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ADJUSTING ENERGY FOR ZERO CARBON

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Contents

Section 1. Overview

This document considers UK national energy use. Starting from 2018 demand statistics. The assumption is made that electricity supply can be zero carbon by use of:

- Solar PV (both large and small scale)
- On and Off-shore Wind
- Storage
- Other renewable sources such as hydro, tidal

As far as possible Natural Gas and Petroleum are replaced by electricity.

Four key changes are investigated:

- Replacement of Internal Combustion Engine light road vehicles with Electric Vehicles (**EV**)
- Replacement of Natural Gas and Oil for heating with Air Source Heat Pumps (**ASHP**)
- Replacement of gas cooking with electricity.
- Retrofitting all existing buildings to PassivHaus Retrofit standards (**EnerPHit**), and construction of new buildings to PassivHaus (**PH**) standards.

The calculations are only rough and essentially illustrate the consequences for the electricity network and the resulting proportion of energy required from zero carbon sources. Calculations also assume that take-up of proposed changes is immediate (this is highly unlikely). However, this is still a worthwhile calculation because:

- It sets the bounds of what can be achieved in terms of carbon reduction by this means.
- It demonstrates changes that will be needed to electricity supply if these changes are realised.

The document considers the impact of electrification above on the electricity network with local generation/balancing discussed. Energy consumption data is later converted to its equivalent CO_2 emissions and the implications for Teignbridge are calculated. Finally, options for Carbon sequestrations are considered.

1.1 Summary of key findings

For the UK:

If electrification of Heating and light vehicle Transport occurs without any demand reduction (apart from that implied by electrification, which is more efficient), then electricity energy demand increases by 110%. Peak power is likely to increase by 449% from current levels. Clearly the electricity grid cannot be re-enforced to deliver this in any reasonable timeframe. This would also require an increase of 591 TWh (432%)[1] of Renewable energy generation compared to current levels.

However, if demand is further reduced by improving building standards and managing EV charging to spread it evenly through the day, electricity energy demand is only increased by 53%. Peak power is likely to increase by 34% from current levels. Although significantly lower, it remains a challenging undertaking to reinforce the grid. This would also require an increase of 420 TWh (278%)[1] of Renewable energy generation compared to current levels.

It has been argued that low Carbon gas could be used for heating in place of, or in combination with ASHP. This would further reduce heating energy requirements and Peak electrical power demand thereby reducing the extend of grid reinforcement from the figures above. This could be a more practical option when compared to grid re-enforcement and additional renewable + storage capacity.

Even with the sectors above fully decarbonised through electrification, the zero carbon content of energy demand would only account for 52%[2] of the total energy demand. Therefore, additional steps will be needed to achieve near zero carbon emissions.

If the following sectors were also decarbonised through electrification or zero Carbon gas, then zero carbon content improves to 78%[2]:

- Air Transport
- Industrial Gas
- Heavy Road Vehicles (HGVs, buses and coaches)

[1] - based on 2018 figures for electricity in TWh: 299.6 total of which was 111.1 renewable

[2] - Excludes Non-energy use of petroleum and natural gas (99.3TWH) – (lubricants, chemicals and plastic)

For Teignbridge:

The Teignbridge bulk electricity supply point at Abham does not have sufficient demand headroom to meet the peak power demand increase of between 449% and 75% resulting from the proposals explored in this paper.

Local generation could remove the need to reinforce both the Abham supply point and the National grid beyond. This already happens for self-supply behind the meter, but there are regulatory barriers to using the public network to supply customers connected to the same substation (i.e. in front of the meter). These regulatory barriers make renewable generation less competitive which limits the role that can be played by local generation.

The additional local Renewable generation of 770GWh/year would need to come from PV, On-shore wind and other technologies complemented by short and longer-term storage. Wind is very likely to be needed to satisfy winter peak demand.

If the full Zero Carbon electrification and reduction in heat energy consumption are undertaken, Teignbridge's emissions would reduce to 222 kTonnes CO_2 equivalent, a reduction of 71% from current levels.

The energy and eCO_2 emissions of goods imported into the UK are not included in the numbers used. Neither are emissions from exported goods subtracted from these figures, these are normally lower than for imported goods. It is therefore important to recognise that a substantial amount of 'embodied emissions' are not included. In 2015 this accounted for 175 Mt CO_2 of net imported emissions (ref. https://www.mdpi.com/2071-1050/11/2/488). These are significant additional indirect emissions when compared to 364 Mt CO_2 UK emissions in 2018 (ref. DUKES) and should be accounted for.

Section 2. UK Energy Demand 2018

2.1 Data Sources

Digest of UK Energy Statistics (DUKES) – Aggregate Energy Balances – alternative units, peta joules and TeraWatt Hours

https://www.gov.uk/government/statistics/energy-chapter-1-digest-of-united-kingdom-energy-statistics-dukes

Energy and Environment – Data Tables – Data about fuel consumption prepared by Department of Transport – Table ENV0101 – Petroleum consumption by transport mode and fuel type.

https://www.gov.uk/government/statistical-data-sets/energy-and-environment-data-tables-env

2.2 Simplified base Energy Demand 2018

The final consumption figures in DUKES – Aggregate Energy Balances are shown in simplified form in the following table:

Table 2-1 Gross caloric values of final demand simplified from DUKES

Gross calorific values								TeraWatt Hours
	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Total
Industry	11.9	3.1	26.0	105.4	16.9	93.0	7.9	264
Air Transport			157.8					158
Light Road Vehicles	0.0	0.0	359.5	0.0	12.3	0.2	0.0	372
Heavy Road Vehicles	0.0	0.0	92.8	0.0	3.2	0.0	0.0	96
Rail	0.1		7.7			4.7		13
Other Transport	0.0	0.0	11.2	0.0	0.0	0.0	0.0	11
Domestic	4.1	2.0	28.8	309.2	27.5	105.1	3.0	480
Other non-domestic	0.3	0.0	43.3	94.7	14.9	96.6	3.8	254
Sub-Total	16.5	5.1	727.2	509.2	74.8	299.6	14.7	1647.09
	1.00%	0.31%	44.15%	30.92%	4.54%	18.19%	0.89%	
Non Energy Use	0.0	0.6	94.0	4.8	0.0	0.0	0.0	99.33
Total	16.5	5.6	821.1	514.0	74.8	299.6	14.7	1746.4
%	0.94%	0.32%	47.02%	29.43%	4.28%	17.16%	0.84%	

The following adjustments have been made:

- Industry is shown as a total only for each fuel type.
- Primary Oils and Primary Electricity columns are removed as these do not appear in final consumption.
- Road transport is split into light and heavy vehicles, as electrification of light vehicles is much more feasible than heavy vehicles. Factors from Table 2 (below) are applied to energy demand in DUKES, factors are derived from the light and heavy vehicle fuel consumption figures in ENV0101. Since originally writing this a significant number of electric HGVs have been announced both from established manufacturers (Tesla, Mercedes Benz) and startups, so it may turn out that electrification of HGVs is practical as well.

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- Transport is then presented as Air Transport, Light Road vehicles, Heavy Road Vehicles, Rail, Other Transport.
- Domestic energy use is shown separately
- Public Administration, Commercial, Agriculture and Miscellaneous are shown as a single total Other non-domestic use. In a later table agriculture is separated out.
- The first sub-total excludes non-energy use as this probably doesn't directly emit CO_2, non-energy use is things like plastics. The total row includes non-energy use.

2.3 Breakdown of road transport by mode and petroleum-based fuel type

The section of ENV0101 relating to road transport is rearranged so that rows are shown for:

- Light vehicles (Cars, taxis, light vans, motorcycles and mopeds).
- Heavy vehicles (HGVs, buses and coaches)

This gives some useful proportions to use later in the calculation.

Table 2-2 – Breakdown of petrol and diesel sales to light and heavy vehicles

Type	Petrol	Diesel	Total	%	Definition
Light Vehicles	11.95	17.13	29.08	79.48%	Cars, Taxis, Light Vans, Motor Cycles and Mopeds
Light vehicles %	41.09%	58.91%			
Heavy Vehicles		7.51	7.51	20.52%	HGVs, buses and coaches
Total	11.95	24.64	36.59		
%	32.66%	67.34%			

Units in this table are Million Tonnes of Petroleum

Light Vehicle and Heavy vehicle percentages have been used to split the DUKES road transport figure between light and heavy vehicles.

