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Act on CO2 Calculator: Public Trial Version

Data, Methodology and Assumptions Paper

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Contents

I. Summary

1. This paper outlines the data/factors that have been agreed for use in the public trial version of the Government's Act on CO_2 Calculator. Developing the calculator has required development and use of fuel emission factors, as well as the creation of a relatively simple, yet robust, methodology for estimating energy consumption, and hence CO_2 emissions, within the home and through personal travel. This work will feed into any further updates of domestic emissions factors for cross-government use as necessary.

II. Background

2. Defra has taken the lead on developing an integrated calculator, working closely with other Government departments. The Act on CO_2 Calculator covers both home and personal transportation, and is aimed at helping increase public understanding of the link between individual's actions and behaviour and CO_2 emissions and, hence, climate change. Consistency between the information datasets used for calculations across government is essential. Work on the calculator was seen as an opportunity to develop a consistent set of data and sources.

3. The public trial or "beta" version of the calculator is being launched in June 2007. Over the next months we will be evaluating and seeking feedback on the product, primarily through the feedback option on the calculator itself. The comments received will help inform development of the full release version.

4. The Act on CO_2 Calculator covers *annual end-user (direct) CO_2 emissions* from personal energy use in the home (i.e. space-heating, hot water and all electrical equipment) and for personal transport (i.e. cars/motorbikes, flights). Unlike many calculators, it also encourages users to input information about their lifestyles, to allow the tool to produce customised advice and recommendations based on the user's own circumstances. Life-cycle (indirect) emissions are not currently included, i.e. emissions resulting from waste disposal (or savings from recycling), or from the production of consumables, fuels, etc. We will be exploring whether and how to extend the coverage to life-cycle emissions in the future.

III. General Approach

5. The Act on CO_2 Calculator allows the user to choose, at the outset, whether to calculate his or her own *individual* CO_2 footprint or the footprint of his or her *household*.

6. The calculator also provides the user with two alternative methods of calculating their CO_2 total. The more accurate route is through the input of fuel bill data. However if this data is not available, (for example, the user may not be responsible for paying the fuel bill), the calculator will be able to infer the amount of CO_2 emissions from user responses to a number of general questions regarding the home and appliances within it, alongside their transport preferences.

7. These additional questions are asked, whether or not the bill data is available, in order to allow the calculator to place the user's footprint in the context of their particular property type and lifestyle and give them customised advice on how to reduce their footprint cheaply and effectively. An added advantage of this route is that the bill data can be split in the same proportions as the lifestyle data, and hence a breakdown of which elements of the user's Home and Appliances are using the greatest energy can be presented.

8. When the user is asked to input fuel bill data, they can choose to enter this information using a number of different options; i.e. in terms of either the amount of fuel used (typically kWh for electricity and gas, kg or litres for coal/biomass or oil/LPG respectively) and litres/gallons of petrol/diesel for vehicles, or the monetary cost of these fuels. This can be inputted as a monthly value (e.g. from an average monthly Direct Debit amount), a quarterly value or a yearly total. If kWh readings are given, a very accurate calculation of the total CO_2 emissions for the individual or household will be carried out. Information presented in terms of cost will also present the user with a figure that represents his or her total direct emissions CO_2 footprint.

9. However, if the user does not have bill information to hand he or she can still complete the calculator and receive an 'estimated' footprint. The calculating engine built specifically for the application infers energy consumption from the general answers the user supplies. In this option the user, on answering 'No' to the question regarding fuel bills, is taken directly to the lifestyle questions[1], without having to answer bill data questions, and is asked for information about home and appliance use (for details see following sections). From this information, the calculator is able to infer the user's typical CO_2 emissions. This method is based on in-built, generalised assumptions about average emissions for each type of home, appliance or travel mode and hence has limitations, but can give the user a first approximation of his or her footprint.

10. As with the first, bill-derived route, the calculator will use responses to these questions to generate individual, tailored recommendations on what the user can do to reduce their CO_2 footprint in the form of an Action Plan.

11. Through the Action Plan, users are encouraged to return to the calculator at a later date when they do have their bill information to hand. The calculator would then be able to work out a more accurate CO_2 footprint than the approximated value originally created for them.

[1] These are the same set of questions asked of users who have inputted their bill data. However, in this case the answers will be used to perform a calculation as well as to create a 'CO_2 Action plan' to help the user reduce their CO_2 footprint.

IV. Detailed Methodology and Data/Factors

12. The Act on CO_2 Calculator is divided into 3 main sections, namely:

- Heating, Hot Water and Lighting (Home)
- Household Appliances
- Personal Transportation and Flights.

Each sector has its own approach and characteristics within the calculation engine, dealt with under the following headings.

4.1 Heating and Hot Water (Home)

13. Based on the latest DEFRA and DTI datasets, space and water heating together are the largest single source of domestic CO_2 emissions, accounting for approximately 46% of all domestic emissions and 74% of total emissions from home energy use. Therefore it is crucial that these emissions are calculated with as great a degree of accuracy as possible.

14. The approach taken for the pubic trial version of the calculator is for CO_2 emissions from household energy use to be calculated directly from data provided by the user in the form of energy consumption or costs (e.g. from utility bills). Where this data is not available from the user, an alternative estimate is generated. These estimates are derived from look-up tables compiled using the Building Research Establishment's Domestic Energy Model (BREDEM) [2]. However, in the longer term it is proposed to use a direct calculation based on the current version (2005) of The Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP2005) and Reduced Data SAP (RDSAP2005), both of which are based on the BREDEM model.

15. As noted above, the more accurate version of the Home segment of the calculator simply requires annual metered fuel consumption data or household expenditure on energy to be entered, from which the amount of CO_2 emitted is calculated. This requires users to have actual readings from their utility bills/meters or knowledge of their annual or monthly expenditure on energy. If energy expenditure is entered then a default set of (annually) updated fuel and electricity prices is used to determine the actual energy consumed.

16. In parallel with the above calculation, or substituting for it if users do not have their energy use or their bill payments, the calculator uses a procedure to infer their 'typical' CO_2 profile for heating and hot water based on answers to a set of simple questions regarding their home environment.

17. For each question the user chooses from a series of pre-defined answers that give an indication of the size and type of home they live in. It is acknowledged that to ensure user engagement with the calculator, a balance must be struck between the number of questions asked and accuracy of results.

[2] Building Research Establishment Domestic Energy Model. This model (version 9 provides the basis of the SAP methodology, BREDEM-12 forms the basis of the National Home Energy Rating (NHER) scheme as well as generates the savings used to evaluate the impact of the Energy Efficiency Commitment (EEC).

