Title: Internet-based carbon tools for behaviour change
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Abstract

Internet-based carbon calculators have the potential to be powerful tools to help people understand their personal energy use (mainly derived from fossil fuels) and for motivating actions to reduce carbon emissions. This paper assesses thirty carbon calculators, based on their accuracy and effectiveness and shows that in most cases this environmental learning tool is falling short of i) giving people the ability to accurately monitor their energy use, ii) providing them with meaningful feedback and guidance for altering their energy use, iii) connecting them with other users also going through the same learning process of saving energy and conserving carbon. Suggestions for the development of the "next generation" of carbon calculators are then provided, aiming at tackling the short-comings of the existing carbon calculators. A number of tools, presently in *beta* development, are included in this review and are good indicators of some of the exciting directions these tools could go. The Environmental Change Institute also has developed a beta tool, IMeasure, for measuring, benchmarking and targeting personal energy use reductions.

Introduction

The development of a low carbon energy society necessitates that all actors take responsibility for the greenhouse gas (GHG) emissions they release into the atmosphere from burning fossil-fuels. To achieve this objective effectively, actors need accurate and appropriate information tools to help them make informed investment decisions and behavioural choices. These information tools should give actors the ability to identify, quantify and monitor GHG emissions as well as to access meaningful feedback on opportunities to reduce those emissions. The tools need to be designed to meet the specific needs of energy end-users, be they governments, organisations, companies, or citizens. Previous studies of energy feedback through energy billing, display devices and awareness campaigns have demonstrated that household and personal energy savings could be potentially significant if well-designed and targeted feedback, supporting the energy learning process, is available (Wilhite & Ling, 1995; Brandon & Lewis, 1999; Wood & Newborough, 2003; and Darby, 2006). The Internet, as a vehicle for supporting energy learning and action, has not been studied in much depth, but initial studies seem to positively indicate that it can complement energy awareness campaigns. The Internet also has the ability to give personalised feedback, as opposed to generic advice, the former securing larger energy savings (Benders et al., 2006).

The focus of this paper is to examine one particular information tool available on the Internet, commonly known as "carbon calculator", which is aimed at giving individuals and households' feedback on their direct carbon emissions. A review of thirty English language Internet-based carbon calculators was undertaken in this study. Of the thirty calculator tools reviewed, eighteen were developed for the UK and thirteen for non-UK countries.

The review firstly evaluated the accuracy with which the calculators estimate personal carbon emissions and secondly assessed their effectiveness in supporting carbon numeracy and literacy. The latter assessment was performed by scoring each calculator using a common set of criteria. The findings of the review are presented and suggestions are put forth for developing the next generation of carbon calculator tools. The Environmental Change Institute is actively using the insights of this review to inform work on the development of iMeasure, an online energy and carbon measurement tools.

Internet technology if successfully applied and used offers a powerful tool by which to support the learning, understanding and actions of people wanting to take responsibility for their carbon emissions. It is argued that for carbon calculators to be a more beneficial tool to people they need to be accurate, to allow on-going interaction, to be socially networked and to provide appropriate feedback on carbon reduction measures. If this is achieved calculators can support the key tenets of social learning theory attention, retention, replication and motivation (Bandura, 1977).

Personal carbon calculators

Carbon calculator tools have been developed by a wide variety of bodies including non-government organisations, commercial companies, government agencies, universities and media groups. Carbon calculators have been developed primarily to increase awareness of the connection between fossil fuel use and carbon emissions and/or to enable people to invest in carbon saving projects to offset their emissions. Personal carbon calculators are tools that aim to quantify the amount of carbon an individual or household emits into the atmosphere from either a specific fossil fuel energy-use or in total from a combination of activities using fossil fuel based energy. The majority of existing carbon calculators endeavour only to estimate the emissions from home energy and travel use. Calculators are mainly concerned with providing users with feedback on their annual carbon emission impact. There are a few calculators that estimate the embodied carbon emissions from the food, goods and services consumed by individuals, however given the methodological difficulties most only given a crude indication of the carbon impact. One of the calculator reviewed, developed at Berkeley University, goes into the greatest depth in providing a lifecycle assessment of a U.S. household's full greenhouse gas impact.

Section 1: Carbon Accuracy of Calculators

The accuracy with which carbon emissions are measured is important if people are to be able to benchmark and monitor the changes in their carbon emission profiles over time. Without being able to accurately quantify carbon emissions people will not be able to know if the technology investments and lifestyle changes they make are actually translating into real carbon savings. The accuracy of the carbon calculators is to be in the results given which is strongly influenced by the data inputted.

The process of completing a carbon calculator typically involves users providing some general household information (e.g. number of persons in the household, type of house etc…) and then inputting more specific information about home energy and personal transport use for the year. The calculators translate the data provided into a quantity of energy for each activity and then multiply this by a corresponding carbon emission conversion factor to derive the carbon emissions generated by each activity. All these different carbon emissions are then summed up to give a total annual carbon impact result. Calculators typically use the same emission conversion factors as used by the national government corresponding to the country of target audience. For instance, UK calculators those emission conversion factors are mostly based on the Digest of United Kingdom Energy Statistics. However, there can be variation between calculators using the same type of data, because they might be using the same source, but of different publishing years or be making different assumptions when interpreting data.

In nearly all cases carbon calculators give users an annual carbon emission result. However, this annual value is normally estimated from a single data entry per activity, which can represent a year, quarter, month or week of energy use. For example, the user might input gas use or expenditure for the last quarter and from that input the calculator extrapolates an annual carbon figure for gas use. Relying on a single one data input for the year means the calculator will not be able to give feedback to the user on seasonal and lifestyle variations over the course of the year.

Calculators can be framed as either calculating carbon emissions for an individual, the household or both. Most calculators do one or the other. A calculator may ask the user for the number of people in the household, but this will not necessarily mean results are given in terms of per person emissions. Therefore, users have to be conscious when entering in data and interpreting results as to whether they are looking at the carbon results for a single individual, or the total household, as it is often not clearly stated.

The carbon accuracy of a carbon calculator depends also on the type and quality of the data inputted. There are three types of data that calculators will commonly use to calculate the carbon emissions of an individual or household – 1) building fabric- and technology-based, 2) energy expenditure-based and 3) energy quantity-based. Oftentimes calculators will use a combination of each of these and will often times give users the choice.

Building fabric and technology data are used to calculate the carbon emissions resulting from home energy use. The user is asked a series of questions, for instance, about the type of house, windows, boiler, lights and appliances. Calculators relying on this approach are only able to give users an indication of their carbon emissions based on the energy performance of the building fabric. Without actual energy use data the information is not sufficient to give users an accurate carbon emission profile.

Energy expenditure data is a commonly used data input from which to quantify carbon emissions. Users are asked to input information on how much they spend by fuel-type for the year, quarter, or month. This approach is unlikely to be accurate because energy expenditure is only a proxy for energy use.

Inputting energy-quantity based data is commonly offered by calculators. There are two forms of quantity-based information – 1) the amount of home energy used, which for example is often asked for in terms of kilowatt hours electricity and gas (or cubic feet gas/therms gas) and occasionally there is the option of inputting litres of petrol or diesel for private vehicle travel; and 2) the distance travelled by different modes (either private or public). The quantity-based approach especially in the first form has the potential to give reasonably accurate carbon results if accurate annual data is known.

