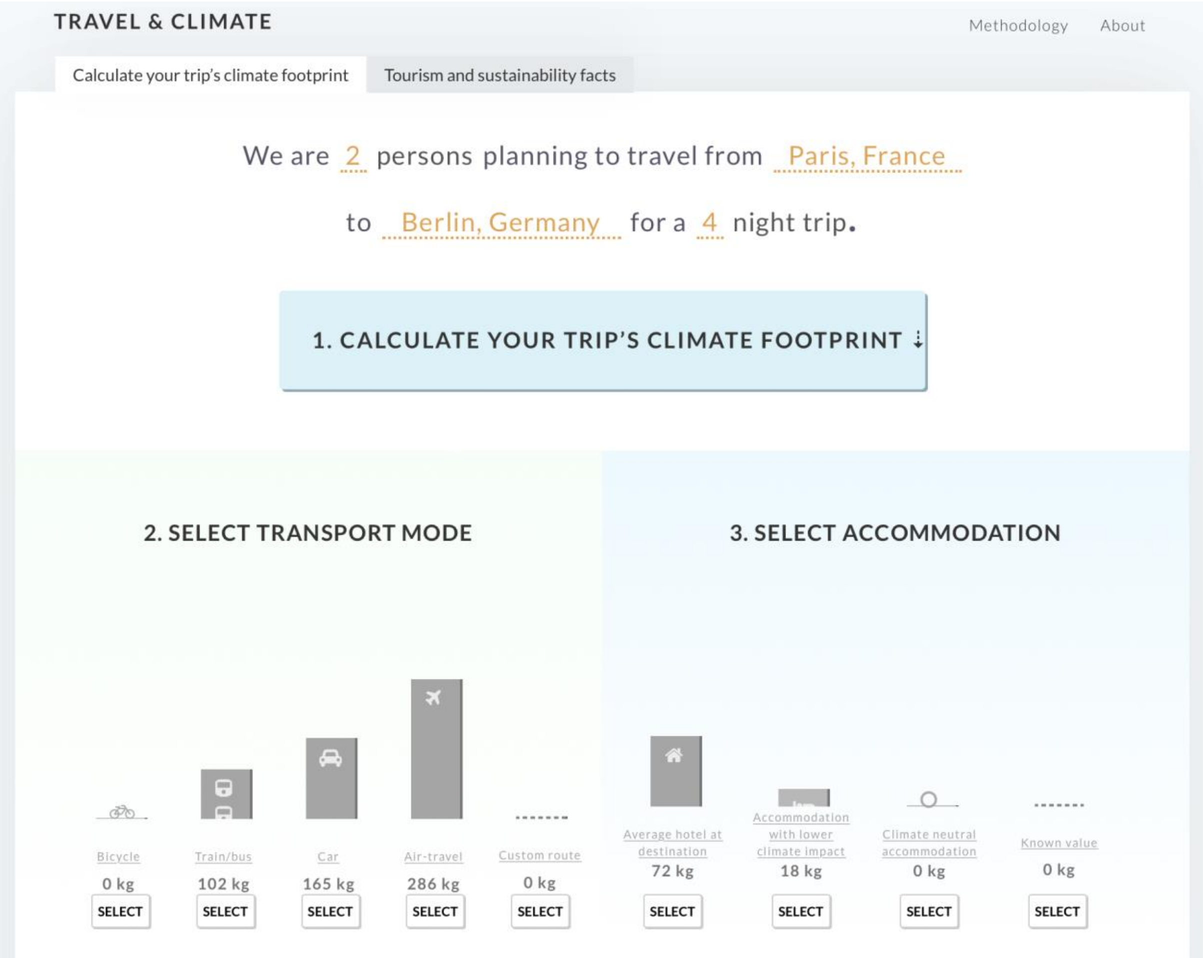
CHALMERS

Travel and climate

Methodology Report. Version 2.0



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1 Background and introduction

Tourism, including business travel, is one of the fastest growing industries in the world. This increase has resulted in economic growth and positive social and cultural exchanges, but several challenges from a sustainability perspective have also attracted attention from the media and researchers, including e.g.: polluted seas, prostitution, displacement of local peoples and greenhouse gas emissions (Mowforth & Munt, 2015). The tourist industry is dependent on (air)transport. Flights account for 60-95 percent of tourism's climate impact and tourism growth goes hand in hand with increased air travel (Gössling, Peeters et al. 2005). The flights conducted by the Swedish population has a climate impact equal to that of all car traffic in Sweden (Kamb, Larsson et al. 2018). The symbiotic relationship between flying and tourism has created a clear conflict of interest, where destinations are trying hard to attract international tourists at the same time as we are all under pressure to reduce our carbon footprint.

The aim of the *Travel and Climate Calculator* is to contribute to a more sustainable private and business travel by supplying independent and user friendly information in order to make it easier for people to choose trips with a low climate impact. The project also aims to contribute to the work of the industry and policy makers to make travel more sustainable.

The online calculator is unique in that it calculates the climate impact of different transport modes (such as aircraft/trains/ferries/types of cars/buses) as well as different types of accommodation. The calculations are based on scientifically generated data, inter alia from our own earlier studies, and from life cycle analyses carried out by other researchers and organisations.

The online calculator was initially produced in Swedish, www.klimatsmartsemester.se. This version in English is hovewer relevant for Europeans, but for users outside Europe it has some major drawbacks (e.g. that diesel trains may be more prevalent than in Europe).

The project was initiated by the "Climate Smart Holidays Network", which brings together researchers, public bodies and tourism actors in Gothenburg, Sweden, with the aim of addressing collectively tourism's contribution to climate change. The network is affiliated with both the Centre for Tourism at The University of Gothenburg and Mistra Urban Futures. The project, including the methodology report and the website, was financed by Region Västra Götaland, the West Sweden Tourist Board, the City of Gothenburg, the The University of Gothenburg, Chalmers University of Technology, Mistra Urban Futures and Mistra Sustainable Consumption, and the Swedish Energy Agency.

Principal for the project and the website is the Centre for Tourism at The University of Gothenburg, where Erik Lundberg is Project Manager. The Project Leader is Fredrik Warberg.

Jörgen Larsson, researcher at Chalmers, is responsible for the content and has directed the work to produce the data. Anneli Kamb has done most of the research and report writing. Marcus Wendin from Miljögiraff has provided the data basis for the accommodation calculations. Erik Nylund has been the carrying out the programming and the design of the website.

2 Transport mode – calculation of emissions

You can choose from several different transport modes in the calculator. As standard, four alternatives are presented for the user to choose from; bike, train/bus, car and aircraft (see Figure 1). Each bar shows what size the carbon emissions would be for each transport mode to the chosen destination and the figures show emissions per person for a return trip. This is based on default options covering, for instance, the size of car or which fuel is used. You can also make your own choices, and in addition create your own specific combination of different modes of transport for different stretches in the "Custom route" column.

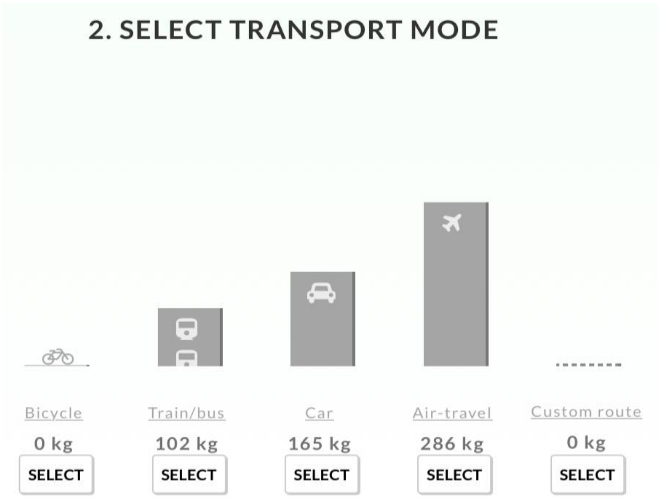

Figure 1 The various transport modes in the Travel and Climate calculator

The emissions cover the full life cycle of fuels, in other words emissions from production, distribution and use of fuels, but not the emissions generated by production of vehicles (cars, trains, aircraft etc.) or infrastructure (roads, airports, railway tracks, ports). The production/distribution of fossil fuels for cars and buses adds an extra 20 percent.[1] Emissions from production/distribution of aviation fuel add an extra 24% (SOU 2019:11)[2].