Therefore, whilst it is possible to obtain a relatively accurate heating energy estimate with around thirty questions, this is far too many for the calculator considering that further user inputs are required for transport and appliance emissions. A set of questions, not numbering more than ten, has been employed in the heating section of the calculator; this will be reviewed with user feedback after launch of the public trial version.

18. This calculation derives inferred carbon emissions from look-up tables based on BREDEM modelling[3] of a range of different:

- property types, e.g. detached and terraced houses, flats, bungalows;
- sizes, derived from number of bedrooms;
- thermal performance characteristics, these being based on the approximate dwelling age which has a significant affect on the default thermal characteristics; and
- heating systems/fuels available in the UK .

19. The user simply selects the most appropriate combination of dwelling type and size, age and fuel/heating system and an estimated CO_2 value is returned. Coupled with information on the hot water and fixed lighting systems, the calculating engine works out the consequent CO_2 footprint for that home. If an individual footprint has been requested, the footprint is divided by the number of people in the household.

20. This method was the simplest to implement via a web platform given the timescale constraints for the release of the public trial version of the calculator. However, while relatively straightforward, to run it in real time a significant amount of energy modelling was required in advance to pre-fill the lookup tables needed in the calculation engine. This option provides a technologically straightforward solution given the timescales, allowing for development of a more flexible version in future.

21. Appendix A lists the conversion factors and fuel property information that are included in the calculator.

Behavioural indicators

22. In addition to the CO_2 calculation, it is the intention to provide additional personalised information / recommendations to the user on ways to reduce their carbon emissions. These include a number of measures with semi-quantified impacts, such as those indicated in Table 1 below.

[3] Tabulated energy consumption figures for use in a carbon calculator tool, Client Report 234810, BRE, January 2007.

Table 1: Examples of impacts of behaviour on carbon emissions

Action	KgC saved per year	Assumptions
Lower space heating temperature by 1°C	80	Per household, per yr. Heating fuel & property mix weighted average based on BREDEM modelling assuming a 10% reduction in space heating energy consumption
Turning off un-needed lighting when leaving room etc	10	Per household, per yr, based on MTP SP06 Reference scenario data & assuming a 10% saving in lighting energy is possible (DECADE 2MtC report, Environmental Change Institute 1997)

Future Development/Enhancement

23. The BREDEM model, upon which the SAP and RDSAP are based, already takes into account useful gains from occupants (metabolic gains) as well as those from lights, appliances and cooking. The value of these gains is proportional to the floor area of the dwelling. Further investigation of how these could be further factored into the calculations will be useful, especially with the risk of summer overheating (and potential need for cooling) as a result of high energy consumer electronics equipment such as flat panel TVs. Additionally, the potential loss of useful gains via the Heat Replacement Effect following the installation of more efficient lights and appliances could also be considered.

24. The SAP methodology is designed so that a dwelling in Scotland is rated the same in terms of its energy performance as an identical dwelling in the South West of England. However, in practice, for these two dwellings to maintain the same heating standard, they would use different amounts of energy due to the differing local climate. Therefore, to improve accuracy in emissions estimation, regional degree day data could be used to more closely align heating demand with local conditions, akin to a more complete BREDEM-12 calculation.

25. For future versions, weather compensation functionality could be considered. This would adjust the metered energy consumption, and therefore emissions, on the basis of the previous year's weather so that a 'true' picture of weather independent emissions could be presented.

4.2 Household Appliances

26. In making calculations on energy use and CO_2 emissions it is important to use consistent conversion factors and fuel properties for different fuels. The dataset produced for the calculator is based on the Defra's Conversion Factors[4] for carbon intensity, and largely on official government figures (from DTI) on other fuel properties. The dataset for all fuels is presented in Table 1 in

[4] DEFRA's Conversion Factors, released with the Company Reporting Guidelines (CRG) 2007, produced by AEA

Appendix A together with information sources. Although indirect (fuel cycle) emissions are not currently included in the calculator, they may be in future versions once agreement is reached on the values and sources of suitable factors.

27. Emissions from the use of electrical equipment are calculated directly from the grid electricity emission factor and the total kWh annual electricity use. The emission factor has been calculated from information in DUKES (2006) Table 5.6[5] on GWh supplied to the grid from major power producers and the total CO_2 emissions from these major power producers, factoring in the 7.5% grid losses indicated in DUKES. The figure for carbon emissions is 46.97MtC for major power producers from the UK Greenhouse Gas Inventory (GHGI) for 2005 (excludes crown dependencies and overseas territories to be consistent with DUKES).

Coverage of electrical equipment / appliances within the Calculator

28. The range of electrical equipment / appliances covered is limited by the extent of data availability. The Market Transformation Programme (MTP) funded by DEFRA is currently the most comprehensive data source available and focuses on the items responsible for the most energy consumed nationally. However, this does mean that very high energy use equipment in low circulation (e.g. outside patio heaters, heated swimming pools, etc.) are not covered. A list of the items covered in the Act on CO_2 calculator from this dataset is provided in Table 2:

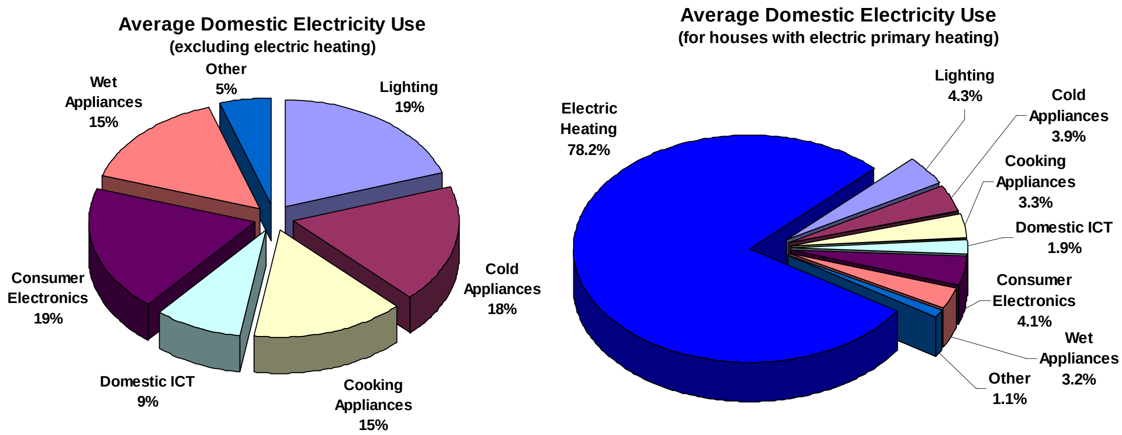
[5] DUKES (2006) Table 5.6: Electricity fuel use, generation and supply