Breakdown of road transport in Teignbridge

Figures are published for road transport energy demand by Local Authorities are for up to 2017. https://www.gov.uk/government/statistical-data-sets/road-transport-energy-consumption-at-regional-and-local-authority-level

These are expressed in Tonnes of Oil equivalent.

This is a summary for Teignbridge

Table 2-3 - Teignbridge Road Transport Consumption 2017

	Tonnes Oil Equiv.	GWh
Buses	2,446	28.45
Diesel Cars	38,461	447.30
Petrol Cars	39,586	460.39
Motorcycles	626	7.28
Diesel LGV	24,629	286.43
Petrol LGV	743	8.64
HGV	17,796	206.96

The local equivalent to table 2-2 is

Table 2-4 - Teignbridge breakdown of road transport by mode and fuel type

Vehicle Type	Petrol	Diesel	Total	%
Light Vehicles	476.30	733.73	1,210.03	83.71%
Light Vehicles %	39.36%	60.64%		
Heavy Vehicles		235.41	235.41	16.29%
Total	476.30	969.14	1,445.45	
%	32.95%	67.05%		

Units in the above are GWh

The split of petrol and diesel is extremely close to the national figures, but the proportion of heavy vehicles is significantly lower.

2.4 Breakdown of other non-domestic to separate out agriculture

Other UK non-domestic breaks down as follows:

Table 2-5 – Detailed final demand from other non-domestic other

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Total
Public administration	0.2	0.0	8.4	37.0	0.6	18.3	1.2	-
Commercial	0.0	0.0	18.8	45.9	12.5	74.0	2.6	-
Agriculture	0.0	0.0	11.2	1.0	1.8	4.3	0.0	-
Miscellaneous	0.1	0.0	4.9	10.7	0.0	0.0	0.0	-

Units in this table are TeraWatt Hours (TWh)

Petroleum has significant use in agriculture which is likely to be red diesel used for tractors and other machinery, whereas other petroleum use is likely to be for heating.

The following table breaks separates out agricultural petroleum use.

Table 2-6 – Non-domestic other petroleum with agriculture split out.

Domestic	28.8	28.8
Public administration	8.4	32.105
Commercial	18.8	
Miscellaneous	4.9	
Agriculture	11.2	11.2

Units in this table are TeraWatt Hours (TWh)

2.5 Breakdown of Industry energy usage

Industrial energy use breaks down as follows:

Table 2-7 - Breakdown of Industrial Demand

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Total
Unclassified	0.000	0	14.711	0.007	0.482	0.000	0.000	15.200
Iron and steel	0.250	3.089	0.053	4.028	0.000	2.560	0.000	9.980
Non-ferrous metals	0.205	0	0.090	3.168	0.000	4.088	0.000	7.550
Mineral products	4.662	0	2.174	14.840	3.290	6.310	0.000	31.275
Chemicals	0.450	0	1.455	21.685	1.057	15.268	2.742	42.657
Mechanical engineering etc	0.082	0	0.005	11.612	0.016	6.514	0.000	18.229
Electrical engineering etc	0.037	0	0.010	3.115	0.000	6.087	0.000	9.249
Vehicles	0.398	0	1.902	5.327	0.000	4.768	0.000	12.394
Food, beverages etc	0.586	0	1.430	21.007	1.269	11.818	0.054	36.165
Textiles, leather etc	0.473	0	0.549	2.901	0.000	2.721	0.000	6.645
Paper, printing etc	0.685	0	0.393	4.629	5.890	10.382	0.000	21.979
Other industries	4.071	0	0.486	8.258	4.883	21.108	5.080	43.886
Construction	0.042	0	2.703	4.832	0.000	1.396	0.000	8.973
Total industrial use	11.941	3.089	25.960	105.409	16.886	93.020	7.876	264.182
%	4.52%	1.17%	9.83%	39.90%	6.39%	35.21%	2.98%	

Units in this table are TeraWatt Hours (TWh)

It is noted later in this document that industrial gas demand of 105TWh accounts for a significant proportion of fossil fuel consumption that is difficult to remove.

It is likely that gas in some industries is used for heat (e.g. Food, beverages etc.) that can easily be replaced by electricity, however, more detailed analysis of each industry category is required to quantify this.

There may be use of heat which cannot easily be replaced by electricity or at least the efficiency of the replacement cannot be assumed. (You probably can't replace a Bunsen burner with a heat pump!)

2.6 Summary mix of energy sources

The summary mix of energy sources is:

Table 2-8 – Summary breakdown of fuel demand for 2018

	Totals	%	Total	%
Bio-fuels and waste	74.79	4.54%		
Fossil	1257.97	76.38%		
Non zero carbon			1332.76	80.92%
Electricity and Heat Sold	314.33	19.08%		
Zero carbon			314.33	19.08%

Units in this table are TeraWatt Hours (TWh)

In Table 2-8:

Fossil fuels are Coal, Manufactured fuels (mainly coke), Petroleum and Natural gas

Total non-zero carbon are Fossil fuels together with Biofuels and waste

Electricity and Heat sold can potentially become zero carbon. They will be shown later as zero carbon based on the assumption that all electricity and heat will come from renewable sources.

2.7 Associated Spreadsheet

The tables within this document are copied from an associated spreadsheet:

AdjustingEnergyForZeroCarbon_0.12.xlsx

This has the following tabs:

DUKES_2018 – source copy of DUKES – Aggregate Energy Balances

Petroleum – copy of ENV0101

DUKES_Simplified – data from DUKES_2018 and Petroleum tabs rearranged to provide the tables in this section.

Cars – analysis of data relating to cars

Heating – analysis of data relating to heating

Adjusted – Tables derived from the previous tabs that appears in sections 2 and 3

Electricity – Tables used in Section 5 – Electricity of this document.

Carbon – Tables using in Section 6 – Translating energy to carbon emissions

Conclusion – Copies of figures calculated elsewhere that are used in the conclusion and the summary of key findings.

NOTE to editors

If the spreadsheet is changed then relevant tables should be pasted as pictures into this document. Above each table is a table number in this document, these numbers also appear in the spreadsheet.

Section 3. Increase in energy demand due to electrification

3.1 Scenario description

If we imagine a situation where all electricity was generated from zero carbon sources, then significant carbon reduction would occur if major demands for fossil fuels were replaced with electricity. These demands (from Table 2-1) are:

Table 3-1 - Summary of demands to be electrified

	TWh
Petroleum used in light vehicles	369.3
Natural gas used in domestic heating and cooking	309.2
Natural gas used for other non-domestic use assumed heating and cooking	94.7
Use of petroleum for domestic use assumed to be heating	28.8
use of petroleum for non-domestic use(except agriculture) assumed to be heating	32.1

x*Units in this table are TeraWatt Hours (TWh)*

This section considers the impact of a straight replacement of these with electricity on the energy mix.

3.2 Electrification of light vehicles

It isn't as simple as just moving the light vehicles figure from the petroleum column to the electricity column, because of the different efficiencies of petrol, diesel and electric vehicles.

Our earlier version of this calculation considered the relative efficiencies of specific new vehicles, however, this approach is flawed because the fleet is made up from vehicles of varying ages that are in general less efficient than models that could reasonably be compared with a current EV.

Our revised approach is to consider:

- The number of vehicles currently on the road
- Vehicle annual mileage
- Electricity consumption of a typical EV

We choose figures for 2018 as this is the year we have energy balances for.

Number of vehicles currently on the road

The number of vehicles currently on the road is the same as the number of licenced vehicles. The number of licensed vehicles at the end of each quarter since 2002 is given by table VEH0101 of the all vehicles dataset from DVLA.

https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01

The table 3-2 shows the numbers of vehicles at the end of 2018:

Table 3-2

Body Type	Vehicles
Car	32493258
Motorcycles	1265142
Light Goods Vehicles	4127556
Total	**37885956**

Vehicle annual mileage

There are 2 possible sources for this:

- National Transport Survey, which is a sample of about 7000 vehicles and gives 7600 miles for 2018
- MOT test certificates for 2017. In raw form this is a csv file of about 2.7GB in size, which will require significant processing to get useful data from it. Fortunately, Bymiles magazine have published analysis of this data, which gives a headline figure of 7134 miles.

https://www.bymiles.co.uk/insure/magazine/2019-jan-mot-data-shows-motorists-continue-to-drive-less-each-year/#average-mileage-by-postcode

This analysis also includes overall figures for each postcode EX (7105) and TQ (6452). Bymiles do not say how new vehicles that are not subject to an MOT are handled. It is assumed that mileage up to a vehicle's first MOT is accounted for.

