Time valued life cycle greenhouse gas emissions from buildings

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Time Valued Life Cycle Greenhouse Gas Emissions from Buildings

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Short Summary

The UK has adopted legally binding carbon reduction targets of 34% by 2020 and 80% by 2050 (measured against the 1990 baseline). Buildings are estimated to be responsible for more than 50% of greenhouse gas (GHG) emissions in the UK. These consist of both operational, produced during use, and embodied, produced during manufacture of materials and components, and during construction, refurbishments and demolition. A brief assessment suggests that it is unlikely that UK emission reduction targets can be met without substantial reductions in both Oc and Ec. Oc occurs over the lifetime of a building whereas the bulk of Ec occurs at the start of a building's life. A time value for emissions could influence the decision making process when it comes to comparing mitigation measures which have benefits that occur at different times. An example might be the choice between building construction using low Ec construction materials versus building construction using high Ec construction materials but with lower Oc, although the use of high Ec materials does not necessarily imply a lower Oc.

Particular time related issues examined here are: the urgency of the need to achieve large emissions reductions during the next 10 to 20 years; the earlier effective action is taken, the less costly it will be; future reduction in carbon intensity of energy supply; the carbon cycle and relationship between the release of GHG's and their subsequent concentrations in the atmosphere. An equation is proposed, which weights emissions according to when they occur during the building life cycle, and which effectively increases Ec as a proportion of the total, suggesting that reducing Ec is likely to be more beneficial, in terms of climate change, for most new buildings. Thus, giving higher priority to Ec reductions is likely to result in a bigger positive impact on climate change and mitigation costs.

Keywords: Carbon, CO_2, emissions, time value, embodied, operational, discount, life cycle, weighting.

1. Introduction

Global temperatures are expected to rise by between 1.1 and 6.4°C by the end of this century, depending, to a large extent, on the quantity of man-made (anthropogenic) greenhouse gases (GHG) emitted in to the atmosphere from now onwards. This warming is expected to have very negative effects on many peoples and ecosystems and, therefore, minimising our greenhouse gas emissions is a priority and is a long-term, large-scale challenge.

The UK, along with many other countries, has adopted a target limit of 2°C of warming relative to pre-industrial temperatures, which requires global greenhouse gas emissions to peak by 2020, be cut by 50% by 2050 and approach zero before 2100. For equal worldwide per capita emissions to be achieved by 2050 (in developed and developing nations), per capita cuts in the UK of more than 80% below 1990 levels are required before 2050.

The UK has therefore adopted legally binding carbon reduction targets of 34% by 2020 and 80% by 2050 (measured against the 1990 baseline) [1], [2].

Buildings are estimated to be responsible for more than 50% of GHG emissions in the UK [3]. These consist of both operational emissions (Oc), produced during use, and embodied, emissions produced during manufacture of materials and components, and during construction, refurbishments and demolition (Ec).

To date the major effort has focused, quite rightly, on reducing operational emissions but can we reach our reduction targets by just reducing Oc without reducing Ec?

To get an indication we can assume that buildings have to contribute their share of the targets (34% and 80% of the 1990 building emissions) and that the Ec:Oc ratio is 30%:70% over a 60 year service life. Generally different building types exhibit different Ec:Oc ratios but for this purpose a fairly representative 30%:70% ratio is used [4], [5].

Figure 1 shows typical building Ec and Oc profiles for a new building constructed in 2013 and with a service life of 60 years, up to 2073, together with the UK emissions profile from the 1990 baseline through to 2100 using actual emissions up to 2012 and targets up to 2100 [6], [7]. The building emissions are based on the premise that building emissions have already reduced towards their target by 26% in line with the overall UK reduction [6].