Table 2 Appliances covered by Act on CO2 Calculator

1) Lighting a) Lighting **2) Cold Appliances** a) Fridges b) Freezer (upright or chest) c) Fridge-freezer **3) Cooking Appliances** a) Electric hob b) Electric oven c) Gas hob d) Gas oven e) Microwave	**4) Domestic ICT** a) Personal Computers (Desktops and Laptops) b) Printer c) Monitor **5) Consumer Electronics** a) External PSUs (power supply units) b) Set-top boxes c) TVs d) Video recorders (VCR / DVD / PVR) e) Digital radios (non MTP) **6) Wet Appliances** a) Dishwasher b) Tumble dryer (or washer-dryer) c) Washing machine (or washer-dryer)

29. The MTP stock model describes the stock and the age profile of a particular product type used in UK business or households. It contains historical information on demographic, technical, ownership and usage data to estimate energy consumption and emissions. Figure 1 shows the approximate apportionment of different electrical demands according to the MTP dataset (and taking into account additional demand from other items calculated from DUKES Table 5.3).

Figure 1: 2005 Average Domestic Electricity Use[6]



Data and calculations

30. The data available from MTP (via their online 'What-If Tool'[7]) on each of the pieces of electrical equipment from the list is too extensive to list easily in a table, but includes broadly, by year:

- Total national stock;
- Typical kWh per use and number of uses per year/week
  OR On-energy use from Watts (W) and load factor (hrs use/day); and
- Stand-by W and average number of hours/day.

31. In some cases equipment has more than one 'on-energy use' (e.g. washer-dryer for different temperature washes, and for drying setting) or stand-by power (e.g. PC equipment with on, 'sleep' – i.e. on but not active, or off/stand-by).

32. Also, in a number of cases, energy use figures are currently only available from the MTP dataset for the top energy-efficiency rated products (e.g. A++, A+ and A) and an overall average for 'Other'. Complete coverage is expected at a later date.

33. In all cases the average total annual kWh can be calculated for any given piece of equipment, and the resulting CO_2 emission calculated using the electricity emission factor. Values for stock/energy use for the average household (or per person) can be calculated from MTP statistics on the number of households (and number of people) in the UK, sourced from the Communities and Local Government Department.

34. Lighting calculations are also based on the MTP dataset.

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[6] Calculated from data from MTP, DUKES Table 5.3 and figures from BRE on the number of households with primary electric heating.
[7] Available at: http://www.mtprog.com/WhatIf.aspx

User-supplied detail

35. Users of the calculator will be able to select the number of pieces of equipment and either default average values for usage, or additional information on more specific use patterns (e.g. number of hrs/day or week, or number of uses per day/week) and in some cases the sub-category of equipment (e.g. efficiency rating, or technology type). The additional information can be used to generate a more tailored electricity use profile for these items. As already mentioned, energy usage is only available from the MTP dataset for the top energy-efficiency rated products in many cases presently. Information for the full range is expected to be available in the future and will be used to update the values currently used in the calculator. Appendix B lists the data items available for the domestic appliances featured in the current calculator.

36. Televisions can individually, for large flat-screen technologies, be one of the single highest annual energy consumers of the whole electrical appliance sector. It is possible to use information from the MTP's 'What-If Tool' dataset in conjunction with information on TVs to generate data on Watts/cm^2 (for in-use and stand-by) to allow more user specific indications of their household TVs (and use). Differences between the alternative technologies and varying screen sizes can be significant. This data is presented in Table 3, with stock average estimates used in the calculator in Table 4; these were calculated based on the MTP dataset.

Table 3: Average power consumption of new televisions and the average screen size of newly sold units.[8]

TV technology	Typical size, inch	Typical Aspect	On Power (W)	Watts per cm^2	Stand-by power (W)
CRT	28	4:3	120.1	0.04798	2.9
LCD	32	16:9	148.0	0.04667	1.7
Plasma	42	16:9	305.5	0.05592	3
Rear Projection	42	16:9	261.7	0.02227	2
All				**0.04791**	**2.5**

[8] Data provided by the Market Transformation Programme, January 2007

Table 4: Average power consumption of televisions for average UK 2006 stock by typical screen size categories (calculated from MTP dataset)

Size Category (inches)	On energy consumption, W (Average for 2006 stock)				Stand-by energy consumption, W (Average for 2006 stock)			
	CRT	**LCD**	**Plasma**	**Rear Projection**	**CRT**	**LCD**	**Plasma**	**Rear Projection**
<14	9.8	10.2			4.2	1.8		
14-19	32.2	35.8			4.2	1.8		
20-22	67.5	61.7			4.2	1.8		
23-25	88.2	81.6			4.2	1.8		
26-28	118.3	104.2			4.2	1.8		
29-33	154.5	157.9			4.2	1.8		
34-37	198.5	211.1	263.9	192.3	4.2	1.8	3.6	2.0
39-43		259.2	340.1	261.7		1.8	3.6	2.0
44-48		326.3				1.8		
49-53		385.5	482.0	370.9		1.8	3.6	2.0
54-58		466.5	583.2	448.8		1.8	3.6	2.0
59-64		555.1	694.0	534.1		1.8	3.6	2.0
65+		651.5	814.5	677.0		1.8	3.6	2.0

37. In addition to the specifically named appliances, there is a large number of other pieces of electrical equipment that might be included but which are currently not covered by MTP. Some of these will utilise external power transformer type plugs (ePSUs), similar to mobile-phone chargers and laptop chargers. An estimate, at a minimum, of the stand-by electricity consumption of such devices with ePSUs is made based on a user estimate of the number of such additional devices they have plugged in and switched on regularly.

Behavioural indicators and recommendations for reducing impact

38. In addition to the CO_2 emission calculations, the Act on CO_2 Calculator provides additional information/tips to the public on ways to reduce their carbon emissions through their use of appliances. These include a number of measures with semi-quantified impacts, such as those indicated in the following Table 5.

