Imperial College London
Consultants

Bulb Calculator: An Independent Review

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This report is the independent expert opinion of the authors.

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1. Context

This report presents a brief review on Bulb Energy's Carbon Calculator (here abbreviated as BulbCalc), as it was available online[1] in January 2020. This review was commissioned by Bulb Energy Ltd to Imperial Consultants (ICON) and developed by the authors, as independent researchers affiliated to the Centre for Environmental Policy at Imperial College London. Therefore, the comments and opinions here shown are those of the authors alone and do not necessarily reflect the views of Imperial College London, ICON or Bulb Energy. The objective of this review is to provide an independent assessment of the carbon calculator (beta version), particularly its webtool and supplementary documentation (spreadsheet), including suggestions and recommendations for further improvements. Thus, it was not aimed at validating the model or assessing its code (algorithm) more specifically.

The use of carbon calculators either for assessing carbon footprints or projecting carbon emissions scenarios have become available for different purposes and scales, from private companies and NGOs, to national and global calculators led by governments. Some important examples are the *2050 Calculators*[2], which are currently available in more than 25 nations, including local (city level, e.g. Beijing), regional and national calculators, as well as the *Global Calculator*[3]. The UK was the pioneer in developing this type of approach through the former UK Department of Energy and Climate Change (DECC), which became an international benchmark. The *UK 2050 Calculator*[4] was recently updated by the UK Department for Business, Energy & Industrial Strategy (BEIS, formerly DECC). More recently, the EU Horizon 2020 Programme supported the development of a *European Calculator* (EUCalc)[5], led by PIK-Potsdam (Germany), including several partners such as, Imperial College London, Climact (Belgium), Delft University (Netherlands) and other institutions. The 2050 Calculators are user-friendly tools aimed at policy makers, business leaders and NGOs, rather than technology or sector- specific models from the energy sector, such as *Markal*, *Times, TIAM* and *Message*.

Moreover, some media groups and NGOs have developed their own calculators. The Financial Times, for example, developed a climate change calculator for assessing the impacts of major countries while implementing their respective Intended Nationally Determined Contributions (INDCs) by 2050, which were pledged in the occasion of the UNFCCC 21st Conference of the Parties (COP21), held in Paris in 2015. This *FT Calculator*[6] was prepared by Imperial College researchers in collaboration with the Indian Institute of Science (IISc Bangalore). Another example is the *WWF Environmental Footprint Calculator*[7], which was initially developed to

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[1] Beta version of BulbCalc available at: https://bulb.co.uk/carbon-calculator/

[2] See more on the 2050 Calculators at: https://www.gov.uk/guidance/international-outreach-work-of-the-2050-calculator

[3] The Global Calculator is available at webtool: http://tool.globalcalculator.org

[4] Access the UK 2050 Calculator at: https://www.gov.uk/guidance/2050-pathways-analysis

[5] The EUCalc is available at: http://www.european-calculator.eu/

[6] FT Calculator: https://ig.ft.com/sites/climate-change-calculator/

[7] WWF Environmental Footprint Calculator: https://footprint.wwf.org.uk

estimate carbon footprint in terms of ‘planetary boundaries’ and it is now focused on per capita greenhouse gas (GHG) emissions. In the WWF Calculator, the user is asked to answer a brief questionnaire that is used as the model’s input in order to estimate an approximate carbon footprint displayed in the end of its webtool.

In addition, some energy companies have also become interested in having their own calculators either for internal use or for use by their customers or potential clients. The Bulb Calculator, for example, is aimed at providing the general public, whether customers or not, with the capability of calculating their approximate carbon footprint and how ways in which they might mitigate their own GHG emissions. In order to gain traction, this type of calculator must be simple, with a user-friendly interface, because the user may not be interested in answering too many questions or in completing a complicated survey. At the same time, the calculator must be transparent and scientifically consistent, in order to provide a credible result with a reasonable accuracy level.

Most calculators currently available are based on system dynamics, which is a modelling approach based on changes of stocks and flows over time, for example the exploitation and use of natural resources (e.g. oil and gas) and their associate GHG emissions over a defined time period. These models can be developed using software such as *Stella*, *Vensim*, *Powersim*; however, it is also possible to develop system dynamics models using *MS Excel*, *Mathematica*, *Visual Basic*, *R*, *Ruby*, *Knime*, *Python*, *C* and other languages (Voinov, 2008). In contrast, some calculators are not aimed at projecting GHG emissions, but instead to estimate approximate current emissions, usually providing an estimate of annual per capita emissions. This could be done by using annual values or a sum of daily, weekly or monthly emissions – which are obtained according to available data in the literature or official databases, or through surveys (e.g. online questionnaires) – as well as GHG emission factors such as for the use of power, transport, lighting, food production, and manufactured goods. In general, they are simpler to develop than scenario-based models. This is the case of the BulbCalc.

2. Assessment of the Bulb Calculator

The BulbCalc webtool was initially assessed by simulating a ‘standard’ user running the tool online in order to avoid a potentially biased look at the model by the reviewers. Only after this analysis, the model was assessed against the supporting material provided by Bulb Energy and some available references in the literature. Therefore, the methodology of this review is based on three steps: firstly, we systematically simulated different usages of the BulbCalc webtool by a range of possible inputs to each question in order to check the model’s sensitivity; secondly, the values were compared with the database and emission factors provided by Bulb to the authors in supplementary information; and thirdly, we compared the values, modelling logic, and results with literature-derived values. After this, some recommendations for further improvements of the current calculator are also provided.

The BulbCalc is based on an online questionnaire, which is voluntarily answered by the user, who is probably not an expert in carbon accounting. The results from the questionnaire are used as input variables for the calculations. Usually the values are multiplied by GHG emissions factors and then summed for estimating an approximate annual per capita carbon footprint, which is then compared to an average UK citizen, as a reference. The final emissions are also graphically shown per emission source (e.g. aviation, food, etc.) as the final summary output of the tool.

The following sections present a brief analysis of each question asked in the BulbCalc questionnaire.

a) Road and rail transport

Question: *Which of these do you use?*

In this question, users are asked to select the type (mode) of terrestrial transport they normally use, in terms of number of hours used per week. The available options are car, motorbike, train, tram, underground and bus; otherwise, the option is “I just use muscle power to get around”.

For each transport mode, a number of simulations were carried out to generate a sensitivity analysis. We did this by increasing the number of hours of an individual single transport mode journey, without changing any other parameter in the model. Thus, only the per capita GHG emissions associated with that specific change in duration and mode are assessed. If they selected ‘car’, the user is redirected to a list of sub-options regarding technology and fuels, namely: petrol (gasoline), diesel, hybrid, plug-in hybrid, and electric. The number of hours per week were simulated for 0, 1, 2, 7, 14 and 21 (in order to check whether the variations were linear or not), and the respective GHG emissions noted. The weekly emissions were then converted to annual emissions and, thus, the respective emission factors were indirectly obtained, as shown Table 1. The same exercise was made for the other transport modes, which in contrast, did not have any sub-questions regarding their technology type. This assumes that only one type of fuel or technology (or technology mix) was considered for each transport mode, as a mean to be multiplied by the respective GHG emission factors per amount of used fuel. In the calculated GHG emission factor (kgCO_2/hour) in Table 1, the higher the number of hours per week, the closer the average (values shown in bold) to the emission factor used in the model, because of the decimal approximations. Hence, calculated emission factors for a small number of hours driven a week are apparently not linear due to numerical rounding by the webtool[8]. Minor impacts may not be noticed, too, because they are below the decimals shown.

[8] Increasing the number of decimals of the carbon footprint value displayed on the top right-side corner of the web interface (e.g. from one to two decimals) would be useful. On the other hand, the number of decimal places implies the accuracy of the value reported and the uncertainty in the footprint does not allow accuracy to tens of kilograms a year. Ideally, the decimals should be in line with the number of significative figures across the calculations.

