AECB
building knowledge

"A person often meets his destiny on the road he took to avoid it."

Jean de La Fontaine, Fables

Can we build our way out of climate crisis?

Just exactly how much, and how quickly, can we reduce carbon emissions from heating England's new and existing homes – and can we justify the embodied carbon emissions of the materials and products used? The AECB takes a deep dive into the figures using their simple PHPP-based building stock modeling tool as Andrew Simmonds and Lenny Antonelli chart the group's recent work with Tim Martel and Green Party energy policy advisor Tony Firkins.

Policymakers expect the building industry and home owners to make deep cuts in their energy use to dramatically lower greenhouse gas (GHG) emissions because perhaps, at least in theory, reducing emissions from buildings is seen as easier than in other areas – such as decarbonising the UK's heat supply and industrial sector.

The thinking goes that if you retrofit existing homes so they use 'much less energy', and construct new buildings so they use 'almost none', you can dramatically cut the sector's heating energy needs, and therefore CO_2 emissions. Then alongside taming heat demand we can decarbonise the UK's heat supply (this is going to be very challenging). But is it really that straightforward to decarbonise England's homes, and how can we validate or improve policy assumptions underlying these aspirations?

The AECB decided to try to add up the main CO_2 emissions related to heating, improving and constructing England's housing stock, as well as factoring in the need to emit CO_2 to invest in retrofit materials and products – the 'Carbon Burp'. The model also factors in: the rate of dwelling demolition and conversions from non-domestic buildings; the rate of building new homes; the number of listed buildings unlikely to be significantly improved; and the levels of building regulations and new build & retrofit energy performance being aimed for. This initiative is in essence an informed, 'back of the envelope' exercise intended to be thought provoking and useful. The fully referenced spreadsheet is available for those who want to check the method and the figures. If there is sufficient demand the AECB will run an interactive webinar on this piece of work.

The intention was to keep the model as simple and transparent as possible, with all assumptions and key numbers clearly stated. They wanted to be able to adjust basic input data and change key assumptions easily to allow 'sensitivity testing' - to get a feel for what factors are more important, which are less so, and even inform fine-tuning for policy.

The Green Party (GP) energy policy[1] appears to be the most radical and most detailed of all UK political parties when it comes to decarbonising the building sector, and therefore most closely aligned with the Committee on Climate Change's more recent work. The AECB was keen to collaborate with the party's energy and housing policy advisors to explore the performance of its policies as they specifically relate to building England's new homes, retrofitting old ones - and heating the entire housing stock.

The GP advisors were also keen to see how their ambitious policies delivered against the rapidly diminishing GHG emissions budgets that climate science indicates the UK has available. The AECB were keen to bring their technical expertise — developed through the last few years of the CarbonLite retrofit programme, a solid theoretical and practical understanding of buildings, and that of partner organisations such as the Passivhaus Trust — to explore the impact of their members' work at a national scale.

The GP's overarching policy ambition – set out in their national energy scenario, is for the UK to become net-carbon zero by 2030. This radical target is based on two factors: the UK making its share of carbon cuts in a scenario that gives the world a strong possibility of limiting warming to 1.5C, whilst recognising that we have, compared to many other countries, a high GDP / high historical emissions per capita: as such when budgets are found to be stretched we should accept *even lower* allocations from the remaining carbon budget[2].

As part of this, the GP proposes to 'deep' retrofit 11 million homes (that's about 9 million homes in England) to a 'very low energy' standard — by 2030. This was originally envisaged as being to the Passivhaus 'EnerPHit' Standard. However during discussions the GP moved to use the space heat demand target ranges developed for the AECB CarbonLite retrofit training course for different house types, as whilst these are still pretty ambitious they were seen as perhaps being more realistic when applied in the context of English house types.

[1] Green Party energy policy is located here: https://policy.greenparty.org.uk/ey.html. However, the party has also shared more detail from internal policy documents with us for the purposes of this modeling exercise.
[2] For more on equity, see https://www.ipcc.ch/sr15/

*Below: t*he three CLR house types represent about 63% of the English dwelling stock [3] and AECB are assuming that by using the weighted-average consumption for these three common house types the related emissions for the stock as a whole are adequately represented[4].

Annex Table 2.1: Stock profile, 2016

all dwellings

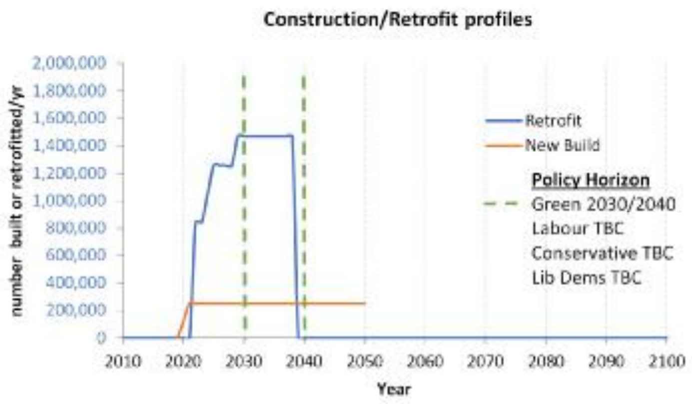
	all tenures *percentages*
dwelling age	
pre 1919	21.2
1919-44	16.1
1945-64	18.9
1965-80	19.8
1981-90	7.8
1991-2002	8.4
2003 onwards	7.8
all terraced houses	28.4
semi-detached house	25.3
detached house	16.7
bungalow	8.9
converted flat	3.9
purpose built flat, low rise	15.1
purpose built flat, high rise	1.7

The GP proposes to almost immediately move to build new homes to achieve better performance than the 2013 building regulations, here they referenced the Passivhaus Standard, at a national rate of 300,000 units a year (pro rata c.250,000 in England).

[3] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676910/2016-17_Section_2_Housing_Stock_annex_tables.xlsx Tab: AT2.1

[4] For more see: Summary of analysis using the National Energy Efficiency Data-Framework https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/65969/6861-need-report-nov-2012.pdf

Below*:* what level of construction activity have we seen in the past? At Britain's peak of house building (in 1968) 425,000 dwellings were built across the UK that year – in comparison, below, is an indication of the numbers of new homes (England) built under the GP policy. The graph also illustrates the far greater number of retrofits proposed, and the rates over time.