[1] Different calculations of emissions from production and distribution of fuel give differing results. Life cycle analyses from a Swedish perspective have shown lower emissions than the European average, where important aspects are the allocation of emissions from the refinery to the different products, likewise assumptions about, amongst other things, flare stacks, refinery technology and system boundaries Eriksson, M. and S. Ahlgren (2013). LCAs of petrol and diesel: a literature review, Department of Energy and Technology, Swedish University of Agricultural Sciences.. The additional emissions for production and distribution in Europe for fossil fuels is 20% according to certain sources Edwards, R., J.-F. Larivé, D. Rickeard and W. Weindorf (2014). Well–to–Tank Report Version 4. a. JRC Technical Reports. Luxembourg, Knörr, W. and R. Hüttermann (2016). EcoPassenger. Environmental Methodology and Data. Heidelberg/Hannover.. The baseline for clean fossil gasoline that the EU Commission states is higher than that (Swedish Energy Agency, 2017), while other sources give lower figures (Gode et al., 2011).

[2] Different calculations of emissions from production and distribution of fuel give differing results. Life cycle analyses from a Swedish perspective have shown lower emissions than the European average, where important aspects are the allocation of emissions from the refinery to the different products, likewise assumptions about, amongst other things, flare stacks, refinery technology and system boundaries Eriksson, M. and S. Ahlgren (2013). LCAs of petrol and diesel: a literature review, Department of Energy and Technology, Swedish University of Agricultural Sciences.. The additional emissions for production and distribution in Europe for fossil fuels is 20% according to certain sources

Table 1 shows a summary of the most common emission factors used in the calculator. After the table there is a section for each respective transport mode where the method used is described, and several fuel options are presented (for example, for cars there are 32 alternatives in total).

Table 1 Summary of emission factors for different transport mode

Transport mode	gCO_2e/pkm [a)]	gCO_2/km/vehicle	Primary source[b)]
Small car, petrol	63	181	(Energimyndigheten 2018)
Medium car, diesel	54	157	(Energimyndigheten 2018)
Large car, diesel	71	207	(Energimyndigheten 2018) Swedish Energy Agency, 2018)
Motorhome/caravan, diesel	106	307	(Energimyndigheten 2018) Swedish Energy Agency, 2018)
Economy scheduled flight	163	-	(Kamb and Larsson 2019)
Business scheduled flight	366	-	(Kamb and Larsson 2019)
Economy charter flight	143	-	(TUI GROUP 2017, Thomas Cook Airlines 2019)
Electric train Nordic countries	10	-	(SJ 2013, Energimyndigheten 2018)
Average train Europe	45	-	(Knörr and Hüttermann 2016)
Electric train Europe	34	-	(Knörr and Hüttermann 2016)
Diesel train	91	-	(Knörr and Hüttermann 2016)
Bus	27	-	(NTM 2018)
100% biodiesel bus	14		(Energimyndigheten 2017, NTM 2018)
Ferry	170	-	(Åkerman 2012)

[a)] For the different examples of cars, emissions per km have been divided by 2.9 because that is the average number of people in Sweden per journey over 300 km. Source: own calculations based on the The Swedish National Travel Survey 2011-2016 (RVU 1116 Sweden)(Transport Analysis, 2017).

[b)] In addition to the primary sources shown in the table full source references are given in each respective section. Furthermore, comparisons have been made with other sources, including SJ's Miljökalkyl (Swedish Railway's Environmental Calculator) (SJ, 2018) http://www.miljokalkyl.port.se/default.cfm;jsessionid=184E5160C5BA6BE2B7A5762B39760E24.cfusion?CFID=286387&CFTOKEN=31381902, Swedish Transport Administration's "Compare traffic types" (Trafikverket 2017) and Lenner (1993).

Edwards, R., J.-F. Larivé, D. Rickeard and W. Weindorf (2014). Well–to–Tank Report Version 4. a. JRC Technical Reports. Luxembourg, Knörr, W. and R. Hüttermann (2016). EcoPassenger. Environmental Methodology and Data. Heidelberg/Hannover.. The baseline for clean fossil gasoline that the EU Commission states is higher than that (Swedish Energy Agency, 2017), while other sources give lower figures (Gode et al., 2011).

2.1 Cars

The emissions per passenger km when you drive a car vary depending on the size of the car, which fuel it runs on and how many are in the car. To present the emission calculations that reflect the specific trip that the user is planning as accurately as possible, we have compiled emission factors for a range of different combinations of fuels and car sizes. The user can also fill in how many are planning to go on the trip, which is used to calculate the emissions per passenger km. Emissions in the default alternative for cars in the calculator are for a "medium car, diesel" with emissions of around 160 g CO_2 per km. If a different vehicle is used the size of car and type of fuel can be selected according to the table 2 and 3 below.

The starting point has been emissions from medium cars[3] with different fuel types. For large cars an extra 34% is added, which is based on a a weighted average for large petrol and diesel cars compared with medium petrol and diesel cars[4]. Small cars are more or less entirely petrol powered. These use on average 24% less energy than medium petrol cars. This value has been applied to all types of fuel.

Table 2 Index for size of car

Small car	0.76
Medium car	1.00
Large car and seven-seater car[a)]	1.34
Motorhome[b)]/caravan[c)]	1.96

[a)] Seven-seater cars are assumed to be as big as large cars in the HBEFA.

[b)] Motorhomes are not included in the HBEFA model. Our estimate is derived from the average total weight of motorhomes (more recent models) taken from the vehicle registry related to vehicles with an equivalent weight in the HBEFA model. This only applies to diesel vehicles. For other fuels the same relationship between motorhomes and medium cars, regarding energy consumption, has been assumed.

[c)] Caravans are not included in the HBEFA model either. The difference in emissions between a medium car and, on the one hand, a car trailing a caravan, and on the other hand, a motorhome is approximately the same (Hammarström 1999).

The emissions for different fuels are those applied to the fuels used in Sweden in 2017, according to the Swedish Energy Agency (2018, p 26). Emissions per km are higher than those usually shown for different models of cars. The reason for this can in part be that the values are based on real energy consumption, not from test cycles, and in part that the emissions from production of the fuel are included.

[3] Statistics from the Swedish Energy Agency use the term "average car" for respective fuel types. We have taken that to be the same as a medium sized car.

[4] The basis for this has been obtained from IVL - Swedish Environmental Research Institute which does analyses based on the HBEFA model which includes statistics for all Sweden's road transport. The figures have been compiled with the help of Martin Jerskö at IVL.

Table 3 Grams CO_2 emissions per km (vehicle)

	Petrol	Diesel	Electricity Nordic[a)]	Electricity Europe [b)]	Natural gas[c)]	Vehicle gas[d)]	Biogas 100% [g)]	Ethanol E85	Bio-diesel 100%[e)]
Small car	181	119	14	45	131	58	31	92	60
Medium car	239	157[f)]	19	60	172	64	41	121	79
Large car / seven seater car	315	207	25	79	227	84	54	160	103
Motorhome / caravan	468	307	37	117	337	1124	81	237	154

[a)] Emissions from the production of electricity in a mix of the Nordic market regarding to a certain extent import and export. Source: Table 7 in 'Fuels 2016 – Amounts, components and origin reported according to the Swedish Fuel and Sustainability Act' (Swedish Energy Agency, 2018). In subsequent years' reports the Energy Agency (2018) changed method and has used "final consumption" in Sweden, which has resulted in much lower emissions. As we think it is most appropriate to use the average from the market where the electricity is purchased, we continue to use the Nordic mix.

