appropriate depth to avoid freezing the ground during the winter.

Current domestic demand for heat from gas in Frome (before energy efficiency measures): 127,534,167kWh per annum

Proportion of gas consumption assumed to be for cooking: 3%

Energy required for cooking (using gas): 3,826,025kWh per annum

Average energy per day per household for cooking: 0.9kWh

Average energy per day per person for cooking: 0.4kWh

These figures may seem low, but they only represent the energy for cooking from gas. Many households will cook with gas *and* electricity and there will households in Frome that only use electricity for cooking.

As discussed above, we need to add these daily consumption figures to the energy which needs to be generated renewably.

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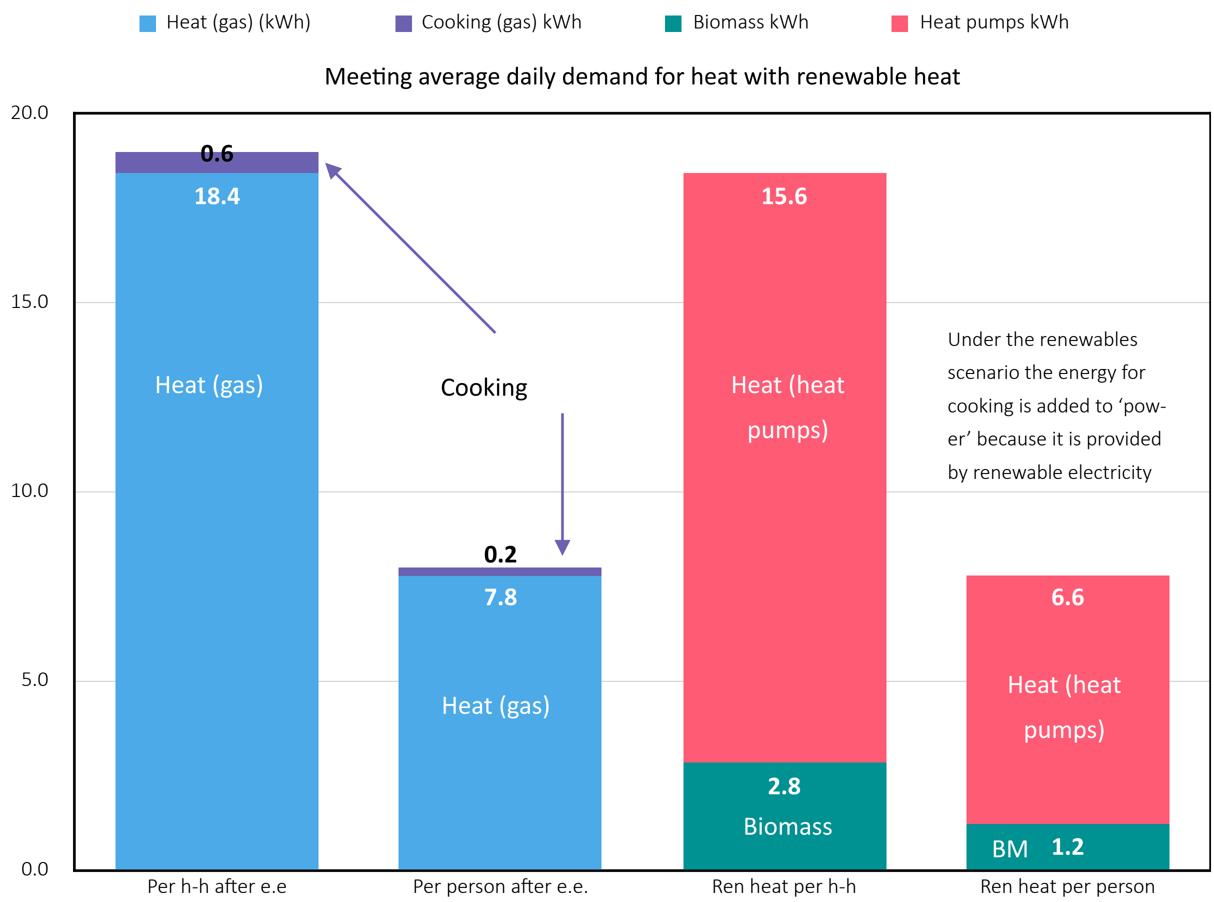
Renewable heat - summary

The graph below illustrates how a combination of biomass and heat pumps could meet the daily requirement for heat after energy efficiency measures have been applied to reduce demand.