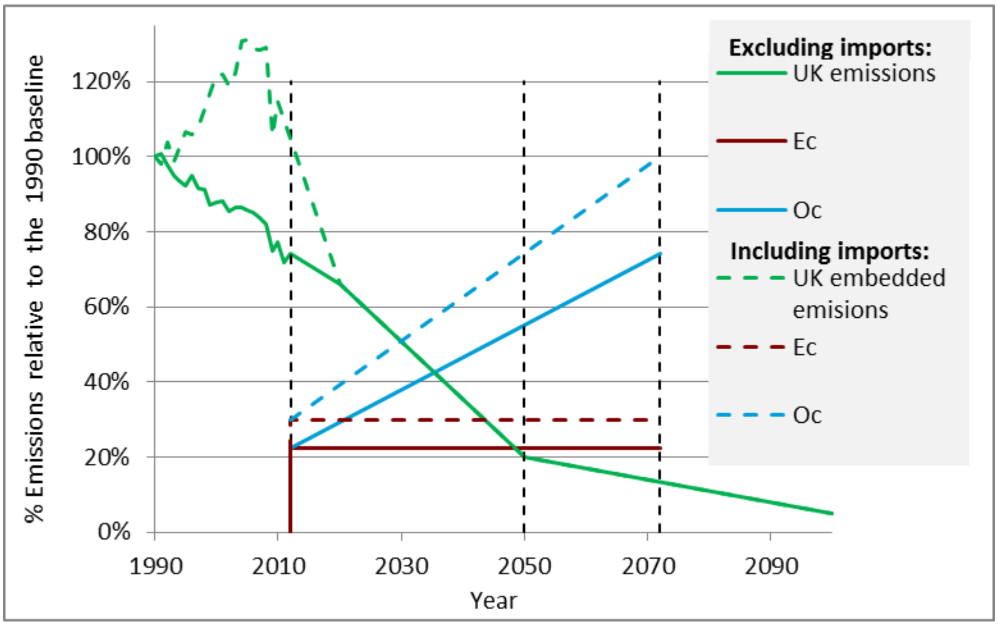

Fig.1: Typical building Ec and Oc profiles with UK emissions

The figure suggests that even if Oc is reduced to zero, Ec would need to be reduced by 10% to reach the 2050 80% target.

If we consider the current thinking for Oc reduction in terms of the ‘zero carbon’ definition for new homes, which applies to ‘regulated’ emissions only (space heating, hot water, fixed lighting and building services), and is estimated to be between half and two thirds of Oc, the required reduction in Ec rises to more than 85%. This ignores the issue of ‘allowable solutions’ which can effectively reduce the amount of regulated emissions which need to be included [8].

To make things worse, a recent report by the UK Committee on Climate Change [8] shows that actually, far from reducing GHG emissions since 1990, the UK has increased its emissions by more than 10% if ‘embedded emissions’ are considered, including imported materials and goods, with building emissions increasing by 2% over this period. This scenario is shown in dotted lines in Figure 1. If we assume that the 1990 and 2012 emissions are the same (an approximation) and we have made no effective reductions over this period, then if Oc is reduced to zero Ec would need to be reduced by around 30% to reach the 2050 80% target, or reduced to less than zero to meet the target implied by the ‘zero carbon’ definition.

The exact numbers used above can be debated, however, the example is sufficient to suggest that it is unlikely that emission targets can be met without substantial reductions in both Oc and Ec.

One of the main differences between the two is that Oc occurs over the lifetime of a building, for example 60years and 100years, which are commonly used metrics for the service life of buildings, whereas the bulk of Ec occurs at the start of a building’s life during the production of materials and components and building construction. So the timing of building emissions, and in some cases removals as with sequestered carbon during the production of biogenic materials such as wood, varies across the building life cycle.

Therefore, an important issue that needs to be addressed is the time value of these emissions, in other words do emissions that occur now have the same impact as emissions that occur in the future. Or conversely, are emissions avoided now more beneficial than emissions avoided in the future.

A time value for emissions could influence the decision making process when it comes to comparing mitigation measures which have benefits that occur at different times. An example might be the choice between building construction using low impact construction materials but with high operational impact versus building construction using high impact construction materials but with low operational impact.

As operational emissions reduce and further reductions become more difficult and costly, consideration of early embodied GHG reductions, rather than just future operational reductions may be more beneficial, particularly in view of the short 2020 and 2050 timeframes for GHG reductions in the UK.

2. Issues affecting time value

There are a number of time related issues which lead to the idea that emissions occurring at different times during the building life cycle should perhaps be valued differently. The issues considered in this paper are:

- the urgency of the need to achieve large emissions reductions over the next 7 to 37 years (by 2020 and 2050)
- the findings of the Stern Review [9] that the earlier effective action is taken, the less costly it will be
- future decarbonisation of energy supply and more energy efficient building equipment
- the reduced time that delayed emissions are present in the atmosphere during the assessment period
- the carbon cycle and the relationship between the release of GHG’s and their subsequent concentrations in the atmosphere over time

2.1 The urgency and cost savings by early effective action.

We need to achieve large emissions reductions over the next 7 to 37 years (by 2020 and 2050). If we don’t achieve these reductions we will probably have missed the chance of keeping global temperature below the 2°C target (with the likely extremely serious global impacts) and, because of the way emissions persist in the atmosphere and are only gradually re-absorbed, emission reductions after this date will not help to keep temperatures below this threshold. So it can be argued that the emission savings during the early life (the earlier the better) of buildings built today should be our first priority, and are therefore more valuable.