[b)] Average electricity in the EU28, final consumption. In the source the emissions calculated are for 2013 and were then 447 g CO_2e/kWh. As the emissions from electricity consumption in the EU are continuously decreasing we have estimated the same yearly linear decrease for electricity production, which gives 389 g CO_2e/kWh 2019. For electricity production see https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5#tab-googlechartid_chart_11

[c)] Natural gas (100% fossil gas) is commonly used for cars in many countries. https://www.miljofordon.se/tanka/tanka-fordonsgas/

[d)] Mix of biogas 83% and natural gas 17%, which is the average for vehicle gas in Sweden 2016 (Trafikverket 2017).

[e)] The value used for biodiesel (relating to both HVO and FAME) is here 50% of the value used for fossil diesel. This estimate is at the same minimum level of emission reductions that apply to biofuels according to the Swedish Sustainability Act. The reason for making such an approximate estimate is that different analyses of biofuels give very different results. The differences depend on what type of raw material is used and what system boundaries are chosen. Emissions from HVO biodiesel are, according to the report from the Swedish Energy Agency, 28 g CO_2 and from FAME biodiesel 91 g CO_2. These calculations don't take into account that an increased use of biofuels can contribute to a changes in land use. Studies of emissions from biodiesel where palm oil has been used, amongst others, and where the effects of land use changes have been included, give close to 200 g CO_2 per km according to Ahlgren and Di Lucia (2014) and nearer to 300 g CO_2 according to Transport & Environment (2016).

[f)] Default option in the calculator.

[g)] This figure is based in that biogas has a 76% lower climate impact than natural gas according to the Swedish Energy Agency (2017, p. 37).

In the Travel and Climate calculator the emissions factors in Table 3 are used, and these are divided by the number of people stated for the planned journey. If the number of people exceeds five the assumption is made that the party will travel in more than one car. The number of cars is arrived at by dividing the number of people by five and rounding up. In other words, if the party is six to ten people it is assumed they will be travelling in two cars, 11-15 people in three cars, and so on. If the user selects seven-seater car the same method is used but calculated using seven people per car instead.

2.2 Aircrafts

Just as in other transport modes, emissions caused by a aircraft journey depend on a range of different factors. The emissions per passenger km vary according to the type of aircraft, distance, flying altitude, the number of seats in the aircraft and the load factor. We have taken into account several of these in the calculator by giving the user a number of choices.

Other calculators often use advanced algoritms for calculating air travel emissions. We find that using a uniform emission per passenger km, regardless of the distance, is a better options (due to reasons described in section 2.2.2). The default option in the calculator is for a scheduled economy flight with emissions of around 160 g CO_2e per passenger km. The basis used is a global average for all passengers of around 190 g CO_2e per passenger km. This figure is made up by 90 g CO_2 per passenger km from fuel combustion (Kamb and Larsson 2019), 80 g CO_2e from non CO_2 effects (see section 2.2.1) and 20 g CO_2 in upstream emissions.

In the calculator the user can then choose between several alternatives. To start with, different types of flights can be chosen. Charter flights typically have a higher load factor than scheduled flights, which results in lower emissions. *Charter*[5] is therefore included as an alternative, with a figure based on average emissions of 69 g CO_2 per passenger km[6] (TUI GROUP 2017, Thomas Cook Airlines 2019) and adjusted upwards in the same way to include upstream emissions and high altitude emissions. This gives emissions of just under 150 g CO_2e per passenger km for charter flights.

Emissions are furthermore affected by which seat class the passenger chooses (Miyoshi and Mason 2009). As premium seats (premium economy and business) take up more floor space in the aircraft there's room for fewer passengers during each flight. On that basis, premium passengers are responsible for a greater proportion of emissions per passenger. By surveying ten common airlines we calculated that a business seat on average takes up 2.2 times more space than an economy seat, and an economy premium seat takes up 1.2 times more space[7]. If we also take into account the distribution between the number of passengers in each respective class (Bofinger & Strand, 2013) we can adjust the respective seat class in comparison with the average passenger, shown in Table 4.

[5] It would be useful to develop an emission factor for turboprop aircraft as well, as these typically are not flown at high enough altitude to cause non CO_2 effects (see section 2.2.1). Turboprops are primarily flown for distances under 500 km in Europe Amizadeh, F., G. Alonso, A. Benito and G. Morales-Alonso (2016). "Analysis of the recent evolution of commercial air traffic CO2 emissions and fleet utilization in the six largest national markets of the European Union." Journal of Air Transport Management **55**: 9-19. and account for a smaller proportion of journeys, just 0.9% of global emissions Alonso, G., A. Benito, L. Lonza and M. Kousoulidou (2014). "Investigations on the distribution of air transport traffic and CO2 emissions within the European Union." Ibid. **36**: 85-93.. It was however hard to find data to calculate average emissions for the whole turboprop fleet. Since they are mostly used for shorter distances they are still likely to have CO_2 emissions at level of the global average.

[6] Both sources state 67 g CO_2 per passenger km, but this includes additional distance compared to the great circle distance to better reflect the true flight distance. We have therefore adjusted the figure upwards by 3% to 69 g CO_2 per passenger km in order to combine it with the estimated great circle distance.

[7] Survey of several aircraft types on https://seatguru.com/ for the following companies: Norwegian, SAS, KLM, Swissair, Austrian, Brussels Airlines, United, American Airlines, Lufthansa and Thomas Cook Airlines.

Table 4 Index for seat class.

Type	Economy	Premium economy	Business
Scheduled	0.84 [a)]	1.0	1.9
Charter	0.97	1.2	-

[a)] Default choice in the calculator.

Table 5 shows the results for the different flight alternatives. This clearly shows that the type of flight that is chosen plays an important role in the size of emissions.

Table 5 Emission factors for different flight alternatives, in CO_2e per passenger km.

	Seat class		
Type	Economy	Premium economy	Business
Scheduled	163 [a)]	199	366
Charter	143	174	-

[a)] Default choice in the calculator.

The distance for the chosen journey is calculated using the Google Maps API, based on the great circle distance[8]. Emissions for the journey can then be calculated by multiplying that distance with the chosen emission factor.

The emissions from the journey therefore becomes:

$$U_{WtW}^{CO2e}(\mathrm{x}) = u_{TtW}^{CO2}\,(1 + HF + u_{WtT}) \cdot k_i \cdot \mathrm{x}\ \ [kg\ CO_2\mathrm{eq}]$$
$$= 2.14 \cdot u_{TtW}^{CO2} \cdot k_i \cdot \mathrm{x}\ \ [kg\ CO_2\mathrm{eq}]$$

where:

$$u_{TtW}^{CO2} = \begin{cases} 0.091\ (scheduled) \\ 0.069\ (charter) \end{cases},\ (emissions\ from\ combustion, Tank\ to\ Wheel)\left[\frac{kg\ CO2}{pkm}\right]$$
$$u_{WtT} = 24\%\ (emissions\ from\ fuel\ production, Weell\ to\ Tank)$$
$$HF = 0.9\ \ (\ non\ CO2\ effects)\ \left[\frac{kg\ CO2\mathrm{eq}}{kg\ CO2}\right]$$