***Table 1**: Which of these do you use? (BulbCalc)*

Transport mode	Webtool		Calculated	
	How many hours do you drive each week?	**tCO_2e/y**	**Hours per year**	**$kgCO_2e/hour$**
Car (petrol)	21	9.5	1095.7	**8.7**
	14	6.4	730.5	8.8
	7	3.2	365.2	8.8
	2	0.9	104.4	8.6
	1	0.5	52.2	9.6
	0	0.0	0.0	0.0
Car (diesel)	21	9.1	1095.7	**8.3**
	14	6.1	730.5	8.4
	7	3.0	365.2	8.2
	2	0.9	104.4	8.6
	1	0.4	52.2	7.7
	0	0.0	0.0	0.0
Car (hybrid)	21	6.0	1095.7	**5.5**
	14	4.0	730.5	5.5
	7	2.0	365.2	5.5
	2	0.6	104.4	5.7
	1	0.3	52.2	5.7
	0	0.0	0.0	0.0
Car (plug-in hybrid)	21	6.1	1095.7	**5.6**
	14	4.1	730.5	5.6
	7	2.0	365.2	5.5
	2	0.6	104.4	5.7
	1	0.3	52.2	5.7
	0	0.0	0.0	0.0
Car (electric)	21	3.2	1095.7	**2.9**
	14	2.1	730.5	2.9
	7	1.1	365.2	3.0
	2	0.3	104.4	2.9
	1	0.2	52.2	3.8
	0	0.0	0.0	0.0
Motorbike	21	6.1	1095.7	**5.6**
	14	4.1	730.5	5.6
	7	2.0	365.2	5.5
	2	0.6	104.4	5.7
	1	0.3	52.2	5.7
	0	0.0	0.0	0.0
Train	21	4.5	1095.7	**4.1**
	14	3.0	730.5	4.1
	7	1.5	365.2	4.1
	2	0.4	104.4	3.8
	1	0.2	52.2	3.8
	0	0.0	0.0	0.0
Tram	21	1.3	1095.7	**1.2**
	14	0.8	730.5	1.1
	7	0.4	365.2	1.1
	2	0.1	104.4	1.0
	1	0.1	52.2	1.9
	0	0.0	0.0	0.0
Underground	21	1.1	1095.7	**1.0**
	14	0.7	730.5	1.0
	7	0.4	365.2	1.1
	2	0.1	104.4	1.0
	1	0.1	52.2	1.9
	0	0.0	0.0	0.0
Bus	21	2.3	1095.7	**2.1**
	14	1.5	730.5	2.1
	7	0.8	365.2	2.2
	2	0.2	104.4	1.9
	1	0.1	52.2	1.9
	0	0.0	0.0	0.0
I just use muscle power to get around	N/A	0.0	N/A	0.0

The results show a linear pattern (Figure 1), which shows that the GHG emission factors are not expected to change if the person uses more or less hours of a certain transport mode. These variations may not be linear in practice, for example, short car journeys on cold days are known to result in greater emissions per km travelled than longer journeys, but the average provides a reasonable approximation. The user can also combine different transport modes. The results are calculated independently and then summed.

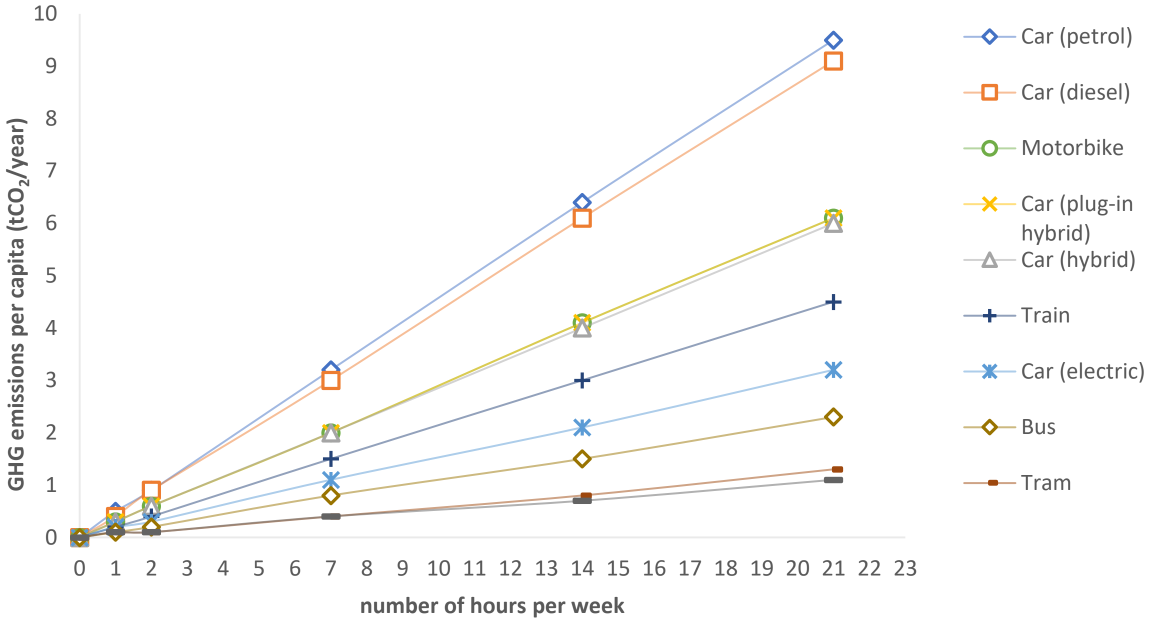

***Figure 1**: Annual per capita GHG emissions according to the use of different transport modes in the UK*

Note: values obtained from BulbCalc webtool analysis.

The assumptions provided in the supplementary documentation (spreadsheet) include GHG emission factors based on UK Government (2019), according to different transport modes. As shown in Table 2, these values were then compared to the emission factors indirectly obtained by running the webtool alone (see Table 1), presenting minimal variations, as expected due to decimal approximations for the results shown on the webtool. This demonstrates that the algorithm (model's transcripts) is processing the calculations correctly. In the spreadsheet, it is also noted that the emission factors are related to average car and motorbike size, and average UK bus. The national rail and the London underground were used as references for all of UK, for train and metro (tube) GHG emission factors, respectively, which are reasonable assumptions as approximate figures. However, this information may not be clear for a user that only interacts with the webtool, without a further interest in checking some technical references and blog comments available on the company's website.

***Table 2**: Values of reference for the BulbCalc estimates, on a per capita basis.*

Units	Cars					Motorbike	Tube	Train	Bus	Light rail and tram
	Petrol	Diesel	Hybrid	Plug-in Hybrid	Battery EV					
$kgCO_2e/mile$[1]	0.29103	0.27901	0.18464	0.18559	0.09688	0.18589	0.04963	0.06623	0.16852	0.05646
$kgCO_2e/km$[1]	0.18083	0.17336	0.11472	0.11531	0.06020	0.11550	0.03084	0.04115	0.10471	0.03508
Average speed (mph)[1]	30	30	30	30	30	30	20.505	62.5	12.5	20.505*
$kgCO_2e/hour$[2]	8.73090	8.37030	5.53920	5.56770	2.90640	5.57670	1.01776	4.13924	2.10654	1.15768
Webtool[3]	8.7	8.3	5.5	5.6	2.9	5.6	1.0	4.1	2.1	1.2

[1] Values reported in the BulbCalc supplementary document (spreadsheet) except the $kgCO_2e/km$ for cars and motorbike, which were not available but estimated by the authors, using the same conversion ratio (1 mile = 1.609425473 km).

[2] Emission factors calculated by the authors using the factors available in the previous lines.

