CHALMERS

Methodology Report
Travel CO_2

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1 Background and introduction

Tourism is one of the fastest growing industries in the world. From having once been an activity for the rich and privileged, tourism and travel today are part of the everyday lives of the growing middle class in the world. Since the start of mass tourism in the 1960s, the number of tourists has doubled many times over. This rise in tourism has brought economic growth and positive social and cultural exchanges, but a number of sustainability challenges from tourism have also been highlighted in the media and by researchers: polluted seas, deforestation and soil erosion, littering, prostitution, displacement of local populations, and greenhouse gas emissions (Mowforth and Munt, 2015). The last challenge, in particular, has attracted increasing focus. The tourism industry is dependent on (air) travel. Flights account for 60-95% of the climate footprint of tourism, and growth in tourism goes hand in hand with more flights (Gössling et al., 2005). In 2017, air travel by Swedish residents had almost the same climate impact as all passenger vehicle traffic in Sweden (Kamb et al., 2018). The symbiotic relationship between air travel and tourism has created a clear goal conflict as destinations are investing more and more in trying to attract international tourists while there is simultaneous pressure on them to reduce their climate footprint.

The data used in the Travel CO_2 project is fetched from the Travel and Climate initiative. The low carbon holidays and travel network is behind the initiative. This network brings together researchers, public sector organisations and tourism actors in Sweden to jointly address the contribution of tourism to climate change. The network is run by the Centre for Tourism at the University of Gothenburg. This initiative has received funding from Region Västra Götaland, the West Sweden Tourist Board, the City of Gothenburg, the Centre for Tourism at the University of Gothenburg, Chalmers University of Technology, Mistra Sustainable Consumption, and the Swedish Energy Agency.

The calculations are based on scientifically produced data, including from our own previous studies, and on life-cycle analyses carried out by other researchers and organisations.

The principal for the initiative is the Centre for Tourism at the University of Gothenburg, where Erik Lundberg is the project manager. Fredrik Warberg has been the project manager for the development work. The Travel and Climate trip calculator was originally developed in 2018 and continues to be developed with the aim of being updated with the latest statistics and data from scientific analyses. Jörgen Larsson, docent in sustainable consumption and senior researcher at Chalmers University of Technology, and Anneli Kamb, doctoral student at KTH Royal Institute of Technology, chose the methodology and are responsible for the figures.

2 General assumptions and system boundaries

In order to calculate the climate footprint from different options, we have had to make many assumptions and choices with regards to system boundaries. The general assumptions that affect many the different modes of transport/accommodation choices are described below. Assumptions that only relate to one mode of transport/accommodation choice are described in their respective sections in chapter 3.

2.1 Emissions from fuels are included – but not from vehicles & infrastructure

The calculated emissions cover the emissions from the entire lifecycle of fuels, i.e., from the production, distribution and use of fuels, but not the emissions from the production and maintenance of vehicles (cars, trains, aircraft, etc.) nor from their infrastructure (roads, airports, railways, ports).

The markup for the production and distribution of fossil fuels for cars and buses is based on the Swedish Energy Agency's calculations; however the Agency does not provide specific figures for this (Energimyndigheten, 2021, page 19). In previous reports, they have reported the figure of 20% as the markup for fossil fuels (Energimyndigheten, 2018), which is at the same level as reported by Knörr and Hüttermann (2016) and Edwards et al. (2014). We have used a markup of 24% for the production and distribution of aviation fuel (SOU 2019:11)[1].

Different calculations of the emissions from the production and distribution of fuel produce different results. Lifecycle analyses of fuel production in Sweden have shown lower emissions than the European average, the differences being due to how the refinery allocates emissions to its various products, assumptions about gas flaring, refinery technologies, and the choice of system boundaries, among other things (Eriksson and Ahlgren, 2013). The baseline for pure fossil fuel as reported by the European Commission (Energimyndigheten, 2018) is higher than the 20% that we assume, while other sources report figures below 20% (Gode et al., 2011).

2.2 Climate footprint from electricity

Electricity is used for trains, electric cars and in accommodation, and we describe in this section how the calculations were made for the emissions caused by electricity based on where it is consumed.