[8] The great circle distance is defined as the shortest stretch between two points, with coordinates (lat1, lon1) and (lat2, lon2), on the surface of a sphere. It is calculated by: gcd = Rcos-1[sin(lat1)sin(lat2) + cos(lat1)cos(lat2)cos(lon1-lon2)], where R is the earth's radius. R = 6371.01 km. Some calculators add e.g. 50 km to take into account the circuitous routes aircraft fly around, for instance, airports. As the global emission factor we apply Kamb, A. and J. Larsson (2019). Climate footprint from Swedish residents' air travel. Göteborg, Chalmers. is calculated based on the great circle distances, we don't add any extra as the journey's emissions then would be double counted.

$$\mathrm{k}_r = \begin{cases} 0.84\ (economy) \\ 1.0\ (premium\ economy) \\ 1.9\ (scheduled\ business) \end{cases} ,(seat\ class\ scheduled)$$

$$\mathrm{k}_c = \begin{cases} 0.97\ (economy) \\ 1.2\ (premium\ economy) \end{cases} ,(seat\ class\ charter)$$

$$x = great\ circle\ distance\ [km]$$

2.2.1 The climate impact of fuel production, and aviation non-CO2 effects

Emissions that occur during production of fuel are included for all transport modes in the Travel and Climate calculator, for instance emissions from the production of electricity for trains and petrol/diesel for cars. To also include those for aviation fuel an extra 24% is added on top of the emissions generated by combustion. This estimate is based on the report on fuel in the aviation industry (SOU 2019:11).

As discussed in section 2, different life cycle analyses give different results depending on, for instance, system boundaries, and how emissions from refineries are allocated, where a Swedish perspective typically gives lower emissions than a European one (Eriksson and Ahlgren 2013). An average of two Swedish refineries gave an extra 8.3% from the production and distribution of aviation fuel (Gode et al., 2011). A comparison of different allocation models for emissions from an average European refinery (which is used in EU legislation) gave instead an additional 23-27% depending on the choice of model. (Moretti, Moro et al. 2017). Unnasch and Riffel (2015) report similar figures based on a comparison of different studies. As most of the fuel used in the aircraft that Swedes travel on comes from refineries outside Sweden we consider 24% a reasonable figure to use.

When aircraft emissions occur at high altitude there are other climate impacts than just CO_2 to consider, such as the contrails that build up when hot and humid exhaust from jet engines mixes with the surrounding cold air and builds ice particles (Lee, Pitari et al. 2010, Azar and Johansson 2012, Boucher, Randall et al. 2013)[9]. In certain conditions the contrails from the aircraft can last a couple of hours, in other cases they disappear after minutes. From a climate point of view, it is only the persistant contrails that need to be taken into consideration. Furthermore, aviation emissions can cause an increase in the development of high cirrus clouds, primarily because the persistent contrails become cirrus clouds. In addition, there are other warming effects in the form of nitrous oxide emissions, among others. There is, moreover, research that preliminarily indicates that emissions of aerosols can have a cooling effect. Simplified, we can call these non-CO_2 effects "high altitude effects".

It's uncertain how significant these different high altitude effects are, and scientific understanding of the different mechanisms of high altitude effects also varies. We make no scientific evaluation of our own in this area, but refer to the overall assessment made by the UN

[9] Emissions of other greenhouse gases than CO_2 are caused by other transport modes as well, but these effects are on average a lot less than for air travel and therefore don't affect the model greatly Peters, G. P., B. Aamaas, M. T. Lund, C. Solli and J. S. Fuglestvedt (2011). "Alternative "global warming" metrics in life cycle assessment: a case study with existing transportation data." Environmental science & technology **45**(20): 8633-8641..

Panel on Climate Change, IPCC (Boucher, Randall et al. 2013). The IPCC emphasizes that not insignificant high altitude effects exist and they point out that in 2011 persistent contrails contributed to global warming by “Radiative Forcing” [10] of +0.01 W/m^2 (medium confidence level). The combination of contrails and clouds formed from contrails is moreover judged to contribute with “Effective Radiative Forcing” [11] of +0.05 W/m^2 (low confidence level). (Boucher, Randall et al. 2013, Myhre, Shindell et al. 2013).

In several flight calculators the Radiative Forcing Index (RFI) is used to include these high altitude effects, most usually using the IPCC estimate from 1992 with an RFI of 2.7 (IPCC, 1999). The problem with RFI is that it reflects current climate impacts from historic emissions, instead of future climate impacts from current emissions, which is what we are interested in. CO_2 has a significantly longer lifetime than other emissions, and RFI doesn’t take into account that CO_2 will have a very long-term effect on the climate. Because of that Fuglestvedt, Shine et al. (2010) points out that it is wrong to use RFI for air travel. They consider the Global Warming Potential (GWP) to be a better index as it measures future climate impact of current emissions. The IPCC does not give any figures for GWP however, so we have used the most established scientific estimate and that is, measured with GWP100[12], that the total climate impact is around 1.9 times higher than the impact from CO_2 emissions alone (Lee, Pitari et al. 2010). This estimate is in line with what both the Swedish Environmental Protection Agency (2018) and the Swedish Transport Agency (2018) state.

How great the high altitude effects are for a specific journey varies a lot according to, for example, the length of the journey, the time of year, weather conditions and time of day, and can be both higher and lower than the factor of 1.9 that we use. We can however say with certainty that it is on average lower for shorter flights because the aircraft doesn’t get up to, or spends a shorter portion of the flight time in, high enough altitude. This means that a weighting factor of 1.9 is an overestimate for shorter journeys (Fichter, Marquart et al. 2005). Correspondingly, CO_2 emissions should be adjusted upwards by a higher factor for the longest journeys, so that the global average ends up at 1.9. It would of course be desirable to at least take into account the length of the journey when adjusting upwards for CO_2, but as far as we know there isn’t currently a good enough calculation to allow that. Figure 2 illustrates what two different journeys could look like, where the shorter European flight spends a smaller portion of the journey at high altitude compared to intercontinental journeys.

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[10] Radiative Forcing (RF) is defined by the IPCC as the change in the net radiative flux in the tropopause after the stratospheric temperatures have been re-adjusted to radiative-dynamical equilibrium, while the surface and tropospheric temperatures and condition variables (like vapour and cloud cover) are fixed at their unperturbed values relative to non-warmed values Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee and B. Mendoza (2013). "Anthropogenic and natural radiative forcing." Climate change **423**: 658-740..

[11] Effective Radiative Forcing (ERF) also takes into account rapid adjustments in the troposphere, and in some cases is a better measure of climate impact than the other measure just called Radiative Forcing ibid..

[12] Global Warming Potential with a 100 year time horizon.

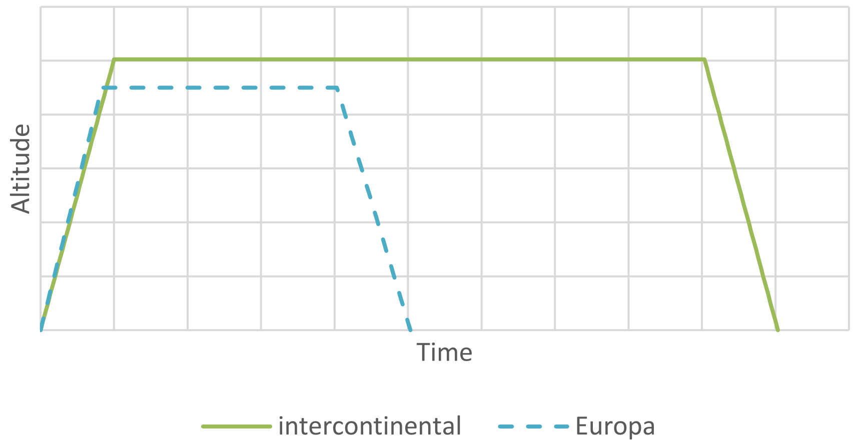

Figure 2 Illustration of two journeys' altitude profiles.
Please note that this is an illustration and not real altitude data.