[3] Values indirectly obtained by the authors through the BulbCalc webtool (see Table 1)

* The light rail and tram's average speed was not available in the supplementary document, but it was assumed by the authors that the BulbCalc has used the same speed as for the underground trains (tube), given that it resulted to a close emission factor to the webtool.

Additional comments and notes regarding some unclear assumptions and uncertainties involved in the calculations for road and rail transport are following described:

- The use of electric buses has been gradually increasing in several UK cities, including London. However, the adopted GHG emission factor in the BulbCalc is for a UK average for local buses: 0.10471 $kgCO_2e/km$, according to the DEFRA 2019 GHG emission factors report (UK Government, 2019). While this is not incorrect, the emission factor varies significantly by region. In London for instance the emission factor for a local bus is 0.08208 $kgCO_2e/km$. Bulb might consider asking for approximate geographical location, such as the county, in order to give more accurate results without adding complexity.
- Light rail and tram's average speeds were assumed to be the same as for the underground. We were able to verify this calculation gives the correct value, but only by circumstance. The two speeds are not necessarily equal and come from separate sources, it is coincidental that the same speed (33 km/h = 20.505 mph) has been reported by both Transport for London (TfL, 2019) and the EU light rail and tram report (ERRAC & UITP, 2012, p. 32, chart 16). As a suggestion, the calculator should separate these two values in the calculation step as we trust in the future the calculator will need updating as new data are available. In addition, it would be useful to include hyperlinked references to the sources for the speed values used and the source date of the data.
- The average emission factors are for the UK more broadly and, therefore, they do not reflect the average speed of road vehicles in different places, for example, streets with heavy urban traffic vs an open highway or roads in a small village or a rural area, as well as the local topography (e.g. slope). These variations in traffic speed could potentially affect the user's GHG emission for transport. Asking the user whether s/he lives in a dense urban area or not, among other possible questions, could reduce these uncertainties but, as a trade-off, the questionnaire would have to be expanded.

- There is also an uncertainty related to the vehicle efficiency. The user may have a low- or a high-efficiency vehicle, but the calculations are made based on an average for UK vehicles. The same occurs for new vs old trains and trams.
- The use of carsharing and car hire vs. own car may also affect the results and is not covered in the calculator. The Global Calculator (see link for the webtool in previous footnotes), for example, has a lever only about this topic[9], and some insights could be explored from this experience. GHG emissions related to the vehicle's manufacturing and lifetime were not covered in the BulbCalc either. The calculator could be reformulated to include these issues too; otherwise, it is recommended that these uncertainties should be at least clarified in a tooltip or supporting document.
- Average per capita GHG emissions in public transport, such as buses, trains, trams, and underground, are subject to large uncertainties too. For example, if a passenger uses a busy (full capacity) underground train for commuting, the emissions may be lower than the same underground train relatively empty in a different line, among other possible examples. Thus, any average value would probably have a large associated standard deviation, which could be estimated. However, this is difficult to measure accurately and, since Bulb only asks for average hours per week, it seems fair to use the average carbon intensity. The UK 2050 Calculator (see link for the webtool in previous footnotes, and spreadsheet[10] used for the calculations), although aimed at emissions scenarios rather than current assessment, may provide some useful insights about the use of domestic transport in the UK[11], among other sectors.
- Regarding the GHG emission factor associated with the use of electric vehicles, if the user charges her/his car at home, say using 100% renewable electricity, or not, the emission factor remains the same in the calculator. Home electricity is the subject of a specific question in the very end of the questionnaire, but a possible interaction between these two issues could be better explored in order to increase the accuracy of the calculations. For example, a question about where the vehicle is usually charged (e.g. home, street parking) could be useful. Reordering the questions with home energy before transport so that the changes do not have to be back-propagated is also a possibility. Otherwise, this is an uncertainty that should be clarified in supplementary documentation and/or through a tooltip in the calculator.

b) Air transport

***Question**: How many flights have you taken in the past 12 months?*

This question is highly sensitive and may require to be better explained to the user, who may not be aware of the magnitude that the aviation sector can have in total GHG emission. On the other hand, this is an important message to the user, i.e. to realise that aviation can be very impactful. Like in the previous question, a simulation was firstly made by running the BulbCalc

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[9] See more at: http://tool.globalcalculator.org/gc-lever-description-v23.html?id=7/en

[10] Available at: https://www.gov.uk/government/publications/2050-pathways-calculator-with-costs

[11] See more at: http://classic.2050.org.uk/assets/onepage/23.pdf

webtool alone. The previous question was kept as “I just use muscle power to get around” so that the balance of GHG emissions in calculator remained null. The number of flights, 0, 1, 2, 5 and 10, were then simulated one at a time to identify potential variance for different flight durations, in order to assess the impact of each additional incremental flight, analogously to a sensitivity analysis. The GHG emission factors were then indirectly calculated from the results obtained through the webtool, as shown in Table 3. The larger the number of flights, the closer the average emission factor (values in bold) to the fixed factor used in the model, due to decimal approximations on the webtool.

***Table 3**: How many flights have you taken in the past 12 months? (BulbCalc)*

Flight duration	Webtool		Calculated	
	number of flights per year	tCO_2/y	Mean number of hours per year	$kgCO_2$/hour
Under 4 hours	0	0.0	0	0.0
Mid-point = 2	1	0.6	2	300.0
	2	1.1	4	275.0
	5	2.9	10	290.0
	10	5.7	20	**285.0**
4-8 hours	0	0.0	0	0.0
Mid-point = 6	1	2.1	6	350.0
	2	4.2	12	350.0
	5	10.6	30	353.3
	10	21.1	60	**351.7**
8-12 hours	0	0.0	0	0.0
Mid-point = 10	1	3.5	10	350.0
	2	7.0	20	350.0
	5	17.6	50	352.0
	10	35.2	100	**352.0**
Over 12 hours	0	0.0	0	0.0
Minimum point = 12	1	4.2	12	350.0
	2	8.5	24	354.2
	5	21.1	60	351.7
	10	42.3	120	**352.5**
None	N/A	0.00	N/A	0.00

As shown in Figure 2, the GHG emissions factors used for one or more flights are the same, given that all flight durations presented a linear pattern. It is worth noting that one long haul return flight (over 12 hours) has approximately as much GHG emissions as 10 short haul return flights (under 4 hours).

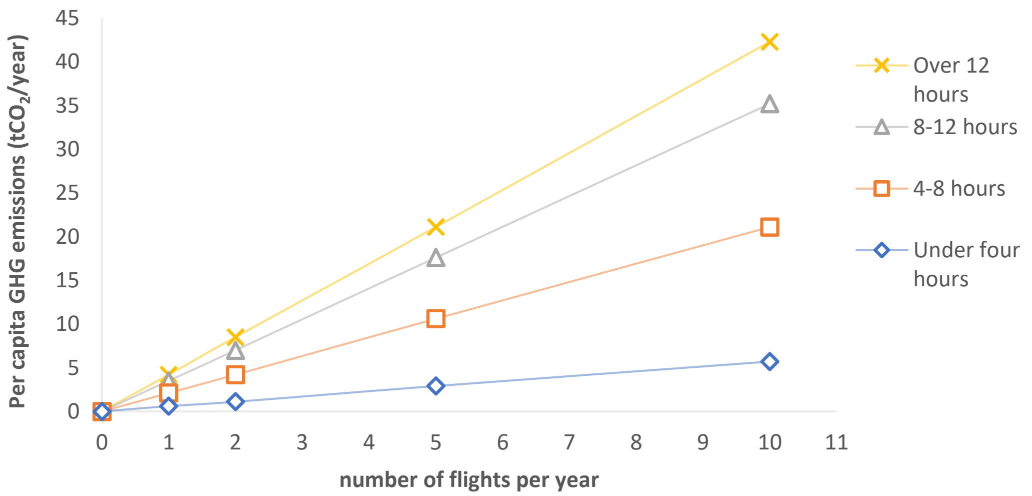

***Figure 2**: GHG emission per flight duration, BulbCalc*

Note: values obtained from BulbCalc webtool analysis.