The bars on the left show existing average consumption after energy efficiency measures have been applied. Heat required for cooking has been separated out and the two bars show average daily consumption by household and per person.

The two bars on the right show how the major part of the demand for heat could be met renewably. Cooking has been removed because heat from gas for cooking will be met by renewable electricity. This additional requirement will be added to the power stack, along with the electricity required to drive the heat pumps.



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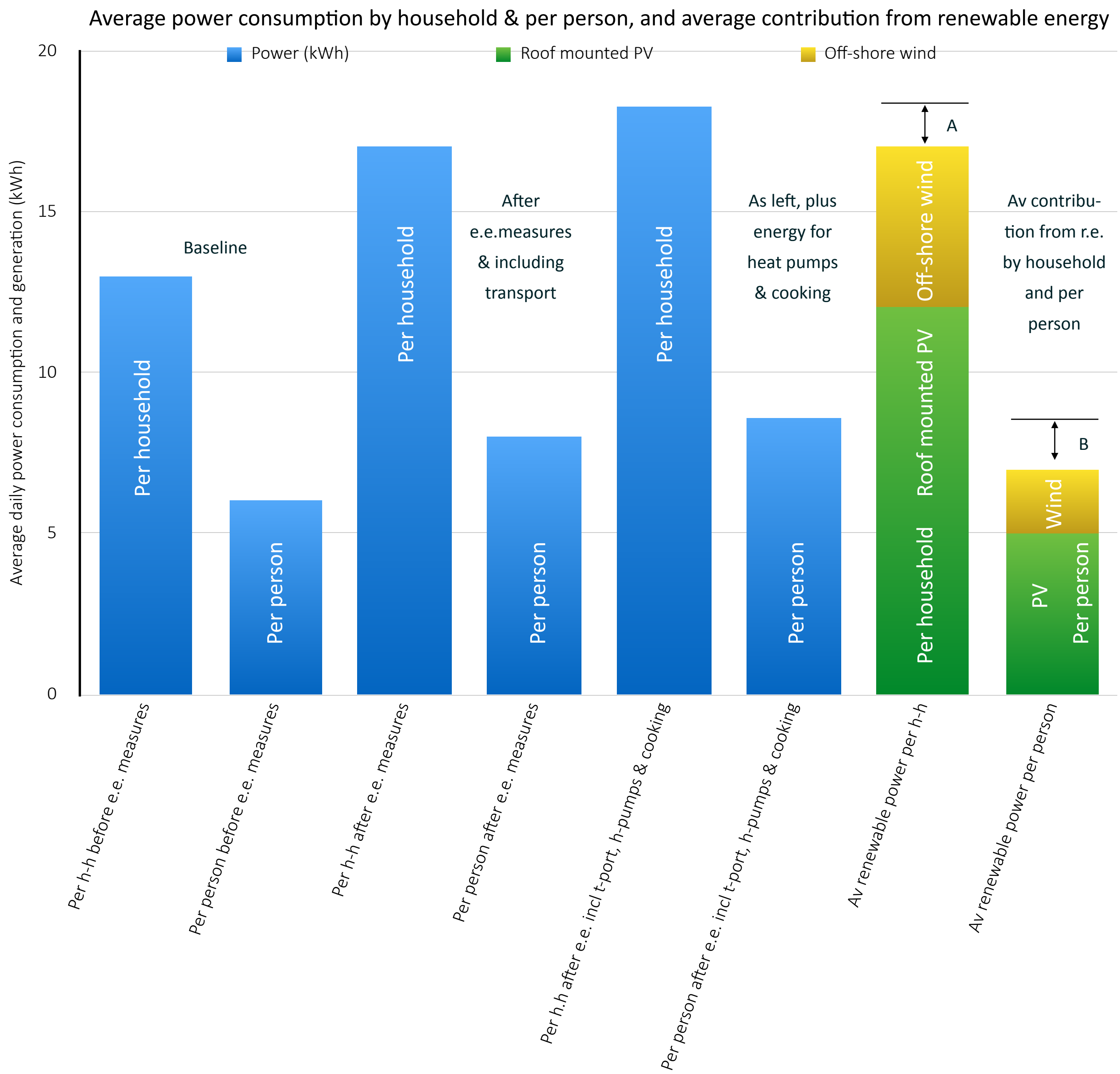
Summary of average daily power consumption and generation including requirement for renewable heat and cooking

