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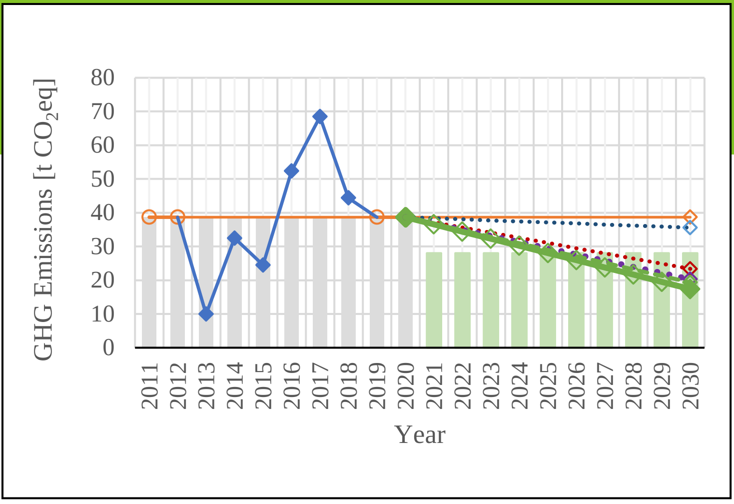


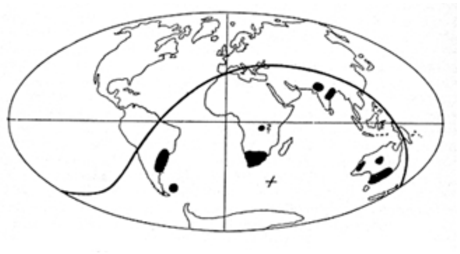
Lower Carbon Mobility: Towards More Sustainable International Scientific Travel of Wegener Center and Beyond

Stefanie Hölbling

September 2020

The **Wegener Center for Climate and Global Change** is an interdisciplinary, internationally recognized research and graduate education institute of the University of Graz that is pooling the University's expertise in Climate, Environmental and Global Change. It brings together research teams and scientists from fields such as geophysics and climate physics, meteorology, economics, geography, and regional sciences. At the same time close links are maintained and further developed with many national and international cooperation partners. The research interests range from monitoring, analysis, and modeling of climate and environmental change to the investigation of climate change impacts and the analysis of the human dimensions of these changes related to mitigation, adaptation, and loss&damage. (more information at www.wegcenter.at)

This report is the result of a Master thesis work completed in February 2020.



Alfred Wegener (1880–1930), after whom the Wegener Center is named, was founding holder of the University of Graz Geophysics Chair (1924–1930). In his work in the fields of geophysics, meteorology, and climatology he was a brilliant scientist and scholar, thinking and acting in an interdisciplinary way, far ahead of his time with this style. The way of his ground-breaking research on continental drift is a shining role model – his sketch on the relations of continents based on traces of an ice age about 300 million years ago (left) as basis for the Wegener Center Logo is thus a continuous encouragement to explore equally innovative ways:
paths emerge in that we walk them (Motto of the Wegener Center).

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Contact: Stefanie Hölbling
stefanie.hoelbling@gmail.com

Wegener Center for Climate and Global Change
University of Graz
Brandhofgasse 5
A-8010 Graz, Austria
www.wegcenter.at

Lower Carbon Mobility: Towards More Sustainable International Scientific Travel of Wegener Center and Beyond

Master Thesis

zur Erlangung des akademischen Grades Master of Science
an der Universität Graz

vorgelegt von
Stefanie Hölbling

am Wegener Center für Klima und Globalen Wandel

Begutachter: Univ.-Prof. Mag. Dr.rer.nat. Gottfried Kirchengast
Mitbetreuer: Jakob Mayer, MSc

Abstract

In this study, we analyse the greenhouse gas emissions of the Wegener Center, an institute of the University of Graz in the field of "Climate, Environmental, and Global Change". Considering the overall emissions of the institute itself, we explore emissions coming from the heating, electricity and resource use (paper use, etc). However, our focus lies on the part coming from international scientific travels (IST) of the personnel of the Wegener Center. We find that these IST emissions account for the biggest part (about half) of the total emissions of the institute and examine the development over 2013 to 2018, taking into account flight and train travels that went beyond the borders of Austria and distinguishing between long distance and short/regional distance travels. Additionally, we take a closer look on three levels of differentiation across travellers, which are gender, scientific seniority level, and scientific field examining possible systematic differences in IST behaviour and the resulting GHG emissions. A core task of the analysis is to come up with robust estimations of emission factors, which vary with modes of transport. We use literature research as well as basic descriptive data analysis. Based on the analysis of the development of the recent years, we discuss possible future pathways up to 2030 and options to decrease greenhouse gas emissions to reach more sustainable IST.