Fight durations were presented as ranges on the BulbCalc, but it is not very clear on the webtool what duration was effectively used in the calculations. For example, for <4 hours, it was assumed by the authors 2 hours on average, i.e. the mid-point between 0 and 4 hours. The same rationale was adopted for the other ranges, except for the last duration (over 12 hours), in which it was assumed the minimum point i.e. 12 hours (although 12 hours is also the maximum value for the previous category). After checking the supplementary material, it was found these are exactly the assumptions used in the calculator, but the user may be confused about those ranges. Alternatively, asking the duration of their flights could make a substantial improvement in the estimation of emissions.

The dataset reference used by the BulbCalc for GHG emission factors in flight transport was also UK Government (2019). It is noted in the supplementary documentation (spreadsheet) that all flights are from/to the UK, which sounds reasonable, given that the target audience is British citizens, although this information is not available on the webtool. The documentation also states that the emissions factors include radiative forcing, but without specifying how the radiative forcing was used in the estimates, and mentions that the BulbCalc assumes average passenger emission factor across classes, although flying in economy, business or first class has significantly different impacts in terms of GHG emissions per passenger. Thus, values represent broad averages, possibly with large associated errors margins in the mean values. On the other hand, additional details may unnecessarily increase the model's complexity, considering its purpose, which is to provide an approximate carbon footprint for an average person, through a simple and interactive webtool.

It is important to highlight that, although this question refers to return flights, some users may think that the ranges of flight duration refers to the total elapsed time, but in fact it is about each leg of the journey, rather than the total (i.e. out and back combined). Moreover, the calculator uses different emission factors for short haul (under four hours) and long haul (over four hours), but the ordinary user may not be aware of that. It is not clear either why four hours was chosen as a reference for this variation. For example, a per capita emission factors of 'long-haul' flights to the south hemisphere, say London to Rio de Janeiro, Johannesburg or Sydney, are most probably different to those for mid-distance flights, e.g. London to Cairo or Tel Aviv, which are also over four hours. Normally, the difference between short-haul and long-haul is about <500km to >500km and therefore >2 hours duration would be considered a 'long-haul'. In general, these differences are to do with the cost of taking off c.f. time in the cruise with taking off requiring much more fuel than cruising.

Table 4 shows the dataset and assumptions provided in the BulbCalc supplementary spreadsheet used for the estimates, as well as the calculated emission factors from both the spreadsheet data and the indirect values obtained from the webtool, as previously shown in Table 3, showing very minor variations (at decimal level) between them both. This confirms that the algorithm is making the right calculations whilst using the raw dataset and displaying the results on the web interface.

***Table 4**: Air transport assumptions and calculations on a per capita basis for a reference flight, BulbCalc*

BulbCalc spreadsheet							Calculated	
Flight duration (hours)	Reference duration (hours)[1]	Distance[2]	Per capita emission per single journey[3]		Per capita emission per return journey[4]		Based on BulbCalc spreadsheet	From BulbCalc Webtool[5]
			$kgCO_2e$	tCO_2e	$kgCO_2e$	tCO_2e	$kgCO_2e/h$	$kgCO_2e/h$
<4	2	1,800	285	0.28	570.0	0.6	285.0	285.0
4-8	6	5,400	1056	1.06	2113	2.11	352.1	352.0
8-12	10	9,000	1761	1.76	3521.2	3.5	352.1	352.0
>12	12	10,800	2113	2.11	4225.4	4.2	352.1	352.0

[1] Number of hours effectively used in the calculations.

[2] Average speed for all flights = 900 km/h.

[3] GHG emission factors: short haul = 0.15832 kgCO2e/passenger.km; long haul = 0.19562 kgCO2e/passenger.km.

[4] Inbound and outbound flights are assumed to be equivalent.

[5] Indirectly obtained from BulbCalc webtool, see GHG emission factors in Table 3.

The assumptions used in the calculations are very broad and general for a rather complex sector. Flight emissions may substantially vary not only according to the distance, but also the airplane model, altitude, wind speed and direction, aerodynamics, time for taking off and landing, average number of passengers per flight, baggage sizes, jet turbine vs turboprop engine, among other variables which add uncertainties to the model. Hence, neglecting these details directly affects the accuracy of the results. This section could be entirely reformulated by assessing further literature, such as DfT (2016 and 2017, see Chapter 3 on CO_2 emissions modelling), Sustainable Aviation (2018) and CAA (2017), among others, as well as by reorganising the algorithm logic and structure.

While Bulb may not easily be able to improve on directly on the underlying carbon emission factors, it can clarify that there are strong uncertainties associated with this figure. Furthermore, as discussed above, explicitly prompting the user to enter the duration of each ‘leg’ of the journey would improve accuracy without increasing the number of questions asked.

c) Diets

Question: What do you eat?

Users are asked to provide the number of meals eaten per week including different types of food. As done for the previous questions, Table 5 shows data obtained from the webtool, as well as the GHG emission factors indirectly estimated. The number of meals per week were tested for 0, 1, 2 and 7 (dairy was also tested for 21), and the emissions values noted, keeping all other variables unchanged, analogously to a sensitivity analysis.

***Table 5**: What do you eat? (BulbCalc)*

Food type	Webtool		Calculated	
	meals per week	**tCO_2/y**	**meals per year**	**$kgCO_2/kg$**
Beef Serving size = 75g	0 1 2 7	0.0 0.4 0.8 2.8	0.0 52.2 104.4 365.2	0.00 102.2 102.2 **102.2**
Pork Serving size = 75g	0 1 2 7	0.0 0.1 0.2 0.7	0.0 52.2 104.4 365.2	0.00 25.6 25.6 **25.6**
Chicken Serving size = 75g	0 1 2 7	0.0 0.1 0.1 0.5	0.0 52.2 104.4 365.2	0.00 25.6 12.8 **18.3**
Lamb Serving size = 75g	0 1 2 7	0.0 0.2 0.5 1.6	0.0 52.2 104.4 365.2	0.00 51.1 63.9 **58.4**
Fish Serving size = 140g	0 1 2 7	0.0 0.1 0.2 0.7	0.0 52.2 104.4 365.2	0.00 13.7 13.7 **13.7**
Shellfish Serving size (crustaceous): 5 king prawns = 250g	0 1 2 7	0.0 0.2 0.4 1.3	0.0 52.2 104.4 365.2	0.00 15.3 15.3 **14.2**
Dairy Milk = 200 ml (approx. 200g) Cheese = 30g	0 1 2 7 21	0.0 0.1 0.1 0.2 0.7	0.0 52.2 104.4 365.2 1095.7	0.00 9.4 4.2 2.4 **2.8**
Eggs Serving size (2 eggs) = 100g	0 1 2 7	0.0 0.0 0.1 0.2	0.0 52.2 104.4 365.2	0.00 0.00 9.6 **5.5**
I only eat plants	N/A	0.0	N/A	0.00

Note: serving sizes were not available on the webtool but were obtained from the BulbCalc spreadsheet. The approx. mean mass of an egg and a king prawn was suggested by the authors, based on Hills (2019) and Sea-Ex (2019), respectively.