The chart below summarises average daily power consumption in Frome per household and per person. This increases against the baseline because the energy required for transport, most heat production and cooking shifts from other fuels to electricity. The two bars on the right hand side show the average contribution from roof mounted PV and offshore wind. The gaps ‘A’ and ‘B’ are the difference between anticipated demand and supply which would need to be met by other non-fossil fuel means.



Section 6 - conclusions

Overview

In April 2016 Climate Works Ltd published a discussion document setting out a proposal for Frome to become 'fossil free' within 30 years. This report has looked at how Frome might generate the power and the heat it requires on a daily basis from renewable energy within that time frame.

Beyond emphasising the critical importance of reducing energy demand through energy efficiency the report is not intended to be prescriptive. There are any number of possible routes for meeting Frome's energy requirements without burning fossil fuels. Rather it is intended to provide some guidance on the relative contribution that different renewables could contribute, the implications in terms of things such as land area, and to highlight some of the political barriers for example on energy efficiency and onshore wind.

We have approached this by looking at the domestic demand for heat and power now, and breaking this down into average daily consumption by household and individual. The use of average consumption by household and per head is intended to make the numbers more meaningful and enable comparison between technologies. But as we make the transition away from fossil fuels, the uneven nature of both energy demand and supply (from renewables) needs to be accounted for.

Consumption of heat and power in Frome 'now' has been based on data produced by Energy Map, an on-line tool which draws together a variety of data in the public domain. The current version of Energy Map uses data from 2011/12. Though Frome has changed and grown since then, we think this is still a reasonable baseline to use, particularly if considering daily consumption by household and per person. To normalise this we have used population data from the 2011 census.

A notable difference between fossil fuels and renewable energy is energy density. Fossil fuels are exceptionally energy dense, meaning that per unit of volume they provide very high levels of energy that can be converted into heat, and in turn electricity. (One consequence of this characteristic is that we have been able to use fossil based energy very inefficiently without having to a great deal of attention to this). By contrast the energy density of renewables is very much lower meaning that to harvest an equivalent amount from what are different forms of solar energy[35] requires large areas of land. Though there are ways of concentrating this solar energy this remains a very important distinction. For this reason it is generally difficult and usually impossible for towns and cities to generate their annual energy requirement renewably

35 Wind, hydro and biomass are all driven by solar energy. Heat pumps are used to harvest solar energy from the air, ground or water.

within the boundary of the town or city itself. This is the case in Frome. In this report we have assumed, as have other studies, that a proportion of the heat and power needed in the town would be generated outside the town itself. For this report we selected off-shore wind, because of the constraints applicable to on-shore wind, but the balance could equally be made up using field scale PV, hydro, or technologies such as tidal singly or in combination.

Another obvious distinction between fossil fuels and renewables is the intermittency and seasonality of renewables. Wind turbines require a minimum windspeed to generate electricity. Photovoltaic panels generate most of their energy during the summer months, and shut down at night. Though there is a tendency, in the media to over-emphasise the significance of what are inherent features they clearly have to be addressed in order to provide a reliable and secure energy system.

It's likely that this will be done though a combination of electrical energy storage, some storage of heat, enhanced connectivity with electricity grids in other parts of Europe, (and potentially North Africa), demand management coupled with 'smart grids' and forms of renewable energy such as 'green gas' which are responsive - meaning they can be turned on and off very rapidly to meet changes in demand.

In considering the contribution from renewable energy a distinction needs to be made between low grade heat, high grade heat and electricity and the usefulness of each. Low grade heat may be suitable for domestic hot water and some forms of space heating. High grade heat can be used for a variety of applications including space heating, industrial applications and cooling[36]. Most useful of all is electricity which can generate heat and most importantly power machines and appliances. These differences are important when considering for example how to make best use of limited south facing roof space.