The radical GP policy ambition demonstrates the unprecedented urgency and scale of action needed for the UK buildings sector to play its part in keeping global warming to 1.5C. AECB modelling of their policies implies a *massive* upscaling of the repair, maintenance and improvement (RMI)[5] sector – it also illustrates the potential value of the enhanced RMI market that would result[6]. This might amount to (cumulatively) more than a trillion pounds of repair, maintenance and improvement work by 2040. What might the building industry think about their ability to gear up to deploy the necessary skills and resources for a commercial opportunity of this magnitude?

Achieving any retrofit policy outcomes would also require massive scale up in the area of retrofit *training* and *quality control* in order to ensure the work is done properly, and to avoid retrofit disasters like those seen at Preston, and more tragically, at Grenfell. But it certainly represents an eye-watering economic opportunity across industry professional services and building companies of all sizes.

[5] Repair, Maintenance and Improvement (in this article we see 'energy efficiency retrofit' activity as being part and parcel of the RMI market – but increased commercial activity related to 'whole house' training, professional, surveying, QA, construction & trades services, as well as increased manufacturing and installation opportunities etc.

[6] The figures quoted are based on the model's year one *capital* costs for the 3 CLR house type deep retrofits, where the capital cost (as distinct from the *marginal cost* of energy efficiency measures) is used here as a proxy for the value of the market in retrofit. This is all set out in module 8 (free public access to some lessons) of the CarbonLite retrofit course: https://carbonlite.net/lesson/8-1-the-costs-of-retrofit-2/?v=79cba1185463

The Carbon Burp

	million m3 by 2050
wood fibre	104.03
PUR (polyurethane)	91.65
Expanded Polystyrene	306.93
mineral wool, k0.042	438.11
PIR (Polyisocyanurate)	59.79

Left: the retrofit of England's housing stock will require the deployment of a lot of insulation. Potential volumes calculated by the AECB model based on the currently entered assumptions about potential currently available materials are shown above. Materials in the model can be changed for different scenarios, the current selection is simply representative of generic types in this scenario: Woodfibre represents a capillary active, condensation controlling internal wall insulation, PUR – a high performance cavity wall insulation, polystyrene and mineral wool are common type of external wall / floor insulation, PIR similarly under solid floors.

A massive upsurge in retrofit construction activity has a carbon footprint related to the extraction, transport, manufacture, distribution, deployment on-site and ultimately removal and reuse, recycling and disposal of the materials needed. AECB call this the 'carbon burp'. It is often not factored into emission reduction scenarios. The model uses figures for embodied energy from the ICE database, which provides data for the important *early part* of this footprint, and allows for inclusion of 'cradle to gate' emissions, for 'year one' of building or retrofitting a house.[7]

To show the effect from constructing enough new build homes to meet the demand and policy targets the AECB use a notional figure of 65 tonnes[8] of CO_2 for a 'typical' new build home, and so illustrate that emissions from the activity of constructing 300,000 new houses a year make up a surprisingly large portion of the building industry's carbon emissions — almost 20 million tonnes of $CO2_e$ each year at the peak. The embodied emissions quickly fall however, *if* manufacturing industries also quickly decarbonise their manufacturing energy (see graphs below)[9].

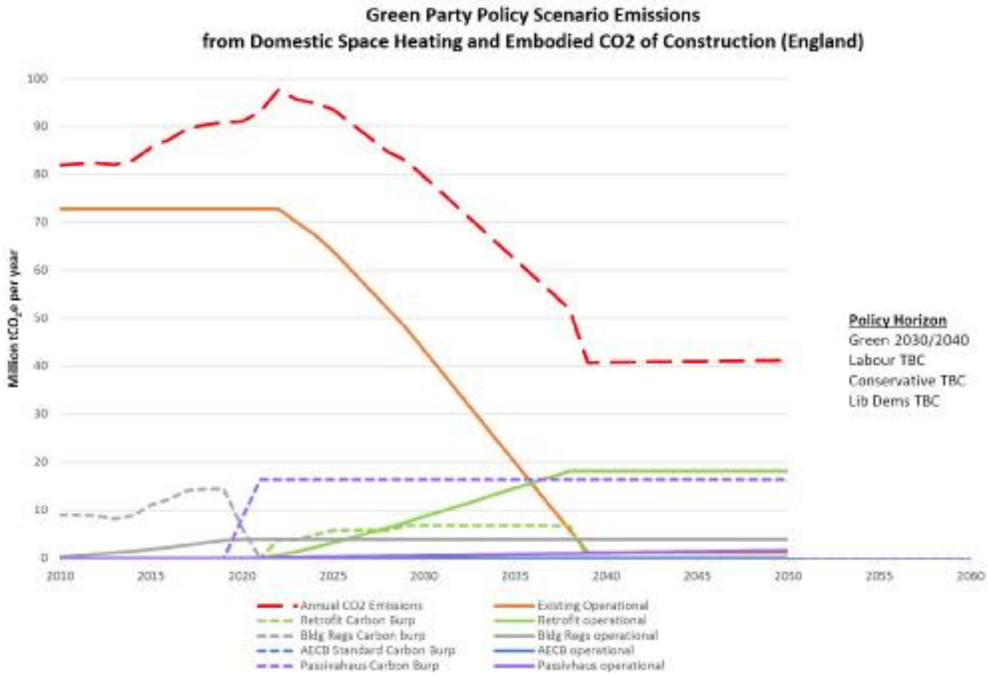
Below: England's housing *s*tock and industry annual emissions under the GP housing (and housing retrofit) scenario but *without* the GP's decarbonisation of either the heat supply or manufacturing energy factored in. the effects of GP housing policy indicate that space heating and embodied carbon emissions combined, reduce to about 40 million tonnes of CO_2/yr by 2040

[7] Read about this open source database here: http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html

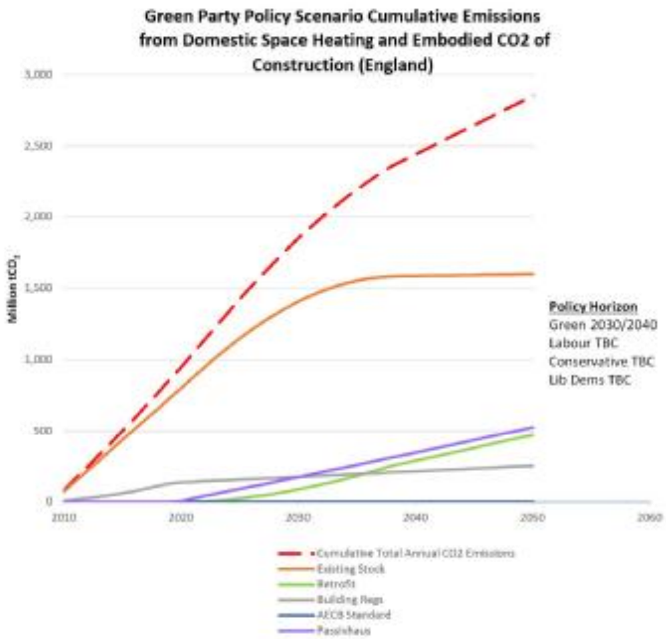
[8] We have seen figures for the embodied carbon for typical new homes of 20 - 80 tonnes, we use 65 as default for now and assume decarbonised manufacturing energy and materials substitution to low embodied carbon ways of building allow room to reduce this significantly – the lower figures are used for sensitivity testing of scenarios.