Table 5: Examples of impacts of behaviour on carbon emissions

Action	KgC saved per year	Assumptions
Switch-off/unplug 1 power supply type plug when not in use	5	Based on average 23 hrs/day stand-by, with an average 2006 stand-by power of 2.91W for power supplies (from http://whatif.mtprog.com/ProductData.aspx)
Part fill kettle instead of full 4 times a day	27	
Change 1 high-usage (e.g. living room) light bulb to a low energy one	47	
Dry clothes in spring summer on a clothes horse /on an outside line instead of tumble dry	99	Per household, per yr
NOT replacing standard 5 foot fluorescent Tube with set of 6 halogen spotlights	99	
Turn off standby on multiple appliances (also includes power supply type plugs)	173	Per house, per yr
Install solar panels	803	2kW installation

Future Development/Enhancement

39. In addition to the specifically-named appliances, there are a number of pieces of electrical equipment that are not currently listed, due to lack of coverage by MTP, but which may contribute significantly to individual household electricity consumption where used, for example, the following items[9] :

- Hi-fi Amplifier or Home Cinema AV Receiver and individual hi-fi/home cinema components and speakers;
- Outdoors electrical equipment with high or intensive energy use, such as water pumps, patio heaters, hot tubs, heated swimming pools, etc.;
- Additional kitchen appliances, e.g. food processors, blenders, coffee makers, etc.;
- Other high consumption or frequently used items, such as personal care equipment (such as hair dryers / curlers / straighteners), games consoles, etc.

40. Ways to incorporate/take into account such items in the calculator will be explored with MTP experts for possible future inclusion.

41. How to take into account the additional heating factor from use of electrical equipment will also be investigated and may be incorporated into a future version of the calculator.

42. Furthermore, additional work may be possible to provide a split of average energy use by size of cold appliances, where there is a significant range of energy use within existing efficiency bands due in part to the variation in sizes of equipment. This variation is not as significant in other energy rated appliances.

Subdivision of bill information

43. Where the user has supplied bill information which leads to a direct calculation of the carbon footprint, the footprint is subdivided to indicate the relative importance of each end use. This subdivision of the actual CO_2 is proportional to the split of emissions derived from the inferred calculation. This can only be confirmed for both home and appliances sections when all the relevant questions have been answered by the user, that is, at the end of the appliances section. It is important to note that the emissions from electricity have to be split between the home and appliance sections, because lighting (and where appropriate, electric heating) are allocated to “home”, and the rest to appliances.

4.3 Personal transport and flights

44. For transport, users will have two options for levels of input: for a basic (less accurate) calculation users may select from a series of default options, for example vehicle type and annual mileage/trips; for a more accurate result, more

[9] An indicative but not exhaustive list.

detailed information can be provided, for example, individual vehicle consumption (miles per gallon -mpg), or annual mileage. The detailed questions will enable a more precise calculation to be employed and enable provision of more personalised suggestions of ways for the user to reduce their emissions. Additional supplementary questions may also be answered to allow further personalisation of recommendations (e.g. on transport choices or driving behaviour).

45. For the basic calculations the approach is to use default average data developed for the updated DEFRA Conversion Factors. These were last updated in July 2005 and the revised factors for 2007 passenger transport are to be made available online, alongside the Company Reporting Guidelines, to coincide with the launch of the Act on CO_2 calculator. These figures have been updated from the previous 2005 factors using the following information:

1. For Cars based on average CO_2 from new car registrations from 1997-2005 from SMMT (Society of Motor Manufacturers and Traders), and adding a factor of 15% to account for 'real-world' effects on fuel consumption that act to increase values over 'official' type-approval values[10];
2. For aviation, based on more recent statistics on average journey length, and load factors (from DfT statistics) for air travel;
3. Additional information on fuel properties is sourced from DTI's annual DUKES[11] publication.

Conversion factors and fuel properties

46. In making calculations on energy use and CO_2 emissions it is also important to use consistent conversion factors and fuel properties for different fuels. As with the transport modal default assumptions, the dataset produced for the calculator is based on the Defra Conversion Factors (released alongside the Company Reporting Guidelines) for carbon intensity, and largely on official government figures (from DTI) on other fuel properties. The dataset for all fuels is presented in Table 1, Appendix C together with information sources. Although indirect (fuel cycle) emissions are not currently included in the calculator, they may be in future versions once agreement is reached on the values and sources of suitable factors. Relevant calculations will be performed using Net CV factors.

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[10] Effects include driving style, maintenance and tyre pressure, use of air conditioning, etc.

[11] Digest of UK Energy Statistics, see DUKES 2006 at:

http://www.dti.gov.uk/energy/statistics/publications/dukes/page29812.html

Cars

47. The calculator will allow essentially 3 options in increasing order of accuracy for users calculating their car CO_2 emissions from factors in gCO_2/km and total distance travelled per year (in km):

1) **Basic:** the user is asked to input fuel type and engine size and the system defaults to the figures based on the DEFRA Company Reporting Guidelines (see Table 2 in Appendix C).
2) **Detailed:** Additional information is provided on either:
    a. the car's official MPG (miles per gallon) (and a 15% is applied to convert CO_2 calculated from fuel consumption to typical 'real-world' data); or
    b. the actual average MPG as observed from driving the vehicle (from trip computer /dashboard reading or better calculated from volume of fuel and distance travelled).

48. For the basic calculation the dataset used is based on the Conversion Factors annexed to the 2005 Company Reporting Guidelines, modified to take into account SMMT data on car registrations and CO_2 emissions from 1997-2005 and with a 15% uplift factor to take into account 'real-world'[12] impacts on fuel consumption. Default average annual mileage figures are used with these for the basic calculation. For the detailed calculation the user may input his or her own annual mileage.

49. No official figures are readily available for motorcycles and mopeds, so there will only be the option to use average data or user-supplied actual MPG data.

Public transport (bus, taxi, train, underground)

50. We have excluded public transport options from the public trial version of the calculator. The justification for this decision is two-fold: first there is no simple way of helping the user quantify their use of public transport and there is a desire to keep the number of questions to a minimum. Second, the result would not be essential from the perspective of identifying potential for reductions in emissions. However, public transport will be considered for future versions for completeness in the detailed calculations. And use of public transport, cycling and walking are included in the recommendations for reducing one's travel-related CO_2 footprint.

Flights

51. The methodology is based on the user inputting the number of different single or return flights (domestic, international short- and long-haul) and using default average factors for CO_2 emissions and flight distance. Work is ongoing

[12] 'Real world' effects not accounted for in test-cycle based emission factors includes: use of accessories (air con, lights, heaters etc), vehicle payload (only driver +25kg is considered in tests, no passengers or further luggage), poor maintenance (tyre under inflation, maladjusted tracking, etc), gradients (tests effectively assume a level road), weather, more aggressive/harsher driving style, etc.

to develop suitable methods for a detailed calculation based on inputting actual origin and destination airports and factors more tailored to the resulting variation in flight distance and this may be included in later versions of the calculator. In both cases calculations are based upon emission factors per passenger-km (for domestic, international short- and long-haul), with an additional factor of 9% (8.2.2.3 of IPCC's 1999 report on aviation[13]) added to take into account delays and indirect flight paths. Non-CO_2 effects such as from Radiative Forcing from NO_x and water vapour emissions are not factored into the calculation on the advice of DEFRA's aviation consultant[14] and others. This is because of the uncertainty and ongoing scientific research and debate around the scale of these wider impacts. Explanatory text can be found in Appendix D. However, the calculator Frequently Asked Questions and Action Plan pages highlight the wider impacts of aviation, and note that the Government currently uses a Radiative Forcing factor of 2 when offsetting ministerial and official flights.