Some companies buy green or eco-labelled electricity (e.g. some railway companies) and based on that they report very low emissions. However, we do not deem this to be reasonable, since paying extra for this does not have any effect on emissions in the real world. This view is also described in a report from the IVL Swedish Environmental Research Institute (Gode et al., 2009, p 8) where they argue that the same mix of electricity sources will in fact be used, regardless of whether the customer made this choice or not. It is said that there is no additionality linked to the customer's active choices. This means that the purchase of renewable electricity does not entail any short-term real improvements in the environment, nor does it have any direct impact

[1] However, different lifecycle analyses give different results depending on, for example, system boundaries and how the emissions from the refinery are allocated, where a Swedish approach typically results in lower emissions than a European approach (Eriksson & Ahlgren, 2013). An average of two Swedish refineries gave a markup of about 8.3% for the production and distribution of aviation fuel (Gode et al., 2011). A comparison of different allocation models for the emissions from an average European refinery (the one used in EU legislation), instead gave a 23–27% markup depending on the choice of model (Moretti et al., 2017). Unnasch and Riffel (2015) report similar figures based on a comparison between different studies. Since much of the fuel used in aircraft in which that Swedish residents travel in comes from refineries outside Sweden, we believe that 24% is a reasonable figure to use.

on the development of the electricity system. One reason for this is that the supply of hydropower in the Nordic energy market is much greater than the demand for green electricity. Another reason is that decisions on investments in new wind power, for example, are primarily influenced by trends in production costs and what the current policy instruments are.

Emissions from the electricity consumed are instead based on the average emissions for the Nordic electricity market as a whole. These emissions are calculated, according to a SMED report commissioned by the Swedish Environmental Protection Agency, at 90 gCO_2e/kWh (Sandgren and Nilsson, 2021). This figure refers to average emissions from electricity consumed in the Nordic electricity market during 2017–2019, taking into account imports and exports of electricity from and to neighbouring countries. Emissions from electricity consumption in the rest of Europe are estimated at 301 gCO_2e/kWh (Larsson et al., 2021, p 56). These figures refer to an average for emissions from different energy types within each geographical area, and also include upstream emissions as well as transmission losses.

2.3 Climate footprint from biofuels

There has been controversy for some time over the climate footprint that should be attributed to the use of biofuels, which is evident from the breadth of articles published in scientific journals and in the Swedish and international media, as well as in policy positions within the EU. One position is that biofuels have a very low climate impact and that they are a key part of the solution to the climate issue. The Swedish Energy Agency's annual report on fuels reflects this position (Energimyndigheten, 2021).

Another position is that a global switch to biofuels is neither possible nor desirable, and this position emphasises the potential threat to biodiversity and the questionable climate benefits. Analyses that include changes in land use have shown that crop-based biofuels can even have a greater impact on the climate than fossil fuels (Searchinger et al., 2018).

The climate impact of biofuels is affected not only by the choice of system boundaries (e.g., whether changes in land use are included or not) but also by the feedstocks used in the fuels analysed, such as whether they constitute residue flows or cultivated crops. The Swedish Energy Agency (2021) reports on the feedstocks used for producing the biofuels used in Sweden. For biodiesel, residue flows are mainly used (e.g., slaughterhouse waste accounts for 72% of the feedstock), but also a small proportion of palm oil/PFAD (10% of the feedstock). For the production of ethanol, maize, wheat and sugar beet are mainly used. These figures refer to 2020 and change from year to year.

We use figures from the Swedish Energy Agency's annual report on greenhouse gas emissions from different fuels, and these form the basis for calculating emissions from cars and buses (Energimyndigheten, 2021, pages 21-22). CO_2 emissions from the exhaust pipe are counted as zero and the emissions that are taken into account are those that occur in the production of biofuels. According to the Swedish Energy Agency, the climate impact is 56% lower for E85 than for standard petrol, and 73% lower for HVO100 compared to standard diesel.

3 Transport mode – calculations of emissions

3.1 Car

The emissions per passenger km when you drive a car vary greatly depending on the size of the car, the fuel used and the number of people in the car. To be able to present emissions calculations that reflect reality as accurately as possible we have developed emission factors for a range of fuel and car size combinations. The emissions calculations use data from the Swedish Energy Agency's annual report "Fuels 2020" (Energimyndigheten, 2021) which updates well-to-wheel figures for all fuels annually. The figures include emissions from the extraction, production and distribution of the fuels, but not emissions from the production of vehicles and their infrastructure (see Section 2).