[9] Pending further investigation with the Committee for Climate Change (CCC) we have had to assume 100% of products' embodied carbon are manufactured in the UK, rather than imported (CCC carbon budgets use 'country based-', not 'consumption-based' accounting), in reality the CCC have been advised on carbon budget working assumptions for the % of products imported for the industrial sectors.

(a GP policy horizon). This illustrates the critical importance of the need to also decarbonise the heat supply and manufacturing.



Below: as before but cumulative emissions. The UK needs to see total cumulative emissions flatten out as soon as possible. This is clearly not happening as shown below if heat and manufacturing is not decarbonised - quickly.



Below*:* *s*ummary figures for GP new housing, mass scale retrofit but no decarbonisation of heating and manufacturing[10]:

	Emissions	2030	2050
1	Annual emissions, $MtCO_2$/yr	79.53	41.25
	% of budget (not consumption based)	27%	40%
2	Cumulative emissions, $MtCO_2$/yr	1,848	2,851
	Cumulative emissions trend	rising	rising
3	Tot homes retrofitted (millions)	10.7	22.5
4	House Build Rate	252,000	252,000
5	Total avoided emissions, $MtCO_2$ Based on flat 2019 rate	8	822

☐ Decarbonised heat supply

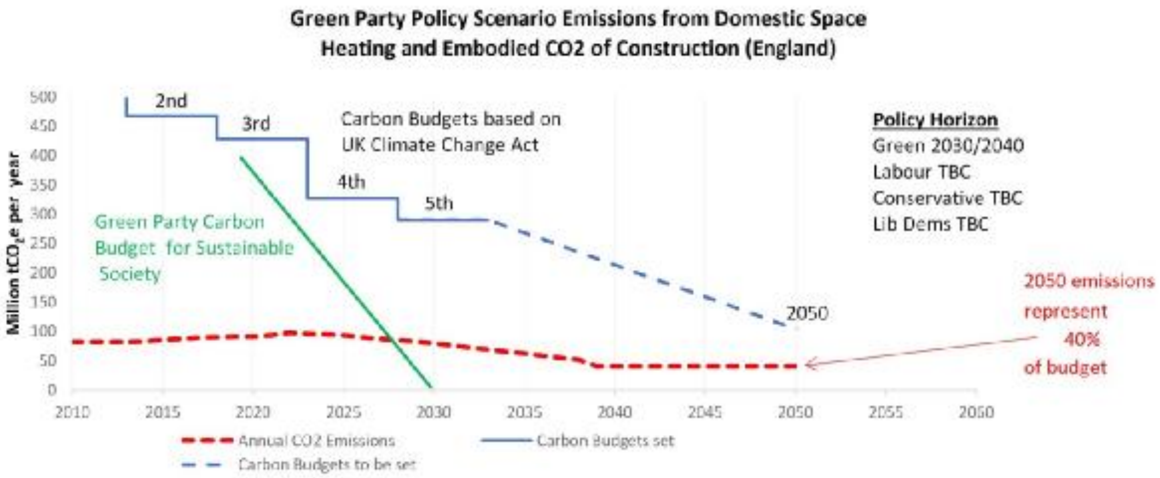
☐ Decarbonised manufacturing

Start date of PH/AECB homes being mandatory: starts being phased in 2020

Total value retrofit works, £m 2020	-
Total value retrofit works, £m 2030	554,000
Total value retrofit works, £m 2040	1,162,052
Total value retrofit works, £m 2050	1,162,052

[10] GP have lower estimates for the costs of retrofit. In this work the authors have used AECB capital cost estimates per house type for the deep retrofits as used in the CLR programme. There are opportunities over the decades relating to the learning curve, street by street deployment, a national infrastructure programme approach, technological and process innovation etc. which could lead to different costs for deep retrofits compared to simply multiplying up the CLR house type costs. It is also important when talking about retrofit costs to follow standard investment appraisal practices rather than the over-simplified 'simple payback' method. See AECB CLR Module8.

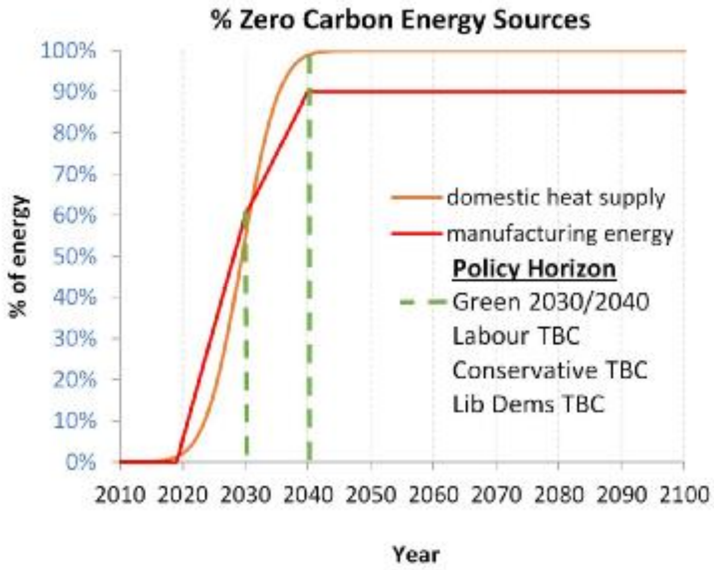
Below*:* without decarbonisation of heat and manufacturing, even ambitious retrofit and very low energy new home policies means that the space heating and embodied construction energy for only England's homes consume around 40% of the *entire* UK carbon budget in 2050. It is also evident that the UK carbon budget is currently too generous and cannot deliver the emissions cuts consistent with the latest climate science.[11]