Zusammenfassung

Diese Arbeit beschäftigt sich mit der Analyse der Treibhausgasemissionen des Wegener Centers, ein Institut der Universität Graz, das im Bereich „Klima und Globaler Wandel“ arbeitet. Bezogen auf die Emissionen, welche am Institut selbst anfallen, werden jene aus dem Wärmebedarf, der Elektrizität und Produktnutzungen untersucht. Der Fokus liegt jedoch auf jenen Emissionen, welche von internationalen Reisen des wissenschaftlichen Personals stammen. Wir finden, dass diese für den größten Anteil (rund die Hälfte) der Treibhausgasemissionen des Instituts verantwortlich sind. Unter Berücksichtigung von Flug- und Zugreisen, wobei zwischen Lang- und Kurzstrecken unterschieden wird, wird die Entwicklung der internationalen Reiseemissionen im Zeitraum von 2013 bis 2018 untersucht. Zusätzlich wird die Gruppe der Reisenden mittels der drei Kriterien Geschlecht, akademische Seniorität und wissenschaftliches Feld differenziert, um eventuelle systematische Unterschiede im Reiseverhalten und den daraus resultierenden Emissionen aufzudecken. Eine Kernaufgabe der Untersuchung ist die Entwicklung von stabilen Schätzungen von Emissionsfaktoren, welche vom gewählten Verkehrsmittel abhängen. Es werden sowohl Literaturrecherche als auch grundlegende deskriptive Datenauswertung angewandt. Basierend auf der Untersuchung der Entwicklung der letzten Jahre werden mögliche zukünftige Pfade bis 2030 und Optionen aufgezeigt, Treibhausgasemissionen zu reduzieren, um ein nachhaltigeres wissenschaftliches Reisen zu ermöglichen.

Acknowledgements

Primarily, I would like to thank my supervisor Gottfried Kirchengast for the opportunity to work with him and the Wegener Center on this study. Thank you for the perfect amount of guidance and support, independence and trust, for your professional and personal enthusiasm.

Next, I would like to thank my co-supervisor Jakob Mayer for offering the best support and for all the helpful and particularly fast answers to all my questions – no matter how insignificant or complicated they seemed.

Many thanks go to different employees of the University of Graz, who carried out additional work in order to provide us with all the data we needed for this study. Thanks to Mag. Ralph Zettl and Mr. Raimund Klöckl for the fast and unbureaucratic delivering of data concerning Wegener Center's heating and electricity consumption. Thanks also to Dr. Ralf Aschemann for some valuable advice.

Furthermore, I would like to express my appreciation for the support, workload and invested time of Mag. Ralph Duschek and Mrs. Claudia Knoll, who were – after problems that seemed just about insoluble – able to provide us with the main raw data for this study: aggregated personnel information on Wegener Center scientist's scientific travels.

Thanks to Dr. Manuela Postl and her colleagues, who took care of the mentioned problems and solved the case juridically, which was the first one of this kind on the University of Graz, after a lot of work and research. I would also like to thank the works council and the Rector of the University of Graz at the time, Prof. Christa Neuper, for the cooperation and the consent dealing with the personnel data.

I want to express my gratitude to Sabine Tschürtz, Bettina Schlager, Lena Zechner, and Wim De Geeter – employees of the Wegener Center – who supported me with great dedication by providing helpful contacts and required data. At this point, many thanks also to the whole Wegener Center for this special workplace.

Special thanks go to my colleagues in the office – Melissa, Matthias, Max and Flo – for providing a work atmosphere that made coming to work something to look forward. Thanks for all the coffee breaks, for conversations about everything and anything, for the welcome distractions and the acceptance of concentration and tranquillity when needed.