The serving sizes assumed by the model are not clear on the webtool, and the values available in the supplementary document (spreadsheet) may not reflect an accurate mean value, although the user can change the number of meals per week in order to adjust a total value of preference. Some adjustments could be implemented in this question based on some additional considerations and references, such as Lewis *et al*. (2012), Church (2008) and Reeves *et al*. (2011). The World Health Organization – WHO (2008) suggests that per capita meat consumption should not exceed 90g/person/day. Figure 3 and Table 6 show the meat supply in the UK (2017 base year), using data from the FAO (2020), suggesting an apparent consumption of approximately 177 g/person.day, i.e. about the double of the WHO reference, similar to the c. 200 g/person.day estimated from Strapasson *et al*. (2016, p. 2, graph 2). It is worth noting that meat and meat protein are different concepts, given that protein represents a fraction of the total meat weight. Moreover, the assumed serving size for fish (140g) in the BulbCalc is almost the double those considered for beef, lamb, pork and chicken, all with 75g of serving sizes. This issue may require a note for clarity either on the webtool, in a supplementary document, or in a list of frequently asked questions[12].

[12] Alternatively, this Bulb's webpage could be improved: https://bulb.co.uk/carbon-calculator/calculating-carbon-emissions/

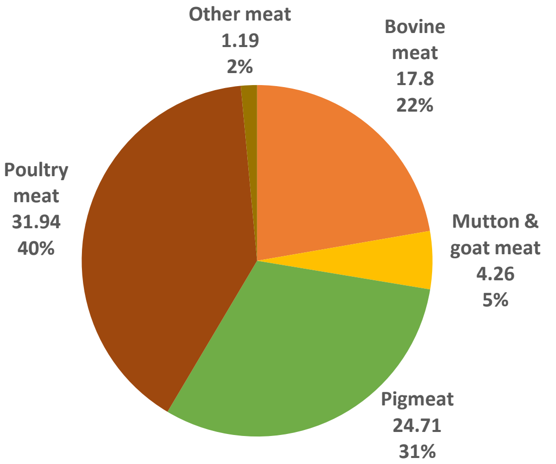

Figure 3: *Meat supply in the UK, kg/capita.year (2017 base year), excluding fish. Source: FAO (2020)*

Table 6: *Meat supply in the UK (2017 base year)*

Total supply in kg[1]	79.9	kg/capita.year
Total supply in g	79900	g/capita.year
Daily supply in g	219	g/capita.day
Wastes and losses[2]	19	%
Apparent consumption[3]	177	g/capita.day

[1] Source: FAO (2020)
[2] Source: Lipinski *et al.* (2013), in energy terms (adapted).
[3] It represents the meat intake, obtained from the amount of meat supply minus total losses in the production chain.

In the BulbCalc, the mass of other food products like shellfish and eggs has not been specified either on the webtool or on the spreadsheet, though this information is important to assess the GHG emission factor per gram of food consumed. Shellfish is a colloquial term for a broad range of aquatic food, particularly molluscs (e.g. mussels, winkles, oysters, scallops, and clams) and crustaceous (e.g. shrimp, lobsters, crayfish, and crabs). However, the reference available on the spreadsheet is for 5 king prawns as a representative reference for shellfish on average, although some users may think that it refers to animals that necessarily live within a shell, not prawns (apart from the lobster icon displayed on the webtool). Independently of these variations, as an exercise for testing, it was assumed that each king prawn has about 50 g (Sea-Ex, 2019) and, hence, the "shellfish" serving size (i.e. five prawns) equals 250 g, which is much above the serving size for other meat types.

Regarding eggs, the question does not ask how many eggs per meal. The serving size shown in the supporting material (spreadsheet) is two eggs and it is here assumed that one large egg has approximately 50 g (Hills, 2019), resulting in 100 g per serving size. Also, it is relevant to mention that the icon used for selecting the number of eggs consumed shows three eggs, while the portion size used in the calculations is in fact two (a tooltip[13] could be added to indicate the serving size).

As for dairy, it is not clear on the webtool what dairy exactly represents. On the spreadsheet, dairy apparently refers to 30 g of cheese plus 200 ml of milk (approx. 200 g), i.e. presumably 230 g in total per serving size of dairy products on average. However, dairy serving size described on the webtool may be confusing for the user, because it makes an analogy to "mac 'n' cheese" portions and that 'it is not like the milk in the tea'.

[13] A tooltip is a box which appears when hovering over a piece of text. Alternatively, an icon for further explanation could be included in each frame of the EUCalc, which may work better for a mobile phone version as well.

Based on these assumptions and data obtained and calculated from the BulbCalc webtool (as previously shown in Table 5), the GHG per capita emission factors per different types of food are summarised in Figure 4.

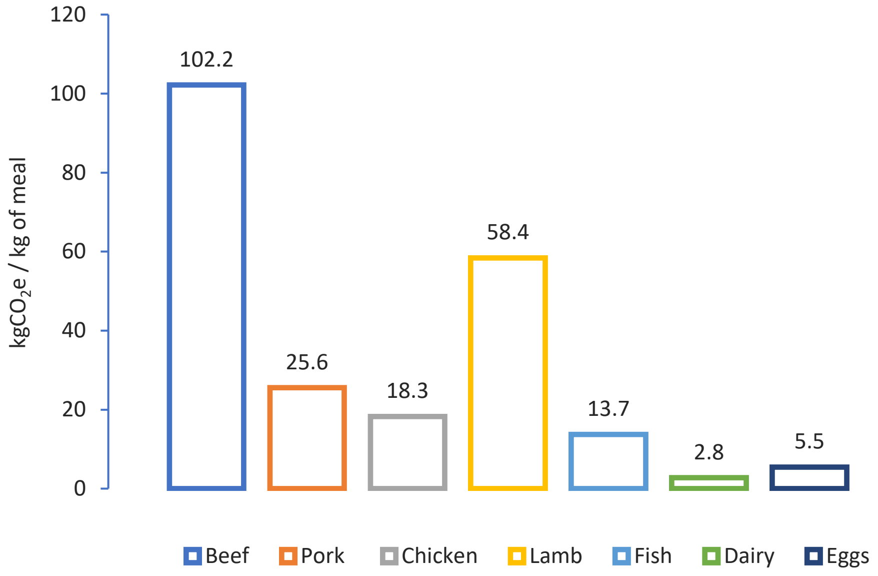

***Figure 4**: GHG emission factors for different types of food*

Note: values obtained from BulbCalc webtool analysis and assumptions shown in Table 5.

According to the information available in the supplementary document (the spreadsheet), the reference (apparently the only reference) used for the diet question was Poore and Nemecek (2018). This study is an important review of a large number of surveys; however, it takes the global average carbon footprint of foods, and not specifically food sold in the UK. Table 7 shows a comparative analysis, in which the assumptions available in the spreadsheet were used to obtain GHG emission factors per type of food, which are then compared to the values indirectly obtained by running the webtool. Most emission factors are convergent, which means that the algorithm is consistent. However, for dairy, the result was significantly different, which highlights the need for a double check in the BulbCalc calculations and algorithm in order to identify any possible mistakes in the model; otherwise, to clarify in greater detail the assumptions used for dairy products.

Table 7: Diet assumptions and calculations for different types of food on a per capita basis, BulbCalc

BulbCalc spreadsheet			Calculated		
Food type	Serving	$kgCO_2e$ per serving	Adjusted serving size (grams)	Based on BulbCalc spreadsheet $kgCO_2e/kg$	From BulbCalc webtool[3] $kgCO_2e/kg$
Beef	75 g	7.726	75	103.0	102.2
Lamb	75 g	4.334	75	57.8	58.4
Fish	140 g	1.871	140	13.4	13.7
Crustaceans[1]	5 king prawns	3.441	250	13.8	14.2
Pork	75 g	1.797	75	24.0	25.6
Chicken	75 g	1.361	75	18.1	18.3
Cheese	30 g	0.964	30	32.1	-
Milk (dairy)	200 ml	0.627	200	3.1	-
Dairy (total)[2]	**230 g**	**1.591**	**230**	**6.9**	**2.8**
Eggs	2 eggs	0.553	100	5.5	5.5

[1] Crustaceans is a term used in the spreadsheet, whereas on the webtool the term shellfish is used. In both cases, it represents the portion of 5 king prawns

[2] Dairy (total) was not available in the spreadsheet, but it was calculated by summing milk (approx. 200 g) plus cheese (30 g), i.e. 230 g in total. In contrast, dairy is available on the webtool, but not milk and cheese.

