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Estimating greenhouse gas emissions from travel – a GIS-based study

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Abstract. Conferences, meetings and congresses are an important part of today's economic and scientific world. But the environmental impact, especially from greenhouse gas emissions associated with travel, can be extensive. Anthropogenic greenhouse gas (GHG) emissions account for the warming of the atmosphere and oceans. This study draws on the need to quantify and reduce greenhouse gas emissions associated with travel activities and aims to give suggestions for organizers and participants on possible ways to reduce greenhouse gas emissions, demonstrated on the example of the European Geography Association (EGEA) Annual Congress 2013 in Wasilkow, Poland.

The lack of a comprehensive methodology for the estimation of greenhouse gas emissions from travel led to an outline of a methodology that uses geographic information systems (GIS) to calculate travel distances. The calculation of travel distances in GIS is adapted from actual transportation infrastructure, derived from the open-source platform OpenStreetMap. The methodology also aims to assess the possibilities to reduce GHG emissions by choosing different means of transportation and a more central conference location.

The results of the participants of the EGEA congress, who shared their travel data for this study, show that the total travel distance adds up to 238 000 km, with average travel distance of 2429 km per participant. The travel activities of the participants in the study result in total GHG emissions of 39 300 kg CO_2-eq including both outward and return trip. On average a participant caused GHG emissions of 401 kg CO_2-eq. In addition, the analysis of the travel data showed differences in travel behaviour depending on the distance between conference site and point of origin. The findings on travel behaviour have then been used to give an estimation of total greenhouse gas emissions from travel for all participants of the conference, which result in a total amount of 79 711 kg CO_2-eq.

The potential for reducing greenhouse gas emissions by substituting short flights with train rides and car rides with bus and train rides is limited. Only 6 % of greenhouse gas emissions could be saved by applying these measures. Further considerable savings could only be made by substituting longer flights (32.6 %) or choosing a more central conference location (26.3 %).

1 Introduction

Conferences can be very resource-demanding processes with extensive environmental impacts. Travel activities, accommodation, materials used and waste generated lead to the emission of greenhouse gases (GHGs). Hischier and Hilty (2002) along with Høyer and Næss (2010) identified travel activities of participants as the main source of GHG emissions associated with conferences. The transport sector accounts for 14 % of global anthropogenic GHG emissions (IPCC, 2014a). These GHG emissions contribute to the warming of the atmosphere and oceans. This results in changes in the global water cycle, in reductions in snow and ice cover, in global mean sea level rise and in the increase of climate extremes (IPCC, 2013).

Estimations of GHG emissions from travel activities can be found in studies such as Hischier and Hilty (2002), Coroama et al. (2012) and IPCC (2014b). A vital part in assessing the environmental impact of events, like sporting events, are GHG emissions from travel, as demonstrated by Collins et al. (2009) and Collins et al. (2007). Even though the basic concept of estimating GHG emissions from travel is indisputable, with the result being based on the distance travelled multiplied with the emission factor of the means of transportation used on this distance, there is no comprehensive and standardized method available yet. Emissions factors indicating the amount of GHG emitted on a certain distance by a means of transportation are well documented in the literature and in databases, such as the ecoinvent database or the Handbook Emission Factors for Road Transport (HBEFA). The emission factors in these databases include emissions directly linked to the operation of vehicles and also emissions caused in the production and transport of fuel or electricity.

Even though there are many online carbon calculator tools available for travel or household, studies from Birnik (2013) and Pandey et al. (2011) show that a standard or consensus regarding how personal carbon footprints should be calculated does not exist. As a result, calculators vary widely in results from similar input assumptions. The findings of Birnik (2013) also show that online carbon calculators often lag behind scholarly best-practice prescriptions. Furthermore, the documentation of these tools is generally poor. As a consequence, results lack comparability because users do not know which GHGs are included in the calculation and which sources were used for emission factors.

When it comes to calculating travel distances, different methods are found in studies and online tools. Often these calculations are assumptions based on the direct distance between the point of origin of the participants and the location of the conference or event. This is a viable method especially if there is no adequate information available on how the participants travelled.