Finally, I thank my friends in Graz, Vienna, my hometown, as well as Martina and my parents for supporting me during my whole studies and accompanying me all the way.

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Abbreviations

BC	…	Black carbon
CCD	…	Climb, cruise, descent phase
CH_4	…	Methane
CO	…	Carbon monoxide
CO_2	…	Carbon dioxide
CO_2eq	…	Carbon dioxide equivalent of GHG emissions
$CO_{2.\ \text{with RF}}$	…	Amount of emissions accounting for RF
Defra	…	Department for environment, food & rural affairs
EEA	…	European Environment Agency
EF	…	Emission Factor
EPA	…	Environmental Protection Agency
EU-28	…	European Union with its 28 member states
GCD	…	Great circle distance
GHG	…	Greenhouse gas
GWP	…	Global Warming Potential
H_2	…	Hydrogen
HC	…	Hydrocarbons
HNO_2	…	Nitrous acid
HNO_3	…	Nitric acid
HO_2	…	Perhydroxyl radicals
H_2O_2	…	Hydrogen peroxide
IATA	…	International Air Transport Association
IEA	…	International Energy Agency
IPCC	…	Intergovernmental Panel on Climate Change
IST	…	International Scientific Travel
LTO	…	Landing and take-off
mW/m^2	…	milliwatt per square meter
NMVOC	…	Non-methane volatile organic compounds
N_2O	…	Nitrous oxide
NO_x	…	Nitrogen oxides
NO	…	Nitrogen monoxide
NO_2	…	Nitrogen dioxide
OH	…	Hydroxyl radical
pkm	…	passenger kilometer
PM_{10}	…	Particulate Matter
pmi	…	Passenger mile
RF	…	Radiative Forcing
RFI	…	Radiative Forcing Index
SO_x	…	Sulphur oxides
SO_2	…	Sulphur dioxide
UF	…	Uplift Factor
UIC	…	International Union of Railways
UNFCCC	…	United Nations Framework Convention on Climate Change
VOC	…	Volatile organic compounds
WTT	…	Wheel-To-Tank emissions

1. Introduction

Knowing the amount of greenhouse gas emissions that arise due to the work of an institution is important to assess and reduce them in a next step. Decreasing the emissions of greenhouse gases mitigates climate change, which causes several negative impacts. Summarising results from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change IPCC (2013), climate change leads to temperature rise in the near surface atmosphere, in soil and in oceans. Hence, glaciers and snow coverages are melting and the ocean water volume expands, causing sea level rise. In addition, oceans acidify, which has negative impacts on its ecosystem. Extreme weather events such as droughts or floods become more frequent and influence agriculture and habitats. All these consequences lead to social impacts, concerning e.g. human's health or food supply. Additionally, feedback loops play an important role (IPCC, 2013). Contributions to reaching the Paris Agreement on climate change mitigation (United Nations, 2015) is hence an essential requirement for every institution worldwide.

As an institute of the University of Graz, the Wegener Center deals with climate, environmental and global change. Therefore, it seems essential that the Wegener Center acts at the same time as a role model concerning its own efforts to reduce its contribution to the climate change. In this master thesis, we examine two main research questions. In a first step, we explore the recent past development of Wegener Center's greenhouse gas emissions. Regarding the second research question, we try then to reflect on different future pathways until 2030 that possibly reduce Wegener Center's emissions. Focus of the work are the international scientific travels, as they are expected to contribute a large part of the total emissions.

International scientific travel (IST) refers to travel movements that go across the national borders. In this case, it means travels outside of Austria. Travel itself means a trip from point A to point B and retour (i.e. 'round-trips') where the starting point A is always the University location Graz. IST practically consists of two main parts. One is "conferencing travel" for workshops, symposia and other scientific conferences. The second one is "scientific-visiting travel", which means trips for research visits. As we are talking of scientific travels, private travel is not included in the study. We expect IST to be a main source of Wegener Center's annual greenhouse gas emissions, which is found confirmed in the course of our evaluation.