[3] Indirectly obtained from BulbCalc webtool, see GHG emission factors in Table 5 and Figure 4.

Land use change is also an issue that brings large uncertainties for average emissions related to food consumption, especially emissions related to livestock and pastureland dynamics, and international food trade flows, including potential deforestation outside the UK. The main reference used in the BulbCalc for this question includes land use, given that Poore and Nemacek (2018, p.1) claim that their analysis "covers five important environmental impact indicators: land use; freshwater withdrawals weighted by local water scarcity; and GHG, acidifying, and eutrophying emissions", whilst also citing Steffen *et al*. (2015). However, using a GHG emission factor to express any food and meat related GHG emissions, as an average for a UK citizen, is a large extrapolation. These uncertainties should be clarified somewhere in the calculator or in its supplementary documentation. There is a vast literature discussing how complex it is to address these type of impacts, some examples are the IPCC Fifth Assessment Report's Chapter 11 on Agriculture, Forestry and Other Land Uses – AFOLU (Bustamante *et al*., 2014), as well as Aleksandrowicz *et al*. (2016), Hillier *et al*. (2009), Nijdam *et al*. (2012) and Strapasson *et al*. (2016, 2017).

d) Personal purchases

In this part of the questionnaire the user is driven to different questions about the personal purchases of different types of goods, which are arranged into four different categories: clothes and shoes; toiletries and health; electronics; and home furniture and appliances. The BulbCalc then associates the amount of money (in GBP) spent per month or per year with an average GHG emissions factor for that type of respective product. Like the tests made for the previous BulbCalc questions, an assessment analogous to a sensitivity analysis was carried out for the different categories by firstly running the webtool alone. The respective GHG emission factors for the clothes & shoes, health & beauty products are shown in Table 8.

Table 8: *Per capita GHG emissions for the purchases of clothes & shoes, health & beauty products, BulbCalc*

Question	Webtool		Calculated	
	GBP/month	tCO_2/y	GBP/year	$kgCO_2/GBP$
How much do you spend on clothes and shoes each month?	1,000	4.0	12,000	**0.33**
	500	2.0	6,000	0.33
	100	0.4	1,200	0.33
	10	0.0	120	0.00
	0	0.0	0	0.00
How about toiletries and health and beauty products?	1,000	7.2	12,000	**0.60**
	500	3.6	6,000	0.60
	100	0.7	1,200	0.58
	10	0.1	120	0.83
	0	0.0	0	0.00

Similar to the previous table, Table 8 shows the respective GHG emission factors for electronics (called 'Computers and IT equipment' in the spreadsheet), and furniture & appliances for home. It is worth noting that the questions about these products are in terms of total expenses per year, rather than per month, as in the previous two questions. From the phrasing of the question it is not clear if it refers exclusively to the purchase of electronics, or the rental e.g. phone contract. It should avoid double counting as well as omitting areas, so it is worth clarifying for the user, perhaps in a tooltip.

On a user interface perspective, although the period is clearly shown on the webtool, it is easy for users to fail to notice this information.

Table 9: *Per capita GHG emissions for the purchases of electronics, furniture & appliances for home, BulbCalc*

Question	Webtool		Calculated
	GBP/year	tCO_2/y	$kgCO_2/GBP$
In the past 12 months, how much did you spend on electronics?	10,000	6.5	**0.65**
	5,000	3.3	0.66
	1,000	0.7	0.70
	100	0.1	1.00
	0	0.0	0.00
What about furniture and appliances for your home?	10,000	5.0	**0.50**
	5,000	2.5	0.50
	1,000	0.5	0.50
	100	0.1	1.00
	0	0.0	0.00

The GHG emission factors indirectly calculated through the webtool for the different goods are summarised in Figure 5. The supplementary document (spreadsheet) offers the respective emission factors and all of them exactly match the calculated GHG emission factors via the webtool. This confirms that the algorithm is working properly.

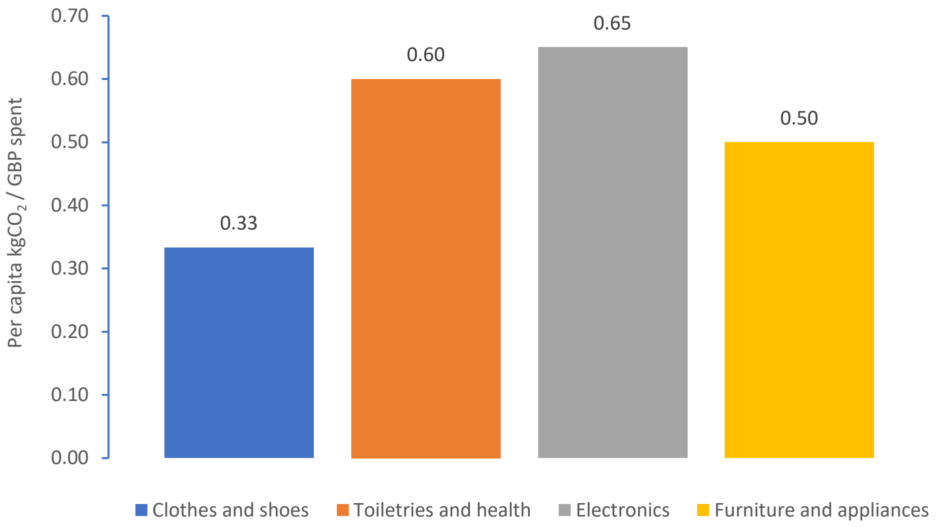

Figure 5: *GHG emissions factor for personal expenditures in the UK*

Note: values obtained from BulbCalc webtool analysis.

The calculation of the emissions from purchases were obtained from the Carbon Footprint Calculator (2019). This calculator is based on Environmentally-Extended Input-Output (EEIO) tables published in the 2012 DEFRA report, extrapolated by CarbonIndependent.org to the year 2019 using inflation. This method introduces significant inaccuracies. It does not account for changes in supply chains or infrastructure over time, for instance decarbonisation of the UK grid (or changes in transport). This can only be used as a very approximate measure, given that GHG emissions depend on a large number of complex issues related to the acquired product, for example, its price, brand, material, durability, size, if locally produced or imported, among several other issues, and economic inflation does not account for any of these factors.

In addition, it may not be consistent with the scope in other areas of the calculator, as it aims at including the full chain of impacts, whereas in the energy part of the questionnaire for instance, the impacts of the energy provider companies operations/suppliers are not included. Although it introduces significant inaccuracies, EEIO is a fairly good way of avoiding overlooking the significant impacts within purchases. However, more up to date EEIO sheets should be used. The Eora Global Supply Chain Database[14], for example, publishes comprehensive Multi-Region Input-Output (MRIO) tables, including for environmental impacts, which have been updated more recently. Among other references, these updates could help improve the accuracy of the model.

[14] See more at: https://worldmrio.com/. Apparently, Eora gives easier to use GHG intensity data but requires that organisations purchase a license for the GHG footprint data in order to support their work. Linking these carbon footprints to the Bulb data would require a careful and detailed work on assessing these databases, among other references that could be used in future updates of the model.

e) Home electricity and gas

In this section of the questionnaire, the user is invited to answer two questions about the use of electricity and gas at home. Whist selecting 100% renewable for the electricity or 100% carbon neutral for gas, the GHG emission factor is null for any case (Table 10); otherwise, there is a GHG emission associated with the energy used, based on the assumption that the energy would partially come from fossil fuel sources. However, it is worth noting that commercial renewable energies (e.g. solar, wind, hydropower, biomass) also have a carbon footprint associated with them. This includes emissions related to the construction and operation of renewable energy plants, e.g. emission regarding the production of photovoltaic panels or wind turbines, energy infrastructure, etc. Apparently, this is not included in the base line emissions, which are discussed in the subsequent question. Hence, **this is an area that would deserve an update or further clarifications in future versions of the BulbCalc**. Regarding the renewable energy sources, although Bulb is focused on solar and wind power, the user may consider other sources and/or energy suppliers as well.