The emissions of a medium-sized diesel car are estimated at 137gCO_2/km. This figure is derived from standardised driving cycles based on the new and more realistic metric known as Worldwide Harmonised Light Vehicles Test Procedure (WLTP) (Energimyndigheten, 2021, p 21), and not the previous New European Driving Cycle (NEDC), which greatly underestimated emissions in relation to actual driving (Trafikverket, 2021, p 5). Figures for other fuels are given in Table 2 below.

A markup of 34% has been applied for big cars as a weighted average for big petrol and diesel cars compared to medium-sized petrol and diesel cars. Small cars are almost always petrol cars. These are assumed to use an average of 24% less energy than medium-sized petrol cars. Campers/caravans are assumed to use 96% more fuel than a medium-sized car[2].

[2] Data for our figures regarding car size were obtained from the IVL Swedish Environmental Research Institute, which makes analyses based on the Handbook Emission Factors for Road Transport (HBEFA) model, which includes statistics for all road transport in Sweden. The figures were produced with the help of Martin Jerksjö of the IVL Swedish Environmental Research Institute. In the statistics from the Swedish Energy Agency, the term "average car" is used for each fuel type. We have assumed that this is the same as a medium-sized car. Seven-seater cars are assumed to have the same emissions as other big cars. Campers are not included in the HBEFA model. This estimate is based on the average total weight of campers (later models) taken from the motor vehicle register and on vehicles with an equivalent weight in the HBEFA model. Caravans are also not included in the HBEFA model. The difference in emissions between a medium-sized car and a car with a caravan on the one hand, and a medium-sized car and a camper on the other, is roughly the same (Hammarström, 1999).

Table 1 Grams CO_2 emissions per vehicle per kilometre

	Petrol	Diesel	Biodiesel/ HVO [d]	Electric (Nordic) [a]	Electric (Europe) [a]	Natural gas[b]	Biogas [d]	Blend natural/ biogas[c]	Ethanol E85 [d]
Small car	127	104	28	11	34	137	19	20	56
Car	167	137	37	14	45	181	26	27	74
Big car/7 seater	220	181	49	18	60	238	34	36	98
Camper	327	267	72	27	88	353	50	53	145

[a] For the calculation of emissions from electricity use, see Section 2.2.

[b] The main fuel used abroad is natural gas (Source: miljöfordon.se)

[c] Blend of biogas 95% and natural gas 5%, average for sold gas for cars in Sweden 2021. (Source: Energigas Sverige)

[d] For the calculation of emissions from biofuels, see Section 2.3.

The emission factors in Table 2 are divided by the number of persons on the trip. In cases where the number of persons exceeds five, it is assumed that the group will travel in more than one car. The number of cars is calculated by dividing the number of people by five and rounding up, i.e., if the group is six to ten people, they are assumed to be travelling in two cars, 11 to 15 people are assumed to be travelling in three cars, etc. For a 7-seater car, the same method is used but the calculation is based on seven people per car instead.

3.2 Train

Trains that run on electricity in Sweden and the rest of Europe generate considerably lower emissions than diesel trains. All of 80% of rail travel (pkm) in Europe is by electric train (IEA, 2019, p 50). For travel in Sweden/Norway/Finland, the emission factor for trains is 7 grams CO_2 equivalents per passenger km (abbreviated throughout as g CO_2e/pkm). The corresponding figure for the rest of Europe (including Denmark[3]) is 24 gCO_2e/pkm. The calculation is based on an energy consumption of 81 Wh/pkm[4]. The fact that emissions are higher for electric trains in

[3] Trains operating between Copenhagen and Germany are currently diesel trains. DSB has stated, however, that due to their high occupancy rates and few stops, these trains (IC3) generate only 21 gCO_2/pkm www.dsb.dk/om-dsb/samfundsansvar/miljo/fakta-om-miljoet. We have therefore used the same emission factor for Denmark as for the rest of the EU.

[4] Based on SJ's average for its entire train fleet and with average occupancy. However, many holiday trips in Sweden and abroad are made in high-speed trains with high occupancy rates. For the X2000, SJ reports a lower energy consumption (50 Wh/pkm). For trains in Europe, the energy consumption data states from 38 to 52 Wh/pkm (Source: Project FINE1, page 19). On the other hand, some holiday trips are made in night trains and these have a higher energy consumption per passenger because there are roughly half the number of places per carriage (Source:

Europe compared to Sweden is related to how the electricity is produced (see Section 2.2). We do not take into account that some companies in Sweden and other countries use eco-labelled electricity (see Section 2.2.)