The term "more sustainable" in the title of this study refers specifically to decreasing greenhouse gas emissions; that is reduced tons of CO_2 equivalent emissions (CO_2eq). Every development that shows declining emissions is therefore towards "more sustainable", otherwise it is not. International scientific travels and the work in the institute itself cause the consumption based emissions that we consider in the study. Emissions coming from the work of the personnel in the institute include emissions from heating and from electricity, the latter mainly used for illumination and operating the IT infrastructure. Furthermore, we also estimate the greenhouse gas emissions from the production of IT devices (monitors, PCs, laptops) and from the annual paper use of the Wegener Center. As mentioned, we quantify the greenhouse gas emissions as CO_2eq mass emissions (i.e. g CO_2eq, kg CO_2eq, t CO_2eq; that is grams, kilograms or tons, depending on magnitude of sources), to achieve comparability and comprehensiveness.

The Wegener Center itself is subject of the study. “Beyond” means that the results are estimates of a case study that serves as reference for the whole University of Graz, for comparable scientific institutes, universities, and research institutions worldwide. For upscaling to the whole university of Graz in a next step we provide a brief outlook.

We use different methodological approaches to elaborate our research questions. Literature research is a first important step to get a broader basic knowledge about the issue. A core task are emission factors. We compare the values provided by different organisations and examine their generation to motivate the choice for specific emission factors. A descriptive data analysis follows. As part thereof, we elaborate aggregations and frequencies. We generate pie charts, time dependent recent past emission diagrams and future trends to 2030 from the analysed data and evaluate the emissions. As we obtain the IST data concerning the scientific travels of Wegener Center’s personnel and other input data in form of “Microsoft Excel” spreadsheets, we do our calculations in “Microsoft Excel”; for writing we use “Microsoft Word”.

The Master thesis is structured as follows. Chapter 1 is the introduction, which describes the research question of the Master thesis and introduces the used methods. Chapter 2 describes for context the global amount of greenhouse gas emissions with the focus on greenhouse gases coming from the aviation sector. As the Wegener Center is located in Graz, we describe also the Austrian context of the aviation sector and the development of business travels in the past years. Chapter 3 is the first main part, which focuses on the recent past development of Wegener Center’s greenhouse gas emissions over 2013 to 2018. We divide it into a part that focuses on the IST travel emissions and a part that examines non-travel emissions, which include heating, electricity and product-related emissions. Then we bring the parts together and discuss Wegener Center’s overall recent past emissions. In the second main part, we analyse possible future pathways up to 2030 and options to decrease Wegener Center’s greenhouse gas emissions to reach more sustainable international scientific travel.

2. Context for Aviation Trips

The state of earth's climate system and consequently its change is connected to Earth's radiation balance. According to the IPCC (2013), earth's surface absorbs the main part (about 50 %) of the incoming shortwave solar radiation. As a result, Earth's surface heats up. The surface and the atmosphere reflect about 30 % of the incoming solar radiation, while the atmosphere absorbs the remaining part (about 20 %). The absorbed incoming solar radiation is converted to Earth's heat radiation. This outgoing radiation from Earth's surface is longwave or infrared radiation. Certain gases and clouds absorb a part of the outgoing radiation and reflect it back to Earth's surface, which is the greenhouse effect. To guarantee an overall constant average temperature on the Earth, total incoming and outgoing radiation intensities have to be in balance.

Seinfeld and Pandis (1998) explain the greenhouse effect in the following way. Certain gases are able to absorb a part of the outgoing radiation due to their molecular geometry. Because of asymmetric oscillations, the molecules change their electric dipole moment, which interacts with electromagnetic radiation. Outgoing infrared radiation stimulates these oscillations in asymmetric molecules and they absorb a part of the longwave, infrared radiation that is going out from the Earth's atmosphere. The gases scatter the absorbed radiation. Part of it leaves the atmosphere, while a part of it stays in Earth's atmosphere. The responsible gases are the greenhouse gas (GHG) species that are currently increased from anthropogenic GHG emissions.

The natural greenhouse effect accounts for a stable average surface temperature of 15 °C that allows life on this planet (IPCC, 2013; Kraus, 2004). The natural greenhouse gas effect occurs due to the natural concentration of greenhouse gases in the atmosphere, which is distributed regularly over the globe (IPCC, 2013).