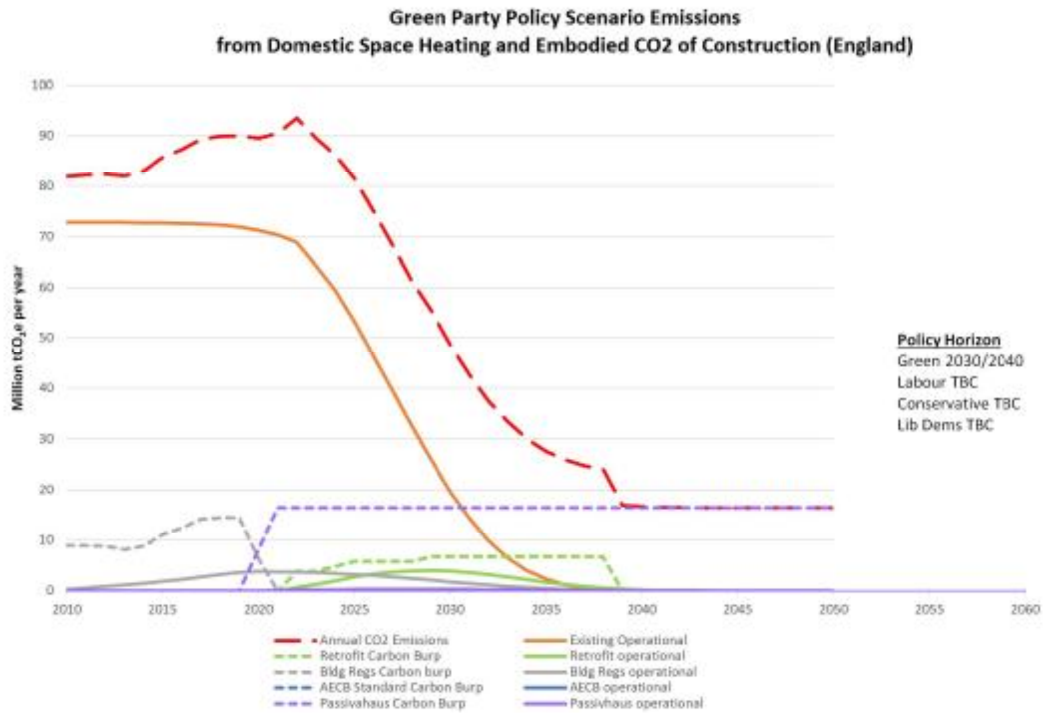
This exercise shines a light on the urgent need to reduce and decarbonise not only the heating energy used to keep us warm and healthy, but also the need to reduce the carbon footprint of construction products, through simply switching to lower carbon construction methods (there are easy wins here) and decarbonising the energy used to extract, transport and manufacture building materials in the first place (presumably more difficult).

[11] The CCC budgets available to UK are uncertain (from the probability factors in the IPCC report) and the GP suggests that they are anyway set too high to be aligned with current climate science and our Paris commitments. Also see notes elsewhere relating to how the embodied energy of imported construction products are treated by the AECB relative to the CCC's country based emissions accounting method.

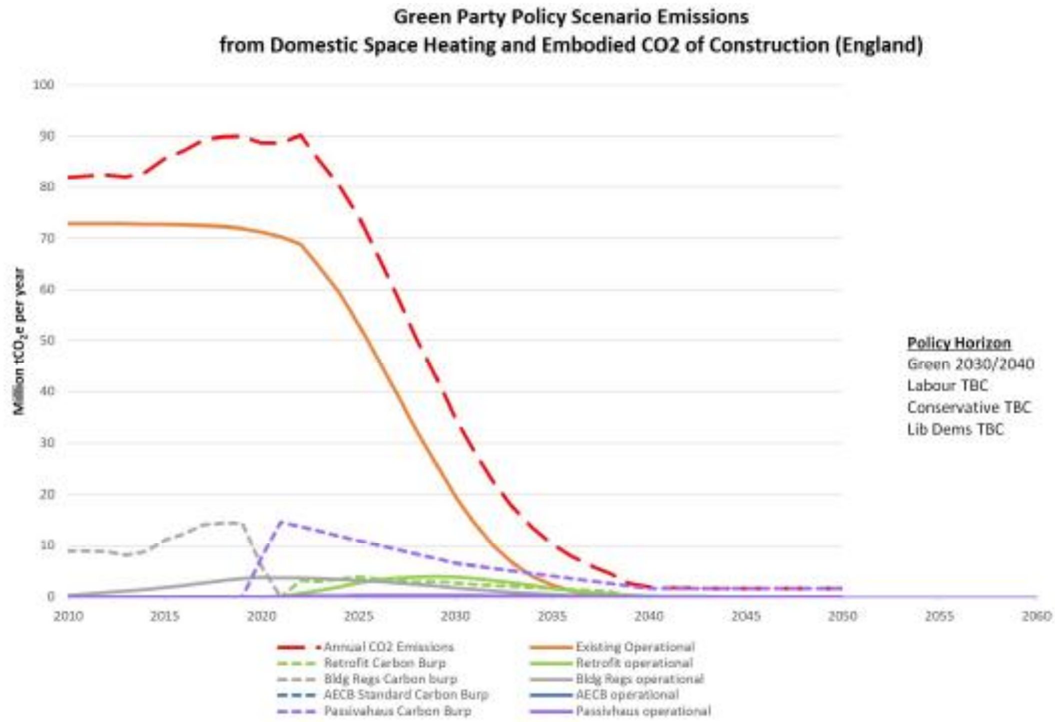
Below*:* the GP policy for decarbonising heat and manufacturing, ambition and timing, is represented on this graph