What is, at the same time, specific to flights compared to other transport mode, is that take off is energy intensive relative to flying at constant altitude. This means that CO_2 emissions per passenger km typically are higher for shorter journeys, because take off comprises a larger proportion of the total emissions from flying. As CO_2 emissions per passenger km typically decrease with distance, and the effects of non CO_2 emissions increase with distance, these two effects on the whole cancel each other out. Figure 3 shows an illustration of how these two cancel each other out. As long as there is no peer reviewed distance based non-CO_2 factor, we argue that our model using uniform emissions per passenger km is better than distance based models.

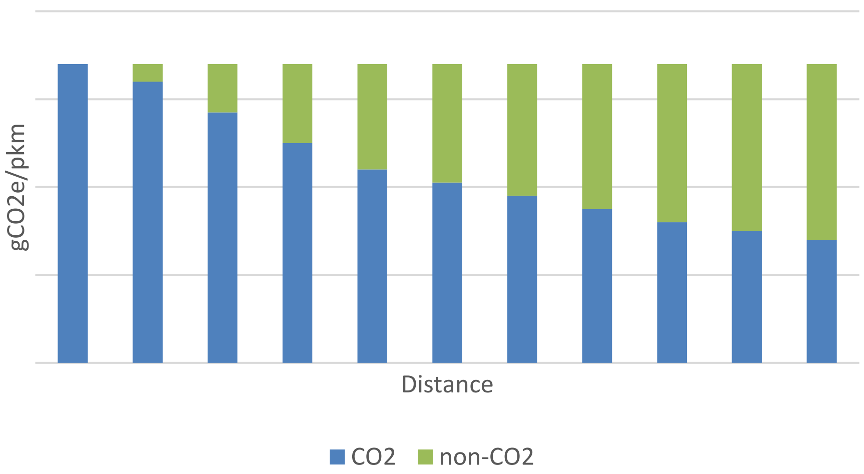

Figure 3 Illustration of the distribution between CO_2 emissions and non CO_2 emissions.
Please note this is an illustration and not real data.

2.2.2 Comparison between our's and ICAO's calculators

In order to assess the outcome of the modell, we have compared it with carbon emission calculators from the International Civil Aviation Organization (ICAO)[13]. To be able to compare the calculators only CO_2 emissions from fuel combustion are included, in other words the climate impact from fuel production and non-CO_2 effects are not included. The exclusion of these two sources of climate impact results on average in a reduction of approximately one half of the emissions. Figure 4 shows only emissions of CO_2 per person-km for the most common routes from Swedish airports, 25 international and seven domestic routes[14].

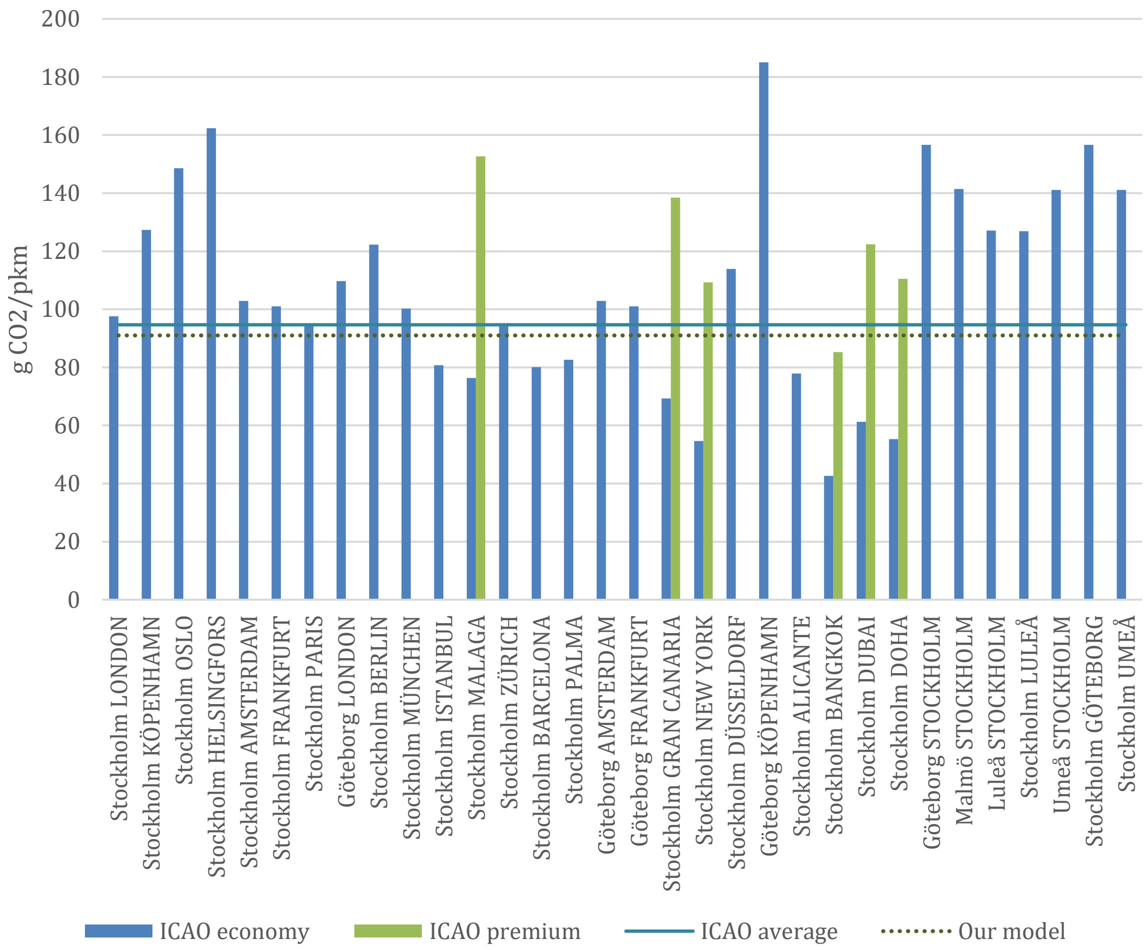

Figure 4 Comparison of ICAO economy and premium class as well as our model, for the most common aviation routes from Swedish airports. Note that it is only direct emissions of CO_2, ie excluding upstream emissions and non-CO_2effects.

In the ICAO calculator you can choose between economy and premium seating. In aircraft models that have these larger seats, these seats are allocated twice the emissions compared to

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[13] ICAO is a specialized agency within the UN for civil aviation. https://www.icao.int/environmental-protection/CarbonOffset/pages/default.aspx

[14] These routes cover just over 50% of passengers in domestic and international traffic in 2018 and are based on Swedavia's Destination Statistics: https://www.swedavia.se/om-swedavia/statistik.

economy class. The blue bar shows economy class and the green bar premium class. For most trips there are no larger premium seats, which is why the blue bar often is absent. Only seven routes have differentiated emissions. What becomes clear in Figure 4 is that the emissions in ICAO's emission calculator typically are lower per person-km for long flights, where Stockholm-Bangkok is by far the lowest with 43 g CO_2per person-km for economy.

The dotted line in Figure 4 shows the direct emissions of $CO_2$from our uniform model where the same emissions are assumed to apply to all flights regardless of distance (see section 2.2.1), i.e. 90 g CO_2per person-km. The solid line shows the average between ICAO economy and business, weighted based on the number of passengers on each route[15]. This average is slightly higher than what we use in our model, but the difference is only a few percent.

For the flights between Stockholm and New York, it is also relevant to compare with energy efficiency evalution for transatlantic trips made by The International Council on Clean Transportation (ICCT). They find, on average, that transatlantic flights emit 74 g CO_2per person-km (Graver and Rutherford 2018), which is higher than the ICAO economy figure of 55 g CO_2per person-km and lower than premium of 109.