The Stern Review [10] demonstrated in economic terms, the need for early effective action. The Review estimates that if no action is taken the costs and risks of climate change will be equivalent to losing between 5% and 20% of global GDP each year from now and into the future. However, with effective action to reduce GHG emissions over the next 10-20 years this can be limited to around 1% of global GDP per year. Although the review findings were not universally accepted at the time (2006), they have been strongly defended [11] and more recent climate data indicates that the review, if anything, underestimated the risks, and the threats to economies [12].

Due to the time lag between taking actions and the effects, the costs of climate change mitigation measures taken now are borne by the present generation but future generations get the benefits and, because of the complexity, many of the effects and consequences are uncertain. So the issue is how to evaluate the costs and the benefits occurring at different times and by different generations.

In terms of economic appraisal, discounting is the generally accepted method of dealing with time, which involves discounting a unit of cost or benefit in the future relative to that unit now. This enables costs and benefits occurring at different times to be converted into a single ‘net present value’ (NPV) number for decision making. In this context, Stern has suggested that discounting is a slightly misleading term as it implies disregarding benefits in the future and has suggested it may be more helpful to describe the process as ‘intertemporal values and valuations’ rather than discounting.

Its application in the field of climate change appears to be very controversial with much debate over whether the use of a simplistic system of discounting is appropriate for the complex issue of climate change and what might be an appropriate discount rate to use [11], [12], [13]. Nevertheless, the consensus appears to be that discounting can be a useful tool to provide guidance in the appraisal of options for mitigating climate change.

The formula for net present value can be expressed as:

$$NPV = \sum_{1}^{n} C(1+i)^{-n} \tag{1}$$

Where C is the cost or benefit in year n at a discount rate of i.

Generally, a positive discount rate is assumed, which reduces the value of a unit of cost or a unit of benefit spent or received in the future in relation to the value of that unit today. The value reduces the further you go into the future and the level of the discount rate considered (generally between 3% and 8%) makes a big difference in assessing options with long-term effects, and therefore finding the correct discount rate for the benefits of reducing GHGs is crucial and is a complex subject giving rise to much disagreement even amongst economic experts.

It is useful to briefly consider the main justifications for discounting. These have been described as [12]:

- Future generations may be wealthier and as you get wealthier the same unit of cost becomes less significant. This leads to the difficulty of forecasting how much wealthier. The problem of climate change could be considered fairly unique in this sense, as it is partly the mitigation actions taken today which will determine the wealth of future generations, and it is by no means certain that they will be wealthier, particularly if only weak mitigation actions are taken.

- ‘Pure time’ discounting based on the idea that it is a natural preference to have a unit of income or benefit now rather than at some time in the future. The argument goes that we are in fact discounting the benefits to future generations just because they are in the future, which seems difficult to justify ethically. One seemingly justifiable reason for ‘pure time’ discounting is risk and uncertainty about whether future generations will continue to exist due to some catastrophic global event unrelated to anthropogenic climate change such as a nuclear war or a meteorite strike. It would seem reasonable to attach slightly less value to benefits occurring in the future over say the next one hundred years to account for the probability (although very low) of such an event happening.

- The ‘opportunity cost’ basis for discounting looks at future costs and benefits in relation to the level of return from other investment alternatives. On this basis, the discount rate for benefits and costs of a project would be at least as high as the expected market rate of return from the best alternative.

The choice of discount rate appears to be fairly subjective and is generally based on a combination of the above. The so called ‘Social discount rate’ (SDR) has been described as the measure used to help guide choices about the value of social projects. It is defined as ‘the appropriate discount rate to use in computing present discounted value for social investments.’ [14], [15], for example to estimate the value of infrastructure projects, schools, or environmental protection schemes. The SDR is used to put a value on both future costs such as maintenance or on future benefits such as reduced pollution emissions, and places less of an emphasis on the market ‘opportunity cost’.

Stern arrived at the relatively low overall value of +1.4%, which includes 0.1% ‘pure time’ discount rate, effectively valuing future generations equally with the current generation but assuming approximately a one in ten chance of the planet being destroyed by the end of this century.

Figure 2 shows discount factors, which can be applied to emissions occurring at different times during a building’s service life. A range of discount rates are shown to demonstrate how they influence the results. Using a discount rate of +1.4%, emissions at year 0 are roughly 2.3 times as ‘damaging’ as emissions at year 60 and 4 times as ‘damaging as emissions at year 100. Or putting it another way, emission savings in year zero are 2.3 times as ‘beneficial’ as those at year 60 and 4 times as ‘beneficial’ as those at year 100.