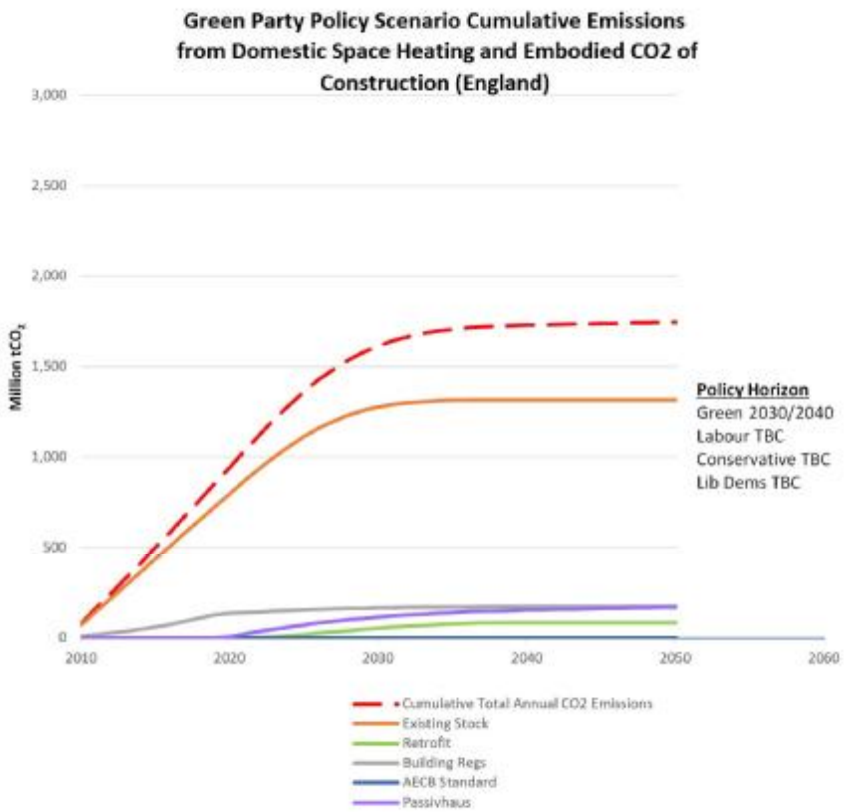
Below: if the GP policy ambition to decarbonise the heat supply to England's housing stock is factored in the effect on annual emissions can be seen



Below: if also now added is the GP policy ambition to decarbonise manufacturing, the full effect of GP policies on emissions can be seen



Below: as before, but cumulative emissions



Below: summary table of headline figures for the full suite of GP policies modelled

	Emissions	2030	2050
1	Annual emissions, $MtCO_2$/yr	34.85	1.64
	% of budget (not consumption based)	12%	2%
2	Cumulative emissions, $MtCO_2$/yr	1,615	1,746
	Cumulative emissions trend	rising	rising
3	Tot homes retrofitted (millions)	10.7	22.5
4	House Build Rate	252,000	252,000
5	Total avoided emissions, $MtCO_2$ Based on flat 2019 rate	229	1,897

☑ Decarbonised heat supply

☑ Decarbonised manufacturing

Start date of PH/AECB homes being mandatory: starts being phased in 2020

Total value retrofit works, £m 2020	-
Total value retrofit works, £m 2030	554,000
Total value retrofit works, £m 2040	1,162,052
Total value retrofit works, £m 2050	1,162,052

AECB modelling of the Green Party policy also raises other, longer-term questions, such as: can the UK sustainably continue this rate of housebuilding beyond 2050? Do we need policies that discourage too many individual dwellings with inherently inefficient shapes (poor 'form factors'), and that instead encourage higher occupancy of existing buildings, or more efficient living patterns such as shared houses, co-housing, and a re-evaluation of (safely designed and built) high rise living? And come 2040, experiencing the all too real impacts of the climate and environmental crisis, will we regret not thinking longer term and developing policies for more resource-efficient, socially joyful, future-proofed living patterns? Or having a compassionate, human-centred and inclusive public discussion about population growth?[12]

'Zero' carbon heat

The AECB modelling of GP policy shows that mass-scale, 'sufficiently deep' retrofit and new build to the Passivhaus standard, does indeed drastically cut the operational carbon emissions from England's housing – meaning the challenge of decarbonising the heat supply[13] (to match a much reduced heat demand) becomes less daunting and capital intensive - more cost effective overall[14].

Using the tool, it is possible to model scenarios either with or without a decarbonised supply of heat. However, with around 80% of English households currently on the gas network, a large-scale shift to 'electrify heating' would require a rapid and massive upgrading of the nation's grid infrastructure. The AECB's 2012 report Less is More: Energy Security After Oil[15] warned that relying on grid electricity to heat all the nation's homes could compromise energy security.

It concluded that if almost everything is electric, even the 'smartest' networks will struggle to protect essential electricity users when extreme peaks in space heating during severely cold weather threaten to overwhelm the network. It explained at length how it is more difficult to keep electricity networks that are used for space heating stable, versus gas or heat networks.

Meanwhile, according to our modelling of Green Party policy, between now and 2040 the emission of ½ a billion tonnes of CO_2 could be avoided if the heat supply is *entirely i.e. 100%,* decarbonized. However, as the GP recognises, this is still not enough to stop these cumulative emissions growing. Another ¼ of a billion tonnes of cumulative emissions during the same

[12] Examples of further reading: https://populationmatters.org/, https://www.oxfam.org/en/research/economy-99, https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/mb-extreme-carbon-inequality-021215-en.pdf

[13] So far, our modelling only looks at the dwellings' space heating demand, as opposed to domestic hot water consumption or power consumption related to electrical appliances, equipment and lighting.

[14] There are more co-benefits (and therefore value to UK citizens) resulting from deep retrofit of existing homes than there are co-benefits relating to decarbonising the heat supply – as the CarbonLite retrofit course explains.

[15] https://www.aecb.net/publications/less-is-more-energy-security-after-oil/

period could be avoided by decarbonising manufacturing energy: by 60% by 2030 and 90% by 2040.

The AECB model shows the GP's combined decarbonisation and housing policies theoretically resulting in cumulative emissions flattening out between 2030 and 2040, but that they still do not bring annual emissions from England's housing stock down to zero by 2030[16].

Growing realisation of the implications of ambitious policies may inspire either confidence in urgent action or for some perhaps defeatism or nihilism. Since the work of Lord Stern and others it is commonly accepted that dealing with these challenges sooner would have been cheaper, easier and more effective – the science (and economics) shows we have little choice but to now act extremely rapidly and boldly.

Experts from all sectors need to inform UK political parties' policies with realism. Policies need to be bold and ambitious, but with policy gaps identified ahead of time where possible in order to improve the policy or to stimulate the development of complimentary policies for other sectors to take up the slack - even if just for 'insurance'. With climate change, the laws of physics rule and the outcome of climate breakdown policy becomes literally a matter of life and death.

Exploring policy gaps.