The methodology used in this study intends to estimate GHG emissions from travel activities accurately based on information on travel activities provided by participants of the event. An important part of the methodology is the process of calculating travel distances with the introduction of geographic information system (GIS) and open-source geographical data for this task. In order to rectify the shortcomings of carbon calculator tools, state-of-the-art data and methods on emission factors and calculation of distances have been applied, joined by comprehensive documentation. To demonstrate how the methodology works, the GHG emissions from travel of participants attending the EGEA Annual Congress 2013 have been calculated and possible savings in GHG emissions by changes in travel behaviour and conference location have been identified. The European geography association for students and young geographers held their Annual Congress 2013 in Wasilkow, Poland, in September 2013 with 193 participants coming from 25 countries.

Table 1. Emission factors without flights.

Means of transportation	kg CO_2-eq pkm^{-1}	Source
Car	0.183	Spielman et al. (2007)
Bus	0.056	Spielman et al. (2007)
Coach	0.041	Spielman et al. (2007)
Intercity train	0.053	Spielman et al. (2007)
Regional train	0.075	Spielman et al. (2007)
Ferry	0.4	Makela (2009)

Table 2. Emissions factors of flight distance classes.

Distance class (km)	kg CO_2-eq pkm^{-1}	kg CO_2-eq rolling traffic	Source
250	0.154	4.38	IFEU (2010)
500	0.174	4.38	IFEU (2010)
750	0.191	4.38	IFEU (2010)
1000	0.280	4.38	IFEU (2010)

2 Materials and methods

2.1 Emission factors

The emission factors in this study are presented in Table 1 and reflect European emission means of cars, buses, coaches, trains, airplanes and ferries. The emission factor states the emissions of carbon dioxide, methane and nitrous oxide expressed as CO_2 equivalents per passenger and kilometre.

The emission factors of flights are divided into four classes depending on the length of a flight, as displayed in Table 2. The energy consumption and hence emissions depend on the aircraft size and flight distance because the energy consumption is highest in the start phase. In shorter flights, the start phase represents a higher share of the total distance than in medium- and long-haul flights. The same applies for detours and turning loops in short flights. In addition to the energy consumption during the flight phases, an amount of 1 kg of kerosene per seat is added for rolling traffic on the airport (taxi-out and taxi-in) for each flight. The emission factors of flights also consider the "radiative forcing index" (RFI). Airplanes that reach high altitudes emit gases and particles – like nitrogen oxides, ozone, water, soot and sulphur – directly into the upper troposphere and lower stratosphere, where they have an impact on atmospheric composition (IPCC, 2013). All of that contributes to climate change on a greater level than the same emissions on ground level. The RFI factor takes these effects into account when it comes to estimating GHG emissions. To apply the RFI factor, the GHG emissions of flights are multiplied with a factor ranging from 1 up to 2.5, depending on the length of the flight at an altitude of more than 9 km (IPCC, 2013).

2.2 Participants information on travel

Information on how the participants of the EGEA Annual Congress 2013 travelled to the conference site and back home has been collected with a survey form that was sent to all participants. In this survey form, the participants described the different steps of their travel and the means of transportation used, including outward and return trip. The answers then were compiled into routes. A route was created for every part of the travel where a different means of transportation was used.

The form was answered by 98 out of 193 participants, which represents a response rate of 51 %. The answers of the 98 participants have been used as a basis for the estimation of GHG emissions from travel.

2.3 Geographical data for routing in GIS

All the data on transportation networks in Europe were derived from OpenStreetMap (OSM). Even though OSM relies on a community of volunteers to gather geodata and monitor the quality of the data, studies from Neis et al. (2011), Girres and Touya (2011) and Haklay (2009) show that the data are geographically accurate. The most important data from OSM that are used in this study are data on road infrastructure, especially highways, and rail tracks in Europe.

OSM data can be downloaded from various sources. The site www.geofabrik.de offers daily updated OSM files for the whole world, continents or countries that are derived from the OSM data set. There are some tools that are needed to prepare, import the data and to execute routing operations in ArcGIS, which include

- Osmosis: Java-based command line application for processing OSM data;
- JOSM (Java OpenStreetMap Editor): Java-based desktop application for editing OSM data;
- ArcGIS Editor for OpenStreetMap: free add-on for ArcGIS to import and edit OSM data;
- Network Analyst extension for ArcGIS: provider of network-based analyses such as routing.

2.4 Calculating travel distances in ArcGIS

To calculate travel distances, routable transportation networks have been created in ArcGIS based on open-source geographical data. The approach is comparable to a GPS navigation system in a car, which can calculate a route between a start and end point.