IPCC (2013) and Seinfeld and Pandis (1998) state that one of the most important natural greenhouse gas emissions is water vapour, which also embodies latent heat. Furthermore, IPCC (2013) describes that anthropogenic direct greenhouse gas emission species are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). Other chemical compounds do not influence the greenhouse gas effect directly, but act as precursors for aerosols or are secondary aerosols themselves. In addition, they are able to take place in chemical reactions that change the concentration of other gases in the atmosphere. These indirect greenhouse gases are nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2) or volatile organic compounds (VOC).

The majority of global greenhouse gas emissions is carbon dioxide, representing 76 % of the total 49 Gt CO_2eq in 2010 (IPCC, 2014). Methane contributes to 16 %, nitrous oxide to 6 % and fluorinated gases to 2% (IPCC, 2014), see Figure 1.

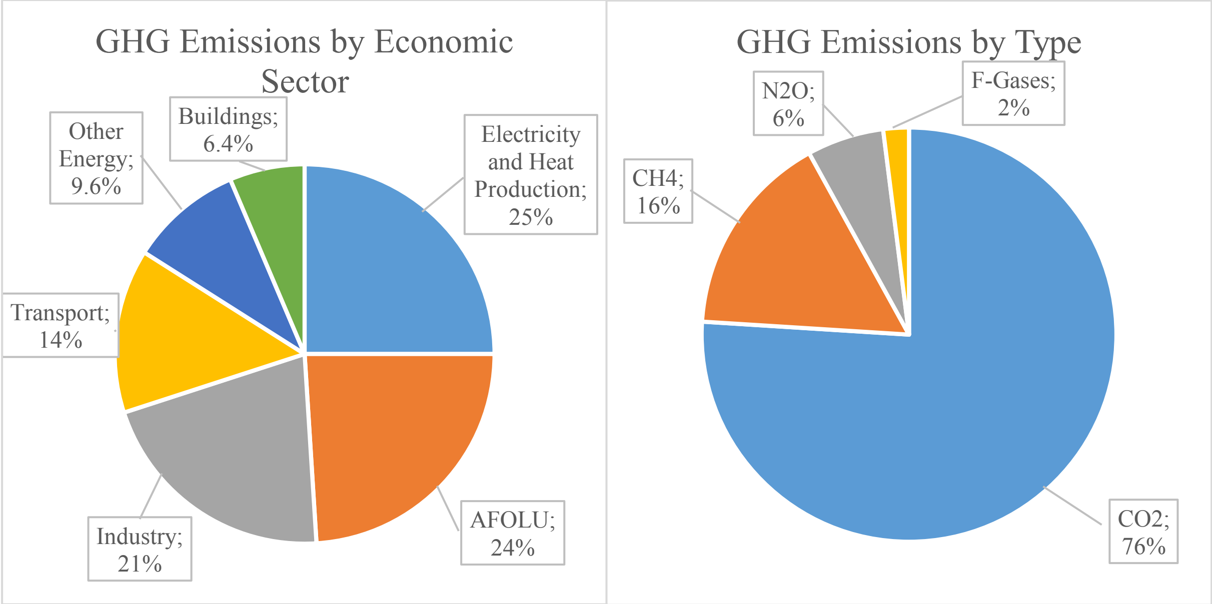

Figure 1: Economic Sector of Greenhouse Gas Emissions and Type of Greenhouse Gas Emissions in 2010; Data Source: IPCC, 2014; Graphics: Own Representation

IPCC's fifth assessment report (IPCC, 2014) lists the sources of greenhouse gas emissions by the economic sector that produces them (see Figure 1). The three major parts come from electricity and heat production, from agriculture, forestry and other land use (AFOLU) and from the industry. Together, they are responsible for 70 % of the global greenhouse gas emissions (in 2010). Transportation contributes to 14 %, while buildings and other energy represent the remaining part. Electricity and heat production, the industry and transportation lead to greenhouse gas emissions due to the burning of fossil fuels. AFOLU describes the production of CO_2, CH_4 and N_2O emissions from livestock, crops and deforestation. Buildings refer to greenhouse gases from heat and energy generation in the building itself. Other energy covers emissions from the fuel extraction, its refining and transportation.