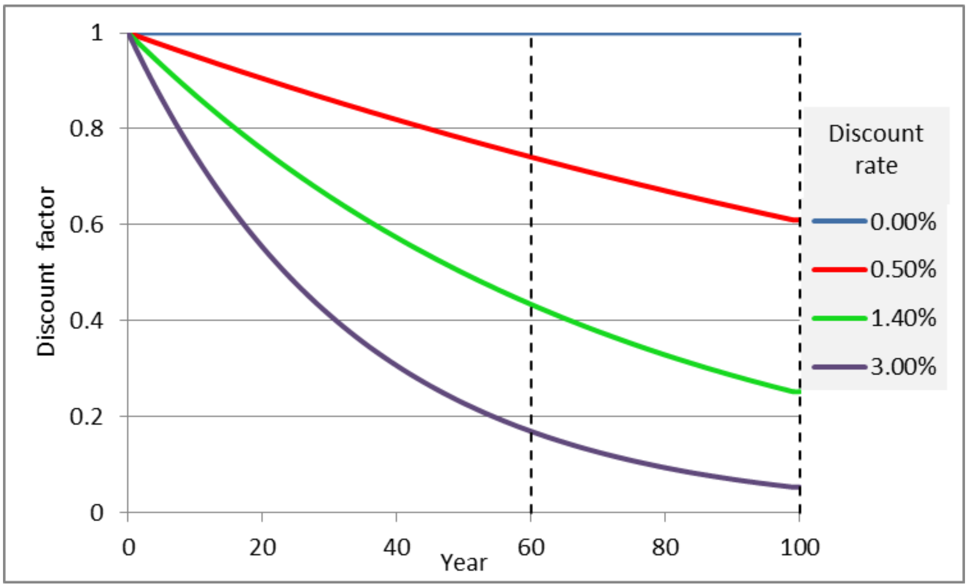

Fig.2: Discount factors for emissions occurring in the future

Assuming equal emissions per year, the NPV of all emissions for a given period is the area under the curve for that period multiplied by the annual emission. In the case of a discount rate of +1.4% and periods 0 to 60 years and 0 to 100 years, the NPVs are 68% and 54% of the non-discounted emissions.

The appropriate discount rate in relation to climate change is still a hotly debated topic amongst economists but the principle of discounting at some level appears to be generally accepted. For the purposes of this paper the methodology and rate put forward by Stern [10] are adopted which results in a discount rate at the low end of the range discussed in the literature. Adoption of a higher rate would give an even higher value to early embodied emission savings.

2.2 Future decarbonisation of energy supply and more energy efficient building equipment

Decarbonising the electricity supply is a key part of the UK's low carbon transition plan. The ambition is to reduce carbon intensity in line with the Markal scenarios [16], all with reductions of around 90% of the 2010 intensity by 2050, albeit at different rates. The 'mean' scenario is shown in Figure 3.

In 2011 electricity comprised approximately 33% of energy consumption in UK buildings resulting in 55% of emissions [6], [17]. Carbon intensity has already reduced by 35% (2011 figures) against a 1990 baseline. However, electricity use increased resulting in a net reduction in emissions of 16%.

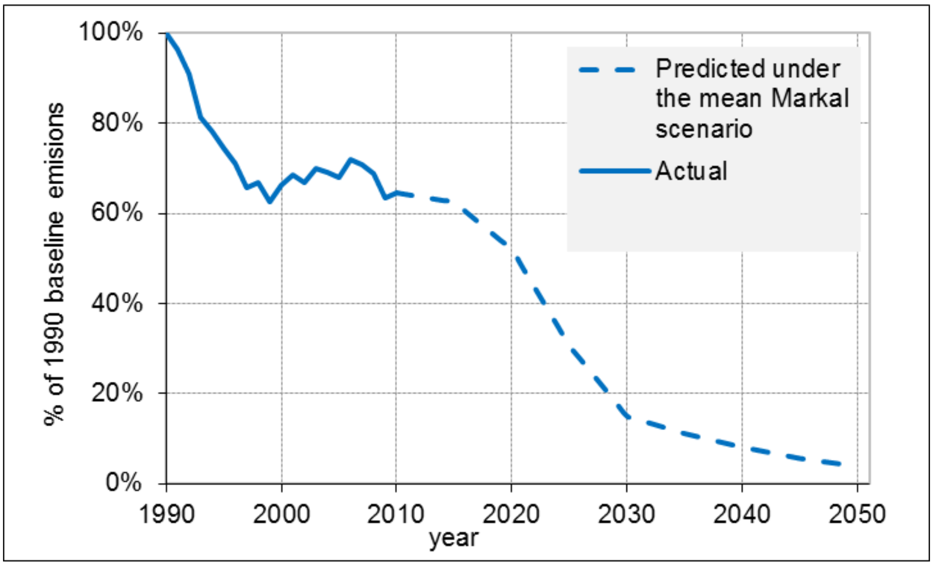

Fig.3: Carbon intensity of grid electricity – rate of reduction based on the mean of Markal scenarios

Gas comprised approximately 57% of energy consumption in UK buildings, resulting in 37% of emissions. There was particularly low gas consumption in 2011 due to a mild winter and more normal percentage emissions would perhaps be 50% from gas and 40% from electricity consumption.