Calculators offering the ability for users to input quantity-based data for home energy often suggest to users they refer to their past energy bills for information on energy use or expenditure. In the UK, energy bills do provide this information, but it is often only an estimation of household energy use rather than actual energy used. Furthermore, in the UK energy companies only provide energy consumption information for the month or quarter that the bill is for. Therefore, if users want to enter in a full year of home energy use into a calculator they will need to carefully decipher their bills and it still may only be an estimate unless they have provide energy meter readings to their utility. Utilities in other countries might provide more accurate billing information to customers, but the situation in the UK is not unique.

There are two alternative approaches for deriving the carbon emissions from private transport use. The first approach, and most accurate, is for users to input the number of litres of fuels they have used in driving their vehicle(s). This information is available to users on fuel receipts and some newer car models actually have gauges accurately measuring fuel use. However, the drawback to this method is that it requires the user to save and tally up a year's worth of receipts to get an accurate carbon emission result. Only a handful of the calculators reviewed offered the option of entering actual fuel use.

The second approach to calculate carbon emissions from driving is to ask users to input information on the distance travelled over the last year. Sometimes UK calculators suggest to users they refer to their last MOT (Motor Ordnance Tests) certificate, an annual requirement to ensure vehicles are road worthy in the UK, if they want a more accurate input for the number of miles they have driven in a year. The calculators use these data together with information about fuel type, vehicle type, engine size, and fuel efficiency. This approach is only able to give users a theoretical estimation of transport carbon emissions, as it does not incorporate driving behaviour, which is a significant determinant of fuel consumption and therefore carbon emissions.

In addition, the quantity-based approach is often used by calculators for calculating public transport and aviation emissions. Users input the distance travelled and then the calculator will use an average carbon emission factor for each transport mode to estimate the carbon emissions. This approach will not provide accurate estimates of transport carbon emissions, because in the case of public transport there are many altering factors including the mode, fuel type, fuel efficiency and passenger occupancy. Therefore, to simplify calculations the distance travelled by public transport is multiplied by an average carbon emission factor for the fleet. In the case of aviation there are further methodological issues in estimating the carbon impact of flying, as there is not yet scientific consensus on how to calculate aviation emissions' impact beyond carbon dioxide (Dokken et al., 1999). As a result there is no clear standard methodology for calculating the emissions from flying, which as will be seen from the trialling of carbon calculators leads to significant discrepancies between calculator results.

In summary, there are a number of different approaches for calculating personal carbon emissions. The carbon accuracy of the feedback given by a carbon calculator will depend on the type and quality of the information inputted by the user. A carbon calculator can only be as good as the quality of the energy data inputted. A carbon emission profile drawn from actual energy use for home energy and personal travel will be the most accurate. Profiles calculated from actual energy use figures are able to capture personal and household energy-related behaviour. Carbon emission profiles derived from information on technology efficiencies, building fabric and energy expenditure will not be accurate as these are only theoretical proxies for energy use. Furthermore, calculations based on average energy consumption figures will not be able to give users an indication of where they fall within the population distribution of personal carbon emissions. Most people using carbon calculators will be aware of the shortcomings of relying on theoretical estimations of energy use rather than actual energy use data. There are substantial challenges to making it easier for users to input actual energy use data, but the "next generation" of carbon calculator, as will be discussed later, should have the functionality to help users monitor, benchmark and target their carbon emissions.

Methodology for comparing the carbon accuracy of calculators

A list of the carbon calculators can be seen in Table 4. Each calculator was trialled with the same user data, as far as possible, on the general household characteristics; home energy consumption; and travel use (refer to table 1). These data inputs were selected as they represent a plausible annual personal energy use profile of someone living in the United Kingdom. The limitation in this approach was that each calculator varied in what format data should be inputted (e.g. nine of the calculators did not cover public transport). The aim of trialling each calculator was to get an individual rather than a household carbon impact result, as this research is primarily concerned with individual carbon footprint feedback. However, it is acknowledged that the separation between personal and household energy use is a false distinction, as many home energy and transport decisions are made at the household level rather than at the individual level.

For twenty-five of the thirty calculators reviewed it was possible to input actual quantities of gas and electricity used at home. However, because the aim of the trial was to get an individual rather than a household carbon result, it was often necessary to input a person energy-use based on the three-person household size. For all the calculators trialled, private vehicle emissions were calculated either by inputting the vehicle type, engine size, fuel efficiency and distance travelled. For the calculators reviewed, aviation and public transport emissions were all calculated on the basis of entering distance travelled and when applicable number of flight hours.

The comparative analysis of carbon accuracy focuses on UK calculators because it is not possible to compare the non-UK calculators with each other or with UK calculators. This is because the carbon emission conversion factors differ from country to country, particularly in the area of home energy, as the energy generation mix will vary. However, non-UK calculators were also trialled for the second part of the assessment, which focuses on the communication effectiveness of the calculators. In addition, five "next generation" type calculators, which allow the user to measure energy use over time, were identified for the review. They are listed in table 4, but because these tools require incremental data entry it was not possible to input the annual data of table 1 and get an annual carbon footprint result so they were excluded from table 2.

Table 1: Annual information and data inputted into each calculator

Area	Data input
General household information	3-person household semi-detached house built in late the 1970s - early 1980s 100 m^2 or 1080 ft^2 floor area gas central heating, combi-boiler partial double glazing, some energy efficient light bulbs
Household energy consumption	Gas: UK 20,000 kWh (6667 kWh pp), 638 thousand cubic feet (213 thousand cubic feet pp, £380/yr (U.S. 682 therms natural gas (228 therms pp), $880/ yr Electricity:UK 3600 kWh (1200 kWh pp), £324/$360/yr
Transport use	Car: 1.4 litre petrol engine, 35 mpg, 6,250 miles / 10,000 km, (U.S. 2003 Honda Accord (automatic)) Train: 1,625 miles / 2,600 km Flights: 1 Return flight from London to New York, 6,926 miles / 11,082 km / 1 Return long-haul flight, 14 hrs flying.
Other	Resident:Oxford(UK),Maryland (US), Queensland (Au)

Results of calculators for carbon accuracy

The detailed results of trialling the calculators are in table 4 – grouped by UK calculators and then non-UK calculators and within each group the calculators are ranked by from lowest to highest carbon footprint result. Almost all calculators presented results as tonnes of carbon-dioxide, a few expressed the result as tonnes of carbon dioxide equivalent and only one gave the option of seeing results as tonnes of Carbon (National Energy Foundation (NEF)). Some of the U.S. calculators presented results in tons (US short ton metric) rather than metric tonnes.

The mean personal carbon result for the UK calculators reviewed was 5.79 t CO_2 (with a standard deviation of ± 1.68 t CO_2), which is based on the amount of energy used at home, and for car, air and train travel (table 2). This figure is in the same range as the UK national average for personal direct carbon-dioxide emissions. The minimum carbon result given by a UK calculator estimating an individual's home, car, aviation and train emissions was BP – Carbon Footprint with 3.92 t CO_2 and the maximum was Resurgence with 10.28 t CO_2 (table 4), a factor of more than double.