Concerning this work, the transportation sector is important. According to Le Quéré et al. (2015), the efficiency of the aviation sector increased in the years between 1990 and 2011, but the amount of flight activities increased, too. Therefore, the emissions from the international aviation sector grew by 53 % in this period. International scientific travel contributes to a big part of it, which makes researchers and scientists to high emitters.

The Paris Agreement commits the Parties in its Article 2 to keep the average global temperature rise under 2 °C compared to pre-industrial times. In addition, it requires endeavouring to achieve the 1.5 °C goal (United Nations, 2015).

Until July 2019, 185 of 197 Parties ratified to the agreement (UNFCCC, 2019). To reach the goal, only a limited amount of greenhouse gas emissions is allowed to accumulate in the atmosphere.

2.1. Global Context: International Aviation and Maritime Transport

Greenhouse gas emissions from international aviation and international maritime transport are not included in the inventory of domestic emissions attributed to a specific country (Cames et al., 2015). Nevertheless, they contribute to a relatively large part of the global greenhouse gas emissions. The International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) represent these international emissions for international aviation and international maritime transport, respectively.

According to Cames et al. (2015), the amounts of global aviation and shipping greenhouse gas emissions in 2012 are as follows. International and domestic aviation is 2.1 % of total global GHG emissions from which 62 % are across national borders. International aviation defines flights where the departure and landing point are not in the same country. For the shipping sector, the values are similar. Maritime and domestic shipping is 2.8 % of total global GHG emissions from which 79 % are across national borders. Both sectors contribute to 4.9% of total global GHG emissions.

Table 1: Percentage [%] of Global Greenhouse Gas Emissions coming from the Aviation and the Shipping Sector Referred to the Total Global Greenhouse Gas Emissions of the Respective Year (2012); Data Source: Cames et al., 2015; Table: Own Representation

	Total	**International**	**Domestic**
Aviation	2.1 %	1.3 %	0.8 %
Shipping	2.8 %	2.2 %	0.6 %
Total	4.9 %	3.5 %	1.4 %

IMO (2015) gives the total amount of greenhouse gases emitted by the shipping sector as 961 Mt CO_2eq, which are composed of almost 98 % CO_2, 1.3 % CH_4 and less than 1 % N_2O (IMO, 2015). While IMO (2015) consider the three main greenhouse gas emissions, Comer et al. (2017) states the high impact of the short-lived black carbon (BC) on the CO_2eq emissions from shipping.

The Emissions Gap Report 2017 (UNEP, 2017) states that in 2015 the aviation sector emitted 0.9 Gt CO_2eq on a global scale, whereupon 62 % came from international aviation. This corresponds to 558 Mt CO_2eq (UNEP, 2017). For comparison, in the European Union the international aviation emitted 143 Mt CO_2eq in 2015, which corresponds to 3.3 % of Europe’s total greenhouse gas emissions excluding land-use, land-use change and forestry (EEA, 2017). Combining these two sources, EU-28 contributed to 25 % of global international aviation greenhouse gas emissions. 2014 was the first year that the amount of EU’s greenhouse gas emissions from international aviation was higher than the ones from international shipping in the European Union (EEA, 2017).

Considering only emissions of greenhouse gases in the transport sector of Europe, international aviation contributed a large part. According to the EU Commission (2018), which refers to EEA (2017) data, the transport sector emitted 1,051.1 Mt CO_2eq including emissions from international aviation. The greenhouse gas emissions from international aviation were responsible for 13.5 % in this sector, while domestic aviation contributed to 1.4 %. Figure 2 represents EU's international aviation and maritime transport GHG emissions (1995-2015).

In 2017, international aviation emitted 0.5 Gt CO_2eq (UNEP, 2017). According to the Emissions Gap Report 2018 (UNEP, 2018), the global greenhouse gas emissions of that year represented a new record with 49.2 GT CO_2eq, excluding land-use change. The largest influence on that amount has the combustion of fossil fuels, the cement production and other industrial processes (UNEP, 2108).