In summary, our model is on more or less the same emission level as the average for the ICAO emission calculator. If ICAO were to include the climate impact from fuel production and from non- CO_2effects, their average emissions would be fairly identical to klimatsmartsemester.se. However, emissions from ICAO's calculator vary widely between different routes, which is probably depends on the types of aircraft used and the distance for each route.

2.3 Trains

Trains in Europe are mainly powered by electricity, although diesel trains are also commonly used in some countries. Emissions from the electricity used to power the trains also differs across Europe. Several emission factors have therefore been produced; electric train Scandinavia, average train Denmark, average train Europe, electric train Europe and diesel train.

For journeys in Sweden, Norway and Finland electric train in Scandinavia is used as the default option, with an emission factor of 10 g CO_2e per passenger km. This is based on an energy consumption of 80 Wh per passenger km[16] and a Nordic electricity mix with emissions of 124 g CO_2e per kWh (Swedish Energy Agency, 2018). The proportion of trains that are electrified are: Sweden 96%, Finland 92% (Eurostat 2017) and in Norway 64% of railways are electrified[17].

[15] It is assumed that 20% of passengers travel with premium seats on the routes that have premium seats (own calculations based on Bofinger, H. and J. Strand (2013). Calculating the carbon footprint from different classes of air travel, The World Bank.). This means that approximately 3% of all passengers for these 32 lines are assumed to travel with a premium seat.

[16] This is based on data from SJ Swedish Rail (2013). The load factor on SJ's trains is higher than the average for all trains in Sweden, but as most trips are presumed to be made on long distance trains this is a better estimate than statistics that include regional and local trains.

[17] In the absence of data on what proportion of travel volumes happen on electrified trains we have chosen electric train as default. There are however two long stretches in northern and eastern Norway that are not electrified so if

In Denmark a significantly lower proportion of trains are electrified: 42% (Eurostat 2017). An average figure of 58 g CO_2e per passenger km is therefore used as default for sections of a journey that start in Denmark, which is the average of the values for electric train Scandinavia and diesel train.

For journeys in the rest of Europe, average train Europe is used as the default option, with an emission factor of 45 g CO_2e per passenger km. It is significantly higher than for Scandinavia, which is partly because more diesel trains are used in Europe, and partly because the emissions from electricity consumption are higher in Europe than in Scandinavia. Regarding the proportion of electric trains (calculated in train km), the average is 81% in Europe (UIC 2014), and the proportion of passenger km on electrified railways is around 80% in Europe (IEA 2019, sid 50). In for example France 77% of trains are electric powered, in Austria 68% and Italy 48% (Eurostat 2017). The distribution in passenger km is, however, not necessarily proportional to the proportion of electrified trains or railways. We do not take into account that some companies in Sweden and other countries purchase green electricity.

Anyone who knows the details about the train type can select electric or diesel train in the Travel and Climate calculator. For electric trains in Europe an emission factor of 34 g CO_2e per passenger km is used. This is based on an energy consumption of 88 Wh per passenger km (Knörr and Hüttermann 2016) and emissions of 389 g CO_2e per kWh for EU28[18] (Moro and Lonza 2018). For diesel trains an emission factor of 91 g CO_2e per passenger km is used (Knörr and Hüttermann 2016).

For journeys that are split between trains in both Scandinavia and the rest of Europe, the parts of the journey that either start or finish in Scandinavia are calculated as electric train Scandinavia, and other parts as average train Europe or Denmark.

Table 6 Summary of emission factors for different train types.

Transport mode	g CO_2e/pkm
Electric train Scandinavia[a)]	10
Average train Europe[a)]	45
Average train Denmark[a)]	58
Electric train Europe	3
Diesel train	91

[a)] Default choice in the calculator.

people know that they will be travelling on these stretches it is better to input diesel trains in the calculator. https://en.wikipedia.org/wiki/Rail_transport_in_Norway

[18] See Table 3 footnote b) for details about how this figure has been arrived at.

2.4 Buses

Emissions per passenger km on bus journeys depend mainly on the load factor of the bus, and which fuel is used. We have used the Network for Transport Measures (NTM) [19] emission calculator, which gives the default choice for buses as 27 g CO_2 per passenger km. This is based on a load factor of 60% which is the standard figure in NTM's calculation model, and on a long distance Euro 5 – SCR bus with a fuel consumption of 3.3 litres diesel per 10 km. For more details on the method see NTM's Methods and Manuals (NTM, 2018a).

Biodiesel can also be selected as fuel type for buses. The emissions factor that we use for that is 14g CO_2 per passenger km. There are different ways of calculating emissions from biofuels. Our calculation is based on the Swedish Sustainability Act's assertion that emissions from biofuels must be at least 50% lower than for fossil fuels (for more information, see the section 2.1). [20]

2.5 Ferries

As with the other transport mode, emissions per passenger km vary due to several factors. An important one is the speed of the ferry. Fast ferries are three times more energy intensive per passenger km than slower ferries (Åkerman, Isaksson et al. 2007). These fast ferries however account for a small share of the travel volume by ferry. Furthermore, how emissions are divided between passengers and freight also has an impact.

The average emission factor used in calculators for ferry journeys is 170 g CO_2 per passenger km, relating to normal (not fast) ferries. This figure is taken from a study by Jonas Åkerman (2012) who collected data from from ferries between Sweden and Finland. The emissions were converted into energy consumption and then allocated between passengers and freight, based on the respective space taken up on the ferry.

Ferry journeys with a cruising speed of 20 knots are assumed in this travel emissions calculator to have an energy consumption of 0.6 kWh per passenger km. Emissions per passenger km are therefore 170g CO_2 per passenger km (Åkerman 2012)[21]. We have contacted several Swedish ferry companies but have not gotten access to any other figures as yet.

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[19] NTM is a non profit organisation comprising businesses and organisations wanting to promote and develop the transport sector's environmental work, acting, amongst other things, for a method for calculation of emissions for modes of transport. NTM has around 160 members, including hauliers, transport purchasers, vehicle manufacturers, authorities, universities and consultants; e.g. Bilsweden, SJ AB, Buss i Väst AB. https://www.transportmeasures.org/sv/

[20] Buses are also powered by bioethanol, bio and natural gas, and electricity. These fuels are however primarily used for local transport (The Swedish Bus and Coach Federation, 2018).

[21] This is in line with an estimate by Lenner Lenner, M. (1993). Energiförbrukning och avgasemission för olika transporttyper, Statens Väg-och trafikinstitut. of 200 gram CO_2 per passenger km.

3 Accommodation – calculation of emissions

The size of climate impact per guest night depends on a range of different factors. It's easy to believe that a large luxury hotel will always have a higher climate impact and that more basic accommodation automatically has a lower climate impact, but that isn't always the case. It is certainly likely that accommodation with a larger floor area will use more energy per guest night, but how the building is heated and which type of energy is used is often more important from a climate impact point of view. A luxury hotel can consequently either have significant emissions per guest night if they, for example, use energy with a high fossil content, but can also have a low climate impact if they, for instance, heat up premises with bio based district heating and produce their own solar electricity. In the same way, a hostel or rented accommodation can have a high climate impact if they are heated with, for instance, an oil fired boiler.

The accommodation's density load also affects the size of climate impact per guest night. Accommodation that only has guests during the summer season, for example, but which is also heated during winter, will have a higher energy consumption and climate impact per guest night than accommodation with many guests all year round. The calculation of emissions from accommodation in the trip calculator includes climate impact from heating, electricity consumption, warm water and washing (irrespective of whether this is done themselves or bought as a service). These emissions normally comprise over half of the climate impact from hotel businesses (Moberg, Wranne et al. 2016). Important aspects not included are climate impact from building and repairs, and climate impact from the food that is served.