Table 2: summary of UK carbon calculator results

	Home	Car	Aviation	Train	Total
Tonnes of carbon-dioxide (t CO_2)					
Mean	1.82	1.82	2.22	0.16	5.79
Standard deviation	0.16	0.29	1.52	0.03	1.68
Minimum	1.36	1.15	1.12	0.10	3.92*
Maximum	2.04	2.25	6.09	0.20	10.28

** The Global Action Plan calculator had a result of 3.85 t CO_2, but the air calculator was not working so has been excluded as the minimum.*

Home energy and emissions

Hardly any variation could be seen in the results given by UK calculators for emissions from home energy. The mean carbon result was 1.82 t CO_2 per person for home energy with a standard deviation of ± 0.16 t CO_2 per person (table 2). This was because with nearly all the UK calculators enable the user to enter an annual quantity of gas and electricity use and then the calculators use the recent UK government published data for carbon emission conversion factors. The variation in home carbon emissions results more likely to be due to calculators using different a different carbon emission conversion factor for electricity. The UK government standard carbon emission conversion factor for electricity generation has been 0.43 Kg CO_2 per kilowatt hour since 2000 (DUKES, 2006), but in 2007 was revised to 0.523 Kg CO2 (Defra, 2007). However, in actuality this is not constant because the generation fuel mix changes depending on availability, time of day and season. The Electricity Disclosure policy in Europe, requiring energy companies to provide information to customers on their generation mix, provides calculators with an opportunity to link personal carbon emission with the carbon intensity of their energy supplier (Boardman & Palmer, 2007). Currently none of the calculators offer this feature.

The calculators that gave slightly higher carbon results were those that i) only gave the option for inputting energy expenditure (MSN-Estimator), ii) used a high carbon emissions factor for electricity (for example COIN, with 0.5 kg CO_2 per kilowatt hour compared with the DUKES 0.43 Kg CO_2 for grid electricity) or iii) based carbon results only on building fabric and technology information (BP-Carbon Footprint and Eco-Speed).

Travel & emissions

The variation between the carbon results of UK calculators can mostly be explained by the different emission results given for the aviation (mean of 2.22 t CO_2 per person ± 1.52, Table 2). The carbon results for air travel, taking a London to New York flight as an example, vary greatly because calculators use significantly different carbon emission conversion factors for air travel (Table 3). When the methodologies behind air travel were examined it was found the emission conversion factor used varied by a factor of 4 from the highest to the lowest.

Calculators such as the Act on CO_2 developed by the UK Government does not include the non-CO_2 effect of flying, whereas other calculators such as Safe Climate developed by the World Resources Institute (WRI) almost double carbon-dioxide emissions to reflect the potentially additional climate impacts associated with flying. Several calculators, such as Environmental Defense and Native Energy reference the Climate Neutral Network for what the recommended approach is for calculating the climate impacts of air travel. The Network estimates that non-CO_2 greenhouses gases are as significant as CO_2, and therefore suggest a doubling of CO_2 and possibly a further 8% for high altitude effects. Despite both calculators referencing the Climate Neutral Network both calculators have significantly different results for air travel of 2.51 t CO_2 and 7.8 t CO_2 for Native Energy and Environmental Defense respectively.

In addition, some calculators like Atmosfair and The Carbon Account add a further dimension by suggesting to users to add a further carbon emission impact if flying business class. Given the uncertainty of the climate impacts of aviation it is not surprising there be variations in results. However, calculators should be transparent on what factor they are using in the calculation to avoid the user being confused.

Table 3: Emission conversion factors used by different carbon calculators for air travel

Calculator	Emission Conversion Factors Used	Result – Return Flight London - New York (11,082 km)
Act on CO2 (UK)	0.105 kg CO_2 / km	1.16 t CO_2
Climate Crisis (U.S.)	0.106 kg CO_2 / km	1.17 t CO_2
National Energy Foundation (UK)	0.18 kg CO_2 / km	1.99 t CO_2
WRI – Safe Climate (U.S.)	0.18 kg CO_2 / km	1.99 t CO_2
Resurgence (UK	0.54 kg CO_2 / km	5.98 t CO_2
Environmental Defense (U.S.)	0.571 kg CO_2 / km	6.32 t CO_2

Note: These results might vary from table 4 because not all the above calculators allow users to specify the distance travelled (for example, Environmental Defense asks user for hours in the air). Climate Crisis references DEFRA as the source for their emission conversion factor.

The variation between the results given by the UK calculators for the private vehicle emissions, represented by the car (1.82 tCO2/p ± 0.29, Table 2) is mostly due to the level of detail it was possible to specify about the vehicle engine size and its fuel efficiency. Only three calculators (BP, Environmental Defense and Southampton Sustainability Forum) did not allow users to specify this information and simply asked the size of the car and number (or range) of miles driven. As discussed earlier, in order to get an accurate carbon result for driving, which would capture behaviour aspects of driving, the number of litres of fuel would need to be inputted into the calculator and only three calculators allow this **-** NEF, COIN and Landcare Research.

Nine of the thirty calculators reviewed did not cover public transport emissions therefore deriving a carbon impact for train travel was not possible. This affects the total carbon results slightly, as those calculators excluding public transport emissions naturally had lower totals. Of the UK calculators that did cover public transport the mean carbon result was 0.16 t $CO_2 \pm 0.03$ per person per year (table 2).