Emissions from oil and solid fuel use were around 8%.

So the question is how will these emissions change in the future? Figure 4 shows emissions from the four main energy sources and the combined total from 1990 to 2011.

Crude linear trend lines have been added, together with the mean Markal profile for reduction of carbon intensity of grid electricity. The trend lines suggest that the UK will not even meet the overall 80% reduction target for all emissions by 2050, whereas, in actual fact the reduction in emissions from new buildings is required to be greater than 80% to make up for the existing building stock, of which a large proportion will still be in use in 2050, and other sectors of the economy, which will be unable to make the same level of reduction [15].

Any future increase in exploitation of shale gas is predicted to increase the carbon intensity of gas supply due to increased fugitive emissions, although the recent report from the Committee on Climate Change [9] has stated that improvements in extraction techniques could possibly maintain the current level of intensity. Overall, it seems unlikely that the carbon intensity of gas supply can be improved significantly and therefore reducing the reliance on fossil gas seems unavoidable.

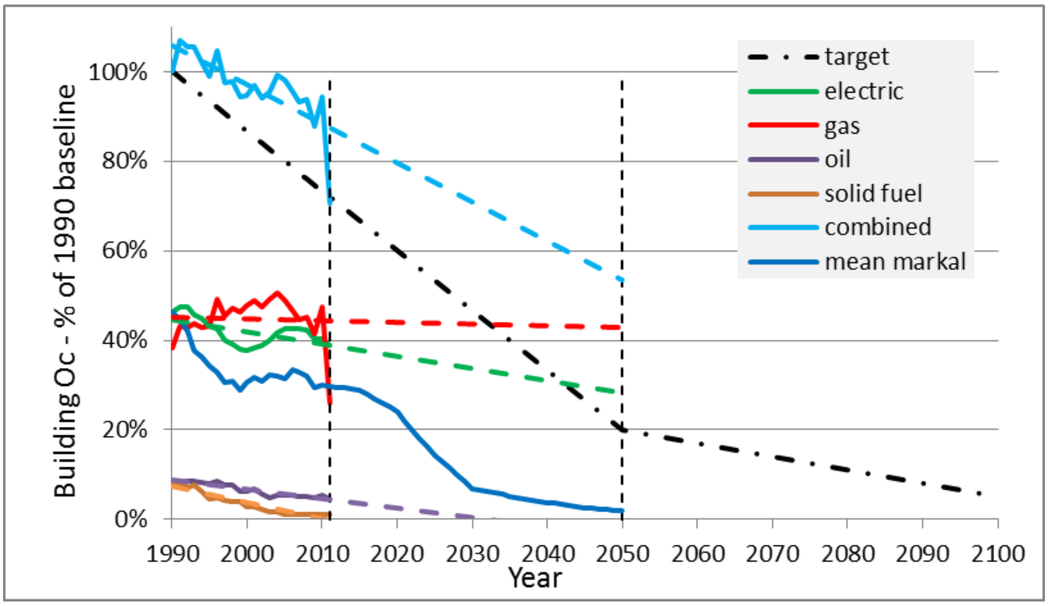

Fig.4: Building Oc- target, emissions from different energy sources, trends based on 1990-2011 emissions and mean Markal scenario for decarbonisation of grid electricity

Substantial changes in energy supply and energy use will be needed to achieve the sort of emission reductions required. These are likely to include: accelerating the reduction of carbon intensity of grid electricity in line with the Markal scenarios; reduced use of fossil gas and oil; more energy efficient replacement equipment in building upgrades and refits, increased use of biogenic fuel sources and consumer behaviour change.

For the purposes of this paper it is assumed, and some would argue we have little option, that the reduction of emissions from buildings built today will generally follow the path of the overall UK emissions, reducing by 80% from 1990 to 2050 and by 95% by 2100 [7], although predicting what reductions may be required at the end of the century can at best be described as somewhat speculative.