For diesel trains, an emission factor of 91 g CO_2e/pkm is used (Knörr and Hüttermann, 2016). There are country-level statistics on the share of train travel (not the share of pkm) by diesel train: Sweden 4%, Finland 8% Norway 36%[5], Denmark 58%, France 23%, Austria 32% and Italy 52% (Eurostat, 2017). For the rest of the world, it may be relevant to mention that the Trans-Siberian railway is electrified[6]. Non-electrified railway lines are mostly used for local trains (Bundesnetzagentur, 2019).

Table 2 Summary of emission factors for different types of trains.

Transport mode	gCO_2/pkm
Electric train (Nordic countries)	7
Electric train (Europe) [a)]	24
Diesel train	91

3.3 Bus

The emissions per pkm for bus legs of a trip depend mainly on the occupancy rate of the bus and the fuel used. The emissions calculation is based on the assumption that the average number of bus passengers is 28, and with an average fuel consumption of 26 litres per 100 km (Sveriges Bussföretag, 2022). This translates into emissions of 25 gCO_2e/pkm.[7] In countries with no or lower biofuel blend-in mandates this emission factor is an underestimation. The emission factor for a bus running on 100% biodiesel (HVO100) is estimated at 7 gCO_2/pkm (see Section 2.3).

3.4 Ferry

As with the other modes of transport, emissions per pkm may vary depending on many factors. One important factor is the speed of the ferry. High-speed ferries (used for some trips to Gotland, for example) use twice as much energy per pkm as conventional ferries (Åkerman et al., 2007). However, these high-speed ferries account for a small proportion of the total volume of ferry traffic in Swedish waters.

When calculating the emissions from ferry traffic, you need to choose a principle for allocating the total emissions between the two main types of services sold by ferry companies: transport

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European Parliament, page 25). We estimate that the figure of 81 Wh reflects well a reasonable average for holiday trips. It is also close to a figure for the European average of 87 Wh (Knörr and Hüttermann, 2016).

[5] There are two longer stretches of railway line in northern and eastern Norway that are not electrified (Source: Wikipedia).

[6] Emissions from electricity production in Russia are roughly as high as those in the EU. In 2020, they were 314 gCO2/kWh (Sources: Climate transparency, Wikipedia).

[7] The calculation is: (275*10*0,26)/28=25; 275 gCO_2e/kWh diesel, 10 kWh/litre, 0.26 litres per km, 28 people on the bus.

of passengers and transport of goods (freight). Unfortunately, different ferry companies have chosen to use different principles, making it difficult to compare them.

The principle that we use, which we find to be the most accurate, is *financial allocation.* Here, emissions are divided between passengers and freight based on their share of the ferry company's income from passengers and freight. The logic behind this is that it is the revenue of the ferry companies that drives their ongoing operations and that it is therefore reasonable that the proportions from their revenue are used to distribute the emissions. For example, if 70% of their revenue comes from passengers and 30% from freight, 70% of the emissions are allocated to passengers and 30% to freight.

As far as we know, financial allocation has not been applied in the past for Swedish ferry companies. We have therefore worked with Viking Line and Stena Line and calculated emissions per pkm for them based on the principle of financial allocation[8]. The results for each ferry line are in the range of 200–300 gCO_2/pkm. A weighted average is 226 grams. The figure of 226 grams is an average for passengers travelling with a car and those not travelling with a car. This figure is not relevant for high-speed ferries as they generate much higher emissions.

Another allocation principle is the *area method,* where emissions are allocated between passengers and freight based on the space they take up on the ferry. This method is used in the Swedish Environmental Protection Agency's tool for measuring the climate footprint of travel (Wisell and Jivén, 2020)[9]. It reports average emissions for 7 different ferry lines (not high-speed ferries) as 274 gCO_2/pkm[10]. Other estimates of emissions from ferries (which also use the area method) have been somewhat lower than in the Swedish Environmental Protection Agency's tool for measuring the climate footprint of travel[11] (Åkerman, 2012, Lenner, 1993). Gotlandsbolaget (a ferry company) instead uses the *weight method* for allocating emissions between passengers and freight. This allocation method results in comparatively very low emissions: 40 gCO_2/pkm (excluding high-speed ferries)[12].

3.5 Air travel

As with other modes of transport, the emissions of a flight depend on a number of factors. Emissions per pkm vary depending on the aircraft model, distance, flight altitude, number of seats in the aircraft and the occupancy rate, for example.