What happens if things don't work out as hoped? There are many ways to tweak, challenge and alter the underlying assumptions of the AECB model: but changing some assumptions has more effect on the outcomes than others – which is why many scenarios need to be run to best identify which are the most critical assumptions. However it is useful to start somewhere, so here is a brief, not unreasonable look at changing selected assumptions to 'stress test' the GP policy scenario. This is not a critique of GP policy (indeed the AECB are grateful for their engagement and collaborative approach) it is simply a thought exercise to illustrate the way in which *any* party's policy should be explored. Whilst this 'stressed scenario' factors in things that don't work out as hoped, it also illustrates how some 'policy tweaks or 'insurance policies' intended to improve matters could also be factored in. In this way future decision makers can try to steer national action to manage the risk of policy underachievement – or policy failure.

[16] An assumption being that the policies are implemented *today* and notwithstanding the previous years' cumulative emissions arising from 2010 (which our model currently uses as a notional starting point for this exercise).

For brevity only the combined effect of all these changes are illustrated, though of course it would be possible to quantify each one individually.

1. It is more commonly accepted that the way technology is adopted over time is described by a 'normal curve', possibly still true even with state intervention (rather than leaving it entirely to the market) e.g. see https://www.cse.org.uk/downloads/file/do-the-next-million-first-transforming-the-owner-occupier-retrofit-market.pdf
   So first the modelers have changed the GP retrofit rate profile to a normal curve, reflecting that it will probably take longer to ramp up large scale retrofit and overall that retrofit activity will be spread out over a longer time period: reaching around ¼ million deep retrofits/year by 2025, 1.2 million/yr by 2030 and peaking in 2037 at around 1.5 million/yr - after which the rate starts to ramp down where retrofitters are dealing with the more difficult remaining buildings.
2. For the second stress test of the GP scenario the AECB reviewed the CarbonLite retrofit programme's Specific Space Heat Demand (SSHD) figures for their three representative house types. SSHD (units are kWh per square metre per year) describes how much heat is needed to heat buildings to a given temperature (17C for unimproved homes and 20C for retrofitted homes is the CLR default assumption).

   Below: The first table shows the core data entered to create the GP scenario and the second table the 'GP stressed' scenario. The difference is only for the retrofitted semi-detached homes. Two points of particular interest: the space heat demand for a typical new house built to 2013 building regulations uses an 'in use' figure identified by the Passivhaus Trust in a paper to be published at the end of February 2019, which is also supported by a recently published Committee for Climate Change report[17]. The second point is to note that the modelers have increased the space heating emissions from the retrofitted semi-detached house type about 1 ½ times, from 26 – 44 kWh/m2.a (so in this stress test these types of homes are modeled burning another 1,400 kWh of gas each, every year)[18]. It is striking how poorly the new homes to building regulations seem to perform compared to successful deep retrofits of much older homes.

[17] 'UK housing: Fit for the future?' https://www.theccc.org.uk/publication/uk-housing-fit-for-the-future/

[18] As set out in CLR lesson 8.7 the AECB model assumes a rise in internal temperature after retrofit from 17°C to 20°C – an effect known as 'comfort take' as warmth becomes more affordable. This results in a higher energy use than would occur if occupants were to leave their thermostats at 17°C - the official UK assumed average whole house temperature (i.e. some rooms warmer, some colder). This reduces the financial benefits of reduced energy costs after the retrofit. Comfort take is a well-documented reality after investment in energy efficiency measures and must be factored in even if it makes the economic or performance of retrofit look worse. In a deep retrofit however the additional heating demand for an individual household is pretty small compared to doing the same in an unimproved or shallow retrofit.

type	Number	Space Heat Demand kWh/yr	tCO2 embod energy	SSHD kWh/m2.a	Type of retrofit	TFA, m2	
Unimproved Bungalows	2,086,800	14,720				64	
Unimproved Town Houses	4,173,600	17,316				148	
Unimproved Semis	5,772,000	13,783				77	
Retrofitted Bungalows	2,086,800	4,800	8.7	75	4		
Retrofitted Town Houses	4,173,600	5,920	2.6	40	4		
Retrofitted Semis	5,772,000	2,002	4.5	26	5		
New build PH		1,020	65			68	
New Build AECB		2,720	65			68	
New - 2013 Building Regs in use		10,355	65			68	
Total represented by 3 house types	12,032,400	15,171	Weighted ave Unimproved kWh/yr			99	Weighted average TFA
Total retrofitted	22,464,919	3,846	Weighted ave Retrofit kWh/yr				
			4.6	Weighted ave Retrofit tCO2			
				38.7	Weighted ave Retrofit kWh		

type	Number	Space Heat Demand kWh/yr	tCO2 embod energy	SSHD kWh/m2.a	Type of retrofit	TFA, m2	
Unimproved Bungalows	2,086,800	14,720				64	
Unimproved Town Houses	4,173,600	17,316				148	
Unimproved Semis	5,772,000	13,783				77	
Retrofitted Bungalows	2,086,800	4,800	8.7	75	4		
Retrofitted Town Houses	4,173,600	5,920	2.6	40	4		
Retrofitted Semis	5,772,000	3,388	3.8	44	1		
New build PH		1,020	65			68	
New Build AECB		2,720	65	reduces over time		68	
New - 2013 Building Regs in use		10,355	65			68	
Total represented by 3 house types	12,032,400	15,171	Weighted ave Unimproved kWh/yr			99	Weighted average TFA
Total retrofitted	22,464,919	4,511	Weighted ave Retrofit kWh/yr				
			4.2	Weighted ave Retrofit tCO2			
				45.4	Weighted ave Retrofit SSHD		

Things often don't work as expected. As a proxy for this across the different house types, the modelers stressed the GP policy by assuming that: because of the semi-detached house types' relatively poor form factor; issues arising from working on one half of a house at a time; heat losses to neighbours through party walls; the fact that these dwellings are two storeys and that there may be extensions or conservatories complicating matters; and so on, that in reality achieving a SSHD of 26 kWh/m2.a (NB: the Passivhaus retrofit standard EnerPHit is 25 kWh/m2.a) is likely to be difficult in most cases. So for the stress test AECB used the average SSHD of the internally insulated & externally insulated semi-detached house type i.e. 44 kWh/m^2.a. For comparison, the AECB Building Standard is 40 kWh/m^2.a. [19]