At a later date it may be useful to get a local picture by doing our own analysis of the MOT data.

The RAC foundation has researched the mileage of cars in their first 3 years from MOT certificates, and found that new cars averaged 10,377 miles per year; BEVs did 9,425 miles per year:

https://www.racfoundation.org/research/mobility/new-car-mileage

This article has a link to a table showing new car mileage by make and model.

As our scenario is to replace all vehicles with EVs, and usage by age should not be that significant.

The new BEV with the highest annual mileage is the Tesla model S with 12,392 miles and the lowest is the Renault Zoe with 5,736 miles. The relative consumption of these may be an issue.

The following table compares consumption by annual mileage, and again shows the range across very different types of EV is remarkably similar.

Table 3-3

Model	Annual Mileage	Sample Size	Real world combined cold weather consumption Wh/mile
Tesla Model S	12,392	846	345
Nissan Leaf	8,241	1026	325
Renault Zoe	5,736	394	315
BMW i3	5,885	102	315
Tesla Model 3		0	305
Kia e-Nero		0	325
VW ID.3		0	330
VW e-UP		0	320

Annual mileage and Sample Size from RAC foundation analysis of 3 year old vehicle at their first MOT

Real world combined cold weather consumption from https://ev-database.uk/

A number of popular recently introduced models without mileage history have been included in the above table.

Consumption of a typical EV

Table 3-3 shows typical consumptions of a range of EVs in our scenario it is likely that most will be mid range vehicles, so we take the Nissan Leaf as a typical example. This has consumption of 325 Wh/mile.

Here is a link to the details for the Nissan Leaf.

https://ev-database.uk/car/1106/Nissan-Leaf

The following table provides a comparison between the Nissan Leaf and the smaller ICE Nissan Notes:

Table 3-4 - Consumption of Nissan petrol, diesel and electric cars

Model	**Fuel**	**Engine Power**	**Unladen Weight**	**Consumption conventional units**	**Units**	**Consumption kWh/100km**	**CO2 g/km**
Nissan Note 1.2L DIG-S	**Petrol**	73kW	1187 kg	4.3	L/100 km	40.97	99
Nissan Note 1.5 Dci	**Diesel**	67kW	1185 kg	78.5	mpg	38.70	93
Nissan Leaf 40kWh	**Electric**	110kW	1580 kg	315	Wh/mi	21.28	

- Consumption figure used for the Nissan Leaf is a cold weather combined cycle, this figure is about 50% higher than warm weather which appropriate if considering winter peak demand.
- No figure is shown for CO_2 emissions from an EV. Tailpipe emissions are zero, but actual emissions depend on the emissions from generating the electricity. If the current CO_2 emissions for generated electricity of 0.28307 kg/kWh are used, then CO_2 emissions are 62g/km. If clean electricity is used as is assumed in this scenario the CO_2 emissions are 0.
- The figure of 325Wh/mi with a 40kWh battery gives a range of 123 miles, the quoted range for this vehicle is 168 miles on combined cycle. This figure is consumption from the charging point, rather at the wheel, which would be harder to measure and less meaningful to the consumer.
- The energy drawn from the grid is higher. The paper "Measurement of power loss during electric vehicle charging and discharging" (https://www.sciencedirect.com/science/article/pii/S0360544217303730) studies charging and discharging an E Mini, we are only interested in the charging side as discharge is accounted for in the consumption figures for the battery (EV Battery), power electronics (PEU) and charger attached to the building (EVSE). These are shown in the following table:

Table of charging efficiencies:

Table 3-5- Charging losses in components between meter and EV battery

Component	AC Current	Charging Losses%
EV Battery	10	0.64
	40	1.69
EV PEU	10	6.28
	40	5.77
EVSE	10	0.1
	About 40	0.29
Total	10	7.02
	40	7.75
Efficiency	10	92.98
	40	92.25

Extracted from Measurement of power loss during electric vehicle charging and discharging.

Our own measurements suggest that 92% is an optimistic figure, and suggest that 80% is a more realistic figure when a range of charging scenarios including rapid charging is considered.

For the purposes of calculating how much electricity generation is required transmissions losses also need to be added, these are assumed to be 8%.

Calculation of UK electricity demand from EVs

The following table presents the electricity demand from EVs based on average annual mileage, typical vehicle consumption and number of licensed vehicles.

Table 3-6

Number of licensed vehicles 2018	37885956	vehicles
Average annual mileage	7134	miles
Typical electricity consumption	325	Wh/mile
kWh/100km	20.19	kWh/mile
Single vehicle annual consumption	2.32	MWh
Charging efficiency	80.00%	
Single vehicle at meter consumption	2.90	MWh
Single vehicle weekly consumption at meter	55.73	kWh
Transmission losses	8.00%	
Single vehicle required generation	3.15	MWh
Required generation	119.35	TWh

The means that 359.5 TWh of petroleum energy is replaced with electricity use of 119.35 TWh.

This is based on real world combined cold weather consumption, which is appropriate for calculating peak demand. There are many variables in calculating EV consumption such as BEVs are more efficient when it is moderately warm, but consume more when it is hot because of the need for air conditioning, different driving styles. Also some of the summer demand will be satisfied by domestic PV.

Effect on Teignbridge

ACT has now calculated vehicle kilometres for Teignbridge in 2017 from Dft traffic flows.

Table 3-7

Vehicle Type	Kilometres
Motor Cycles	13806204
Cars & Taxis	1397335553
Light Goods Vehicles	287933866
Total	1699075623
Light Vehicle Miles	**1055759270**

See https://actionclimateteignbridge.org/wp-content/uploads/2020/03/ACT-Calculating-Transport-Emissions-v0.1.pdf

Using this vehicle miles figure the calculation of Teignbridge generation requirement is as follows:

Teignbridge Light Vehicle Miles	1055759270	Vehicle Miles
Typical consumption	325	Wh/mile
Charging efficiency	80.00%	
At meter consumption	406.25	Wh/mile
Transmission losses	8.00%	Wh/mile
Generation/mile	441.58	Wh/mile
Teignbridge consumption	466	GWh

From Table 2-4 light vehicles used 1210 GWh of petroleum based fuel in 2017, if this was all EVs it would be equivalent to 466GWh.

An alternative way of calculating this would be to consider the consumption of vehicles registered in Teignbridge, this might be more useful in forecasting Teignbridge electricity demand, but not for calculating emissions. Table VEH0105 of the DFT all vehicles table gives registered vehicles by authority.

Table 3-8

Vehicle Type	Count
Cars	75838
Motorcycles	4552
Light Goods Vehicles	13691
Total	**94081**

Note that the number of households in Teignbridge is estimated to be 58143, giving 1.62 vehicles per dwelling.

The calculation based on vehicle registrations is as follows:

Table 3-9

Registered vehicles	94081	Vehicles
Single car meter annual consumption	2.9	MWh/annum/vehic
Single car required annual generation	3.2	MWh/annum/vehic
Meter consumption	273	GWh
Required generation	296	GWh

The calculation of Teignbridge consumption on this basis is significantly different. This is probably because:

- a significant proportion of road traffic in Teignbridge is not generated by residents
- some vehicles driven by Teignbridge residents may be registered outside the district

Time of use – National figures

There is likely to be a peak in demand when people get home from work in the early evening. This coincides with the already existing peak demand. If EV charging all occurred during the worst 3 hour period each day it would add load of 119GW. Storage and other management measures could spread this peak over the day. If demand were to be uniform across the day it would be only 14GW. If demand were to be even across the 21 non-peak hours, then it would be 16GW.

Comparison with WPD statement of capacity

Western Power Distribution's Electric Vehicle Strategy states:

"We predict that the majority of our larger local transformers will be able to accommodate one 35kWh charge every five days for each of the customers connected to it. This provides a charged range of around 150 miles in many EVs and it is likely that this will support the demands of home connected EV charging."

Assuming typical winter combined consumption of 325Wh/mile and assuming charging efficiency of 80%, this would only be enough for 86 miles. In 5 days the average car does 97 miles. There are 1.62 for Teignbridge, so average household mileage in 5 days is 158 miles.