For a *Scheduled flight (Economy)* with emissions of approximately 133 gCO_2e/pkm. This figure is based on a calculation of the global average for 2017 and it has then been assumed that the historical rate of reduction (through energy efficiencies and rising capacity utilisation in the

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[8] This information has been obtained through personal communications with Dani Lindberg at Viking Line and Dinis Oliveira at Stena Line.

[9] See page 21 of Wisell and Jivén, 2020. However, the figures themselves are not in the report, but in an Excel file "calculation tool for transport emissions" which is available on the Swedish Environmental Protection Agency website.

[10] This does not include cars accompanying passengers on ferries. To include a car, according to their results, you need to add approximately 500 gCO_2/km.

[11] In 1993, Lenner arrived at 200 gCO_2/pkm, and in 2012 Åkerman estimated 170 grams.

[12] Nynäshamn – Visby 6.3 kg CO_2. Source: Destination Gotland.

plane) of 1.9% per year has continued (Kamb et al., 2018). The figure of 133 grams includes the combustion of aviation fuel (69 grams), high altitude effects (equivalent to 48 grams; see Section 2.2.1) and emissions from the extraction and refining of aviation fuel (16 grams; see 2.1)

Charter companies typically have higher occupancy rates than other airlines, resulting in lower emissions. This is why the *Charter* option is available, and is based on average emissions of 118 gCO_2/pkm (Economy class)[13] (Thomas Cook Airlines, 2019, TUI GROUP, 2017). In addition, emissions per pkm are significantly affected by the seat class chosen by the passenger (Miyoshi and Mason, 2009). Since premium economy and business class seats take up more floor space in an aircraft, fewer passengers can be carried on each flight. Therefore, premium economy and business class passengers should account for a larger share of emissions per passenger. In a review of ten standard airlines, we calculated that an average business seat takes up 2.2 times more space than an economy seat, and a premium economy seat takes up 1.2 times more space[14]. If we also take into account the distribution between the number of passengers in each class (Bofinger and Strand, 2013), we can adjust the emissions of each seat class compared to those of the average passenger, as shown in Table 4.

Table 3 Seat Class Index.

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

The table below shows the outcome of the different flight options. It is clear here that the flight options chosen play a major role for emissions.

Table 4 Emission factors for different flight options in gCO_2e/pkm.

	Seat class		
Type	Economy	Premium economy	Business
Scheduled	133 [a)]	162	298
Charter	118	144	-

[13] These two sources specify 67 g CO_2/pkm for 2017, but this refers to per km of *actual distance travelled,* i.e., including holding patterns due to congestion in the airspace around airports, for example. The actual distance travelled by the flight is therefore longer than the great-circle distance and the emission factor is thus lower in this case than if the great-circle distance had been used. Since we have used the great-circle distance in other emission factors, we have adjusted the figure up by 3% to 69 gCO_2/pkm so it can be compared with other emission factors. Here, too, it has been assumed that the rate of reduction has continued at the historical rate of 1.9% per year, as well as markups for non-CO_2 effects and emissions from the extraction/refining of the fuel.

[14] Review of a number of aircraft models on Seatguru for the following airlines: Norwegian Air Shuttle, SAS, KLM, Swiss, Austrian, Brussels Airlines, United, American Airlines, Lufthansa and Thomas Cook Airlines.

Emissions for the trip are then calculated by multiplying the distance by the selected emission factor. The emissions per trip will then be:

$$U_{WtW}^{CO2e}(\mathrm{x}) = u_{TtW}^{CO2}\,(1 + HF + u_{WtT}) \cdot k_i \cdot \mathrm{x}\ \ [kg\ CO_2\mathrm{ekv}]$$
$$= 1{,}94 \cdot u_{TtW}^{CO2} \cdot k_i \cdot \mathrm{x}\ \ [kg\ CO_2\mathrm{ekv}]$$

where:

$$u_{TtW}^{CO2} = \begin{cases} 0{,}082\ (regulj\ddot{a}rt) \\ 0{,}063\ (charter) \end{cases},\ (utsl\ddot{a}pp\ vid\ f\ddot{o}rbr\ddot{a}nning, Tank\ to\ Wheel)\ \left[\frac{kg\ CO2}{pkm}\right]$$
$$u_{WtT} = 24\%\ (utsl\ddot{a}pp\ fr\mathring{a}n\ br\ddot{a}nsleproduktion, Well\ to\ Tank)$$
$$HF = 0{,}7\ \ (h\ddot{o}gh\ddot{o}jdseffekter)\ \left[\frac{kg\ CO2\mathrm{ekv}}{kg\ CO2}\right]$$
$$\mathrm{k}_r = \begin{cases} 0{,}84\ (economy) \\ 1{,}0\ (economy\ premium) \\ 1{,}9\ (regulj\ddot{a}rt\ business) \end{cases},\ (s\ddot{a}tesklass\ regulj\ddot{a}rt)$$
$$\mathrm{k}_c = \begin{cases} 0{,}97\ (economy) \\ 1{,}2\ (economy\ premium) \end{cases},\ (s\ddot{a}tesklass\ charter)$$
$$x = \ storcirkelavst\mathring{a}ndet\ [km]$$

3.5.1 Climate impact from fuel production and from the non-CO_2 effects

Emissions arising from the production of the fuel used are included in all the modes of transport, including emissions from the production of electricity for trains and the production of petrol/diesel for cars. To also count this for aviation fuel, we used a markup of 24% on the emissions resulting from combustion (see Section 2.1).

Since our flight's emissions occur at high altitudes, there are climatic effects in addition to CO_2 to take into account, such as the contrails formed when warm, moisture-rich aircraft exhaust gases encounter the ambient cold air at high altitudes and form ice crystals (Azar and Johansson, 2012, Lee et al., 2021)[15]. Under certain conditions, the contrails from a flight can persist for several hours; under other conditions they disappear within a few minutes. Only the persistent ones are important to consider in terms of climate impact. In addition, the emissions of the flight can increase the formation of high cirrus clouds, mainly as a result of persistent contrails developing into cirrus clouds. In addition, there are other warming effects in the form of emissions of nitrogen oxides (NOX), for example. We can simply call all of these 'non-CO_2 effects'.

There is uncertainty surrounding how great these non-CO_2 effects are, and the scientific understanding is different for each of the different mechanisms involved in non-CO_2effects. We

[15] Greenhouse gas emissions other than CO_2 also result from other modes of transport, but these effects are on average considerably smaller than for aviation and therefore do not significantly affect the model PETERS, G. P., AAMAAS, B., T. LUND, M., SOLLI, C. & FUGLESTVEDT, J. S. 2011. Alternative "global warming" metrics in life cycle assessment: a case study with existing transportation data. *Environmental science & technology,* 45, 8633-8641..

have not made our own evaluation of the state of the science in this area, but have relied on the assessments made by the IPCC (Boucher et al., 2013) and Lee, et al. (2021).

In a number of flight calculators, the Radiative Forcing Index (RFI) is used to take these non-CO_2 effects into account; usually the IPCC estimate for 1992 is used with an RFI of 2.7 (IPCC, 1999). The problem with the RFI is that it reflects current climate impacts from historical emissions rather than future climate impacts from current emissions, which is what we are interested in. Because of this, the use of RFI for aviation is, according to Fuglestvedt et al. (2010), wrong. They believe that Global Warming Potential (GWP) is a better index as it measures the future climate impact of current emissions. However, the IPCC does not report a figure for GWP. We have therefore chosen to use the most well-established scientific estimate which is, measured using GWP100[16], that the aggregate climate effect is about 1.7 times higher than the effect of CO2 emissions alone (Lee et al., 2021).

The non-CO_2 effects of a specific flight vary greatly depending on the length of the flight, the season, the weather conditions, and time of day for example, and can be both higher and lower than the markup of 1.7 that we have used. However, it can be said with certainty (Miljöförbundet Jordens Vänner, 1997) that for shorter flights it is on average lower, because the aircraft does not reach a sufficiently high altitude, or spends only a small proportion of the flight time there. This means that a markup of 1.7 is an overestimation for short flights (Fichter et al., 2005). Analogously, CO2 emissions should have a higher markup for the longest flights for the global average to end up at 1.7. Of course, it would be desirable to at least consider the length of the flight when applying a markup from CO_2 emissions, but as far as we know there is no sound formula to do this. Figure 2 illustrates how two different flights might look, where the shorter European flight spends a smaller proportion of the time at high altitude compared to the intercontinental flight.