Behavioural indicators and recommendations for reducing impact

52. In addition to the CO_2 calculation, it is the intention to provide additional information / recommendations on ways to reducing CO_2 emissions from personal transport. The Transport Direct journey planner (www.transportdirect.info) already provides some tips on reducing fuel consumption and CO_2 emissions. These include a number of measures with semi-quantified impacts, such as those indicated in the following Table 6.

[13] "Aviation and the Global Atmosphere" available at:
http://www.grida.no/climate/ipcc/aviation/121.htm#8223

[14] Professor David Lee, Director, Centre for Air Transport and the Environment (CATE), Manchester Metropolitan University

Table 6: Impacts of driving behaviour on fuel consumption for cars

Measure	Impact on fuel consumption	Notes	Source
Tyres under-inflated	1% increase	Fuel consumption increase per 3 PSI under inflation (roughly 10% as typical pressure is 30-35 PSI)	EST (reference SenterNovem, Netherlands)
Air conditioning	5% increase	Increase in fuel cons over average mixed annual usage	EST (reference ADEME, France)
	Up to 20-25% increase	Increase in fuel cons with aircon on full power	EST (reference ADEME, France)
Eco-driving	Up to 5-10% decrease	Smooth acceleration and braking, avoiding excess speed	EST
Driving at 60mph instead of 70mph	Up to 9% decrease	Based on speed-dependent emissions calculations from NAEI	EST (AA motoring trust)

53. Other supplementary information may also be provided on impact reduction. These examples would be calculated on the basis of comparisons using the default emission factors, or could in a future version be tailored to an extent depending on the level of detail provided by the user. The Act on CO_2 Calculator also points the user to DfT's Transport Direct journey planning website for comparisons between different modes for individual journeys.

Future Development/Enhancement

54. There are several areas for possible future development and enhancements. For each particular enhancement an assessment will need to be made of the likely complexity versus potential improvement in accuracy. Future development might look at some of the following areas:

- Considering how /whether to include public transport;
- Improving calculations/emission factors within different modes of public transport (e.g. particularly for rail and potentially for buses too);
- Allowing car users to identify their vehicle by car class, rather than small, medium or large;
- Revisiting the approach taken with regards to non-CO_2 impacts of aviation from Radiative Forcing if/when new evidence/research becomes available;

- Investigating the possibility to include life-cycle emissions; and
- Considering the inclusion of weighting factors to take into account differences between different aircraft cabin classes (First, Business, Economy+ and Economy).

55. Changes to transport factors are unlikely to be required on an annual basis for all modes, although they will need to be kept under review to reflect any significant changes in technology or vehicle fleet composition. We will update the emission factors used to be consistent with any new factors developed for the Transport Direct site. It will also be necessary to involve appropriate members of the NAEI (National Atmospheric Emissions Inventory) team to ensure consistency with the National Greenhouse Gas Inventory assumptions.

V. National Averages

56. To provide a benchmark for users of the Act on CO_2 calculator to compare themselves against, 'National Average' figures were developed for the average household and average individual. These factors were developed to be consistent with the coverage of the calculator, so only include direct emissions from the areas covered in the home, appliances and travel sections. The factors used in the calculator are presented in Table 7, with an explanation of the basis of these figures in the following sections.

Table 7: National Average personal CO_2 emissions used in the Act on CO_2 calculator

National Average Direct Emissions	Household kgCO_2	Individual kgCO_2	%
Home	4,569	2,004	44.7%
Appliances	1,556	683	15.2%
Travel	4,096	1,796	40.1%
TOTAL	**10,221**	**4,483**	**100.0%**

57. In the UK in 2005 the population was 59.5 million and the number of households was 25.8 million, with an average occupancy of 2.3 people.

5.1 Home

58. The national average emissions for space and water heating are estimated using energy consumption data supplied by DTI. This data is sourced from Table 3.7 in DTI's publication Energy Consumption in the UK[15]. This details domestic energy consumption by end use and fuel. The standard emission factors used within the calculator for home heating are then used to estimate an emissions total for this sector. This total is then distributed equally over all UK households.

59. The average emissions for household lighting were calculated from total national kWh for domestic lighting from the MTP (2006) dataset provided in their publication 'Sustainable Products 2006: Policy Analysis and Projections'[16].

5.2 Household Appliances

60. The national average emissions for appliances were calculated from MTP (2006) dataset on energy use for domestic appliances[17], plus additional emissions estimated for other electricity use not covered in the MTP dataset – these are presented in Table 8. MTP estimates that their stock model covers about 95% of total domestic electricity use from lighting and appliances, so this other electricity was estimated to equal the remaining 5%.

Table 8: 2005 Energy Use from Domestic Appliances

Category	GWh
Lighting	17,975
Cold Appliances	16,220
Cooking Appliances (gas)	7,381
Cooking Appliances (electricity)	13,674
Domestic ICT	7,942
Consumer Electronics	17,367
Wet Appliances	13,600
Other electricity	4,567

[15] Available at: http://www.dti.gov.uk/energy/statistics/publications/ecuk/page17658.html

[16] Available at: http://www.mtprog.com/ReferenceLibrary/MTP_SP06_web.pdf

[17] For the categories of cooking, cold appliances, wet appliances, domestic ICT, consumer electronics.

5.3 Personal Transport and Flights

Cars and motorbikes

61. Average household and individual personal car and motorbike emissions were calculated from the direct CO_2 emissions from cars and motorbikes from data provided on Defra's environment statistics web pages for the UK Greenhouse Gas inventory (GHGI) for 2005[18]. The portion of total national car CO_2 emissions was estimated as 88%, on the basis of DfT statistics from the National Travel Survey 2005[19] (NTS 2005) on the proportion of all 4-wheeled car's mileage by purpose (i.e. business, commuting and other private mileage).