Network routing determines the route along a network. The selection of routes can be based on different factors, such as shortest distance or fastest route. A route can pass between two selected points or through several points. In a network routing analysis, these points can be the start and end point of a journey and also stopovers. A routing algorithm then searches for a corresponding route between the selected points, while checking for route restrictions to avoid conflicts. Route restrictions can include one-way streets, no turns and other traffic rules. The transportation network has to include the information on restrictions which is included in OSM data in order for the algorithm to find realistic routes that follow traffic rules (Korte, 2000).

All the routes were created as the fastest route between two points. Especially with longer journeys, the fastest route gives a more realistic result because it favours driving on fast motorways rather than trying to find a complicated route that will be shorter but that is associated with a longer travel time. An example of a railway routing process is shown in Fig. 1.

While the distances of car, bus and train routes can be determined with routable network operations in ArcGIS, flight distances have to be calculated in another way since airplanes do not follow roads or tracks. The basic principle of calculating the length of a flight route was to calculate the great circle distance, which is the shortest distance between two points on a sphere measured along the surface, between the two airports and then to use a correction factor to account for the fact that a flight route is longer than the direct distance between two airports. The actual flight distance is longer because flight routes are planned according to weather forecast, wind regime, restricted areas and pre-defined flight pathways. Also circling while waiting for landing clearance adds up to a longer flight distance. Kettunen et al. (2005) have compared actual flight paths via radar to the great circle distances in western European air traffic. Their findings show that the actual flight distance is 10.2 % longer than the great circle distance. Therefore all flight routes based on the great circle distance have been adjusted with this factor of 10.2 % to calculate the total length of a flight route.

2.5 Calculating emissions from travel

The GHG emissions have been calculated with the following formula:

$$\text{travel distance (in km)} \times \text{emission factor} \\ \text{(in kg } CO_2\text{-eq per km and passenger)} \\ = \text{GHG emissions (in kg } CO_2\text{-eq).} \quad (1)$$

Since not all participants shared their travel information in the survey, results had to be extrapolated to get a total result for all participants. The concept of distance classes was used for the extrapolation. With the use of distance classes, the estimation is more realistic than a simple extrapolation based on total means because the different travel behaviour of the participants in the classes is considered. The origin of the 95 participants who did not participate in the survey was known. With that information it was possible to group the participants into distance classes depending on how far away from the conference site they live. With the results of the par-

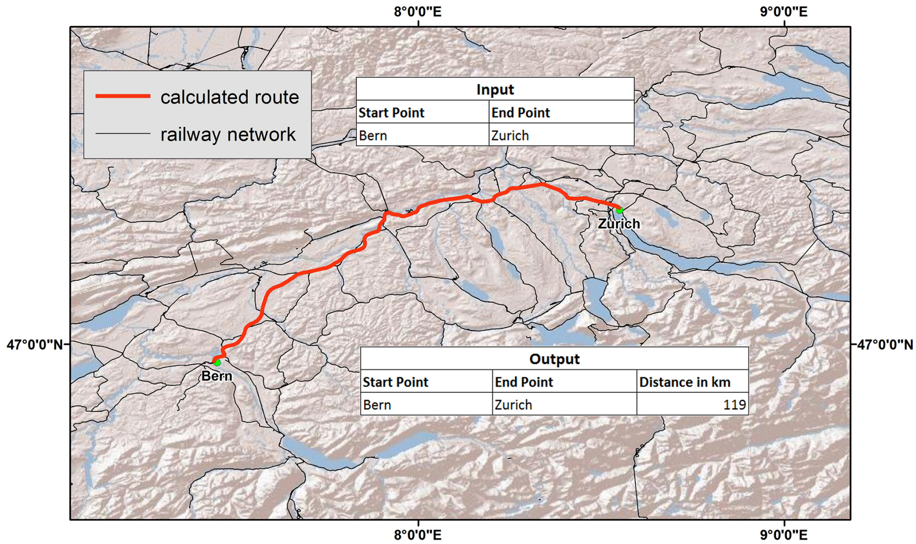

Figure 1. Example of a railway routing process.

ticipants in the survey, the typical travel behaviour and the mean GHG emissions per participant in a distance class was known. The number of participants in each class who did not participate in the survey was multiplied with the mean GHG emissions of the corresponding class.

2.6 Identifying a central conference location

The location of the conference site has an influence on the travel distance of the participants and hence on the GHG emissions from travel activities. A central conference site would decrease the travel distances of the participants. Based on the geographical origin of all participants, the Median Center tool in ArcGIS has been used to determine a central conference location. The Median Center tool identifies the location that minimizes travel distance from it to all the points of origin of the participants.