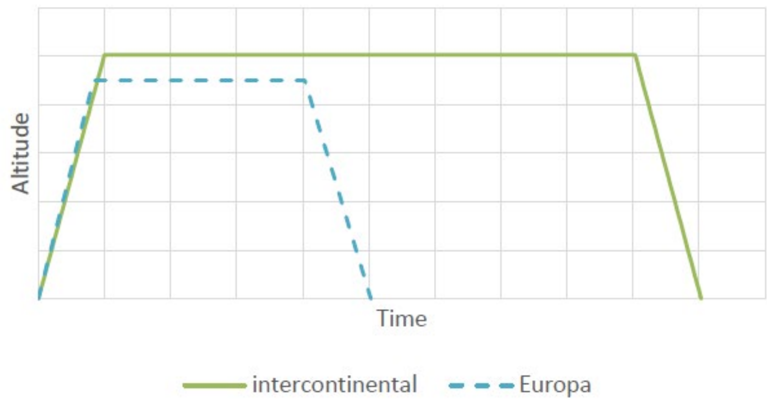

Figure 1 Illustration of the altitude profiles of two flights.
Note that this is an illustration and not based on actual altitude data.

What is also particular for air travel, compared to other modes of transport, is that the take-off (the start of the trip) is more energy-intensive than flying at a constant altitude. As a result, emissions of CO_2 per pkm are typically higher for short flights, because the take-off represents a

[16] Global Warming Potential with 100-year horizon.

larger proportion of its total emissions. Thus, since emissions of CO_2 per pkm typically decrease with distance, and the effects of non-CO_2 emissions increase with distance, these two effects largely cancel each other out.

Non-CO_2 effects come primarily from jet planes when they fly at the altitudes where these effects arise most frequently. Propeller (turboprop) planes typically do not fly at high enough altitudes to cause high altitude effects, as they are primarily used for distances below 500 km (Amizadeh et al., 2016). However, these short flights are likely to cause higher CO_2 emissions than the global average, as their energy-intensive take-offs increase their average fuel consumption for shorter distances.

3.5.2 Comparison of emissions calculators

In order to assess the outcome of the model we have compared it to the carbon emissions calculator used by the International Civil Aviation Organization (ICAO)[17]. To compare the calculators, only carbon emissions during combustion are included; thus, we have excluded the climate footprint of fuel production and air travel's non-CO_2 effects, since the ICAO does not include these in its calculator.

The comparison was presented in its entirety in an early version of the methodology report for the Travel and Climate initiative (Larsson and Kamb 2019). To sum up, our model results in essentially the same levels of estimated emissions as the average obtained from the ICAO carbon emissions calculator. If the ICAO were to include the climate impact of fuel production and the non-CO_2 effects of flights, their average emissions would be roughly the same. However, emissions from the ICAO calculator vary considerably between routes, which is probably due, among other things, to the types of aircraft used and the distance of each route.

4 Accommodation – calculations of emissions

The impact of climate change per guest night (one overnight stay in accommodation by one person) depends on a variety of factors. It is easy to think that a large luxury hotel will always have a greater climate footprint and that a smaller establishment providing less fancy accommodation automatically has a smaller climate footprint. But that is not necessarily the case. While it is likely that accommodation with more surface area uses more energy per guest night, how the premises are heated, and the type of energy used often plays an even greater role for its climate footprint. For example, a more luxurious hotel can have a small climate footprint if they heat their establishment with biofuel-based district heating and produce their own solar power. Similarly, a youth hostel or rented cottage can have a big climate footprint if they are heated with an oil-fired boiler, for example.

In addition, the occupancy rate of the establishment affects the climate impact per guest night. For example, an establishment that only has guests during the summer season, but is heated even during the winter, will have a higher energy consumption and bigger climate footprint per guest night than one with many guests all year round.

[17] ICAO is a UN special body for civil aviation.

The calculation of the emissions from accommodation includes the climate footprint of heating, the electricity used to power the building's always-on systems, hot water and laundry (whether it is done by the accommodation establishment itself or purchased as a service). These emissions normally account for more than half of the climate footprint of hotel establishments (Moberg et al., 2016). Important aspects that are not included are the climate footprint of the establishment's construction and repairs, and the climate footprint of the food served.

We have chosen to include three categories of accommodation: *Climate neutral*, *Hostel* and *Hotel* (see Figure 4). *Hostel* can also include low carbon hotels or basic hotels, as well as various forms of renting or sharing for apartments, etc.