Findings

This study has concluded that Frome could come close to meeting its average daily demand for heat and power, including domestic transport, using a combination of energy efficiency, PV, off-shore wind, and energy storage to generate and store power; and biomass, and heat pumps to generate heat. As these are average daily figures additional energy capacity would be needed to meet demand for power when the solar output is low or zero and wind speeds are low. As discussed above this could be met through a combination of sources and means including demand management. Whilst this report has considered Frome on its own, the shift from fossil fuels implies more not less energy connectivity with other areas.

The contribution of energy efficiency, and the importance of reducing energy demand before applying renewables cannot be over-stressed. Improving energy efficiency is the quickest, easiest and most cost effective means of cutting pollution from fossil fuels. A point often overlooked is that because the infrastructure to bring fossil fuels to our homes and businesses already exists, delivering more heat or power

[36] Through processes such as absorption chilling.

by burning fossil fuels can be done at a relatively low cost. By contrast every additional kilowatt hour of electricity generated renewably requires investment in resources, technology and logistics. Avoiding unnecessary investment is going to be essential to making this transition.

How realistic is this?

As discussed in the body of the report, we have made a number of assumptions and simplifications to do with current and future energy needs. For example we have assumed that there is no inherent growth or fall in energy consumption from the baseline over the next 30 years (aside from the fall due to improved energy efficiency), and have deliberately excluded the cost of measures from this analysis. To simplify the report we have also omitted some technologies including small scale hydro and renewables which could contribute from further afield such as tidal energy. We have included a contribution from off-shore wind, largely because of the political block on on-shore wind. In reality it is likely that combinations of measures will come into play, determined by a range of factors including the interests and preferences of residents of Frome.

In terms of the broad assumptions made here, a report commissioned by the Department of Energy and Climate Change, published[37] in 2012 identified 36% demand reduction potential in the UK by 2030. We have assumed a 40% drop in demand by 2046. The *Power to Transform the South West*[38] estimates that Somerset could meet 152% of total future energy needs from renewable energy, including, as we have done, a contribution from off-shore wind.

On transport and the switch to electric vehicles, the Office for Low Emission Vehicles (a joint initiative by BIS, DECC and DEFRA) assumes that by 2040 all new vehicles are non-fossil fuel, and by 2050 all vehicles on the road are non-fossil fuel. In this report we have assumed that by 2046 all private vehicles in Frome are fossil free. A number of industry commentators believe this transition will be faster than this.

Challenges and opportunities

Challenge - accelerating the pace of transition

Some of the changes and transformation described in this report may wall take place anyway over the next 30 to 50 years without intervention. The ‘normal’ rate of change is in part determined by existing targets and commitments, for example the trajectory set out in the Climate Change Act of 2008 to reduce emissions by 80% by 2050. But the Paris Agreement, agreed at COP 21 in December 2015 implies a rate of change which is faster than these existing commitments, particularly if there is to be any prospect of limiting the average rise in global temperature to 1.5 deg C. The challenge for all towns and cities in the UK, and not just Frome is how to accelerate the rate at which we phase out fossil fuels completely.

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[37]Capturing the full electricity efficiency potential of the U.K. (2012). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66564/7035-capturing-full-elec-eff-potential-edr.pdf

[38] The Power to Transform the South West (2015)Researched and written by The Resilience Centre Commissioned by Molly Scott Cato MEP Funded by the Green/EFA group in the European Parliament.

Challenge - making energy efficiency a political priority

Despite the strength of the financial, technical and environmental arguments in favour of reducing energy demand through energy efficiency it has almost entirely fallen off the political agenda and is not currently regarded as a priority by the UK government.

The Association for the Conservation of Energy has reported[39] that the number of efficiency measures installed through government-backed schemes has fallen by 80% since 2012, from 1.74m a year to 340,000 a year in March 2016. Whilst some energy efficiency measures pay for themselves quickly others, such as solid wall insulation, are expensive and entail high upfront costs. Without concerted support including funding, measures such as solid wall insulation are not going to be adopted at scale and the skills, services and learning required within the industry for their delivery will not develop. Reducing the heat loss from existing buildings is an essential prerequisite to installing renewable heat technologies such as heat pumps.