Our calculations above suggest that peak demand per car is likely to be 56 KWh. Car ownership in Teignbridge is 1.62 so peak demand could be as much as 90KWh

Table 3-10

Single vehicle at meter weekly demand	55.73	KWh
Vehicles per household	1.62	Veh/dwelling
Household weekly demand	90.18	KWh

90KWh is significantly more than 35kWh

Increase in national demand by EV registrations proportion

Though this study investigates the effect of an extreme scenario, we should also consider the more likely we also need to consider the effect of a more likely gradual roll-out

Table 3-11

% of fleet replaced	Number of vehicles	Peak 21 hour demand GW	Annual generation requirement TWh
1.00%	378860	0.16	1.19
2.00%	757719	0.31	2.39
3.00%	1136579	0.47	3.58
5.00%	1894298	0.78	5.97
10.00%	3788596	1.56	11.93
20.00%	7577191	3.11	23.87
30.00%	11365787	4.67	35.80
40.00%	15154382	6.23	47.74
50.00%	18942978	7.79	59.67
60.00%	22731574	9.34	71.61
70.00%	26520169	10.90	83.54
80.00%	30308765	12.46	95.48
90.00%	34097360	14.01	107.41
100.00%	37885956	15.57	119.35

In 2018 renewable generation capacity increased by 4.2TWh. If the increase in demand from EVs is to be met by renewables, then based on 2018 increase in supply an increase in the EV fleet share of registrations of 3.59% of total registrations would be sustainable. This is 1.33 million vehicles. This would take 28.41 years to achieve.

In 2018 2.88 million new light vehicles were registered, so a market share of 46.28% new EVs would be sustainable within 2018 renewables growth, if there were no other increases in electricity consumption.

3.3 Electrification of heating and cooking

Gas

Natural gas is replaced by electricity by replacing:

- Gas boilers by Air Source Heat Pumps.
- Gas hobs by electric induction hobs.
- Gas ovens with electric fan ovens.

It is assumed that domestic gas use and other non-domestic gas use is for heating or cooking.

Again the conversion isn't straightforward because a conversion factor needs to be established first, though it is a bit simpler than is the case for EVs.

Currently 85% of domestic heating uses natural gas. Houses with gas supply tend to use gas for:

- Space Heating
- Hot Water Heating
- Cooking

Both space heating and hot water heating can be done with Air Source Heat Pumps (ASHP).

Information on device efficiencies was derived from the following sources:

https://www.energystar.gov/products/commercial_food_service_equipment/commercial_ovens http://www.northstarenergy.co.uk/images/pdfs/Ecodan_Winter_tests.pdf

https://www.carbontrust.com/resources/guides/energy-efficiency/heat-pumps/

https://www.treehugger.com/kitchen-design/which-more-energy-efficient-cooking-gas-or-induction.html

https://en.wikipedia.org/wiki/Induction_cooking

The following table is summarised from the above sources:

Table 3-12 - Efficiencies of heating and cooking devices

Device	Min Efficiency	Max Efficiency	Ratio
Air Source Heat Pump	3	3.33	0.3
Condensing gas boiler	0.9	0.9	
Induction hob	0.74		0.43
Gas hob	0.32		
Electric fan oven	0.65	0.7	0.46
Gas Oven	0.3	0.44	

Ratio in the above table is minimum efficiency of electric device divided by minimum efficiency of gas device.

Heating is the much larger use than cooking, so for simplicity let's assume that all domestic gas use is replaced by ASHP.

As we don't know the split of cooking to heating and there is anecdotal evidence that heat pumps in some circumstances fall short of claimed performance, assume a pessimistic COP for heat pumps of 2 and a gas boiler efficiency of 0.9, then a factor of 0.45 would apply. This gives heating use of 139.12 TWh for domestic use and 45.6 TWh for non-domestic.

Oil

There is petroleum use under domestic and non-domestic other. This was broken down in Table 2-6 – Non-domestic other petroleum with agriculture split out.

Table 3-13 - non-domestic other petroleum with agriculture separated out

	TWh
Agriculture	11.2
Non-domestic other without agriculture	32.105

Units in this table are TeraWatt Hours (TWh)

- Agriculture is probably tractors and other machinery
- The remainder is likely to be heating

Assuming the same efficiency ratio applies to oil as gas,

Petroleum (heating oil) converts to electricity as follows:

Table 3-14 - Conversion of petroleum for heating and cooking to electricity

Type	Petroleum	Electricity
Domestic	28.81	12.96
Non-Domestic	32.11	14.45

Units in this table are TeraWatt Hours (TWh)

This leaves only 11.2 TWH of oil used in agriculture.

Summary of electricity increased electricity use from electrifying heating

The additional electricity use is as follows:

Table 3-15 - Additional electricity demand from electrifying heating

Category	Original fuel	Original demand	Electricity demand
Domestic	Natural Gas	309.17	139.13
Non domestic	Natural Gas	94.66	42.60
Domestic	Oil	28.81	12.96
Non domestic	Oil	32.11	14.45
Total			209.14

Units in this table are TeraWatt Hours (TWh)

Time of use

Heating use should be proportional to national degree days. For the purposes of this calculation assume that Birmingham airport is representative. Generally, buildings do not need supplementary heating when the outside temperature is 15.5^{C}. Degree days for Birmingham airport to 31/7/2019 were 1965.6. Dividing the extra demand in Table 3-15 by degree days gives an annual demand of 106.4GWH/degree day.

This means that on a day when the average outside temperature is 0^{C} that demand would be 1649GWH.

If on this 0^{C} day heating were to be applied for 10 hours a day, then about 165GW of power would be required.

3.4 Revised Energy Demand after basic electrification

Assuming all heating, cooking and light vehicles in all sectors are converted to run on electricity, the resulting total demand now looks as follows:

Table 3-16 – Revised demand after basic electrication

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Total
Industry	11.9	3.1	26.0	105.4	16.9	93.0	7.9	264
Air Transport	0.0	0.0	157.8	0.0	0.0	0.0	0.0	158
Light Road Vehicles	0.0	0.0	0	0.0	0.0	119.3	0.0	119
Heavy Road Vehicles	0.0	0.0	95.4	0.0	3.3	0.0	0.0	99
Rail	0.1	0.0	7.7	0.0	0.0	4.7	0.0	13
Other Transport	0.0	0.0	11.2	0.0	0.0	0.0	0.0	11
Domestic	4.1	2.0	0.0	0.0	27.5	257.2	3.0	294
Other non-domestic	0.3	0.0	11.2	0.0	14.9	153.6	3.8	184
Sub-Total	16.5	5.1	309.3	105.4	62.6	627.9	14.7	1141.51
%	1.45%	0.44%	27.09%	9.23%	5.48%	55.01%	1.29%	
Non Energy Use	0.0	0.6	94.0	4.8	0.0	0.0	0.0	99.33
Total	16.50	5.63	403.25	110.22	62.61	627.94	14.69	1240.83
%	1.33%	0.45%	32.50%	8.88%	5.05%	50.61%	1.18%	

Units in this table are TeraWatt Hours (TWh)

Big outstanding items are:

Table 3-17 - Big outstanding items

Item	Fuel	TWh	Notes
Air Transport	Petroleum	157.8	Needs reduction or innovation.
Industrial Gas	Gas	105.4	The use of gas in industry has not been analysed. It cannot be assumed that it can be replaced with electricity in the same way as other heating. Further investigation is needed to reduce this.
Non-energy petroleum	Petroleum	94.0	This is lubrication, chemicals and plastics. So should not have associated carbon emissions.
Heavy Road Vehicles	Petroleum	95.4	Could possibly be replaced with hydrogen, biofuels, more local manufacture, transfer to rail.
Total big items		452.6	

Units in this table are TeraWatt Hours (TWh)

Together these use 450 TWh which is 85.28% of the remaining fossil fuel.

It is probably unrealistic to replace these above with electricity. They need to be dealt with in some other way. How much do these impact Teignbridge?

Assume that electricity and heat sold count as zero carbon, then about 58.49% of energy comes from zero carbon sources.

Electricity demand is increased from 299.6 TWh to 627.94TWh or 110% increase.

WPD's (https://www.westernpower.co.uk/downloads/31117) "consumer power" and "2 degrees" estimates of demand by 2032 put this at nearly 100%, but assume more realistic take-up of ASHP, EV and housing stock improvement.