Table 4: Annual tonnes of carbon-dioxide per person result given by calculators

Organisation	Organisation type	Reason for tool	tonnes of carbon-dioxide (t CO_2) per person				
			Home	Car	Aviation	Trains	Total
UK carbon calculators							
1. Global Action Plan – Carbon Calculator	NGO	Educational	1.90	1.75	Not working	0.20	3.85
2. BP – Carbon Footprint	Business	Educational	1.36	1.47[1]	1.12	-	3.92
3. MSN – Carbon Estimator	Media	Educational	1.70	1.80	1.20	0.10	4.80
4. World Land Trust – Carbon Balance	Business	Commercial	1.83	1.80	1.22	0.14	4.99
5. Carbon Neutral	Business	Commercial	1.86	1.80	1.20	0.20	5.07
6. RSA – CarbonDAQ[2]	NGO	Educational	1.78	1.86	1.54	na	5.18
7. Southampton Sustainability Forum	NGO	Educational	1.79	2.06	1.24	0.16	5.25
8. Climate Care	Business	Commercial	2.04	1.88	1.54	na	5.46
9. Act on CO2	Government	Educational	2.00	3.49			5.49
10. CO2 Balance	Business	Commercial	1.86	1.15	2.55	0.16	5.72
11. National Energy Foundation (NEF)	NGO	Educational	1.79	2.25	2.01	0.16	6.21
12. Bestfoot Forward – Stepwise	Business	Commercial	1.90	1.90	2.70	0.20	6.70
13. COIN	NGO	Educational	1.92	1.75	4.25	0.16	8.08
14. Resurgence	Media	Educational	1.78	2.25	6.09	0.16	10.28
15. IMeasure	University	Educational	Calculated based on periodic energy use data entries				
16. Carbon Account	Business	Educational	Calculated based on periodic energy use data entries				
17. Carbon Rationing	NGO	Educational	Calculated based on periodic energy use data entries				
18. The Carbon Diet	Freelance	Educational	Calculated based on periodic energy use data entries				
Non-UK carbon calculators							
19. Atmosfair[3] (Germany)	Business	Commercial	na	na	3.48	na	3.48
20. Climate Crisis (U.S.)	NGO	Educational	1.22	2.00	1.32	na	4.54*
21. TerraPass (U.S.)	Business	Commerical	1.81	1.87	1.22	na	4.90*
22. Climate Friendly (Australia)	Business	Commercial	0.6[4]	1.80	3.30	na	5.10
23. Landcare Research (New Zealand)	NGO	Educational	1.46	2.00	1.45	0.39	5.30
24. The Climate Trust (U.S.)	Business	Commercial	1.13	1.42	2.76	na	5.31*
25. WRI - Safe Climate (U.S.)	NGO	Educational	2.10	1.58	2.00	na	5.68
26. Eco-Speed (Switzerland)	Business	Educational	2.65	1.22	2.32	0.22	6.41
27. Native Energy[5] (U.S.)	Business	Commercial	3.62	1.56	2.51	0.49	8.18*
28. Berkeley Climate Footprint (direct emissions only)[6] (U.S.)	University	Educational	3.01	1.50	2.40	1.40	8.31
29. University of Sydney (Australia)[6]	University	Educational	2.11	4.80	2.08	0.33	9.32
30. Environmental Defense (U.S.)	NGO	Educational	3.20	1.60	7.80	na	12.60
31. Make Me Sustainable (U.S.)	Commercial	Educational	Calculated based on periodic energy use data entries				

All the web-addresses of calculators are listed in the reference section. Calculators were run week starting 20th August 2007. 1. BP calculator presents car and public transport emissions together as 'ground transport'. 2. RSA CarbonDAQ uses the Climate Care calculator engine, but probably has not updated emission factors hence the difference. 3. Atmosfair only calculates the carbon emissions associated with aviation. 4. Climate Friendly only calculates emissions associated with electricity use in the *home. 5. Native Energy uses an adjusted SafeClimate calculator engine. 6. Universities of Berkeley and Sydney both give users the opportunity to estimate indirect emissions, but only the results from the direct emissions for home energy and travel are presented in the table. - = not reported separately, na = not available in these calculators.* These calculators give results only in US tons or pounds CO_2 so were converted to metric tonnes.*

Summary carbon accuracy of calculators

The majority of carbon calculators presently available do not give users the ability to accurately monitor their personal carbon emissions from direct energy use. The basic calculators that do enable users to reasonably accurately quantify carbon emissions from both home and travel are NEF, COIN and Resurgence, but they require users to have a year's worth of complete energy data to hand. Most of the calculators reviewed are only able to give users an estimate of their annual carbon emissions, as the calculations are based on building fabric, energy expenditure, energy used and distance travelled. In terms of calculating the emissions impact of air travel, Atmosfair is the most sophisticated, as it takes into account breaks in journeys (stopovers); fuel efficiency of different aircrafts; occupancy levels; and uses the IPCC suggested radiative forcing multiplier of 2.7 for accounting for the non-CO2 effects of flying.

There are a number of carbon measurement tools in *beta* development that potentially offer users the ability to accurately monitor, benchmark and target their personal or household energy use and carbon emissions. These tools can be described as the "next generation" carbon calculator, because they are not simply an annual snapshot of carbon emissions, but instead tools involving on-going monitoring of energy use and carbon emissions. The tools that have been identified as "next generation" carbon tools are – IMeasure (UK), The Carbon Account (UK), The Carbon Diet (UK), Carbon Rationing (UK), and MakeMeSustainable (US). In addition, the Landcare Research calculator could almost be a "next generation" tool, as it offers monthly carbon emission reporting, but its functionality is still relatively limited. The UK-based "next generation" tools are reliant on users inputting periodically meter readings, quantify of gas/electricity used, vehicle mileage (and/or litres of petrol purchased) and distance travelled (by air and public transport) to enable a user to build up a more in-depth carbon profile. These tools will be discussed in greater depth in sections 2 and 3.

Section 2: Carbon Effectiveness of Calculators

The second part of the review focuses on examining existing carbon calculators for their effectiveness in informing the people of their personal carbon emissions. An effective carbon calculator is one that gives the users the ability to accurately measure and monitor their carbon emissions over time in order to understand what drives their emissions; to support them in taking carbon saving actions; to connect them to a community of others with shared interests; and to allow the access to additional services and products related to energy and carbon saving.

In order to assess the effectiveness of the calculators reviewed, each tool was examined and scored using four key criteria. The four criteria areas were selected because a tool achieving success in each is likely to be meeting the aims of being accurate, informative, social and supportive. The four criteria areas were: 1) presentation and usability, 2) data and information inputs, 3) results, feedback and guidance and 4) context and explanation. A scoring system was devised to evaluate the strengths and weaknesses of each calculator in these four criteria areas (table 5). Each calculator was awarded between 1 to 5 points in each of the criteria area, with 1 indicating the calculator was very weak in this area and 5 indicating the calculator to be very strong in this area. Each calculator could be allocated a maximum of 20 points. The scoring system made it possible to more fairly compare and contrast calculators. The four criteria areas and the corresponding scoring system was developed by the author who has experience of creating Internet-based environmental tools as well as drawing on the research expertise on personal energy behaviour and information feedback at the Environmental Change Institute (e.g. Bottrill, 2006; Darby, 2006).

Table 5: Explanation of the scoring system broken down by each criteria area

Score	Criteria Area
Presentation and usability	
1	calculations are not automated, user does themselves offline.
2	basic design; no images or graphics; all information presented numerically and text-based.
3	effort made to take user through calculation process in manageable steps; navigation not always clear; limited images and graphics used.
4	clear navigation signals all through the calculation process; relatively uncluttered design; clear and concise text – room for improving terminology used; a number of graphics and visual imagery used – but users have no flexibility in setting their own preferences.
5	clear navigation signals throughout; creative design; uncluttered design; clear and concise terminology; a variety of graphics and visual imagery. User able to set results preferences.
Data and information input	
1	user offered only default values.
2	data inputs primarily focused on building fabric and technology.
3	data inputs are energy expenditure per month, quarter or year.
4	data inputs are quantities of energy used per week, month, quarter or year.
5	data inputs can be raw energy data – e.g. actual energy meter readings.
Results, feedback and guidance	
1	only a single figure carbon result given, no further breakdown or additional information
2	each activity separated and thus so is the carbon result. User cannot get a total carbon result; limited additional information about personal carbon emissions is made accessible.
3	user given a total carbon result and it is broken down by activity; results are presented graphically as well numerically; some effort to put user's carbon result in context (i.e. in comparison to the national average); and links to further resources.
4	users can create a profile to add and monitor energy use and carbon emissions; the tool is not linked with social networking tools; more effort could be put for user's to see carbon results in context with other users; only generic advice given.
5	user can build up a carbon profile to monitor energy use and carbon emissions; results presented in clear metrics; relevant feedback is given; results put in context to others and emission reduction targets; not a standalone resource - embedded with social networking tools and linked to advice, services and products.
Context and explanation	
1	minimal information on context of tool or calculator methodology.
2	some context is provided, but there no calculator methodology available.
3	calculator has made effort to link personal carbon emissions and responsibility with climate change, but context too grandiose and abstract to resonate with users; not inspiring or motivating; some calculator methodology available, but it is incomplete.
4	Calculator links personal carbon emissions and responsibility with climate change; the tool attempts to make this links not too abstract, but there is still room for improving the language used (e.g. still might use fear tactics for trying to motivate responsibility). Reasonably good presentation of calculator methodology.
5	The tool uses a context that is inspiring and motivating to a user so s/he remains engaged in investigating and reducing their carbon impact. Calculator methodology well presented.