Challenge - financing the transition

The popularity of community renewable energy projects such as those developed by Frome Renewable Energy Co-op (FRECO) suggests that given the right projects and a reasonable rate of return, people are very willing to invest their own money in new technologies and services including renewable energy. But as discussed above, there are measures which require more support, especially if we are to accelerate the rate at which they are deployed. Finding new ways of attracting inward investment, especially given the imminent cessation of European funding is one of the major challenges for Frome to become fossil free.

Challenge - on-shore wind

On-shore wind is the cheapest form of renewable energy and in certain locations is cheaper than gas. Despite this, and the fact that opinion polls consistently show strong support for on-shore wind, current policy has effectively brought a halt to the majority of new installations not already underway. The absence of on-shore wind will make the transition from fossil fuels more costly and more difficult.

Opportunities - the shared benefits of becoming 'fossil free'

One of the big opportunities for Frome is that there is very good alignment between the need to eliminate pollution from fossil fuels as part of the solution to climate change and the local benefits this brings.

In addition to cutting carbon pollution, energy efficiency directly addresses fuel poverty, can create skilled local employment, increases disposable income, makes homes warmer and healthier, directly addressing a number of chronic health conditions, and increases revenue retained within the local economy.

The switch to electric vehicles will lead to an immediate reduction in local air pollution, and increases in walking and cycling for local journeys bring demonstrable public health benefits.

[39] http://www.ukace.org/wp-content/uploads/2016/03/ACE-briefing-note-2016-03-Home-energy-efficiency-delivery-2010-to-2020.pdf

Big wins

We have identified four big wins for Frome - measures which would accelerate the transition to the town becoming fossil free.

Energy efficiency

This remains the number one priority for the many reasons described above. Measures to encourage behavioural change have the added benefit of generating immediate savings at low cost.

Roof mounted PV and energy storage

Roof mounted PV generates energy at a higher density than field mounted PV and can make a significant dent in the average daily demand for power in Frome. Electrical energy storage is developing rapidly and in combination with PV should enable the useful output of PV systems to be maximised. More work is needed to understand the full impact of electricity storage and how to make best use of this.

Transport

In terms of impact some of the biggest opportunities are in local transport. Measures such as vehicle sharing, switching from private cars to cycling, walking and public transport provide a step change in efficiency. Electric cars are more than 5 times more energy efficient per passenger kilometre than their petrol and diesel equivalents, and bring additional benefits in terms of local air and noise pollution. Cycling is 80-100 times more energy efficient than driving for short journeys.

Heat pumps

Delivering heat electrically using air, ground and water source heat pumps is 3 to 4 times more energy efficient than the best gas boilers and so reduces the energy which needed to generate that heat.

Heat pumps require well insulated buildings so need to be considered in combination with programmes to make homes much more energy efficient.

Annex 1

Baseline data used in Energy Map

As described in the Introduction, baseline data has been derived from Energy Map (http://energymap.theconvergingworld.org/energymap/main). The following extract from the Energy Map website explains how the data is collated and some of the limitations inherent within it.

Energy Map combines data from a number of different sources. Data is available at differing resolutions, and not all data is available at all resolutions. For example, data might be available for a Local Authority region but not when drilling down to street level.

The software holds energy data for the whole of the UK, but data may not be available for every region. For example, some regions do not have a gas supply. Data has been added as it become available, and so does not reflect retrospective revisions.

Data Source	Data Category	Local Authority Area (LA)	Middle Layer Super Output Area (MLSOA)	Lower Layer Super Output Area (LLSOA)
Department of Energy and Climate Change (DECC)	Domestic Electricity and Gas (2008-2012)	X	X	X
	Commercial Electricity and Gas (2008-2012)	X	X	
	Other Fuels e.g. Oil, Coal (2005-2011)	X		
	Transport Fuel (2005-2012)	X		
Office of National Statistics (ONS)	Statistics e.g. Population, Households, Area (2011 Census)	X	X	X
	Central Heating Types (2011)	X	X	X
National Atmospheric Emissions Inventory (NAEI)	CO2 Emissions (2005-2010)	X		

The regions for which data is currently available are, in descending order of size:

Country > Local Authority > Middle Layer Super Output Area (MLSOA) > Lower Layer Super Output Area (LLSOA).