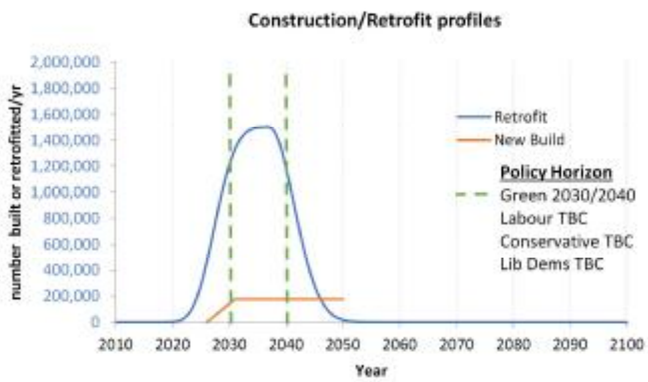
3. The modelers next assume that an ambitious change to improve the UK building regulations - to match the best available energy efficiency new building standards - takes more time than assumed in the GP scenario: specifically that moving from 2013 regulations to low-energy homes (GP policy uses the Passivhaus SSHD) takes 7 years

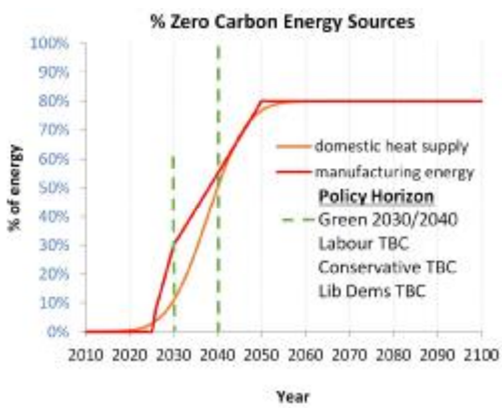
[19] An interesting future exercise, to try to ward off those arguing for retrofits that are: 'too shallow'; that lock in under-performance and future fuel poverty; that are overly reliant on an uncertain outcome for UK-wide decarbonised electrified heat is to put in 'shallow', higher SSHD figures. Currently government and agencies tend to focus on shallow retrofits that are far too unambitious – with dangerous implications for us in the longer term.

from now - for example having to wait for a decision to change after a 2022 General Election and cross party/industry negotiations. It is also assumed as part of this, that *not* all these new efficient homes will be built to the PH standard, rather that this will be a mix of AECB and PH Standard homes (in the ratio of 30:70). The resulting scenario would see any new homes built to the 2013 building regulations phased out during 2027 to 2031 in favour of building to the AECB & PH standards (and assuming all are sufficiently quality controlled and do perform as intended!).

4. Another obvious change for the stress test was to assume that decarbonising the UK's heat supply does not progress as hoped - and only reaches 80% decarbonisation. In addition it was also assumed to take longer than originally aspired to.
5. Likewise, it was next assumed that decarbonising manufacturing takes longer, only reaching 30% of manufacturing energy decarbonised by 2030, but reaching 80% by 2050.
6. In an attempt to tackle still rising emissions, and because it seems a no-brainer, next the modelers assumed that policy makers implement measures to reduce the CO2 emitted from construction materials used to retrofit and build new homes at a rate of 2.5%/yr: reducing the 65 tonnes $C0_{2e}$ / house in 2020 down to 16 tonnes $C0_{2e}$ / house by 2050.
7. It always makes sense to include a fudge factor, something to cover a general under-achievement of policies, that worsens emissions - based on factors such as kickback from technical problems and subsequent policy reformulation in the light of new evidence, buildings' under-performance, skills and labour gaps in the construction sector, market supply-side bottlenecks/increasing material prices, other social and economic disruption etc. All these things will slow progress and so increase emissions – so an input cell to worsen annual embodied and operational emissions figures was added and set at +10%.

This is how 1-7 affects outcomes in the model:





Below: summary table

	Emissions	2030	2050
1	Annual emissions, $MtCO_2/yr$	84.71	9.16
	% of budget (not consumption based)	29%	9%
2	Cumulative emissions, $MtCO_2/yr$	2,001	2,701
	Cumulative emissions trend	rising	rising
3	Tot homes retrofitted (millions)	4.8	22.4
4	House Build Rate	222,190	268,666
5	Total avoided emissions, $MtCO_2$	36	1,330
	Based on flat 2019 rate		