An effective Internet tool for personal carbon auditing must have high-quality presentation of information and good usability (table 5). The users need to understand what the tool does and what is involved to get the most out of the online experience. The overall design and architecture of the site as well as, the wording, graphics and visuals can greatly influence the experience of users and the value they attach to the tool being a beneficial resource to them. The usability of an Internet tool is a key component of its effectiveness; users must be able to easily navigate within and manipulate a calculator to meet their desired aims. Usability can also be about the accessibility of a site in terms of being fully operational in different web browsers and to users with special needs (e.g. sight impaired and colour blind). These latter usability issues are important, but were not considered in this review. Presentation and usability are two core aspects in the development of a tool, but it should be noted that the design of the Internet tool remains a subjective criterion.

As discussed earlier, the carbon accuracy of calculators is linked with the extent with which a user can input actual energy data and specify whether the calculator is calculating a carbon emission profile for an individual or a household. For the second criteria, the calculators were scored for their ability to enable users to input actual data about their home energy and transport use (table 5).

The third criteria the calculator was assessed was in providing meaningful results was the level of feedback and guidance to users (table 5). Developing a carbon tool that gives users informative and motivational feedback on their carbon emissions is an important stepping stone for encouraging carbon responsibility. The calculators were scored on the extent of feedback the user was given about his or her carbon impact; the opportunities for continued engagement; and links to further resources, services and products.

The final criteria area the calculators were evaluated on was for "context and methodology", which refers to how they connected personal carbon emissions to broader climate change and energy issues as well as to what information was given on the methodology used for calculating carbon emissions (table 5). The context used and methodology given can be crucial elements in developing a carbon tool that successfully engages users in understanding why taking personal responsibility for carbon emissions is worthwhile. The context used by a carbon calculator does not necessarily have to be global climate change, but should connect with users' motivation and interest in monitoring their energy use and carbon emissions. For example, motivational drivers might be to improve comfort at home, to appeal to a particular self-image, to save money on energy use and/or to compete with peers. Calculators should draw upon these different levers to engage people in energy and carbon monitoring.

Results of calculators for carbon effectiveness

From the overall carbon effectiveness scores of the carbon calculators reviewed it is argued that the majority of these are falling short of providing users with an accurate, meaningful and social carbon tool by which they can have continuous learning and investigation of their carbon impacts. In table 6, the thirty reviewed calculators are ranked from the highest to the lowest in terms of their overall carbon effectiveness score. The mean carbon effectiveness score was 11.5 ± 2.73, with the highest scores of 18 going to The Carbon Diet and The Carbon Account and the lowest score going to Climate Friendly, COIN and MSN- Carbon Estimator with scores of 8. Four calculators emerging to be "next generation" type carbon tools – The Carbon Diet, The Carbon Account, MakeMeSustainable and IMeasure (the Environmental Change Institute's prototype tool in development). The IMeasure tool has not been scored for its carbon effectiveness in this paper as it would not be an objective assessment.

Presentation and usability

Twenty-one of the thirty carbon calculators reviewed were given a score of 3 or less for their presentation and usability. Calculators receiving this score did so because they had a functional design similar to a spreadsheet with limited use of images and/or graphics to communicate information. There were few or no information pointers for individuals needing clarification on a term or of what information to input. The COIN calculator and the one developed by someone in the Physics Department at the University of Sidney (Australia) were given a 1 for presentation and usability because the user has to do the calculations offline. Twelve calculators were only awarded a score of 2 because although they were designed to automatically calculate carbon emissions they had a formulaic design. In addition, several of the calculators compartmentalised personal carbon activities and did not give users the ability to join-up their results. This was typically the case for the calculators of carbon offset companies that want to make it simple and quick for users to calculate from a particular activity and then offset the emissions.

The carbon calculators that received the top score of 5 in the area of presentation were The Carbon Account and The Carbon Diet because these tools have clear navigation, use of images and accessible language. Eight calculators received a score of 4 for presentation and usability. The Act on CO2 calculator has a well-designed graphic tool taking the user step-by-step through the calculation process. The drawback of this calculator was that it took a relatively long time to complete as well as required a fair amount of detail from the user. The Eco-Speed and Berkeley Climate Footprint tools give users clear section headings and each page is uncluttered with the key questions presented clearly. The BP calculator is a visually appealing tool (presenting animated Lego®-like people) and had clear navigation. The Eco-Speed, Berkeley Climate Footprint and BP calculators showed the results in graphs that adjusted as the user completed the calculator. The calculator tool that had the most advanced functionality was MakeMeSustainable, a *beta* tool from the States. This tool had the ability for users to create a personalised profile (including adding multiple homes and cars) with data sharing and message boarding. Although this tool is one of the most innovative tools currently available the way to navigate and update ones' profile is not straightforward and therefore a score of 4 was given instead of 5. In the area of aviation, Atmosfair scored well because it was easy to input flight details (including stopovers), see results and link to information on how results were calculated.

The language used by a calculator is crucial for successfully encouraging, motivating, and inspiring people to investigate their carbon emissions and in making them feel that their personal actions can make a difference towards the transition to a low carbon energy society. In most cases the language used by calculators was very pragmatic when focusing on environmental perspective. None of the calculators were very imaginative in the phraseology they used to appeal to different types of users especially the "non-greenies" (i.e. the less engaged environmental audiences).