The summary mix of energy sources is:

Table 3-18 - Summary breakdown of fuel demand after basic electrification

	Totals	%	Totals	%
Bio-fuels and waste	75.21	7.04%		
Fossil	436.27	40.81%		
Total non-zero carbon			511.48	47.84%
Electricity and heat sold	557.59	52.16%		
Zero carbon			557.59	52.16%

Units in this table are TeraWatt Hours (TWh)

Section 4. Reducing Demand

4.1 Summary

From the previous calculations, it is clear that simply converting to electric will result in an unrealistic demand on the electricity network. This is already near capacity and it is costly and unrealistic to expand this to carry the additional energy required in the short time available.

Some steps need to be taken to reduce demand:

- Ensure that new buildings meet PassivHaus (PH) or similar standards.
- Retrofit existing buildings to meet PassivHaus Retrofit (EnerPHit)standards.
- Encourage the use of smaller electric vehicles for shorter distances, together with rail.

4.2 Heating Buildings

A major user of fuel is domestic heating.

Average house floor area assume $85M^2$ (All property ages – BBC New article 2011)

The heat required to maintain a standardised temperature of 21^C in houses built to different standards is shown in the following table:

Table 4-1 - Heating rates for different build types to maintain a standardised 21^c

Heating Rates	kWh/m²/year	kWh/year
Average british house	135	11475
Built to current building regs.	90	7650
Built to PassivHaus	15	1275
Retro-fit PassivHaus	25	2125

In 2018 there were about 54000 (https://reports.esd.org.uk/reports/15?pat=LA&pa=E07000045), this is set to increase by 620 per year under the current Teignbridge local plan (https://www.teignbridge.gov.uk/media/7769/tdc-amr-2018-report.pdf), and is likely to increase further under the Greater Exeter plan.

Consider two scenarios:

1. 54000 houses were average, and new houses are built to current building regulations.

2. 54000 houses are retrofitted to PH standards and new houses are built to PH.

Table 4-2 - Evolution of energy use in Teignbridge housing stock under different scenarios

	Number of houses	Scenario 1 – Status Quo GWh	Scenario 2 – Passiv Haus GWh
Current housing stock	54000	619.65	114.75
Annual new builds	620	4.743	0.7905
2019	54620	624.393	115.5405
2020	55240	629.136	116.331
2021	55860	633.879	117.1215
2022	56480	638.622	117.912
2023	57100	643.365	118.7025
2024	57720	648.108	119.493
2025	58340	652.851	120.2835

This shows that if by 2025 Teignbridge housing were to PassivHaus standards it would use 18.42% of that used in scenario 1 in the table above. This factor is applied in section 3 to calculate the revised national demand for electricity after reduction in heating demand.

If all housing were built to low energy standards, in 2018 national heating demand would reduce electricity used for heating from 209.14 TWh to 38.53 TWh. Heating would then accounts for 7.25% of electricity demand.

Time of use

Using the same degree-days based calculation as in the basic electrification scenario. Dividing the extra demand in Table 4-2 for scenario 2 by degree days gives a national annual demand of 19.6GWh/degree day.

This means that on a day when the average outside temperature is 0^C that demand would be 304GWh.

If on this 0^C day heating were to be applied for 10 hours a day, then about 30.4GW of power would be required.

Teignbridge time of use

For an equivalent local calculation, we should use local degree days of 1696[3] from weather station IKINGKE2, which is representative of Newton Abbot. The demands for each scenario are shown in the following table:

Table 4-3 - Teignbridge peak demand

	Scenario 1	Scenario 2	
Degree Days for Kingkerswell station IKINGSKE2	1696		
Demand/degree day	384.94	70.92	MWh
0C outside consumption	5966.50	1099.29	MWh
Assume 10 heating houra	596.65	109.93	MW

These figures are based on average heating rates which are presumably national, so using local degree days which are lower than national will increase estimated peak demand. Teignbridge figures cannot be directly applied to the National grid connection point at Abham (see 5.3).

4.3 Electric Vehicles

Size of electric vehicles

The battery in an EV is a significant component of the weight of an EV. Energy is consumed accelerating a vehicle, the energy used is proportional to its mass. So, for short journeys a vehicle with a relatively short range (and so lighter weight) would be more efficient. It would seem to be more efficient to store energy in static batteries and transfer it to smaller vehicles, than to store it in larger batteries that are in vehicles. The battery is also a major component of the cost of an EV, so a smaller battery means a cheaper vehicle.

If vehicle speeds were regulated to an appropriate local speed limit, then they would not need the level of crash protection provided by a modern car, this would allow for the vehicle to be lighter.

[3] This a simple one year figure, it would be more accurate to use the average of several years.

These vehicles would not then be appropriate for trunk road use, but would be appropriate for most other roads.

A current example of a small electric vehicle is the Renault Twizzy, which has a 6kWh battery, 13kW motor, claimed range of 72 miles (assume 50 in winter), so consumption of 7.45kWh/100km. This is 35.01% of the consumption of a Nissan Leaf. If this vehicle type was used for half electric mileage, then vehicle electricity consumption would be 67.5% of current levels, which would save 63TWh of electricity. This saving has not been included in the final figures. If a storage battery is used to spread the load, then a typical battery can discharge at 3.5 kW, a car with a 7kWh battery will charge in about 2 hours from a 7kW wall charger (but at 3.5kW). A car with a larger battery will probably charge at 7kW, so 3.5kW of this still needs to come from the grid.

Examples of very small electric vehicles suitable for short distance are electric bikes and electric scooters, the later not being legal only for rental in the UK, though they are in many other countries.

4.4 Summary of final energy demand

Assuming basic electrification and heat energy reduction have all been carried out, the following table summarises the final energy demand:

Table 4-4 - Demand after reducing heating demand

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Total
Industry	11.9	3.1	26.0	105.4	16.9	93.0	7.9	264
Air Transport	0.0	0.0	157.8	0.0	0.0	0.0	0.0	158
Light Road Vehicles	0.0	0.0	0	0.0	0.0	119.3	0.0	119
Heavy Road Vehicles	0.0	0.0	95.4	0.0	3.3	0.0	0.0	99
Rail	0.1	0.0	7.7	0.0	0.0	4.7	0.0	13
Other Transport	0.0	0.0	11.2	0.0	0.0	0.0	0.0	11
Domestic	4.1	2.0	0.0	0.0	27.5	133.1	3.0	170
Other non-domestic	0.3	0.0	11.2	0.0	14.9	107.1	3.8	137
Sub-Total	16.5	5.1	309.3	105.4	62.6	457.3	14.7	970.90
	1.70%	0.52%	31.86%	10.86%	6.45%	47.10%	1.51%	
Non Energy Use	0.0	0.6	94.0	4.8	0.0	0.0	0.0	99.33
Total	16.50	5.63	403.25	110.22	62.61	457.33	14.69	1070.23
%	1.33%	0.45%	32.50%	8.88%	5.05%	36.86%	1.18%	

Units in this table are TeraWatt Hours (TWh)

Electricity demand is now increased by 52.63% over 2018 demand. The summary mix of energy sources is:

Table 4-5 -Summary breakdown of fuel demand reduction

	Totals	%	Totals	%
Bio-fuels and waste	62.61	6.45%		
Fossil	436.27	44.93%		
Total non-zero carbon			498.88	51.38%
Electricity and heat sold	472.02	48.62%		
Zero carbon			472.02	48.62%

Units in this table are TeraWatt Hours (TWh)

The following table shows the evolution of carbon reduction:

Table 4-6 - Evolution of demand over the scenarios

	2018 Demand		After Electrification		After PassivHaus	
	Totals	**%**	**Totals**	**%**	**Totals**	**%**
Bio-fuels and waste	75.21	4.53%	62.61	43.70%	62.61	6.45%
Fossil	1270.34	76.53%	436.27	38.22%	436.27	44.93%
Total non-zero carbon	1345.55	81.06%	498.88	43.70%	498.88	51.38%
Electricity and heat sold	314.33	18.94%	642.63	56.30%	472.02	48.62%

Units in this table are TeraWatt Hours (TWh)

This table demonstrates the following reductions:

Table 4-5 - Reductions in use of fossil fuels

Reduction in non-zero carbon	62.92%
Reduction in fossil fuels	65.66%

Difficult to electrify items that make a significant contribution account for 84.50% of remaining fossil fuel.