Flights

62. The total CO_2 emissions by UK residents from personal domestic and international flights are more difficult to accurately estimate. CO_2 from domestic flights is readily available in the UK GHGI. However, data on CO_2 emissions for international flights is only available in the GHGI resulting from 'aviation bunkers', which are based on the supply of aviation fuel to aircraft in the UK. This therefore represents only the fuel supplied to aircraft on the first leg of their outward flights from the UK and not the return flights. Such flights will obviously also include passengers who are non-UK residents. An indicative estimate of the CO_2 from personal flights for UK residents was estimated from the aviation bunkers using detailed data on flight destinations and purpose from the international air passenger survey.[20] At the moment the current estimate used in the calculator may be a slight under-estimate because a satisfactory methodology is yet to be developed for capturing the CO_2 from flights by UK residents between destinations outside of the UK. However, this additional CO_2 would not be expected to make a large difference to the current estimate.

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[18] Available at: http://www.defra.gov.uk/environment/statistics/globatmos/gagccukem.htm, with the estimated emissions of carbon dioxide (CO_2) by IPCC source category, type of fuel and end user: 1970-2005, available at: http://www.defra.gov.uk/environment/statistics/globatmos/download/xls/gatb05.xls

[19] National Travel Survey Table 6.1 'Annual mileage of 4-wheeled cars by type of car and trip purpose: 1995/1997-2005': http://www.dft.gov.uk/pgr/statistics/datatablespublications/personal/mainresults/nts2005/nationaltravelsurvey2005

[20] More information on the International Passenger Survey is available at: http://www.statistics.gov.uk/ssd/surveys/international_passenger_survey.asp

Conversion factors and fuel properties for Heating, Hot Water, Lighting and Appliances

1. In making calculations on energy use and CO_2 emissions it is important to use consistent conversion factors and fuel properties for different fuels. The dataset produced for the calculator is based on Defra's Conversion Factors[21] for carbon intensity, and largely on official government figures (from DTI) on other fuel properties. The dataset for all fuels is presented in Table 1 together with information sources. Although indirect (fuel cycle) emissions are not currently included in the calculator, they may be in future versions once agreement is reached on the values and sources of suitable factors. Factors relevant to home heating and hot water have also been included in the table.

2. Emissions from the use of electrical equipment are calculated directly from the grid electricity emission factor and the total kWh annual electricity use. The emission factor has been calculated from information in DUKES (2006) Table 5.6[22] on GWh supplied to the grid from major power producers and the total CO_2 emissions from these major power producers, factoring in the 7.5% grid losses indicated in DUKES. The figure for carbon emissions is 46.97MtC for major power producers from the NAEI for 2005 (excludes crown dependencies and overseas territories to be consistent with DUKES). Gross Calorific Values (CV) are presented for information only. Relevant calculations will be performed using Net CV factors.

[21] DEFRA Conversion Factors, released with the Company Reporting Guidelines (CRG) 2007, produced by AEA

[22] DUKES (2006) Table 5.6: Electricity fuel use, generation and supply

Table 1: Basic fuel properties and carbon intensity

Fuel	Energy density (GJ/tonne)		Physical density (litres/tonne)	Carbon intensity ($kgCO_2/GJ$)	EF	Units	Source			
	Net CV	Gross CV					NCV	GCV	Density	CO_2-direct
Stationary										
Grid Electricity					0.527	$kgCO_2/kWh$				(4)
Natural Gas	47.78	53.09	1340651	57.17	0.206	$kgCO_2/kWh$	(1)	(1)	(3)	(5)
Gas Oil	43.39	45.67	1193	73.53	0.265	$kgCO_2/kWh$	(1)	(1)	(2)	(5)
Fuel Oil	41.33	43.50	1033	77.99	0.281	$kgCO_2/kWh$	(1)	(1)	(2)	(5)
Burning Oil (domestic paraffin/kerosene)	43.90	46.21	1250	71.73	0.258	$kgCO_2/kWh$	(1)	(1)	(2)	(5)
Coal	25.56	26.90		99.72	2.548	$kgCO_2/kg$	(1)	(1)		(5)
LPG	47.06	49.53	1354	43.04	1.496	$kgCO_2$/litre	(1)	(1)	(5)	(5)
Biomass	18.0			6.94	0.129	$kgCO_2/kg$	(6)			(7)

Source:

(1)	DUKES Table A.1	
(2)	DUKES Annex A	
(3)	Derived from components	
(4)	Based on 46.97 MtC for major power producers from NAEI for 2005 (excludes overseas territories and crown dependencies to be consistent with DUKES), divided by 'Major power producers' (supplied - gross) plus 'Other generators' thermal and non-thermal renewables supplied from Table 5.6 and total losses of 7.5% from paragraph 5.49 DUKES 2006	
(5)	NAEI/Defra Conversion Factors, 2007	National Atmospheric Emissions Inventory / Defra Conversion Factors, released alongside the Company Reporting Guidelines, 2007
(6)	WE, 2007	Wood Energy.IE website for dry wood: http://www.woodenergy.ie/iopen24/defaultarticle.php?cArticlePath=5_29
(7)	SAP2005, Table 12	

Data and calculations

3. The data sets and calculations are in fact more complex for the non-bill driven calculation than for the version which would simply require details of the units of energy used or amount spent. Where actual energy consumption is collected, flexibility is required with regard to the units of measurement. Electricity consumption is straightforward (kWh), however, gas readings could be supplied direct from a meter that may record in m^3; litres would be needed for oil/LPG and kg for solid fuel/LPG/biomass.

4. For the non-bill driven calculation, look-up tables using BREDEM modelling provide the required CO_2/carbon emissions. These tables use property type, size, age and heating system and fuel to derive delivered energy and emissions.

User-supplied detail

5. The bill-driven calculator requires details of energy/fuel consumed, how the home was heated (space & water). From this data and appropriate conversions or emission factors for different consumption units it is possible to calculate the CO_2 emitted over the year. An indication of the relative proportions of each emission source can be provided based on modelled predictions together with the results from the appliances section of the calculator. This being given mainly based on the age of the property and the base inferences that result from this.

6. Regardless of the methodology chosen; users have to select various attributes about their dwelling. It is critical that the questions are easily understood with suitable help text and that the user's engagement is retained throughout the process to ensure that any details provided are as accurate as possible.