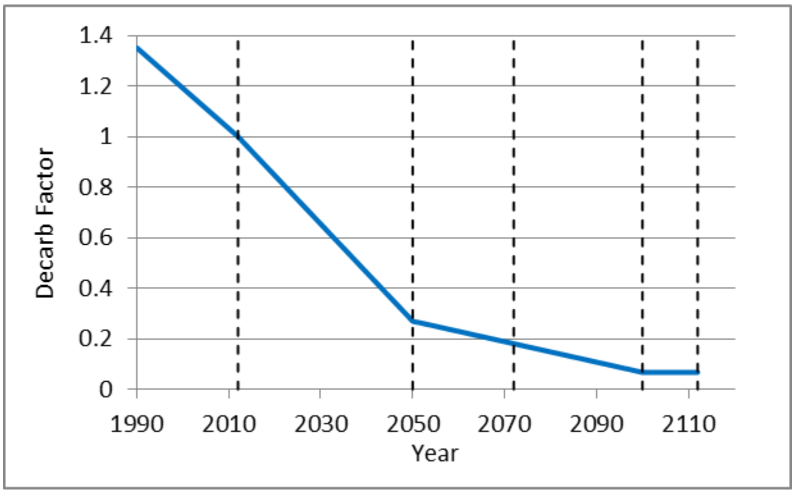

Fig.5: Factors to account for decarbonisation of energy supply

Figure 5 shows the resulting factors, adjusted in accordance with the previously stated premise that building emissions have already reduced towards their target by 26% in line with the overall UK reduction, giving a factor of 1 at the starting point of 2012/13. (1990 was the 100% level, 2012 the 74% 2050 needs to be the 20% level; this effectively means a reduction of 73% of the 2012 level by 2050).

Assuming equal emissions per year, the NPV of all emissions for a given period is again the area under the curve for that period multiplied by the annual emission. For periods 0 to 60 years and 0 to 100 years from 2012/13, the NPVs are 49% and 34% of the unfactored emissions.

2.3 Delayed emissions and the carbon cycle

British Standards Institute publication 'Publicly available specification, PAS 2050, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services' [19] states 'Emissions that are released over time through long use (e.g. light bulbs) or final disposal phases cannot be treated as a single release of emissions at the start of the 100-year assessment period. Therefore, these emissions must be calculated to represent the weighted average time in the atmosphere during the assessment period.'

In addition, all carbon, including anthropogenic carbon, released into the atmosphere is redistributed during the following decades and centuries between the three main reservoirs: atmosphere, ocean, and land biosphere. It is the increase in concentrations of carbon dioxide and other GHGs in the atmosphere, which leads to a rise in global temperature. Some of the anthropogenic carbon released into the atmosphere therefore, effectively 'decays' as it is gradually re- absorbed into the other two reservoirs.

The relationship between anthropogenic carbon emissions and atmospheric CO2 concentrations over time is described by 'the revised version of the Bern Carbon cycle model' [18], which is the basis for calculations of global warming potentials by the Intergovernmental Panel on Climate Change (IPCC).

A weighting factor to account for delayed emissions and 'decay' of atmospheric carbon can be described by Equation 2.

$$\mathit{Weighting\ \ factor} = \sum_{n=1}^{100} x_n (1 - 0.0068n - (3\times10^{-5})n^2) \tag{2}$$

Where n is each year in which emissions occur and x is the proportion of total emissions occurring in any year n.

A simplified version is used in PAS 2050 given by Equation 3.

$$\mathit{Weighting\ \ factor} = (\sum_{n=1}^{100} x_n (100 - n))/100 \tag{3}$$

The emissions from a building are analogous with the light bulb example and therefore it appears entirely consistent to consider emissions from buildings in the same way.

Plots of the IPCC equation and the simplified PAS 2050 version are shown in Figure 6. The areas under the two curves are approximately equal and therefore for annual emissions over a 100 year assessment period both equations give approximately equal total emissions but can differ for emissions not occurring over the full period.

A limitation with both equations is that they apply only to CO_2 emissions and GHG's with different decay characteristics may not be well represented, although the consideration of CO_2 equivalence for other GHG's goes some way to addressing this issue.

Assuming equal emissions per year, the NPV of all emissions for a given period is again the area under the curve for that period multiplied by the annual emission. For periods 0 to 60 years and 0 to 100 years the NPVs are 76% and 56% of the unfactored emissions using the IPCC equation and 70% and 50% using the PAS 2050 equation.

For the purposes of this paper the IPCC equation is used.