Table 5: Scores for carbon effectiveness of calculators reviewed

Organisation	Type	Presentation & Usability	Data & Info Inputs	Results, Feedback, Guidance	Context & Methodology	Total score
IMeasure	Not Scored					
1. The Carbon Diet	C	5	5	4	4	18
1. The Carbon Account	D	5	5	4	4	18
2. Atmosfair	A	4	5	3	4	16
3. Makemesustainable	C	4	3.5	4	4	15.5
4. Act on CO2	D	4	3.5	3	4	14.5
5. Carbon Rationing	D	2	5	3	4	14
6. Berkeley Climate Footprint	D+	4	3.5	3	3	13.5
6. Climate Care	C	4	3.5	2	4	13.5
7. Global Action Plan	D	3	4	3	2	12
7. Resurgence	D+	3	4	3	2	12
8. RSA – CarbonDAQ	C	3	3.5	3	2	11.5
8. Terrapass	C	3	3.5	3	2	11.5
9. Bestfoot Forward	D+	3	4	3	1	11
9. BP - Carbon Footprint	D+	4	2	3	2	11
9. Eco-Speed	D+	4	2	3	2	11
9. WRI - Safe Climate	C	2	4	3	2	11
10. Carbon Neutral	D	3	3.5	2	2	10.5
10. Landcare Research	D+	3	3.5	3	1	10.5
10. The Climate Trust	C	2	3.5	2	3	10.5
11. Climate Crisis	C	2	3	2	3	10
11. NEF	D	2	4	2	2	10
11. Native Energy	D	2	4	2	2	10
11. World Land Trust	D	2	4	2	2	10
12. CO2 Balance	D	2	3.5	2	2	9.5
13. Environmental Defense	C	2	2	2	3	9
13. Southampton Sustainability Forum	D+	2	3	2	2	9
14. University of Sydney	D+	1	3.5	2	2	8.5
15. Climate Friendly	C	2	2	2	2	8
15. COIN	D+	1	4	1	2	8
15. MSN Carbon Estimator	D	2	2	2	2	8

Key for calculator type: A = aviation only, B = home energy only, C = home energy, private vehicle use and aviation, D = home energy, private vehicle use, aviation, and public transportation, D+ indicates these calculators might also have covered additional areas such as water, waste, and food.

Data and information input

The carbon accuracy of a calculator is defined by the quality and frequency of the energy data that a user is able to input. There was a large spread in the calculator scores for this critical area. The majority of calculators available are designed really only to estimate carbon emissions. Twenty-five calculators were given a score of 4 or less because carbon results were extrapolated from estimated or proxy energy data sources mostly likely from energy bills. Because energy bills, especially those in the UK can be quite difficult to understand, relying on this information source is a barrier to encouraging people to investigate their carbon emissions. However, this could change with new EU-wide regulations for informative customer billing and smart metering.

Eleven calculators were given a score of 3.5 because they gave users the option of either providing energy use quantifiers or energy expenditures usually for the year or month. Of these, the Climate Crisis calculator promoted by the Al Gore “Climate Crisis” campaign is an example of a calculator only giving users the option to input home energy expenditure, which is a limited proxy for energy use and carbon emissions. Users specify the monthly expenditure for home energy by fuel type and then this is multiplied up to derive an annual carbon footprint result. The BP calculator was given a score of 2 because carbon results are based solely on information about building fabric and technology. The user has no option to input quantities of energy they use. The BP tool is likely to be effective at introducing people to personal carbon issues, but this type of tool is ineffective at supporting people in monitoring and reducing their actual carbon emissions. The Act on CO2 calculator has similar, but a sophisticated approach, to that used by the BP tool, but the calculations are based on front of mind information about building fabric measures, technology and behaviour so still only an estimated result can be given.

The calculators given a top score of 5 for data inputs were given this score because users could input raw energy data in the form of home energy meter readings (except Atmosfair as only covers flights). This method is the most accurate means of quantifying a home energy use especially when the reading is associated with the day it was taken. Three of the 5 top score calculators - The Carbon Diet, The Carbon Account and Carbon Rationing, also give the user the ability to input litres of petrol/diesel with mileage. This is the most accurate means of calculating driving emissions, but requires diligence from the user to save receipts and record mileage. These calculators require users to create a profile which they can update as frequently as they want to, so that they can measure and monitor energy use and carbon emissions. The user does not have to wait until they have a year worth of data before they receive accurate feedback on their emissions. In fact those calculators, along with Landcare Research, encourage users to update their energy use on a regular basis.

A hand full of calculators do enable users to store a basic profile, such as Landcare Research, GAP, Terrapass, Climate Care or to download their data such as Bestfoot Forward, Berkeley Climate Footprint, and Resurgence. In both cases they offer the user a simple record of their last carbon results. The offset companies usually use the profile saving feature to make it easier for users to offset regular journeys. Atmosfair received a score of 5 for data input because in terms of calculating aviation emissions this calculator is the only one attempting to be the most accurate although the scientific certainty of how to accurately calculate the non-CO_2 effects of aviation remains.

Results, feedback, and guidance

Essential to the effectiveness of carbon calculators for encouraging learning, understanding and action on personal carbon emissions are the carbon results, feedback and guidance users receive through the process. Of the calculators reviewed many took a similar approach for providing users with their carbon results. The majority of calculators provide users with a total carbon emission result (e.g. Act on CO2, Climate Crisis and BP). Many calculators will go a step further and give users a breakdown of their carbon emissions by activity. This breakdown is given numerically (e.g. Climate Care, GAP and Southampton Sustainability Forum, and World Land Trust) and in some cases through a graphic representation such as a pie chart, bar chart or line graph (e.g. BP, Atmosfair, Berkeley Climate Footprint, WRI-SafeClimate, Environmental Defense, and RSA-CarbonDAQ). The “next generation” type calculators go the furthest in presenting carbon results in different numeric and graphic ways (e.g. MakeMeSustainable, IMeasure, The Carbon Diet, and The Carbon Account). Because a user builds up their carbon profile from meter reading data overtime they are able to clearly see seasonality and behaviour changes in their energy use and thus carbon emissions.

Many of the carbon calculators, especially those developed by carbon offset companies, tend to compartmentalise the different emission activities such as home energy, private vehicle travel and flights and do not provide a summary of carbon results (e.g. Carbon Neutral, Terrapass and Climate Trust). The SafeClimate calculator had one of the most imaginative approaches for communicating to users their carbon results by having a flash-based cartoon image with a rating scale going from angel to polluter.

In many cases the calculators reviewed provided limited feedback to users about their carbon results in comparison to other people’s emissions. If a user gets a result of 6 t CO_2 from completing a calculator they are unlikely to be able to know if this value is high or low compared to the national average or to people with similar lifestyles unless this information is also given. A number of calculators do give the user their result with the national average, such as e.g. WRI-SafeClimate, BP, Eco-Speed, Berkeley Climate Footprint, Climate Crisis, Act on CO2 and Environmental Defense. A few calculators also do try to put the carbon result of users in context by comparing their air emissions to the emissions resulting form other energy use or country; for example Atmosfair indicates that driving 12,000 km in a medium sized car is equivalent to 2 t CO_2 or that the annual per capita emission average in India is 900 Kg CO_2. None of the calculators indicated to the user how much the average per capita emission needs to be if, for example the UK is to achieve a 60 per cent carbon reduction by 2050 (DTI, 2003). Also, many of the calculators do not present information on a household and per person basis – IMeasure goes the furthest in this area. Only three of the calculators provide comparative information of how users can view their carbon result in contrasts to others – RSA-CarbonDAQ, MakeMeSustainable and IMeasure. None of the thirty calculators reviewed provide the distribution of carbon emissions amongst users or the population and therefore cannot give users an indication of where they fall with that spread.