Appendix B

Table 1: Detailed electrical appliance technology coverage (also by year) (a subset of the MTP database)

Area / Appliance	Sub-categories	Additional Dimensions
Cold Appliances		
Fridges	(A++ to A), Other	On-energy demand (W)
Freezer (Upright/Chest)	(A++ to A), Other	
Fridge Freezer	(A++ to A), Other	
Cooking Appliances		
Electric oven	All	Energy per use (kWh), stand-by (W)
Gas oven	All	Energy per use (kWh), stand-by (W)
Electric hob	Induction Other	Energy per use (kWh), stand-by (W)
Gas hob	All	Stand-by (W)
Kettle	All	Energy per use (kWh), stand-by (W)
Microwave	All	On-energy demand (W), stand-by (W)
Domestic ICT		
Personal Computers	Desktop + Monitor Laptop	On-energy demand (W), sleep, stand-by (W)/off
Printer	Inkjet Laser	On-energy demand (W), sleep, stand-by (W)/off
Consumer Electronics		
External PSUs (Power Supply Units)	ePSUs 0.5W - 3.5W	Stand-by (W) (no info on on-energy)
Set-top boxes	Cable STB Satellite STB Freeview STB	On-energy demand (W), stand-by (W)
TVs	CRT TV Plasma TV	On-energy demand (W), stand-by (W), size

Area / Appliance	Sub-categories	Additional Dimensions
	LCD TV Rear Projection TV	
Video recorders	DVD VCR PVR (with Hard Disk)	On-energy demand (W), stand-by (W)
Wet Appliances		
Dishwasher (Normal - 65oC)	All	Energy per use (kWh), stand-by (W)
Dishwasher (Eco - 55oC)	All	Energy per use (kWh), stand-by (W)
Tumble-dryer	All	Energy per use (kWh), stand-by (W)
Washer-dryer (40oC)	(A+ to G), Other	Energy per use (kWh, wash), Energy per use (kWh, dry), stand-by (W)
Washer-dryer (60oC)	(A+ to G), Other	
Washer-dryer (90oC)	(A+ to G), Other	
Washing machine (40oC)	(A+ to G), Other	Energy per use (kWh), stand-by (W)
Washing machine (60oC)	(A+ to G), Other	
Washing machine (90oC)	(A+ to G), Other	

Appendix C

Table 1: Basic fuel properties and carbon intensity for transport fuels

Fuel	Energy density (GJ/tonne)		Physical density (litres/tonne)	Carbon intensity ($kgCO_2$/GJ)	EF	Units	Source			
	Net CV	Gross CV					NCV	GCV	Density	CO_2-direct
Transport										
Diesel (DERV)	43.39	45.67	1203	72.93	2.630	kgCO2/litre	(1)	(1)	(2)	(5)
Petrol (motor spirit)	44.69	47.04	1354	69.74	2.315	kgCO2/litre	(1)	(1)	(2)	(5)
Aviation Spirit	44.99	47.36	1401	69.52	2.232	kgCO2/litre	(1)	(1)	(2)	(5)
Aviation Turbine Fuel (kerosene)	43.91	46.22	1251	71.73	2.518	kgCO2/litre	(1)	(1)	(2)	(5)
Biodiesel (FAME)	37.20	41.04	1124	32.745	2.496	kgCO2/litre	(6), (8)	N/A	(6)	(6)
Biodiesel (BtL) /Synthetic diesel (GtL)	44.00	46.31	1282	10.915	2.431	kgCO2/litre	(6), (8)		(6)	(6)
Bioethanol	26.80	29.25	1250	14.248	1.530	kgCO2/litre	(6), (8)	N/A	(6)	(6)
CNG (200bar)	47.78	53.09	5714	51.45	2.732	kgCO2/kg	(1)	(1)	N/A	(5)

Source:

(1)	DUKES Table A.1	
(2)	DUKES Annex A	
(3)	Derived from components	
(5)	NAEI/Defra Conversion Factors, 2007	National Atmospheric Emissions Inventory / Defra Conversion Factors, released alongside the Company Reporting Guidelines, 2007
(6)	JRC WTW, 2006	EC JRC/EUCAR/CONCAWE Well-To-Wheels Study, 2006 update
(8)	Assumption based on EC JRC/EUCAR/CONCAWE Well-To-Wheels Study, 2006 update and other published research. -55% for RME on diesel up to 2015 then -85% for BtL diesel. -80% for bioethanol on petrol emissions.	
(9)	Factor of LNG 2.21m3/t from IEA Automotive fuels survey, Raw materials and conversion, 1996.	
(a)	Includes reduction on direct emissions due to negative net fuel cycle emissions for biofuels.	

1. For the basic calculation the following dataset in Table 2 is proposed, largely based on the conversion factors annexed to the original Company Reporting Guidelines, with an uplift factor of 15% to take into account 'real-world' impacts on fuel consumption. This factor is consistent with information from several sources including the IEA, EST[23] and recent research by TUEV Nord for the German Environmental Agency[24].

Table 2: Default emission factors – personal transport (cars, motorcycles and mopeds)

Vehicle Type	Engine size	Size label	gCO_2/km	MPG	Source	Average annual miles	Source
Petrol car	< 1.4 l	Small	183	35.5	(1)	9000	(1)
	1.4 - 2.0 l	Medium	216	30.1	(1)	9000	(1)
	> 2.0 l	Large	296	21.9	(1)	9000	(1)
Average petrol car			**210**	**31.0**	(1)	9000	(1)
Diesel car	< 1.7 l	Small	151	49.3			
	1.7 - 2.0 l	Medium	188	39.5	(1)	9000	(1)
	> 2.0 l	Large	263	28.2	(1)	9000	(1)
Average diesel car			**199**	**37.4**	(1)	9000	(1)
Hybrid petrol-electric car		Medium	126.2	51.5	(2)	9000	(1)
		Large	224.0	29.0	(2)	9000	(1)
Average car			205.9	32.5	(3)	9000	(1)
Mopeds/Scooters	<125cc		73	89.2	(4)	5500	(5)
Medium Motorcycles	125 to 500cc		94	69.5	(4)	5500	(5)
Large Motorcycles	>500cc		129	50.6	(4)	5500	(5)

[23] A factor of 15.5% is quoted by EST, based on information from ARVAL - the UK's biggest fuel card operator and comparable to the 15% factor used by the IEA in their modelling.

[24] Investigations for an Amendment of the EU Directive 93/116/EC (Measurement of Fuel Consumption and CO2 Emission). Study by TUEV Nord Mobilitaet GmbH & Co.KG, Institute for Vehicle Technology and Mobility. Carried out by order of the German Environmental Agency (UBA). November 2005.