The table above shows the data available and the geographic regions for which it is available.

Limitations

Over the years, the administrative boundaries of the UK change. Since 2008, certain Local Authority mergers have occurred. Also, for the 2011 census, the MLSOAs and LLSOAs were adjusted, so that they continue to be regions of approximately constant population. As a result of this, a small number of these regions were merged or split, and a very small number underwent complex changes in terms of their constituent output areas (OAs). DECC energy data up to and including 2011 is defined for 2001 census boundaries. From 2012, it will reflect the 2011 census boundaries.

Where available, 2011 census data is used for population and households. Therefore 2001 census data is only present where it refers to regions that ceased to exist for the 2011 census.

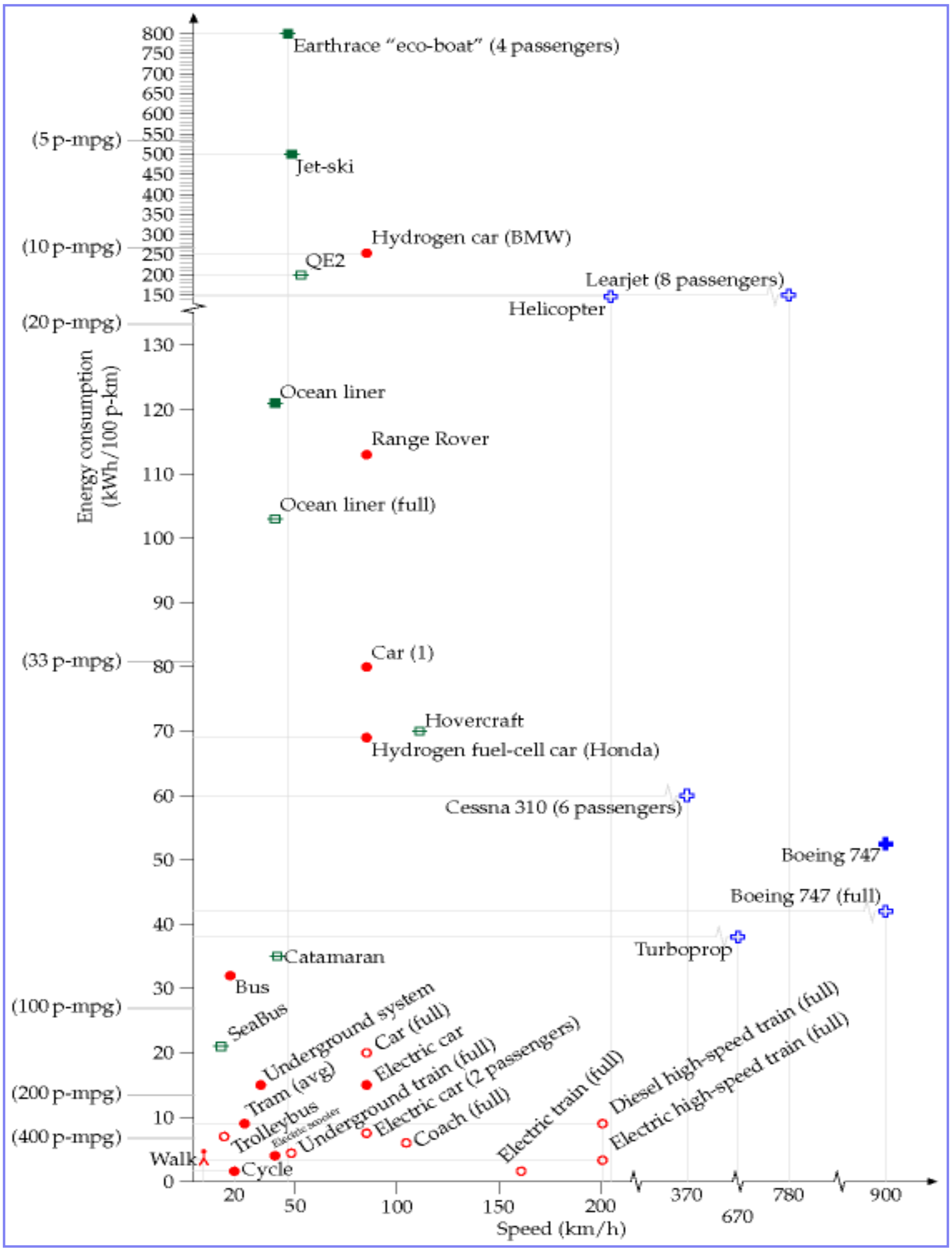
As a result of the boundary changes, there are effectively some new (2011 census) and some old (2001 census) MLSOAs and LLSOAs, while the majority are valid for both census periods. The EnergyHub database, from which Energy Map derives its data, contains all the regions from both periods, and all energy data defined for them.