In the Travel and Climate calculator we have chosen four categories: *Average hotel in the country, Lower climate impact, Carbon neutral* and *Own alternative* (see Figure 5). Average hotel in the country is self explanatory. Lower climate impact here can either be hostel, climate smart hotel, simple unheated hotel without air conditioning and different forms of rental or exchange for apartments, among others.

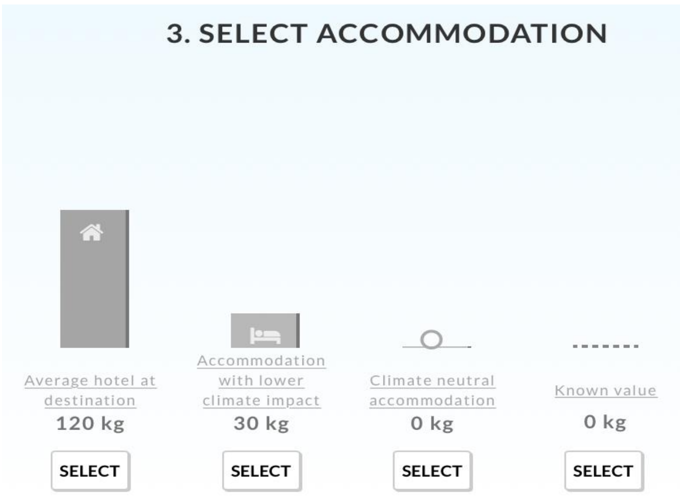


Figure 5 Different forms of accommodation in the Travel and Climate calculator.

Figures for climate impacts from hotels in other countries are based on self reported data from hotels around the world. It is the hotel organisation The World Travel & Tourism Council (WTTC), which within the remit of its Hotel Carbon Measurement Initiative (HCMI) compiles this data (WTTC 2018). The differences between countries depends mainly on how much energy is consumed for heating and air conditioning and which type of energy is used for producing the electricity. For example France has low figures because its electricity comes mostly from nuclear power.

It is however important to emphasise that the figures have significant uncertainty. The basis for figures from respective countries is of varying quality, where the number of hotels per country, and what type of hotel has reported the data, varies a lot. Table 6 shows emissions per guest night in the respective countries, and how many hotels the calculation is based on (column to the right). For a country like the USA the data basis is good, as there are many hotels, including both low budget and luxury hotels, which have reported data. For most other countries it's luxury hotels, or hotels with undefined class, that have reported data. In the case of Thailand, it is only luxury hotels which have provided information, which likely makes the figures higher. If low budget hotels, for example without air conditioning, had also reported information the figure for Thailand would probably be much lower. This potentially applies to several countries, how many, however, is hard to determine. One should be aware of this when interpreting data. This dataset is notwithstanding the best we have identified.

Data from Swedish hotels is unfortunately not included in the HCMI. Instead information has been used from a comprehensive synthesis that the Chamber of Commerce has commissioned from the IVL – Swedish Environmental Research Institute (Moberg, Wranne et al. 2016) which in its turn is based on data from 41 hotels that the Swedish Energy Agency has analysed (Energimyndigheten 2011).The figure for Sweden is 8.5 kilo CO_2 per guest night[22]. As data for the rest of Scandinavia (Denmark, Norway, Finland and Iceland) is also missing from the HCMI, the Swedish figure has also been used for these countries. We see this as an acceptable assumption as Scandinavia has a connected electricity system and similar building standards.

The IVL survey includes emissions per guest night, which in this context means a booked single bed room overnight. In the HCMI the hotels report emissions per occupied room instead. As it is emissions per guest night that are interesting in this context we have assumed that hotel rooms are on average occupied by 1.5 people and have therefore divided the figures by 1.5. This assumption is based on our estimate that approximately half of rooms are used by single guests, typically business travellers, and around half by pairs, typically holiday travellers.

The difference in climate impact between a ”average hotel”, and accommodation with a lower climate impact is based on a Swiss study that showed that "tourist homes and youth hostels" had on average a 75% lower climate impact per guest night than was the case for hotels (Sesartic & Stucki, 2007). The study is based on data from 50 hostels in the Swiss Youth Hostels organisation and 152 huts in the Swiss Alpine Club, as well as several studies of climate impacts from hotels. Our calculation is based on the assumption that this relationship applies to all countries.

[22] This includes electricity, heating, hot water, electronics and laundry. The study assumes Nordic electricity mix with emissions of 84 g CO_2 per kWh, we have adjusted up to 124 g CO_2 per kWh (Energy Agency, 2017), which is the figure we use to calculate emissions from electric cars, electric trains etc.

The last category, *carbon neutral*, includes accommodation at relatives' and friends' homes, hire of rooms via e.g. Airbnb (renting whole apartments are however more similar to a average hotel), accommodation in motorhomes and caravans, tents, night trains or ferry cabins. Emissions from this accommodation category are negligible and are therefore given as 0 kilos per guest night.

Table 7 Kilo CO_2 per guest night in the most common destination countries.

Country	Average hotel in the country [CO_2/guest night]	Lower climate impact [CO_2/guest night]	Carbon neutral [CO_2/guest night]	Number of hotels
France	6.7	1.7	0	22
Spain	30	7.5	0	8
United Kingdom	21	5.2	0	132
Germany	18	4.5	0	34
Austria	12	3.0	0	8
Rest of the EU	17	4.4	0	– [a)]
Turkey	45	11	0	10
Thailand	37	9.3	0	83
USA	24	6.0	0	2109
Sweden	8.5	2.1	0	41
Norway	8.5	2.1	0	– [b)]
Denmark	8.5	2.1	0	– [b)]
Finland	8.5	2.1	0	– [b)]
Iceland	8.5	2.1	0	– [b)]
Rest of the world	31	7.8	0	– [c)]

[a)] Rest of the EU is an average of EU countries we have data for. This also includes Andorra, Liechtenstein, Monaco, San Marino, Switzerland and the Vatican Republic.

[b)] Represented by Sweden.

[c)] Based on Mexico, Russia, China and Australia.

The user can also fill in their own value for accommodation if they know how many kg CO_2 the accommodation generates per guest night.

4 The thermometer

When the user has compared different transport modes and accommodation types for the chosen destination in step one, the preferred options are selected. For many destinations we can say with some certainty however that there aren't any climate smart transport possibilities. It's therefore useful to compare different destinations as well and not just different transport modes and accommodation types. The user will therefore be presented with a relative comparison of how the chosen trip compares with other trips, in the form of a thermometer (see Figure 6). The colour scale goes from dark red for trips with the highest emissions to dark green for the ones with the lowest emissions.

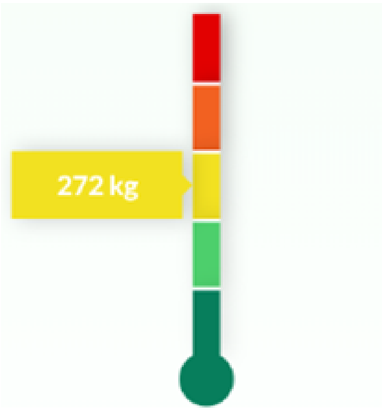


Figure 6 The thermometer giving the user a relative comparison for the chosen trip. Trips with the highest emissions are dark red and the lowest, dark green, including both accommodation and transport.

The basis for the comparison is the climate impact from the most common trips taken by the Swedish people. However, we believe that this comparison also is roughly relevant for individuals in other countries as well. The categorisation is based on the trips of this type identified by Kamb (2015). Kamb identified the most common trips from data about long distance travel collated in the national travel survey carried out by the Swedish government agency Transport Analysis. The survey is based on telephone interviews where the person being interviewed describes their trip. Kamb selected the trips that were at least three days long and had *holiday* or *family and friends* as their main reason. These trips were then scaled up to represent the Swedish population.