Sources:

(1)	Based on previous Conversion Figures annexed to Company Reporting Guidelines, scaled to SMMT data from registrations 1997-2005 and uplifted by 15% to take into account 'real-world' impacts on fuel consumption.
(2)	Factors for medium hybrids are typical for average of Toyota Prius and Honda IMA type hybrid - type approval (NECD test-cycle) data up-scaled to real-world value using 15% value agreed with DfT. Factors for large hybrids are based on the average of the Lexus GS450h and RX400h.
(3)	Calculated from emission factors for small-large cars, weighted according NAEI car vkm for 2004.
(4)	Values based on data reproduced from EC JRC /ACEM (Association of European Motorcycle Manufacturers): http://www.acembike.org/motorcycles&society/pressreleases/MS3-Environment-LMercanti.pdf
(5)	DfT Statistics (Transport Statistics Great Britain, 2006)

2. Calculations for cars are performed on the following basis:

Annual CO_2 emissions for each vehicle = actual gCO_2/km x annual km
Actual gCO_2/km = manufacturer data (test cycle) gCO_2/km x 115%

Or actual mpg (from dashboard display or calculated from fuel consumption and mileage) converted to gCO_2/km using the appropriate fuel factors

3. Often no official figures are readily available for motorcycles and mopeds, so it is likely there will only be the option to use average data or user-supplied actual MPG data.

Appendix D

Average Emission Factors and Flight Distances

1. The proposed emission factors and average flight distances are presented in Table 1 (revised from those annexed to 2005 Defra CRG). Total CO_2 emissions are calculated using the number of each type of flight (x 2 for return) taken for the year and the gCO_2 and average journey distance factors.

Table 1: Default factors for domestic and international flights

Flight type	gCO_2 /pkm	Calculation Assumptions	Source	Av. journey distance for calculator, km	Example journey
Domestic (B737-400 and Dash 8-Q400)[25]	158	0.65 load factor[26] and average journey length 250nm (463 km)	(1)	425	London - Scotland
Short haul international (B737)	130	0.65 load factor[27] and average journey length 500nm (926 km)	(2)	1200	UK – Central Europe
Long haul international (B767-300ER and B747-400)	105	0.797 load factor[28] and average journey length 3500nm (6482 km)	(2)	7,000	UK – East Coast USA

Notes:

- These emissions factors are intended to be an aggregate representation of the typical emissions per passenger km from illustrative types of aircraft for the 3 types of air services. Actual emissions will vary significantly according to the type of aircraft in use, the load etc.
- They do not include radiative forcing i.e. non-CO_2 climate change impacts and are based on great circle distances.

Sources:

(1)	Modified from methodology used for conversion factors annexed to 2005 CRG to take into account shorter flight path compared to average short-haul international flight and updated statistical information and aircraft types.	
(2)	Defra Conversion Factors released alongside CRG, 2007	2007 Conversion Factors (revised from 2005 to take into account updated statistical information and aircraft types).

25 European CORINAIR manual (2001) - http://reports.eea.europa.eu/EMEPCORINAIR4/en/B851vs2.4.pdf

26 Transport Statistics Great Britain – Domestic Aviation Average Passenger Seat Occupancy 2005

27 Transport Statistics Great Britain – assumed to be on average more in line with domestic loads factors

28 Transport Statistics Great Britain – International Aviation Average Passenger Seat Occupancy 2005

2. The factors derived refer to CO_2 emissions per passenger km and are derived from load factor assumptions from national statistics, and fuel consumption data for illustrative typical types of aircraft making these flights, taken from the European CORINAIR manual for reporting emissions[29]. The revised approach splits the factors into domestic, international short-haul and international long-haul. These distances categories are based on the average journey length for the type of journey, and are consistent with the average distance of flights from the Association of European Airlines[30].

3. The new approach splits down the factors to: domestic, international short haul and international long haul. This split captures the three areas where there is considerable variation in emission per passenger km; further splits would not add value as there is little variation in the emissions factors beyond the three journey types covered. The factors have changed downwards since 2005 due to a combination of higher load factors (reflecting the latest data from DfT statistics) and different aircraft types.

4. Emissions impacts in Table 1 have been estimated using the average flight distance (or actual great circle) and therefore should be increased by around 9%. This comes from the IPCC Aviation and the global Atmosphere 8.2.2.3[31], which states that 9-10% should be added to take into account non-direct (i.e. not along the straight line between destinations) routes and delays/circling. Government has been using 9% in its work, which is also consistent with the NAEI approach.

5. Detailed Calculation: Specific Emission Factors and Flight Distances. Possibly to be included in a later version of the calculator, but would likely involve input of specific journey origin and destinations and utilise the same 3 emission factors presented for the basic calculation. In terms of the flight distances/ranges the 3 emission factors are applied to, the short haul international figure should be applied to journeys up to 2000nm (3700km, the maximum range of a 737 according to the CORINAIR manual) and the long distance factor to anything greater than that. Domestic is obviously applied to domestic flights.

Radiative Forcing

6. For aviation the issue of Radiative Forcing needs to be addressed. The following detailed text has been proposed by Professor David Lee (CATE, MMU) to explain the issue of Radiative Forcing impacts for flights. (A less technical summary is provided with the calculator results).

> *Aviation has effects on climate beyond that resulting from its CO_2 emissions, including effects on tropospheric ozone and methane from its NO_x emissions, water vapour, particle emissions and formation of contrails/enhanced cirrus cloudiness. This is usually calculated with the*

[29] Core Inventory of Air Emissions in Europe (CORINAIR), 2001.

[30] See: http://www.aea.be/aeawebsite/datafiles/yearbook05.pdf

[31] Available at: http://www.grida.no/climate/ipcc/aviation/121.htm#8223

climate metric 'radiative forcing'. Aviation was shown by the IPCC (1999) to have a total radiative forcing of 2.7 times that of its CO_2 radiative forcing for a 1992 fleet (the so-called Radiative Forcing Index, or RFI), excluding any effect from enhanced cirrus cloudiness which was too uncertain to be given a 'best estimate'.

More recently, the radiative forcing for the year 2000 fleet was evaluated by Sausen et al. (2005) which implies an RFI of 1.9, based upon better scientific understanding, which mostly reduced the contrail radiative forcing. Similarly to IPCC (1999), Sausen et al. (2005) excluded the effects of enhanced cirrus cloudiness but others (e.g. Stordal et al., 2005) have improved calculations over IPCC (1999), which indicates that this effect may be 10 and 80 mW/m2 (cf 0 to 40 mW/m2 of IPCC) but are still unable to give a 'best estimate' of radiative forcing.

Whilst it is incorrect to multiply CO_2 emissions by the RFI, it is clear from the foregoing that aviation's effects are more than that of CO_2. Currently, there is not a suitable climate metric to express the relationship between emissions and radiative effects from aviation in the same way that the global warming potential does but this is an active area of research. Nonetheless, it is clear that aviation imposes other effects on climate which are greater than that implied from simply considering its CO_2 emissions alone.

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