The guidance provided to users once they get their carbon emissions is limited. Most calculators simply provide users with links to other web resources to gain a further understanding of personal carbon and energy issues. Landcare provide the most in-depth feedback to users by creating a printable carbon monthly report which gives users information both numerically and graphically as well as guidance of how emissions could be reduced. A number of the calculators offer the user the ability to set an action plan to reduce carbon emissions, such as Act on CO2, The Carbon Diet, and MakeMeSustainable. The last two are the most dynamic as the user can update their data if and when they have implemented the action recommended. Three tools (The Carbon Diet, MakeMeSustainable and Carbon Rationing) are starting to experiment with social networking tools, such as blogs, discussion forums, and data sharing to provide users with more meanings for engaging with and learning about their carbon footprint.

Twenty-five of the calculators reviewed are designed to give users only an annual snapshot of their carbon emissions, mostly requiring front of mind information in order to be completed. The user does not need to register or set up a profile to get an indication of their carbon impact. For a continuous learning process the user needs to be able to create and manage their carbon calculator - the emerging “next generation” tools offer this functionality.

Context and methodology

Understanding the context for why action is needed on personal carbon emissions and how those emissions are calculated are important parts of the process of developing carbon literacy and numeracy. Carbon calculators hope to raise awareness about climate change and to give people an insight into how their behaviour contributes to the problem by enabling them to calculate the carbon emissions they are directly responsible for. Many calculators did provide some background information about climate change and the carbon emissions coming from the combustion of fossil fuels, but this tended to be brief and was only presented in text with no pictorial explanations. A few calculators do not provide background information on climate change and energy issues such as Bestfoot Forward’s Stepwise, South Hampton Sustainability Forum, Eco-speed and Berkeley Climate Footprint. In addition, most calculators do not give any information on emission stabilization and what that this will require in terms of changing the energy system and lifestyles. Furthermore, personal emissions are not put in context to the emission contribution of other sectors or national reduction targets.

To be effective communication and support tools, carbon calculators should not overwhelm users with detailed explanations of the methodology used to calculate person carbon emissions. However, some users will want to have access to this information so it is helpful to make methodology easily accessible. Only nine calculators provided sufficiently detailed explanations to determine clearly how carbon results were derived. The calculators with the most detailed information on the methodology used for calculating emission impacts were Atmosfair, Act on CO2, Berkeley Climate Footprint and Climate Care. Calculators such as National Energy Foundation, WRI-SafeClimate, COIN, Climate Crisis, Environmental Defense provided references to the data sources underpinning their calculator methodology. Other calculators such as BP World Land Trust and Landcare Research, made only limited information available about the methodology used.

One of the calculator tools available has a unique context different from the others, which is the carbon rationing tool. This tool has been created to support the Carbon Rationing Action Groups (CRAGs), a grassroots network of voluntary groups, testing the concept of personal carbon allowances. Individuals and groups can create a carbon account through which to monitor carbon emissions, set carbon reduction targets and track carbon costs or savings in relation to their allowance. The shortfall of this tool is that it is not immediately obvious how to set up and operate a carbon account.

Overall

The carbon calculators reviewed were not atypical of the calculators currently available via the Internet. The functionality of these calculators is meeting the objective of introducing the concept of quantifying personal carbon emissions and in the case of offset companies giving people a sufficiently accurate estimate of their emissions, so that they can purchase carbon offsets. The usability and presentation of the tools in many cases reflect a limited attention to imaginative design and engaging language. The carbon accuracy of calculators is determined by what options are available to input the data and to users themselves. Many calculators did have the functionality for users to input the actual quantities of energy used, but these calculators required users to have on the one hand a full year of data available as well as do some data interpretation before it can be inputted into the calculator. This is a significant barrier to successfully engaging people on personal carbon responsibility. Most of the calculators provide only simplistic information to users on their personal carbon impact and limited guidance on the actions to be taken forward. For instance, results and feedback were communicated simply in the form of a number with very little use of visuals and graphics.

The only tools attempting to give users the on-going ability to monitor their carbon emissions were the newly emerging "next generation" tools in *beta* development as well as Global Action Plan (only very basically) and Landcare Research. Generally the calculators assessed here were found to be designed only for a one-off use and therefore did not have the functionality for on-going engagement. In terms of context and methodology, the linkages between the global challenge of climate change and personal contributions to the issue could have been clearer and more tangible. Without the appropriate context for measuring and acting on their carbon emissions individuals are likely to feel that efforts they take to reduce emissions will be insignificant and worthless.

The review of calculators was based on the subjective knowledge of the author. A next step to this research on Internet tool for behaviour change would be to test the validity of the results by asking a number of users to trial these carbon calculators and score them. In addition, there are a number of interactive lifestyle tools that do not quantify energy use and carbon emissions accurately, but do give users much more feedback on behaviour, building fabric and technology measures that if adopted might reduce energy use and carbon emissions. Examples of these tools are The Climate Group's Together.com, British Gas' Home Energy Survey (UK), Global Action Plan's Greenscore (UK), Energy Saving Trust's Save 20% (UK) and Energy Box (Switzerland). Examining these tools in-depth would be helpful in the development of future carbon calculators.

Section 3: The Next Generation of Carbon Calculators

The carbon calculators reviewed here all constitute a useful starting point to engage people on personal carbon issues. However, there is scope for greatly improving carbon calculators so that they are able to provide people better support through a process of learning, understanding, and taking action on personal carbon responsibility. This scope is beginning to be hinted at through the *beta* development of a number of "next generation" type tools. Internet technology gives innovative ways for users to accurately quantify and monitor personal carbon emissions as well as access resources and connect with others to share data, information, ideas and experience. This section presents some ideas about how carbon calculators can be developed into more effective interactive tools. The ideas presented are discussed using the same four criteria used to evaluate existing calculators (see table 4): presentation and usability; data input and information; results, feedback, and guidance; and context and methodology.

Presentation and usability

Calculators should have different levels of sophistication: from enabling people to get an approximations of their carbon emissions based on front of mind information to providing people with an in-depth tool by which they can accurately measure and monitor their personal or household carbon emissions. The interface and architecture of the calculator tool will be crucial to ensure that users can easily navigate through the tool in as little or as much depth as desired. The presentation and usability of a carbon tool will affect the experience users will gain from the tool; users are more likely to return to an Internet tool if they find it well-designed and can access the information they want within a couple of 'mouse' clicks.

Carbon calculator tools need to communicate information more visually and graphically rather than relying heavily on text and numeric presentations of information. Users are likely to absorb information more readily if it is presented in a coherent and visual way. Many people are not numerical and therefore presenting information this way is likely to deter them from being interested in measuring and monitoring their carbon emissions. Calculators could be designed to have flexibility so that users can set default preferences such as having carbon results presented graphically, visually, numerically or a combination of these, so that the feedback information is presented in the way they feel the most comfortable with.

A carbon tool providing on-going support to users requires a registration process. This enables users to create a secure carbon profile, from which they can regularly measure, monitor and investigate their personal carbon emissions.

Data input and information

In order for carbon calculators to give users accurate and effective carbon results and feedback they need to give users the ability to enter in actual energy data. As discussed earlier energy bills do provide energy consumption information, but in the UK these are frequently estimated and tend to be difficult for people to decipher. Calculators can make the process easier for people by enabling them to input actual raw data, such as home energy meter readings and vehicle mileages. The calculators can then use the raw data to accurately assess the carbon emissions of a user. Calculators need to be designed to enable users to regularly input data, so over time users develop an accurate sense of their carbon emissions in contrast to the annual emission snapshot given by most of the existing calculators.