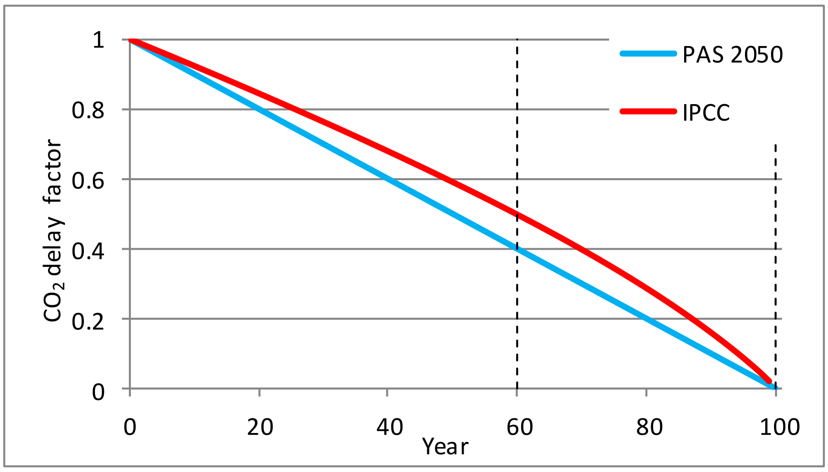

Fig.6: CO_2 delay factors

3. An overall time value of emissions

The overall time value of emissions can be calculated by first applying the decarb factor for the anticipated reductions in energy carbon intensity and energy demand due to energy efficiencies and behaviour change, followed by the decay factor allowing for the atmospheric decay of the resulting emissions, followed by the economic discount factor.

Figure 7 shows these three factors, together with the resulting combined factor and a proposed close fit curve.

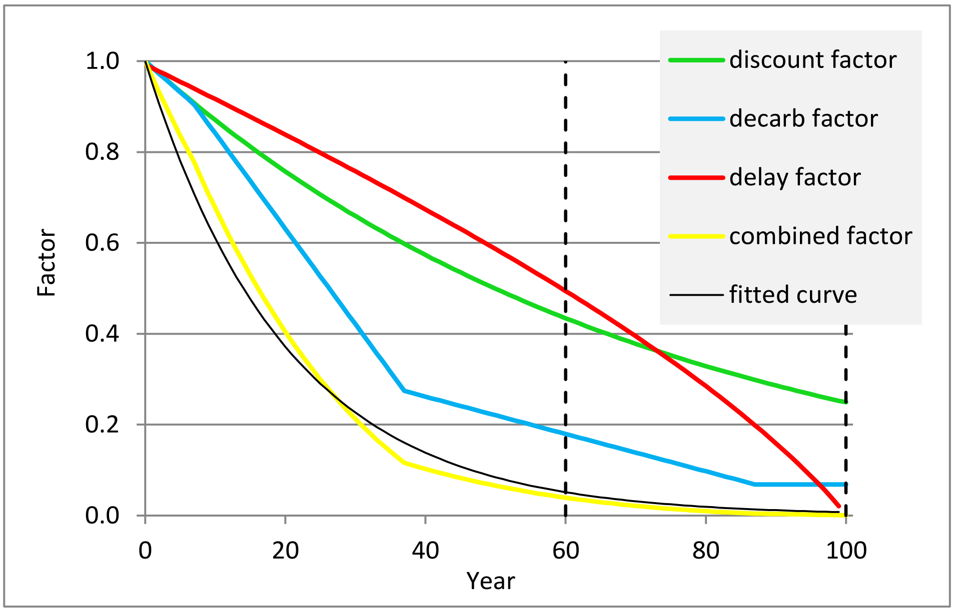

Fig.7: Combined factors for emissions occurring in the future

The close fit curve proposed here is represented by Equation 4

$$\text{Weighting factor} = \sum_{n=1}^{n} x_n e^{-0.0495n} \tag{4}$$

where n is each year in which emissions occur and x is the proportion of total emissions occurring in any year n.

Assuming equal emissions per year, the overall NPV of all emissions for a given period is again the area under the combined fitted curve for that period multiplied by the annual emission. For periods 0 to 60 years and 0 to 100 years the overall NPVs are approximately 32% and 20% of the unfactored emissions.

4. Discussion

There seems a strong case for putting a time value on emissions from buildings. Reduction of carbon intensity of energy supply is a reality and there is already a precedent for the principle of delayed emissions in PAS 2050. The likely economic benefits of early reductions have been clearly stated [10], and the urgent need to make substantial early emissions cuts over the next two or three decades is now the mainstream view.

The proposed time value put forward for discussion and comment in this paper is described by Equation 4. It is suggested that a time value factor (TVF) of this type could be a useful tool for assessing and prioritising building options to achieve the most beneficial overall GHG emissions outcome to minimise climate change impacts.