***Table 10**: Per capita GHG Emissions for annual energy use, obtained from BulbCalc webtool*

BulbCalc webtool		
Question	**Answer**	**tCO2/y**
Is your home electricity 100% renewable?	Yes	0.0
	No	**0.8**
	I am not sure	0.8
Is your home gas 100% carbon neutral?	Yes	0.0
	No	**2.2**
	I am not sure	2.2

Table 11 shows the values and calculations available on the supplementary spreadsheet, against the indirectly calculated emission factors, which are the same. This means that the BulbCalc algorithm is consistent with both the spreadsheet and webtool. The main references used in the spreadsheet for this question were the UK Government (2019) and Ofgem (2019), which are credible sources.

***Table 11**: BublCalc assumptions and calculations for home electricity and gas*

BulbCalc supplementary material		Calculated from the BulbCalc webtool
Elec emissions factor (kgCO2/kWh)	0.25358	-
Gas emissions factor (kgCO2/kWh)	0.18385	-
Average EAC (kWh/year)	3100	-
Average AQ (kWh/year)	12000	-
Electricity emissions (kg/year)	786.098	-
Gas emissions (kg/year)	2206.2	-
Electricity emissions (tonnes/year)	**0.79**	**0.8**
Gas emissions (tonnes/year)	**2.21**	**2.2**
Total energy emissions (kg/year)	2992.298	-
Total energy emissions (tonnes/year)	2.99	-

Energy and gas consumption at a household level may substantially differ depending on the type of house (e.g. detached, semi-detached or terraced houses, bungalow, park-home, flats/apartments etc.), insulation system, home lighting and appliances, electric vs gas-based heating system, home cooking, among other variables. Therefore, by assuming Ofgem average energy consumption for each UK home, the BulbCalc introduces a substantial uncertainty to the model. On the other hand, it seems fair to use an average number, given to the necessary simplification adopted by the model. Alternatively, this section could be reformulated and improved through additional literature review and upgrades in modelling logic and algorithm structure. Some insights could be obtained from previous experiences of the UK 2050 Calculator for example, which already has levers for home insulation[15], home heating electrification[16], home lighting and appliances[17], and electrification of home cooking[18].

Heat pumps have been highlighted as being important in being able to meet in the UK's Fifth Carbon Budget (CCC, 2015), which defines a legally binding limit on carbon emissions for 2028-2032. Currently few households in the UK have heat pumps, only 22,000 (less than 1%) as of 2018, so introducing this question will change accuracy for a small number of individuals. On the other hand, as well as being a means of self-assessment, Bulb's tool could encourage users to consider new ways to live more sustainably. In contrast, some users may not know what a heat pump is. Adding a question on the use of heat pumps could be beneficial by prompting the user to consider installing a heat pump and improve accuracy for certain groups of users. The addition of such questions must be weighted with regard the additional time required to complete the questionnaire.

f) Baseline emission

In this part of the calculator the user is asked to inform the number of persons living in the same house, given that part of the baseline emission is related to residential emissions (particularly wastes and water) and the other part to emissions in general. According to Bulb's supplementary document (spreadsheet) "these are the emissions you have little direct control over, for example your share of government services and the production and distribution of food. It also includes emissions from your household waste and your water usage based on UK averages". Therefore, the baseline emission is a tentative to have an average GHG emission for all other issues not included in the previous questions, without having to ask several additional questions in the calculator. On the other hand, this adds many uncertainties to the model.

Data on the baseline per capita GHG emissions (regardless of other variables) were obtained from the supplementary spreadsheet and summarised in Table 12, which shows constant emissions for living in the UK, unavoidable food-based emissions, and vegan diet. These averages encompass a large number of issues with large variations each. Furthermore, the per capita value attributed to vegan diet is the same, whether the user has a significant meat

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[15] See more at: http://classic.2050.org.uk/assets/onepage/30.pdf

[16] See more at: http://classic.2050.org.uk/assets/onepage/31.pdf

[17] See more at: http://classic.2050.org.uk/assets/onepage/34.pdf

[18] See more at: http://classic.2050.org.uk/assets/onepage/35.pdf

consumption or not. However, if someone increases her/his amount of meat in the plate, s/he may have to slightly reduce the amount of plant-based food in order to keep the same caloric intake; otherwise, the total caloric intake and the respective GHG emissions will be affected; the user may not be aware of this rationale behind the model. This issue could be either improved or better explained on the website or in a technical document. Literature on this topic including data on the difference in the composition of high-meat and low-meat/vegan diets in the UK is available and could assist in this respect, see for instance Bradbury *et al*. (2017). In the Global Calculator, for example, the user has to inform the amount of daily caloric consumption[19, 20], the quantity of meat[21] (which is converted into energy terms) and the type of meat[22] (e.g. beef, lamb, goat meat, pork, chicken). After discounting the caloric amount related to meat consumption out of the total calories consumed per person a day, the rest is associated with a plant-based diet. Although the Global Calculator is a scenario tool, some insights could be obtained from this experience and related literature (Strapasson, 2014; Strapasson *et al*., 2016 and 2017).

***Table 12**: Per capita GHG emissions non-associated with specific questions in the BulbCalc*

Baseline	tCO_2e/year	Source
Living in the UK	1.10	https://www.carbonindependent.org/index.html
Food unavoidable emissions	0.18	https://www.carbonindependent.org/index.html
Vegan diet	0.25	https://www.sciencedirect.com/science/article/pii/S0959378018306101
Total	**1.53**	

In terms of GHG emissions for household wastes and water usage, the BulbCalc assumes average emissions based on different references, as summarised in Table 13, which was prepared according to information available on the supplementary document (spreadsheet). The webtool asks the user to provide the number of persons living in the house. Thus, the house's GHG emission is proportionally shared between its residents. However, this value is an approximation, given that the residents may not have the same consumption pattern, i.e. whilst some people are very concerned with waste production and water consumption, others are reluctant to adopt more sustainable lifestyles, not to mention different ages and time spent at home.

In order to reduce these uncertainties, some additional questions could be incorporated to the questionnaire. For example, the users could be asked to inform their own waste recycling rates. In addition, there may be some potential double counting with previous questions and some issues possibly not well addressed yet. For instance, in the purchase of electronics, some products (e.g. a TV) may be shared with the other residents.

[19] On average, a 'healthy' caloric consumption is around 2,000 kcal/person/day for a woman and 2,200 kcal/person/day for a man, although these values may substantially vary according to age, body structure, physical activity (e.g. active vs. sedentary) etc. See more in Strapasson (2014, p. 44).