The development of technology and software for smart metering and appliance monitoring opens the possibility of automated data collection, which can be made accessible through a visual display in the home (Wood and Newborough, 2007). This information could also be transmitted into an online carbon profile giving the user greater ability to monitor and to analyse energy consumption. This will reduce the level of effort required by users, thereby enabling them to develop a meaningful understanding of their personal carbon emissions without spending lots of time routing for the necessary data. However, these technology devices cannot replace the value of having a human inputting data, interpreting the result of the analysis them and taking action in response. A good online tool could help ensure that people remain in control of their energy use.

Carbon results, feedback, and guidance

This area is the one in which Internet technology can really enhance the value of carbon calculators. To successfully engage people in issues of carbon responsibility, the carbon results need to be communicated to users in a way that is accessible and meaningful to them. Carbon results should be clearly broken down by activity – home energy, private transport, public transport and flights. People are likely to think there is more flexibility in altering their carbon emissions in certain activities over others, for example, changing light bulbs at home rather than modifying their driving patterns. Carbon tools need to take into account users' attitudes and perceptions when communicating carbon results. For example, flying can dwarf other carbon emitting activities and therefore make people feel that it is not worth making any efforts in other areas of their life, as it will not greatly alter their carbon emission profile. Therefore, calculators need to get the balance between communicating to users their full carbon emission impact and still motivating them to change their emissions where they can and want to.

Receiving a carbon impact figure from a calculator is unlikely to resonate with users unless it is presented in the context of other people or households' carbon profile results. People are likely to want to be compared with those they see, as being similar to them. Calculators should be designed to enable users to benchmark themselves against other people they feel have a similar lifestyle – for example, live in a detached house, high home occupancy, no children, travel by car and go on holiday each year in Europe. People should be able to choose the metric by which they want the information to be presented because although they are likely to choose the one that puts them in the most favourable light, it is also likely to keep them involved and motivated to learn and potentially change their carbon emission impact.

Internet technology offers a unique ability to connect people in a time-unconstrained manner. Only a few of the tools reviewed and these are in *beta* development are taking advantage of social networking tools for engaging people in personal carbon, but this is an exciting direction the next generation of calculators should explore. The availability of social networking through carbon calculators could give all sorts of opportunity for data sharing, comparison, grouping, competition, and support. As many of the social networking tools such as Facebook, My Space and Frienster are demonstrating, people gravitate towards these interactive experiences and enjoy being able to identify, connect and network with likeminded people. These social networking tools are described as part of the Web 2.0 phenomenon, which is the movement away from passive Internet information flows to much more social interactive engagement (O'Reilly, 2005). Incorporating social networking into carbon tools could be a way to engage a broader range of people in personal carbon responsibility. Internet social networking can also create links for virtual information exchange or be an additional resource for offline initiatives. For example, communities running carbon neutral programmes could use an Internet-based calculator to quantify and monitor the carbon emissions of participating households, as well as provide a forum to exchange ideas and experience between households as they reduce emissions. These social networking tools are not simple to implement and require considerable effort of the hosting organisation to design the functionality users want and to nurture the virtual community (Preece, 2000).

Context and methodology

Personal calculator tools will benefit from the development of standards and guidelines for how to quantify personal carbon emissions. At the moment, no standard methodology exists and as a result there are significant variations between calculators making it confusing for users to know which one to trust. The Act on CO2 calculator developed by the UK Government is becoming a sort of template as it is open source for users. There are a number of issues which organisations and web programmers developing calculators may find helpful to have guidance on, such as how to carbon count green electricity and bio-fuels as well as embodied carbon, as it becomes possible to more systematically quantify these emissions.

Conclusion

Internet-based carbon calculators offer individuals the ability to quantify, understand and act on their personal carbon emissions, specifically those from home energy and travel. The review of thirty carbon calculators into their carbon accuracy and effectiveness concluded that all are falling short in providing users with a tool that is carbon accurate; enabling on-going monitoring of carbon emissions; providing personalised feedback and relevant guidance; or one that uses social networking tools. Internet technology is developing into multimedia communication tool that is driven by the user. This development of Internet technology holds great potential for connecting people in innovative ways around personal carbon responsibility. The IMeasure tool being developed by the Environmental Change Institute is been actively develop to be a "next generation" carbon calculator.

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Web-addresses to all calculators reviewed

Organisaton	**Web Addresses**
UK Carbon Calculators	
Bestfoot Forward - Stepwise	http://www.bestfootforward.com/carbonacc.html
BP Carbon Footprint	http://www.bp.com/carbonfootprint
Carbon Neutral	http://www.carbonneutral.com//shop/index.asp
Carbon Rationing	http://my.carbonrationing.org.uk
Climate Care	http://www.climatecare.org/index.cfm
CO2 balance	http://www.co2balance.com/home.php
COIN	http://coinet.org.uk/projects/challenge/measure
Act on CO2	http://actonco2.direct.gov.uk/index.html
Global Action Plan	http://www.carboncalculator.com/
IMeasure	http://www.imeasure.org.uk (contact author if like access)
MSN - Carbon Estimator	http://specials.uk.msn.com/carbonemissionsestimator
National Energy Foundation	http://www.nef.org.uk/energyadvice/co2calculator.htm
Resurgence	http://www.resurgence.org/carboncalculator/index.htm
RSA – CarbonDAQ	http://www.rsacarbonlimited.org/emissions/default.aspa
Southampton Sustainability Forum	http://www.southampton-sustainability.org/carbcalc.htm
The Carbon Account	http://www.thecarbonaccount.com/
The Carbon Diet	http://www.carbondiet.org/
World Land Trust - Carbon Balance	http://www.carbonbalanced.org/personal/calculators.htm
Non-UK Carbon Calculators	
Atmosfair	http://www.atmosfair.de
Berkeley Climate Footprint	http://carboncalc.org
Climate Crisis	http://www.climatecrisis.net/
Climate Friendly	http://www.climatefriendly.com/
Eco-Speed	http://eco2.ecospeed.ch/privat/index.html?ln=1&us=1
Environmental Defense	http://www.fightglobalwarming.com/carboncalculator.cfm
Landcare Research	http://www.carbonzero.co.nz/calculators/calculators_home.asp
MakeMeSustainable	http://www.makemesustainable.com
Native Energy	http://www.nativeenergy.com/individuals.html
The Climate Trust	http://www.carboncounter.org/
Terrapass	http://www.terrapass.com
University of Sydney - Physics Dept.	http://www.physics.usyd.edu.au/~cdey/calculator.pdf
World Resource Institute - SafeClimate	http://www.safeclimate.net/calculator/
Other tools referred	
British Gas – Home Energy Survey	http://www.house.co.uk/energysaver
Energy Box	http://www.energybox.ch
Energy Saving Trust – Save 20%	http://www.est.org.uk/myhome/20percent/
Global Action Plan – Green Score	http://www.greenscore.org.uk/
The Climate Group – Together	http://www.together.com/