Effect on Teignbridge

The increase in total increase in demand for Teignbridge is given below

Table 4-6 - Increased demand in Teignbridge

	Scenario 1	Scenario :
Increased demand from housing 2025	652.85	120.28
Increased demand from EVs	466.20	466.20
Total	1119.05	586.48

Units are GWh

Section 5. Implications for the Electricity Network

5.1 National Demand

If the steps outlined so far in this document are taken then national electricity demand will increase to about 457.33 TWh from the 2018 figure of 299.6 TWh. If the additional 157.69 TWh were to be delivered evenly through the year this would lead to power increase of 18GW at 100% network loading. In practice the network should only be loaded at 50%, so its capacity would need to increase by 36GW. The situation for peak demand is much worse because the new demand also has peaks which are likely to correspond with existing peaks.

The following table shows increases in demand resulting from the scenarios described in the previous sections.

Table 5-1 - Summary of increases in peak demand

			% increase over current peak
Additional demand from EVs without storage	108.99	GW	
Additional demand for EVs with storage to avoid peak	15.57	GW	
Additional demand from heating after basic electrification	164.92	GW	
Additional demand from heating after PH	30.38	GW	
Total additional demand after basic electrification	273.91	GW	449.03%
Total additional demand after basic electrification and storage for EV demand	180.49	GW	295.88%
Total additional demand after PH and storage	45.96	GW	75.34%

The current network has a maximum capacity of 80GW (Wikipedia)nationally, with a peak demand of 61GW (National Grid 2017).

The following table projects figures derived into average and peak demand.

Table 5-2 - Projected average and peak demand resulting from the scenarios

	Annual Demand TWH/Year	Average Power GW	Peak Demand	Network Capacity	Peak as % of network capacity	Average as % of network capacity
Original Electricity demand	299.6	34.21	61	80	76.25%	42.76%
Demand after electrification	627.9	71.68	334.91		418.64%	89.60%
Demand after electrification and local storage for EV	627.9	71.68	241.49		301.86%	89.60%
Revised Electricity demand	457.33	52.21	106.96		133.69%	65.26%

In the best theoretical case, peak demand would exceed network capacity by 26.96GW. If electrification is done without local storage and improving buildings to PH standards the situation is far worse with an excess of demand over capacity of 334.91 GW at peak times.

This deals with the national transmission network which operates at 275kV or 400kV and is run by National Grid.

5.2 Local Capacity

This is an average over the whole network, but not all supply points are equal! Specifically, our local supply point is already near capacity.

Electricity is supplied to Bulk Supply Points (BSP) by a national transmission network.

Most of Teignbridge is supplied from the National Grid via the Abham 400kV substation (north of Totnes), which supplies the 132kV Bulk Supply point (BSP). Moretonhampstead and surrounding area is supplied from Exeter City BSP.

Abham supplies Newton Abbot BSP at 33kV, which then supplies most 11kV substations.

Abham has demand headroom of 77MW and generation headroom of 100MW, which is low (National Grid Capacity Map). The capacity map shows that capacity to increase either demand or generation connection at this level is low.

The following table shows demand capacity at Abham:

Table 5-3 - Projected demand at Abham 400 kV Substation

Abham 400 KV Substation	MW
Demand Capacity	240
Peak Demand	163
Demand Headroom	77
75.34% Increased peak demand	285.80
Revised Headroom	-45.80
449.03% Increased peak deman	894.93
Revised Headroom	-731.93

Both the best and worst cases are presented in the table above.

This shows that peak demand at this BSP exceeds capacity by between 45 and 731 MW

This can be mitigated by:

- Reducing demand from current levels
- Shifting demand from peak hours by flexibility (storage, shutdown, supplementary generation)
- Consumption of locally generated electricity (same sub-station area)
- Behind the meter storage and self-generation.
- Grid level storage.
- Rather than replace natural gas with electricity, replace with zero carbon gas (hydrogen)

Western Power Distribution is currently out to tender for (16MW / 2618MWh) of flexibility services in Newton Abbot. This also indicates that the supply to Newton Abbot substation is at capacity at peak times.

5.3 Local generation

Local generation feeds into the grid at lower voltages and satisfies demand in the same local area and does not increase demand at the local BSP. This means that the cost of network reinforcement is either avoided or minimised. The proposition is that local small generators can supply within a substation area with a reduced network use charge that reflects minimal usage of the higher network voltage levels. With smart metering at LV substations, it should be possible to measure and control the proportion of electricity consumed from the local generator and that imported from the grid.

5.4 Generation capability

Zero carbon electricity can be generated from renewables or nuclear.

Nuclear plant is expensive, large and centralised so will need transmission of the primary network. There is also the problem of dealing with nuclear waste.

Renewables are intermittent, so a complementary mix is needed in combination with storage to meet demand. This means Wind as well as Solar. Other, more predictable, renewable technologies such as tidal as well as longer term grid level storage will be necessary to deliver the additional zero carbon electricity.

Given the network constraints this electricity must be generated:

- Locally and fed into the LV network for consumption.
- From a mix of sources to smooth fluctuations in supply.

Nuclear is not suitable for local generation!

Section 6. Translating energy to carbon emissions

6.1 Summary

The changes outlined earlier in this document attempt to reduce the local carbon footprint by:

- Only generating electricity from renewables and using storage to fill the gaps.
- Electrifying all light road transport.
- Heating all buildings with Air Source Heat Pumps (ASHP)
- Improving the insulation of all buildings to PassivHaus or PassivHaus retrofit standards.

This section translates the energy consequences of these changes into CO_2 equivalent emissions.

To do this:

1. A matrix of kg CO_2 equivalent / KWH (factor matrix) is created based on values derived from Defra conversion factors 2018 for company reporting Greenhouse gas (GHG) emissions
2. A kg CO_2 equivalent demand matrix by multiplying each cell of the energy demand matrix by equivalent cell in the factor matrix.
3. The electricity column of the factor matrix uses the 2018 figure to represent the current situation, but uses 0 for later scenarios.

All emissions are expressed in kg CO_2 equivalent, this figure applies to all greenhouse gases, not just CO_2 . This ensures that other gases such as methane CH_4, nitrous oxide N_2O and so on are accounted for in the calculation.

6.2 Derivation of the factor matrix

The Defra conversion factors for GHG reporting are much more detailed than the energy source categorisation used in the overall DUKES statistics used earlier in this document.

The values in the GHG reporting table are mapping in the following table to DUKES fuel categories and units are converted to kg CO_2e / KWh.

Table 6-1 - CO_2 emissions for varous fuels from GHG reporting conversion factors 2018

Category	Fuel	kg CO_2 e/unit	unit	kg CO_2 e/kWh (net CV)	DUKES Category
Gaseous Fuels	CNG	0.20437	kWh(net CV)	0.20437	Natural Gas
	LNG	0.20437	kWh(net CV)	0.20437	Natural Gas
	LPG	0.2303	kWh(net CV)	0.2303	Petroleum
	Natural Gas	0.20437	kWh(net CV)	0.20437	Natural Gas
	Other petroleu	0.20005	kWh(net CV)	0.20005	Petroleum
Liguid Fuels	Aviation Spirit	0.25698	kWh(net CV)	0.25698	Petroleum
	Aviation Turbi	0.26072	kWh(net CV)	0.26072	Petroleum
	Burning Oil	.25963	kWh(net CV)	.25963	Petroleum
	Diesel (averag	.26349	kWh(net CV)	.26349	Petroleum
	Diesel (100%	.26910	kWh(net CV)	.26910	Petroleum
	Fuel Oil	.28544	kWh(net CV)	.28544	Petroleum
	Gas Oil	.29417	kWh(net CV)	.29417	Petroleum
	Lubricants	.28130	kWh(net CV)	.28130	Petroleum
	Naphtha	.24881	kWh(net CV)	.24881	Petroleum
	Petrol (averag	.24607	kWh(net CV)	.24607	Petroleum
	Petrol (100% I	.25349	kWh(net CV)	.25349	Petroleum
	Processed fue	.29417	kWh(net CV)	.29417	Petroleum
	Refinery Misc	.25911	kWh(net CV)	.25911	Petroleum
	Waste Oils	.28515	kWh(net CV)	.28515	Petroleum
	Marine Gas O	.27479	kWh(net CV)	.27479	Petroleum
	Marine fuel oil	.27931	kWh(net CV)	.27931	Petroleum
Solid fuels	Coal (Industria	.34191	kWh(net CV)	.34191	Coal
	Coal (Electrici	.32750	kWh(net CV)	.32750	Coal
	Coal (Domesti	.36288	kWh(net CV)	.36288	Coal
	Coking Coal	.36483	kWh(net CV)	.36483	Coal
	Petroleum Col	.35993	kWh(net CV)	.35993	Petroleum
	Coal (Electricity Generation –	.34028	kWh(net CV)	.34028	Coal
Biofuel	Bioethanol	.41670	GJ	.00012	Bioenergy&Waste
	Biodiesel	1.04543	GJ	.00029	Bioenergy&Waste
	Biomethane	.10473	GJ	.00003	Bioenergy&Waste
	Biodiesel (from used cooking oil)	1.04543	GJ	.00029	Bioenergy&Waste
	Biodiesel (fron	1.04543	GJ	.00029	Bioenergy&Waste
Biomass	Wood Logs	.01506	kWh	.01506	Bioenergy&Waste
	Wood Chips	.01506	kWh	.01506	Bioenergy&Waste
	wood Pellets	.01506	kWh	.01506	Bioenergy&Waste
	Grass/straw	.01314	kWh	.01314	Bioenergy&Waste
	Biogas	.00022	kWh	.00022	Bioenergy&Waste
	Landfill gas	.00020	kWh	.00020	Bioenergy&Waste
Electricity Generated	ctricity Genera	.28307	kWh	.28307	Electricity
Electricity Generated 2017 (from 2019		.25560	kWh	.25560	Electricity
Electricity Distribution losses		.02170	kWh	.02170	Electricity
Composite electricity factor		0.2773	kWh	.27730	Electricity