[20] See more at: http://tool.globalcalculator.org/gc-lever-description-v23.html?id=33/en

[21] See more at: http://tool.globalcalculator.org/gc-lever-description-v23.html?id=34/en

[22] See more at: http://tool.globalcalculator.org/gc-lever-description-v23.html?id=35/en

***Table 13**: Baseline GHG emissions per household, BulbCalc*

Sector	Category	Value	Unit	Source
Wastes	Recycling emissions factor	21.354	$kgCO_2e$ per tonne of waste (emissions factor for municipal waste)	https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019
	Landfill emissions factor	586.514		
	UK average waste	0.975	tCO_2e/y per household	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/784263/UK_Statistics_on_Waste_statistical_notice_March_2019_rev_FINAL.pdf
	Recycling rate	45.1%	Percentage	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664594/LACW_mgt_annual_Stats_Notice_Dec_2017.pdf
	GHG Emissions	323	$kgCO_2e$/year per household	Calculated
		0.323	tCO_2e/year per household	Calculated
Water	Water supply emissions factor	344	kgCO2e/ML	https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019
	Water use	349	L/day per household	https://www.energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf
		127.385	KL/year per household	
		0.127385	ML/year per household	
	GHG emissions	43.820	$kgCO_2e$/year per household	Calculated
		0.044	tCO_2e/year per household	Calculated
Total	**GHG emissions**	**0.367**	**tCO_2e/year per household**	Calculated

As a testing exercise, the total number of people living in a same house were increased on the webtool and the per capita baseline emissions per person noted, as shown in Table 14. Thus, the values obtained are a sum of the total general emission's baseline previously shown in Table 12 (i.e. 1.53 tCO_2e/person/year) and the total emissions presented in Table 13 (i.e. 0.367 tCO_2e/household/year) which is shared according to the reported number of residents; if there is only one resident, then the total value is attributed to the user. The web results are consistent with the spreadsheet, confirming that the algorithm is correctly operating. Some repetitive values may occur because the BulbCalc webtool shows the GHG emission with only one decimal of approximation.

***Table 14**: Per capita baseline GHG emissions, BulbCalc*

Webtool	
Number of people per home	**Per capita baseline emission tCO2/y**
1	1.9
2	1.7
3	1.7
4	1.6
5	1.6

It is important to observe that the higher the number of residents in a house, the lower the resulting baseline GHG emissions associated with wastes and water. Therefore, as shown in Figure 6, the total emission per household (i.e. 0.367 tCO_2e/household/year) will tend to zero (which is inaccurate) as the number of residents increases and, therefore, only the general baseline emission per person (i.e. 1.53 tCO_2e/person/year) will remain. Thus, the total baseline will tend to reach an asymptote (dashed line) equal only to the unavoidable emissions, and not each resident own use of household resources.

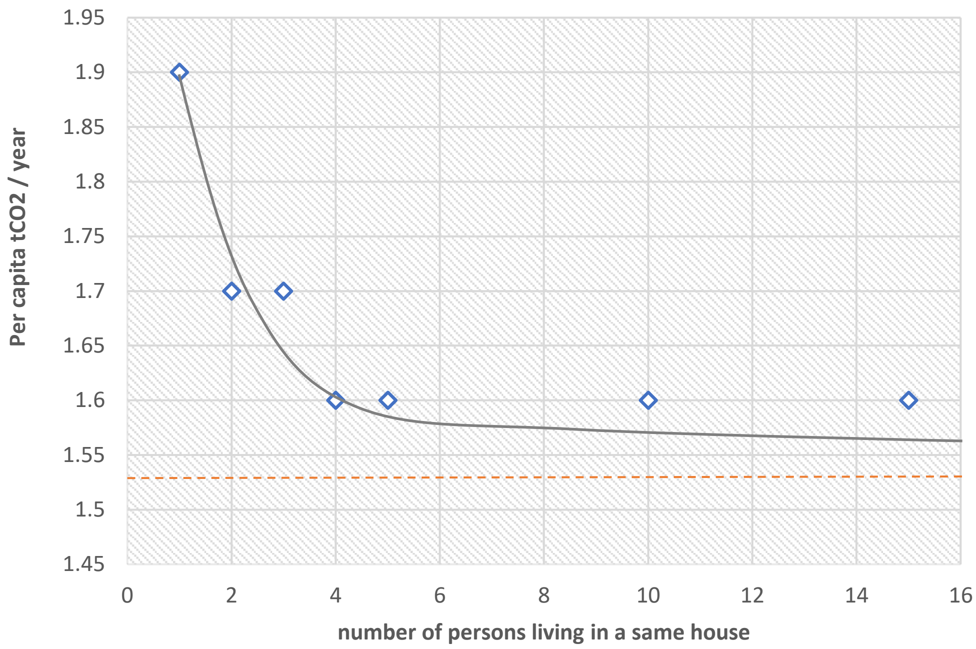

***Figure 6**: Baseline GHG emissions per person*

Note: values obtained from BulbCalc webtool analysis.

It appears the calculator assumes that the more people belong in a household, the more efficiently resources and space are used, which neglects the possibility that more infrastructure is required e.g. floor area per person cannot go to zero, and each person still will require a fairly constant amount of hot water. The opposite may also occur, for instance, families in which children leave home for school or university may not necessarily change house infrastructure because of that. Generally, Bulb's current assumptions probably are sufficient for most households as few households contain very many people. There are exceptions - shared accommodation, e.g. student halls/retirement homes can have hundreds of people living with shared resources, but the use of resources per person is not zero. We suggest Bulb allocates a certain minimum amount of electricity, gas and water consumption per resident.

g) Visual interface and other comments

BulbCalc has a user-friendly interface which can be used by a broad audience. Its results provide several valuable insights on climate change mitigation strategies. In addition to the several comments already made for improving the model, some minor visual edits would be helpful, as following described:

- In the section about diets, if the user selects ‘I only eat plants’, there is no change in the carbon footprint value on the top right-side corner of the webtool. The model only adds it on during the final step, along with other baseline GHG emissions.
- We had trouble using the BulbCalc webtool using Mozilla Firefox (version 72.0.2) when testing on a Samsung ultra-slim laptop, although it worked normally using other browsers such as Google Chrome and Internet Explorer. It may be a localised issue related to the browser’s configuration, but a technical verification is recommended in case this error occurs on other devices.

- While moving back on the webtool to change some previous values, the calculator sometimes do not update the carbon footprint value correctly (on the top right-side corner) and the user may have to refresh the entire tool to resolve the problem.
- Where in this report we have suggested clarification is required, one possible suggestion is to add more text or include tool tips which give further information. This extra information could help people better answer the question or give advice on the limitations of the model.
- A graphical bar chart output breaking down the results by category would be helpful in indicating problem areas (e.g. dairy consumption). The results could also have an associated error margin, which could be represented either analytically or visually, for example, using an error bar or different shades of colour in the graph.
- The carbon footprint shown in the last frame is compared to UK average and number of trees required to absorb the emissions. However, this comparison requires a better contextualisation.
- The result on baseline emissions has a paragraph with some hyperlinked words, but all of them go to a same webpage. A single link would be sufficient; otherwise, the user may keep trying to access all links provided expecting some different information.
- Regarding the unit of assessment for GHG emissions shown on the top right-side corner of the web interface, it must be clearer that the unit is tonnes of carbon dioxide equivalent per year ($tCO_2eq/year$) and not just ‘t’, which may imply tonnes of carbon i.e. C rather than CO_2. It is also important to clarify that the unit is per year, particularly because some questions refer to weeks and months, whereas others are per year.
- On the offsetting price, calculated as £ 7/tCO_2, this is currently a very low value with the EU ETS trading at over € 20/tCO_2 for the last 12 months or more.
- For greater transparency and credibility, it would be important to provide a supplementary document on the website, unless restricted by the copyright. This could be useful to those interested in assessing the tool in detail, by showing complexity on demand, whilst also keeping a simple web interface to the general user. A short explanatory video could also be helpful to explore the Bulb Calculator.
- Another recommendation is to carry out a stakeholder workshop in order to run a demo of the BulbCalc with the participants, such as selected experts from private sector, associations, NGOs, and academia, and to improve the tool. The participants could be asked to provide their critical comments and suggestions. These interactions could be facilitated through group discussions and special talks during the event. A reference document could be circulated in advance to those attending the workshop in order to increase the amount of inputs obtained from the participants. Similar initiatives were already successfully implemented by the authors whilst working on both the Global Calculator and the European Calculator for example. Lessons from these experiences could be potentially shared and extended to Bulb in future collaborations, as well as further technical support.

3. Acknowledgements

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