Figure 8 shows a simplified building emission profile (cumulative) with and without time value factors. This is based on a 30%:70% life cycle emission ratio between unfactored Ec and Oc. Applying the combined TVF changes the ratio to 64%:36%, an almost complete reversal.

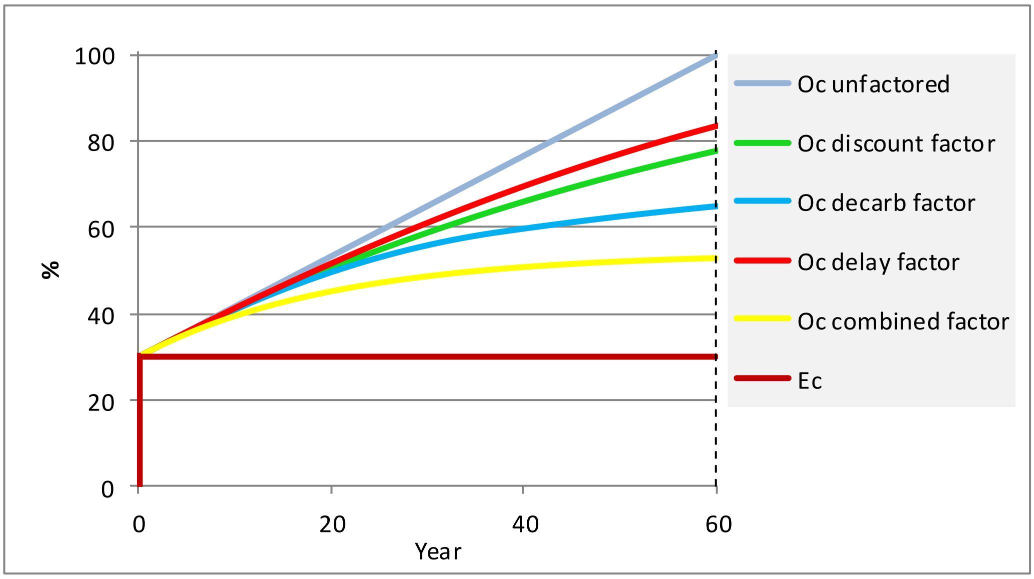

Fig.8: Typical building Ec and Oc unfactored and factored emission profiles over a 60 year service life

Table 1 shows the changes to the Ec:Oc ratio applying the separate TVFs and the final combined TVF for different unfactored ratios ranging from 10%:90% to 80%:20%.

Both the CO_2 and Decarb factors are themselves time dependant and would need to be updated over time.

The CO_2 factor is based on an atmospheric concentration of 378ppm, current at the time the Bern model was developed, but as atmospheric concentrations increase (the 400ppm level has recently been reached) up to the target maximum of 550ppm, the rate of decay may change.

The Decarb factor will need to be updated as the UK progresses down the carbon intensity curve.

Table 1: Unfactored and factored Ec:Oc ratios

Unfactored		Discount factor only		Delay factor only		Decarb factor only		Combined factor	
Ratio (%)		Ratio (%)		Ratio (%)		Ratio (%)		Ratio (%)	
Ec	Oc	Ec	Oc	*Ec*	Oc	Ec	Oc	Ec	Oc
10	90	14	86	13	87	19	81	26	74
20	80	27	73	25	75	34	66	44	56
30	70	39	61	36	64	47	53	57	43
40	60	50	50	47	53	58	42	68	32
50	50	60	40	57	43	67	33	76	24
60	40	69	31	66	34	76	24	82	18
70	30	77	23	75	25	83	17	88	12
80	20	86	14	84	16	89	11	93	7

5. Conclusions

It seems likely that substantial reductions in both Oc and Ec from new buildings will be required to meet the UK emissions targets.

The proposed time value equation could provide a useful tool for comparing different mitigation options giving benefits at different times during the building life cycle, for example when making comparisons between embodied and operational emissions.

A time value for emissions has implications for life cycle assessment methods used for evaluating embodied emissions for materials, products and complete buildings. Factored ‘end of life’ emissions have a much reduced influence and this suggests that ‘cradle to grave’ or ‘cradle to cradle’ assessments may give very similar results to ‘cradle to site’ assessments. If this is the case, embodied carbon calculations using very much simpler ‘cradle to site’ assessments could be justified.

When taken at face value, Oc usually appears to dominate and is the focus of reduction strategies. However, when appropriate allowances are made for future scenarios, reducing Ec is likely to be more beneficial, in terms of climate change, for most new buildings. Thus, giving higher priority to Ec reductions is likely to result in a bigger positive impact on climate change and mitigation costs.

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