Notes on electricity factor

An explanation of the method used to calculated the electricity generated factor is provided in https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/823744/2019-ghg-cf-methodology-paper.pdf, section 3 discusses UK Electricity.

- The electricity generated factor does not include transmission and distribution losses, for 2019 these would add 0.02170 kg CO_2e /kWh.
- The electricity generated factor does not include energy used to transport fuel to a generator.
- The electricity generated factors are based on actual data for 2 years previous, so that the 2018 figure given in the table above relates to emissions in 2016.
- The 2019 GHG conversion factors is 0.2556 kg/kWh, this relates to 2017 actual emissions. A more current and accurate rate is derived by adding transmission and distribution losses to this to get 0.2773 kg/kWh
- The figure given here for electricity generated is significantly higher than given by https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/790626/2018-provisional-emissions-statistics-report.pdf this gives an overall figure of 180 tonnes/GWh across all sources (.180 kg/kWh). The derivation of this figure is not made clear in the report.

Simplifying assumptions

Some simplifying assumptions are made:

Table 6-2 - Simplifying assumptions

Demand row	Demand column	How derived from GHG reporting tables
Industry	Coal	Solid Fuel – Coal (Industrial)
Rail	Coal	Solid Fuel – Coal (Industrial)
Domestic	Coal	Solid Fuel – Coal (Domestic)
Other non-domestic	Coal	Solid Fuel – Coal (Domestic)
Industry	Petroleum	Liquid Fuel – Fuel Oil
Air Transport	Petroleum	Liquid Fuel – Aviation Turbine Fuel
Light Road Vehicles	Petroleum	Weighted Average of Liquid Fuel – Diesel (100% Mineral Diesel) and Petrol (100% Mineral Petrol). Weights are those calculated for the petrol/diesel split for light road vehicles
Heavy Road Vehicles	Petroleum	Liquid Fuel – Diesel (100% Mineral Diesel)
Rail	Petroleum	Liquid Fuel – Diesel (100% Mineral Diesel)
Other Transport	Petroleum	Liquid Fuel – Diesel (100% Mineral Diesel)
Domestic	Petroleum	Liquid Fuel – Burning Oil
Non Domestic Other	Petroleum	Weighted average of Liquid Fuel – Burning Oil and Liquid Fuel – Gas Oil. Weight is based on all agricultural use being Gas Oil (Red Diesel).
All	Natural Gas	Gaseous Fuel – Natural Gas as the factor is the same for all forms of natural gas.
All	Electricity	Electricity Generated – Electricity is used for the baseline matrix, but for later scenarios 0 is used.
Industry	Bioenergy & Waste	Biogas
Light Road Vehicles	Bioenergy & Waste	Biofuel - Biodiesel
Heavy Road Vehicles	Bioenergy & Waste	Biofuel - Biodiesel
Domestic	Bioenergy & Waste	Biomass Wood – Wood Logs (all kinds of wood have the same value
Other – Non Domestic	Bioenergy & Waste	Biogas
Industry	Manufactured Fuel	Average of coking coal and petroleum coke
Domestic	Manufactured Fuel	Average of coking coal and petroleum coke

The resulting factor matrix is:

Table 6-3 - Conversion factors derived for simplified DUKES Matrix

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold
Industry	.34191	0.36238	.28544	0.20437	.00022	.2773	0
Air Transport			0.25885	0.20437		.2773	0
Light Road Vehicles			.26269	0.20437	.00029	.2773	0
Heavy Road Vehicles			.26910	0.20437	.00029	.2773	0
Rail	.34191		.26910	0.20437		.2773	0
Other Transport			.26910	0.20437		.2773	0
Domestic	.36288	0.36238	.25963	0.20437	.01506	.2773	0
Other non-domestic	.36288		.26859	0.20437	.00022	.2773	0

Units are Kg of CO_2 equivalent/KWh.

6.3 Baseline CO2

Applying these factors to the simplified baseline matrix in Table 2-1 section 2.2, 2018 emissions broken down by demand type and fuel are:

Table 6-4 - Baseline CO2 equivalent (MegaTonnes)

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Totals
Industry	4.1	1.1	7.4	21.5	0.0	25.8	0.0	59.95
Air Transport	0.0	0.0	40.9	0.0	0.0	0.0	0.0	40.85
Light Road Vehicles	0.0	0.0	97.0	0.0	0.0	0.1	0.0	97.07
Heavy Road Vehicles	0.0	0.0	25.7	0.0	0.0	0.0	0.0	25.68
Rail	0.0	0.0	2.1	0.0	0.0	1.3	0.0	3.43
Other Transport	0.0	0.0	3.0	0.0	0.0	0.0	0.0	3.01
Domestic	1.5	0.7	7.5	63.2	0.4	29.1	0.0	102.43
Other non-domestic	0.1	0.0	11.6	19.3	0.0	26.8	0.0	57.88
Total	5.73	1.84	195.15	104.07	0.43	83.09	0.00	390.31
%	1.47%	0.47%	50.00%	26.66%	0.11%	21.29%	0.00%	

Units in the above are MegaTonnes (Mt) of CO_2 equivalent.

According to BEIS 2018 UK Greenhouse Gas Emissions, Provisional Figures emissions for 2018 were 364.1 Mt, which compares fairly well with this rough model's figure of 390.31 Mt. Unfortunately, there don't appear to be more accurate published tables that could have been used in this model.

6.4 CO_2 emissions impact of electrification and clean electricity generation

Benefit only derives from electrification if electricity can be generated from low carbon sources. The CO_2 emissions including transmission losses from electricity generated were .2773 kg CO_2 e/kWh, which is still higher that Natural gas (0.20437), Petrol (.25349) and Diesel (.26910). For the purposes of this scenario it is assumed that all electricity comes from renewables, storage or low carbon biofuels, so the factor for electricity is reduced to 0.