At a level of Local Authorities, for a given year their data is aggregated from the MLSOAs that they contained that year. Therefore despite the boundary changes, time series for such regions will remain accurate. Local Authorities themselves have changed since 2008, but present boundaries are used throughout the period we present data for, with data from former Local Authorities that underwent mergers aggregated appropriately.

Further information on Energy Hub and Energy Map and the data used in both may be found here: http://energymap.theconvergingworld.org/docs/data/assumptions

Annex 2

Energy requirements for different forms of passenger transport



Energy requirements of different forms passenger transport. Source: Sustainable Energy Without the Hot Air. David JC MacKay. http://www.withouthotair.com/c20/page_128.shtml The vertical coordinate shows the energy consumption in kWh per 100 passenger-km. The horizontal coordinate indicates the speed of the transport. The “Car (1)” is an average UK car doing 33 miles per gallon with a single occupant. The “Bus” is the average performance of all London buses. The “Underground system” shows the performance of the whole London Underground system. The catamaran is a diesel-powered vessel. Equivalent fuel efficiencies in passenger-miles per imperial gallon (p-mpg) are indicated on the left hand side. Hollow point-styles show best-practice performance, assuming all seats of a vehicle are in use. Filled point-styles indicate actual performance of a vehicle in typical use.

Annex 3 - hydrogen storage

This report has considered different means of storing electrical energy and heat. Much of the current thinking on the storage of electrical energy is focused on batteries, driven in part by technical innovations, rapid cost reductions and scalability.

There are a variety of other ways of storing electrical energy including chemical and mechanical systems. Hydrogen is often considered amongst these, particularly for transport. Though widely presented as a fuel, hydrogen is in fact an energy *carrier*, like a rechargeable battery.

The long running interest in hydrogen is due in part to the fact that in can be burned in an internal combustion engine, producing no carbon dioxide and only water vapour and very small amounts of other pollutants, making it a 'clean' source of energy. Hydrogen can also be used in a fuel cell to produce electricity by a chemical process which doesn't require combustion.

However, producing and storing hydrogen as a gas or liquid is energy intensive, and so raises the question about where the energy required to do this will come from. To date hydrogen vehicles have struggled to match the energy efficiency of current fossil fuelled vehicles and in some cases have required significantly more energy per passenger km[40] and much more than battery powered equivalents.

The UK Government's Office for Low Emission Vehicles (OLEV) maintains and open mind on hydrogen for transport and thinks there may be a role for it as an energy carrier where vehicles need to refuel very quickly. Nonetheless, there are other technical issues which would need to be overcome for it to be a viable, and scalable means of storing energy.

Unlike most liquid fuels hydrogen is bulky which makes it less convenient as a storage medium. At a pressure of 700bar its energy density is 22% that of petrol. The storage tank on BMW's Hydrogen 7 prototype weighed 120kg and stored just 8kg of hydrogen. A further issue is that the hydrogen molecule is very small, in comparison to other gases, and will leak out of any practical container over time.

[40] The BMW Hydrogen 7 for example required 254kWh per 100km. This was a prototype, but it illustrates the gap that hydrogen vehicles need to close on current fossil fuel vehicles and electric vehicles.