To estimate the GHG emissions from travel activities in the central conference site, the method of distance classes was used. Again all participants have been separated into classes depending on how far away they live from the new conference site. The number of participants in each distance class is then multiplied with the mean GHG emissions per participant of the distance class. The mean GHG emissions values per participant and distance class are taken from the analysis of the information by the participants in the survey. It is also assumed that the travel behaviour in the distance classes remains the same with the new conference site and that the number of participants remains the same.

3 Results

The results on GHG emissions from travel of the 98 participants of the survey are presented below, which is followed by an estimation of GHG emissions for all 193 participants of the conference. It should be noted that the results on alternative travel concepts only account for the participants of the survey.

3.1 GHG emissions of participants in survey

The total distance covered by the 98 participants during their travel activities adds up to 238 000 km including both outward and return trip. That is an average travel distance of 2429 km per participant. The travel activities of the 98 participants in this study resulted in total GHG emissions of 39 300 kg CO_2-eq including both outward and return trip. On average a participant was responsible for GHG emissions of 401 kg CO_2-eq.

The comparison of GHG emissions and the travel distance indicates which means of transportation are favourable for travelling with low GHG emissions. While flights are responsible for 76.1 % of total emissions, flights only accounted for 45.3 % of the total travel distance. Bus and coach rides and also train rides show a much better ratio when comparing emissions with travel distance. Bus and coach rides only account for 4.6 % of total emissions, but 18.4 % of the total distance was covered this way. Train rides show a similar picture, with 8.6 % of total emissions and a share of 24.3 % of the total travel distance. Therefore travelling by bus, coach and train should be favoured.

To analyse the way the participants travelled and what means of transportation they used to get to the conference site and back home, the 98 participants of the study have been divided into distance classes depending on how far away from the conference site they live. There are noticeable differences in the travel behaviour of participants in the different distance classes, which are displayed in Fig. 2. The most prominent

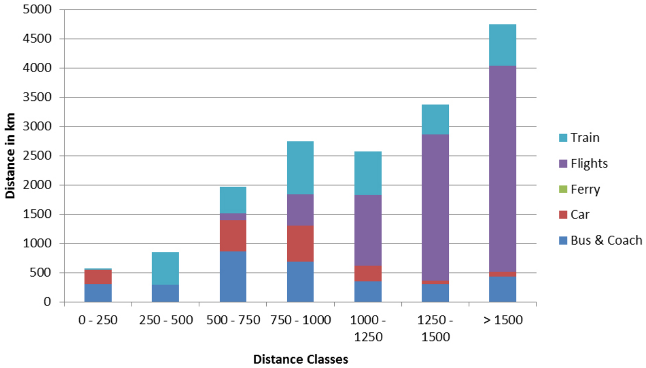

Figure 2. Mean distance per participant in km and the share of means of transportation on that distance.

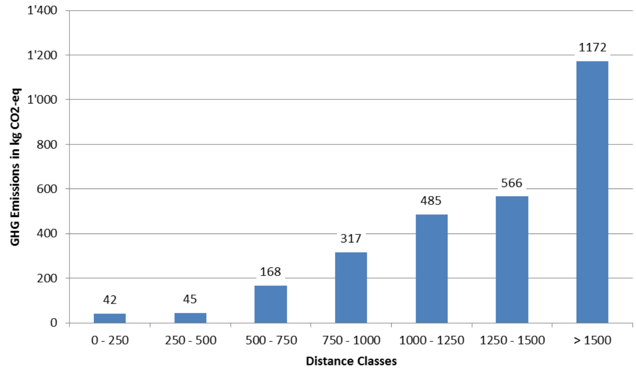

Figure 3. Mean GHG emissions per participant in each distance class in kg CO_2-eq.

feature is the increasing percentage of flights that the participants use to cover their travel distance. The further away participants live from the conference site, the more of the total distance will be covered with flights. Obviously participants living in a radius of less than 500 km of the conference site did not fly. The share of travelling by car diminishes with increasing distance, while travelling by bus is common in every class, with the highest share of the total distance with participants living in a radius of 500–1000 km. The share of train rides of the total travel distance is highest in the classes in a radius of 250–1250 km.