Multiplying demand from Table 3-16 – Revised demand after basic electrication

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Total
Industry	11.9	3.1	26.0	105.4	16.9	93.0	7.9	264
Air Transport	0.0	0.0	157.8	0.0	0.0	0.0	0.0	158
Light Road Vehicles	0.0	0.0	0	0.0	0.0	119.3	0.0	119
Heavy Road Vehicles	0.0	0.0	95.4	0.0	3.3	0.0	0.0	99
Rail	0.1	0.0	7.7	0.0	0.0	4.7	0.0	13
Other Transport	0.0	0.0	11.2	0.0	0.0	0.0	0.0	11
Domestic	4.1	2.0	0.0	0.0	27.5	257.2	3.0	294
Other non-domestic	0.3	0.0	11.2	0.0	14.9	153.6	3.8	184
Sub-Total	16.5	5.1	309.3	105.4	62.6	627.9	14.7	1141.51
%	1.45%	0.44%	27.09%	9.23%	5.48%	55.01%	1.29%	
Non Energy Use	0.0	0.6	94.0	4.8	0.0	0.0	0.0	99.33
Total	16.50	5.63	403.25	110.22	62.61	627.94	14.69	1240.83
%	1.33%	0.45%	32.50%	8.88%	5.05%	50.61%	1.18%	

section 3.4 by the revised factor matrix we get

Table 6-5 - CO_2 equivalent Mt after Basic electrification and clean electricity

	Coal	Manuf. fuel	Petroleum products	Natural gas	Bioenergy & waste	Electricity	Heat sold	Totals	%
Industry	4.08	1.12	7.41	21.54	0.00	0.00	0.00	34.16	30.62%
Air Transport	0.00	0.00	40.85	0.00	0.00	0.00	0.00	40.85	36.62%
Light Road Vehicles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%
Heavy Road Vehicles	0.00	0.00	25.67	0.00	0.00	0.00	0.00	25.67	23.01%
Rail	0.04	0.00	2.07	0.00	0.00	0.00	0.00	2.11	1.89%
Other Transport	0.00	0.00	3.01	0.00	0.00	0.00	0.00	3.01	2.70%
Domestic	1.50	0.72	0.00	0.00	0.41	0.00	0.00	2.63	2.36%
Other non-domestic	0.11	0.00	3.02	0.00	0.00	0.00	0.00	3.13	2.81%
Totals	5.73	1.84	82.03	21.54	0.42	0.00	0.00	111.57	
%	5.14%	1.65%	73.53%	19.31%	0.38%	0.00%	0.00%		

Units in the above are Mt CO_2 equivalent

Emissions are now reduced to 111.57 Mt CO_2 e, a reduction of 71.42%.

Arguably as air transport isn't within the remit of Teignbridge it shouldn't be included, which would reduce the total to 70.71 Mt CO_2 e.

6.5 Effect on CO2 of demand side energy reduction

The scenario described in Section 4 assumes that in addition to the measures taken in Section 3 that all new buildings meet PassivHaus standards and that existing buildings are retrofitted to PassivHaus standards.

The factor matrix remains the same as does the resulting matrix and emissions, so there is no reduction in emissions in this scenario, however, in the real world electricity emissions are not likely to drop to zero for some time, so the energy reduction steps do have an impact on CO_2 as well as making the electrification scenario more realistic.

6.6 Proportion due to Teignbridge

In 2018 the population of Teignbridge was 132844 (https://reports.esd.org.uk/reports/15?pat=LA&pa=E07000045)

In 2017 the UK population was 66M and the 2018 population was projected to be 66.5M (https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/overviewoftheukpopulation/november2018)

This means the population of Teignbridge is 0.1998% of the UK population. Now assume that Teignbridge emissions per capita are typical of National emissions per capita, then Teignbridge emissions are:

Table 6-6 - UK and Teignbridge CO2 reduction

	UK Mt CO_2 e	Reduction	Teignbridge kt CO_2 e
Before	390.31		779.71
After	111.57	71.42%	222.87

This before figure is close to a grand total figure for Teignbridge in 2017 of 785.1 kt CO_2 e given in https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2017 ((2005 to 2017 UK Local and Regional CO2 emissions – data Tables).

6.7 Current Carbon sequestration

There is an interactive map which shows carbon statistics for each local authority area. This is backed by data from the carbon emissions statistics linked in the previous section.

This map also shows Land Use Land Use Change and Forestry (LULUCF) net emissions of -41.51 kt, the absolute value of this has been increasing by a small amount each year. This reduces current emissions to 735.13 kt.

The calculation here is a gross simplification solely to illustrate the scale of the problem. It is likely that sequestration effects by planting will be reversed within a relatively short period. If trees are planted, they only remove carbon if they are used for things like building. They do not remove carbon in the long term if they are used for fuel.

6.8 Teignbridge Areas

Teignbridge has a total land area of 63790 hectares or 637.9 km^2 according to Wikipedia.

It would be useful to have a breakdown of areas by land use type. This could probably be derived by analysis of OS vector mapping of the area. It could certainly be achieved by analysing OS Mastermap Topography Layer, which the council is probably licenced to use. Some data is available in OS Open Data products, which might be useful. For example OS Vector Map District contains woodland polygons. Data derived from these sources could be used to estimate carbon sequestration by area both now, and in any proposed land use change.

According to mapping in https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/fg_grazing_for_carbon_starting_paper_final.pdf the area of grassland in Devon as a proportion of agricultural land exceeds 58.6%.

6.9 Sequestration rates

It is proving quite difficult to determine accurate rates for sequestration rates.

Forest and grassland natural can sequester carbon.

Forest

According to http://www.fao.org/3/y0900e/y0900e06.htm planting forests in temperature forests sequesters between 0.7 and 7.5 tonnes of carbon per hectare in temperate regions. If we assume the Teignbridge is in the middle of this range, then the rate is 4.1 tonnes/hectare. We need to convert tonnes of carbon to CO_2 equivalent. The conversion factor is given by multiplying by the ratio of the molecular weight of CO_2 to the molecular weight of Carbon. This ratio is 44/12 or 3.67. So 15.03 tonnes/hectare.

Grassland

According to https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/fg_grazing_for_carbon_starting_paper_final.pdf

"A study on nine grasslands plots scattered over Europe displayed a net sink of grasslands for atmospheric CO_2 of −240 ± 70 g C m−2 year−1 (mean ± confidence interval at p > 0.95)". This is 2.4 tonnes of carbon/hectare. This again needs to be converted to tonnes of CO_2 e/hectare giving 8.8 tonnes CO_2 e/hectare.

Other land use

Other land use is to a greater or lesser extent an emitter.

Current overall rate

The current overall emissions from land use of -41.5 kt are equivalent to 0.651 tonnes CO_2 e/hectare

Given that a large part of the land in Teignbridge is grassland, other land use must be quite a high emitter, and so worth looking into.

6.10 Planting forest to sequester more carbon

It is beyond the scope of this document to try to accurately estimate the amount of CO_2 that would be sequestered by planting more trees. So a very simple illustration is constructed.

Given the ending scenario we need to convert emissions of 221.52 kt to carbon. If this were done using the sequestration rate for forest over non-sequestering land, this would require 14735 hectares of forest. This is over optimistic, because much of Devon is classified as grassland, so a more likely scenario is converting grassland to forest, which would require 35538 hectares. This is 55.71% of all land converted from grassland to forest.

Section 7. Conclusions

1. Electrification of heat and light vehicle transport (LVT)reduces fossil fuel use by 66%.
2. Electrification of heat and LVT alone would increase average electricity demand by 110%, and if centrally generated would exceed the capacity of the national transmission network at peak times by 319% and the average demand would be 100% of peak capacity. So, to meet demand in this way would require major expansion of the network.
3. Building new buildings to PassivHaus standards and retro-fitting all existing buildings to PassivHaus standards would reduce the increase in electricity demand by 53%, so again if supplied centrally demand would exceed the capacity of the national transmission network at peak times by 34% and average demand would be 65% of capacity. This would still require expansion of the network, though there would be some scope for shifting peak demand to off peak periods.
4. Lighter electric vehicles associated with regulated speeds and lower speed limits might save about 63TWh of electricity if 50% of EVs were this type.
5. There remain some demands that currently use fossil fuels, which it would be difficult to replace by electrification: Air Transport, Industrial gas use, Non-energy petroleum[4], Heavy Road Vehicles. Other means need to be found to deal with these. These use 85% of the fossil fuel remaining after the steps described in this document.
6. The local bulk supply point at Abham does not have sufficient demand headroom to meet the demand increase of between 75% and 449% implied by the proposals explored in this paper.
7. Local generation could remove the need to reinforce both the Abham supply point and the National grid. This already happens for self-supply, but there are regulatory barriers to using the network to supply customers connected to the same substation, this limits the role that can be played by local generation.
8. On-shore wind is needed locally to satisfy demand that is likely in the winter peaks.
9. Electrification of heating and light vehicle transport alone are not enough to achieve zero carbon, and improved building standards are needed to mitigate the consequent electricity consumption.
10. The electrification scenario reduces Teignbridge's emissions to 223 ktonnes CO_2 equivalent, a reduction of 71%.
11. Planting forest in place of grassland to offset even reduced emissions would require 35,540 hectares or 56% of Teignbridge's land area to be planted.

[4] Non energy petroleum may in some cases be carbon that remains locked and so doesn't contribute to CO_2 emissions. Investigation of this is outside the scope of this document.