The figures for the climate footprint from hotels in different countries are based on self-reported and harmonised data from hotels around the world. These are compiled by an organisation called Greenview in what is known as the *Cornell Hotel Sustainability Benchmarking Index*. The index is reported to be the largest compilation for the global hotel industry, covering as many as 18,000 hotels in 2020. We collected emissions data from the countries in which Swedish residents primarily spend their holidays (Vagabond, 2017). The differences between countries are due to the amount of energy used for heating and air-conditioning for example, and the types of energy used for electricity production. France, for example, has low figures because electricity in France comes largely from nuclear power stations.

However, it is important to emphasise that the figures have a high level of uncertainty. The figures from each country are of varying quality, as the number of hotels per country and the type of hotel reported in the data vary greatly. Tabell 6 shows the emissions per guest night in each country and how many hotels were the basis for the calculation. For a country like the USA, the data is good because there are many hotels, and because both low-budget and luxury hotels have reported their data. For most other countries, only luxury hotels, or an undefined class of hotel, have reported their data. In the case of Thailand, for example, mainly luxury hotels have reported their data, which makes this figure high. If basic, low-budget hotels without air-conditioning had also reported their data for example, the figure for Thailand would probably have been significantly lower. This probably applies to most countries; however, to what extent it applies is difficult to determine. This should be borne in mind when interpreting these figures. However, this data set is the best we have been able to identify.

Data from Swedish hotels is unfortunately not included in the *Cornell Hotel Sustainability Benchmarking Index*. Instead, data from a comprehensive compilation produced by the IVL Swedish Environmental Research Institute for the Legal, Financial and Administrative Services Agency, which (Moberg et al., 2016) in turn is based primarily on data from 41 hotels that the Swedish Energy Agency, has been analysed (Energimyndigheten, 2011). The figure for Sweden is 6.8 kg CO_2 per guest night[18]. Since data for the other Nordic countries (Denmark, Norway, Finland, and Iceland) are also missing from the *Cornell Hotel Sustainability Benchmarking Index*, the Swedish figure has also been used for these countries. We see this as an acceptable

[18] This includes electricity, heating, hot water, electronics and laundry. The study assumes the Nordic countries' electricity mix with emissions of 84 gCO_2/kWh. We have adjusted up to 90 gCO_2/kWh (see Section 2.2).

assumption since the Nordic countries have an interconnected electricity system and similar building standards.

The survey from IVL includes emissions per guest night, which in this context means a booked single-bed overnight stay. In the *Cornell Hotel Sustainability Benchmarking Index*, hotels report emissions per occupied room instead. Since it is the emissions per guest night that are interesting in this context, we have assumed that the hotel rooms on average are occupied by 1.5 people and therefore we have divided by 1.5. This assumption is based on our estimate that about half of the rooms are used by single guests, typically business travellers, and about half are used by couples, typically holiday travellers.

The difference in the climate footprint between *Hotel* and *Hostel* is based on a study from Switzerland which showed that "tourist homes and youth hostels" had on average a 75% lower climate footprint per guest night than was the case for hotels (Sesartic and Stucki, 2007). The study is based on data from roughly 50 youth hostels that are members of the Swiss Youth Hostels organisation and 152 cabins that are part of the Swiss Alpine Clubs organisation, as well as number of studies of the climate footprint of hotels. Our calculations are based on the broad assumption that this relationship applies in all countries.

The last category, *Climate neutral*, includes accommodation with family or friends, renting a room via Airbnb for example, accommodation in a camper/caravan, tent, night train or ferry cabin. The additional climate impact from this accommodation category is negligible and is therefore assumed to be 0 kg per guest night.

Table 5. Kg CO_2 per guest night in 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	4.7	1.2	0	75
Spain	29	7.2	0	43
United Kingdom	9.3	2.3	0	439
Germany	11	2.8	0	89
Austria	9.3	2.3	0	15
Rest of the EU	13	3.2	0	– [a)]
Turkey	23	5.7	0	80
Thailand	34	8.5	0	245
USA	13	3.3	0	9301
Sweden	6.8	1.7	0	41
Norway	6.8	1.7	0	– [b)]
Denmark	6.8	1.7	0	– [b)]
Finland	6.8	1.7	0	– [b)]
Iceland	6.8	1.7	0	– [b)]
Rest of the world	27	6.7	0	– [c)]

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

[b)] Represented by Sweden

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

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