The carbon footprint of the most common trips was then calculated using the travel and climate calculator. For all trips abroad we have assumed that an average hotel in the country is used as accommodation. For journeys in Sweden we estimate that more people probably stay with relatives and friends, so accommodation with lower climate impact is adopted in the calculation.

The results and categorisations from dark red to dark green can be seen in Table 8. Dark red trips result in emissions of over 2000 kg CO_2e for travel and accommodation combined. Light red trips emit 500-2000 kg CO_2e, yellow 250-500 kg CO_2e, light green 50-250 kg CO_2e and dark green less than 50 kg CO_2e per trip. Based on this categorisation dark red trips are typically destinations flown to in other continents, and light red trips destinations flown to in and near Europe.

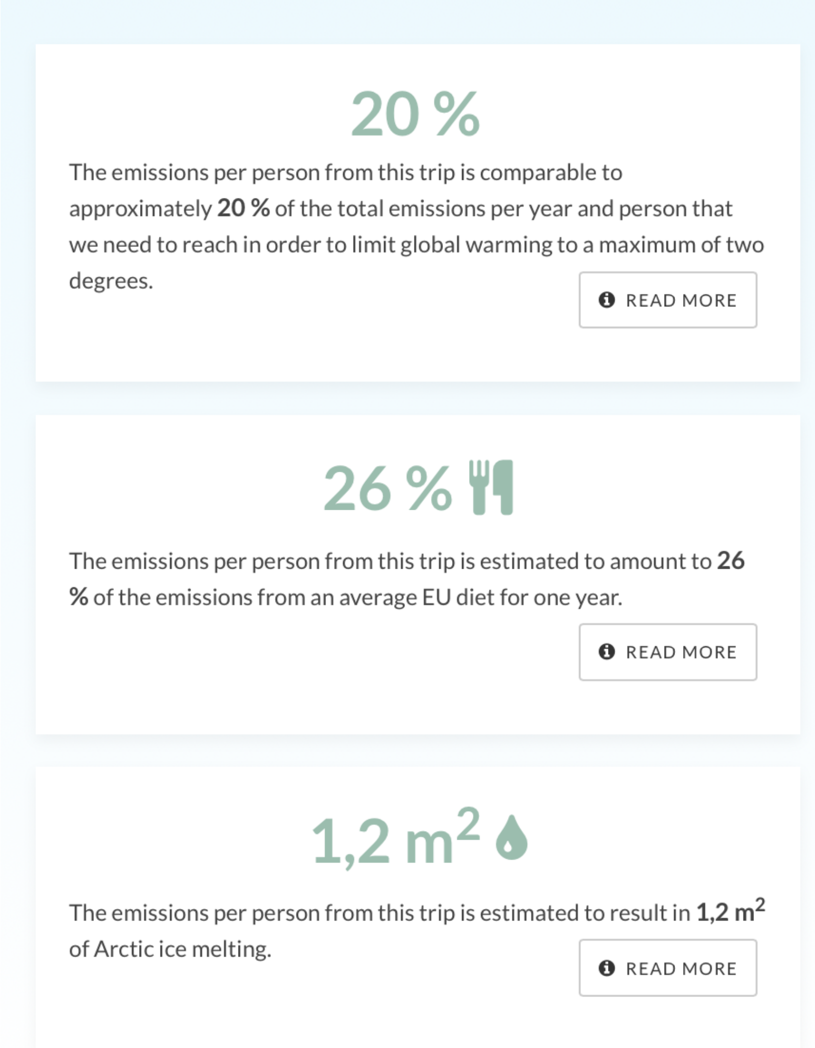
Table 8 Standard holiday trips taken by Swedish people (Kamb, 2015), categorised according to emissions from travel and accommodation.

Category	Most common trip	Number of journeys	Number of days	Distance [km]	Emissions per accommodation [kg CO_2e]	Emissions per journey [kg CO_2e]	Emissions per trip [kg CO_2e]
>2000 kg CO_2e	Flight to Thailand	120 000	20	16 000	666	3 104	3 770
	Flight to USA	270 000	12	14 000	240	2 716	2 956
500-2000 kg CO_2e	Flight to the Mediterranean/ Canary Islands/Egypt	910 000	9	6 200	240	1 203	1 443
	Flight to European cities e.g. Gothenburg-Rome	1 700 000	7	3 500	130	679	809
200-500 kg CO_2e	Flight in Sweden e.g. Gothenburg-Umeå	540 000	6	1 600	8	310	318
50-200 kg CO_2e	Ferry to neighbouring country	320 000	4	800	12	136	148
	Bus to Europe	130 000	7	1 900	87	51	138
	Car to neighbouring country	610 000	7	1 100	36	59	95
<50 kg CO_2e	Car in Sweden	7 300 000	4	600	5	32	37
	Bus in Sweden	310 000	5	540	6	15	21
	Train in Sweden	1 600 000	4	700	5	7	12

The differences in emissions are large, from 12 kg CO_2e per trip for a train trip in Sweden to over 3000 kg for a trip to Thailand by air. The average value is 330 kg per trip. It's interesting to note that transport accounts for 85% and accommodation 15% of the total emissions from Swedish people's trips, according to the above analysis (weighted based on the number of journeys). In other words, the greatest reduction in emissions could be made by switching mode of transport to one with a lower climate impact, or by choosing a nearer destination.

4.1 Comparison of the greenhouse gas emissions figures

Since it isn't so easy to understand what your carbon footprint means in a wider context we have chosen to provide several different comparisons of the emissions. We have selected three different ways of comparing, listed below (the figures apply to a trip emitting 391 kg CO_2eq).



1. The emissions per person from this trip are comparable to approximately XX % of the total emissions per year and person that we need to reach in order to limit global warming to a maximum of two degrees.

The first comparison shows what proportion of an annual sustainable greenhouse gas level would be used up by the planned trip. In order to contribute to global climate goals we need to reduce our emissions of greenhouse gases to under two tonnes by 2050 (Rogelj, Hare et al. 2011). These two tonnes should cover all our consumption generating emissions, including food, daily travel, heating and so on.

In order to reach the climate targets almost all future energy productionneeds to be fossil fuel free, otherwise it is going to be very difficult. In addition, we need to make lifestyle changes, such as reducing our consumption of red meat and dairy products, spending a larger portion of our income on services and going on climate smart trips (Larsson and Bolin 2014).

2. The emissions per person from this trip are estimated to amount to XX % of the emissions from an average EU diet for one year.

If you eat an average European diet for a year it generates emissions of around 1500 kg CO_2 equivalents[23]. One year's food for a vegan generates around around 500 kg (Bryngelsson, Wirsenius et al. 2016).

3. The emissions per person from this trip are estimated to result in X.X m^2 of Arctic ice melting

It's hard to grasp what effect our own emissions have on the climate. Researchers analysed what effect CO_2 emissions have on Arctic ice melt. The analysis is based on calculations of the size of the sea ice in September each year, and the size of the aggregate CO_2 emissions at the same time. By doing this they could calculate that every tonne of CO_2 emissions reduces the area of the ice by 3 m^2 (± 0,3m^2). Because the calculations of ice melt vary, they use a robust linear relationship between the average values of the sea ice area in September, which is when it is at its smallest each year, and the cumulative CO_2 emissions. In this way, using the observed values, the impact on the Arctic sea ice during the summer can be predicted. Based on this linear relationship, the Arctic ice will eventually disappear altogether during September if we generate an additional 1000 billion tons of CO_2 emissions (Notz and Stroeve 2016).

[23] Our own rough calculations based on statistics from FAO (http://www.fao.org/faostat/en/#data/FBS) combined with CO_2e intensities mainly from Bryngelsson et. al. Bryngelsson, D., S. Wirsenius, F. Hedenus and U. Sonesson (2016). "How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture." Food Policy **59**: 152-164..

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