It should also be acknowledged that the mean travel distance of a participant in the distance class of 1000–1250 km is slightly lower than in the distance class of 750–1000 km. Even though the participants live further away from the conference site, the mean travel distance is lower than in the distance class of 750–1000 km. This is due to a higher share of flights in the total travel distance in the distance class of 1000–1250 km. Distance between two points can be covered in a more direct way if one travels by airplane instead of car and train. The different use of transportation modes and the different travel distances are also reflected in the mean GHG emissions of a participant in a distance classes. It is interesting to see that the mean GHG emissions in the first two distance classes are almost the same. As you can see in Fig. 3, in the first distance class, almost half of the distance was covered with cars. In the distance class of 250–500 km no cars were used, but most of the distance was covered with buses and coaches. Therefore the mean GHG emissions are almost similar despite a longer travel distance in the second distance class.

3.2 Estimations of GHG emissions of all participants

The travel activities of the 95 participants who did not take part in the survey result in GHG emissions of 40 411 kg CO_2-eq. On average, one of these participants caused emissions of 425 kg CO_2-eq including both outward and return trip. Added up with the emissions of the participants in the survey, the total GHG emissions of all travel activities result in an amount of 79 711 kg CO_2-eq.

This result here is based on the assumption that the participants who did not take part in the study show the same travel behaviour as the other participants, like the same share of flights on the total travel distance. This assumption was made since the participants of this conference are a rather homogenous and like-minded group of students and young geographers. Changes in the choice of transportation mode, especially using more flights, would alter the result.

3.3 Alternative travel concepts

A way to reduce GHG emissions from travel activities is to use alternative ways of travel, especially the use of means of transportation that are associated with fewer GHG emissions. Since flights cause the highest emissions per passenger and kilometre and also have the highest share of the total travel emissions, a possibility to reduce emissions from travel would be to substitute short flights with train rides. To estimate the possible savings, flights with a total distance of less than 600 km that do not cross open sea were taken into consideration. Substituting flights that cross open sea with train rides, like a flight from Malmö to Warsaw, would mean a long detour with a significantly longer travel time. The substitution of short flights with train rides results in net savings of 809 kg CO_2-eq. This would reduce the total GHG emissions of all participants in the survey by 2.1 %.

Since substituting short flights only leads to a small reduction in GHG emissions, a more rigorous scenario has been analysed. This time all flights on mainland Europe up to a distance of 1500 km have been substituted by train rides. Again flights from Norway or Malta to Poland have been excluded because in these cases a train ride is not a feasible alternative. This scenario would result in net savings of 12 853 kg CO_2-eq. This would reduce the total GHG emissions of all participants in the survey by 32.6 %.

Transportation by car results in more GHG emissions than travelling with bus and train. Car rides are also the second-

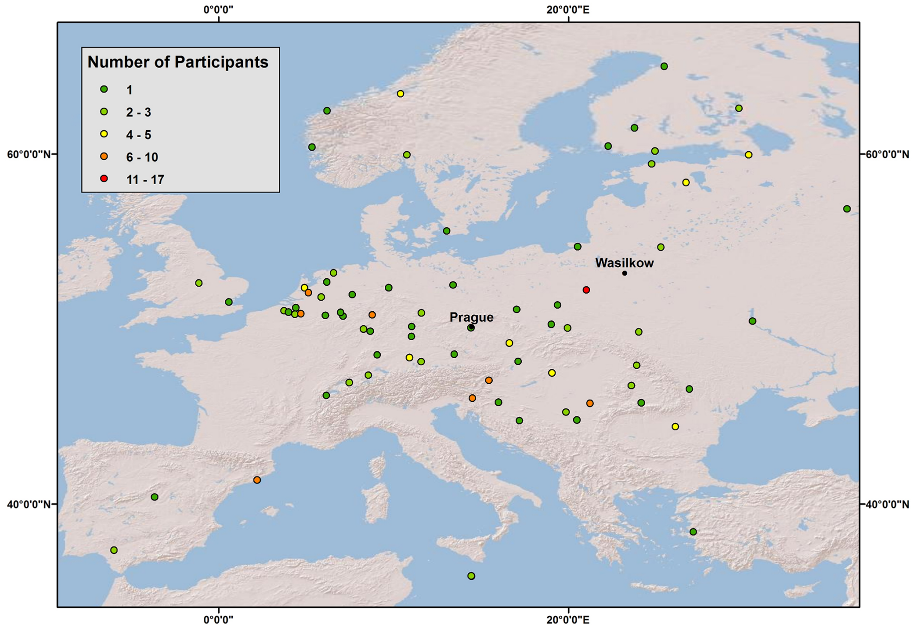

Figure 4. Origin of participants and the two conference sites.

largest source of emissions in this study. To estimate possible savings of GHG emissions, car rides shorter than 100 km have been substituted with bus rides, while longer car rides are substituted with train rides. The substitution of car rides with bus and train rides results in net savings of 1569 kg CO_2-eq. This would results in a reduction of the total GHG emissions of the participants in the survey by 3.9 %.