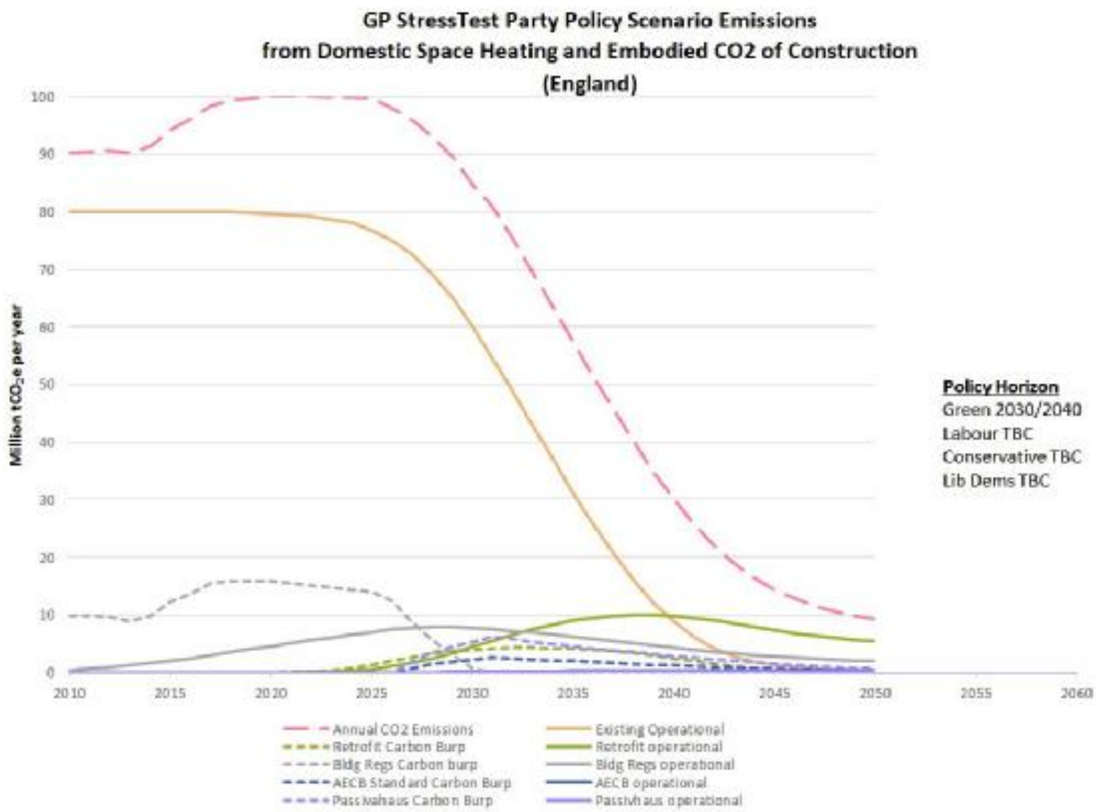
☑ Decarbonised heat supply

☑ Decarbonised manufacturing

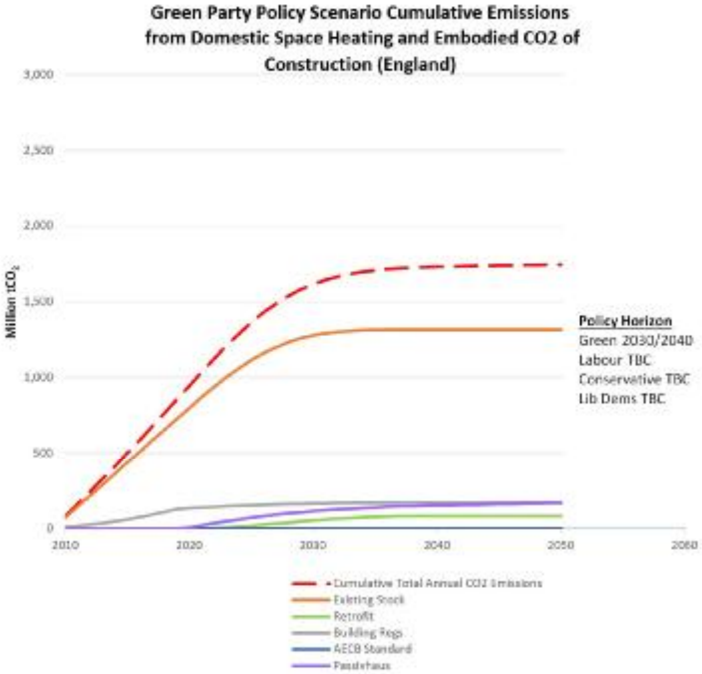
Start date of PH/AECB homes being mandatory: starts being phased in 2020

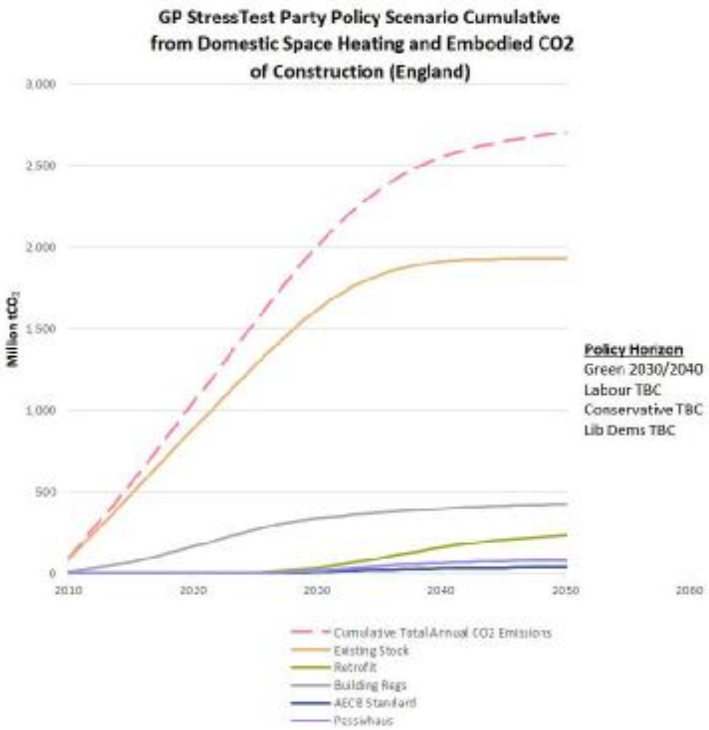
Total value retrofit works, £m 2020	161
Total value retrofit works, £m 2030	246,835
Total value retrofit works, £m 2040	975,850
Total value retrofit works, £m 2050	1,153,089

Below: annual emissions from this sector drop to just below 10 million tonnes per year by 2050, this exercise's policy horizon

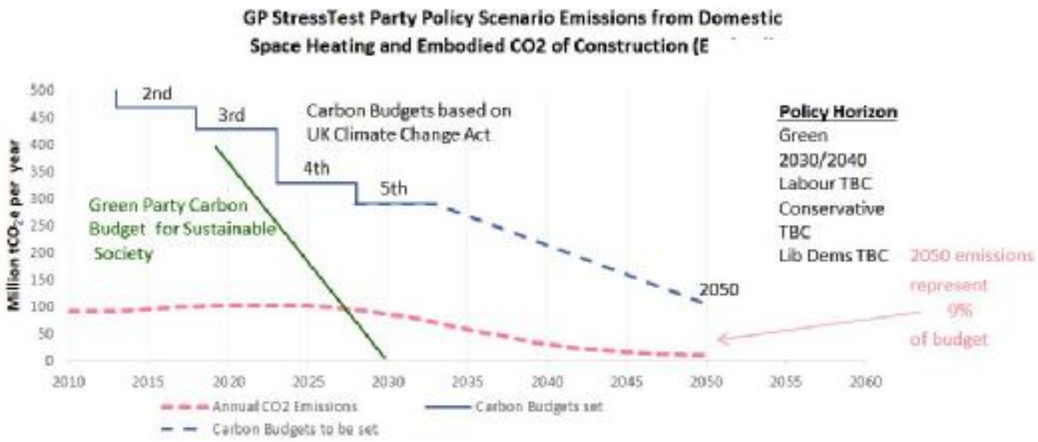


Below: compared to the unstressed scenario (first graph), in the stressed scenario (second graph) by 2050 cumulative emissions are almost a billion tonnes of CO_2 greater and still, albeit slowly, increasing





Below : 'Houston, we have a problem'



Please contact Andrew Simmonds at the AECB if you wish to engage with this work.