3.4 Finding a better conference site

The central point that was identified lies next to the city of Prague, so Prague was chosen as a possible central conference site. The following Fig. 4 shows the origin of the participants and the actual conference site of Wasilkow as well as the proposed new site in Prague.

With the conference site in Wasilkow, the mean direct distance per participant to the site is 993 km. This mean distance decreases to a value of 783 km with the newly proposed conference site in Prague. The estimation of the GHG emissions from the travel activities of all 198 participants, including outward and return trip, amounts to a sum of 58 763 kg CO_2-eq with the new conference site in Prague. This is significantly less than the estimated GHG emissions for all participants with the conference site in Wasilkow, which resulted in a total of 79 711 kg CO_2-eq. This would result in possible savings of 26.3 % of GHG emissions by choosing a central conference site.

4 Discussion

With the methodology presented in this study, it was possible to calculate the total results of GHG emissions for the 98 participants of the survey accurately. This was possible not only because of the methodology used, but also because more than half of the participants of the EGEA AC 2013 conference shared their travel information. The availability of these data is essential to calculate exact results.

The comparison of routing operations and GHG calculation results in this study with other tools, like Ecopassenger, generally shows no significant discrepancies, although results for air travel are higher than in some tools. This is due to the methodology used in this study, which uses corrected flight distances and also applies the RFI factor to the calculations.

Nevertheless, some small aspects should be adjusted. The use of a country-specific emission factor for railway travel should be introduced because GHG emissions associated with the production of electricity and the level of electrification of the train infrastructure differ greatly in many countries. The estimations of GHG emissions from travelling by car could be more accurate if participants indicated the type of vehicle they used. On the other hand, a too-complex and too-detailed survey form might discourage participants from taking part in a survey.

The search for a more central conference site based on the point of origin of attendees showed notable potential in minimizing GHG emissions even though some assumptions had to be made to calculate possible savings, and the result therefore is afflicted with uncertainty. It also has to be stated that a conference like the EGEA congress is usually held in a different place, allowing the participants to get to know a new region with its unique landscape and nature. This important element for a conference of geographers would disappear with a fixed conference site.

A useful advancement would be to create tools based on the methodology presented in this study in order to improve the whole process of calculating GHG emissions through the use of databases and automation of time-consuming intermediate processes.

5 Conclusions

With the use of GIS as a routing tool, problems of some online calculator tools can be bypassed. In that way, it is possible to adapt to parameters that are necessary and to use a methodology that is well documented. It also offers the possibility to store geographical data, such as routes and points of origin, for further analyses of alternative travel modes. From a technical standpoint it can be stated that the necessary tools in ArcMap are available to calculate travel distances based on data that are readily available from OpenStreetMap.

The methodology in this study has then been used to estimate the GHG emissions from participants travelling to the EGEA AC 2013 conference in Wasilkow, Poland. The results enable an evaluation of the environmental impact of the conference and the identification of possibilities to reduce GHG emissions from travel. The results of this study suggest that, in order to reduce GHG emissions related to travel, organizers of conferences should choose a central conference site. The potential to reduce GHG emissions is greater than through participants substituting short flights and car rides. Organizers could identify a suitable conference site by examining the average points of origin of participants that attended previous conferences. If a more central conference site were chosen, GHG emissions could be reduced without depending on participants to change their travel modes. However every participant can further reduce GHG emissions by choosing means of transportation that are associated with fewer GHG emissions, mainly substituting longer flights and car rides with train and bus rides. With carbon dioxide emissions in Europe of 7.12 t CO_2 per capita and year (EIA, 2015), the average GHG emissions from travel of 401 kg CO_2-eq of the participants show that attending a conference can increase the personal GHG budget significantly.

The methodology presented can be adapted to extensively assess the environmental impact of travel activities of other events, such as sporting events or cultural events, in the context of a study. For personal use, choosing a well-documented and user-friendly tool like Ecopassenger (www.ecopassenger.org) remains a viable option since it does not require GIS skills to build routable transportation networks.

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