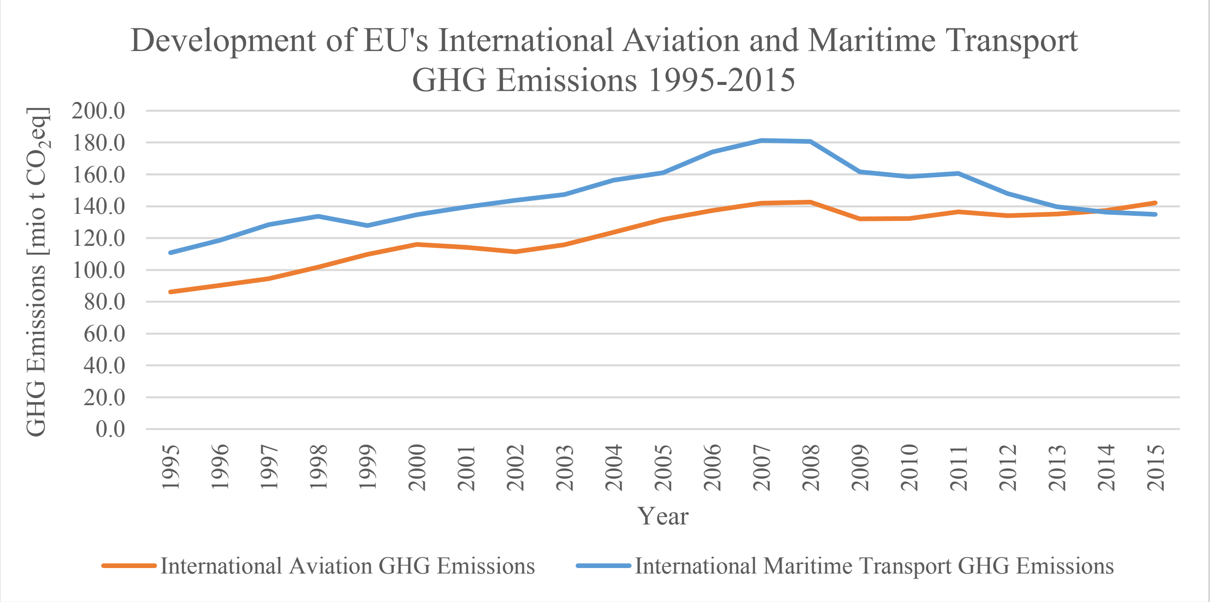

Figure 2: Development of European Union's International Aviation and International Maritime Transport Greenhouse Gas Emissions from 1995 to 2015;
Data Source: EU Commission, 2018; Graphic: Own Representation

Projections predict that the greenhouse gas emissions from international aviation will grow from 0.5 Gt CO_2eq in 2017 to 1.1 Gt CO_2eq by the year 2030 (UNEP, 2017). This is a net growth of 0.6 Gt CO_2eq in 13 years and corresponds to an increase of 120 % compared to 2017.

Comer et al. (2017) give the amounts of greenhouse gases from the shipping sector for the year 2015. Accordingly, the total shipping CO_2 emissions contributed to 932 Mt CO_2, which represent 2.6 % of the global CO_2 emissions from combustion of fossil fuels and industrial processes. The main part of it, namely 87 % or 812 Mt CO_2, came from international shipping. Adding also CH_4 and N_2O emissions, the value from international shipping grows to 849 Mt CO_2eq, while total shipping CO_2eq emissions increases to 971 Mt. Including black carbon, the values rises further. The total shipping sector emitted 1,025 Mt CO_2eq on a 100-year timescale, whereupon the major part, 893 Mt CO_2eq, came from international shipping. This represents 87 % of the total shipping emissions. As mentioned earlier, black carbon represents 7 % of the total shipping emissions.

Furthermore, Comer et al. (2017) state that over the last years, the CO_2 intensity of the shipping sector declined, which means the shipping sector reached a higher efficiency. However, due to an increase in the overall transport supply, the greenhouse gas emissions increased, too. From 2013 to 2015, the CO_2eq emissions from international shipping increased about 1.4 %. Another cause for the higher amount of emissions is the speeding up of huge ships. Therefore, they reach larger distances in shorter time.

2.2. Austrian Context: Aviation Greenhouse Gas Emissions and Business Trips in Austria

The EU Commission (2018) gives the total greenhouse gas emissions for European countries. According to it, Austria's total greenhouse gas emissions in 2016 were 82.02 Mt CO_2eq. Thereof, the transport sector was responsible for 28.6 %. It excludes international aviation greenhouse gases. Adding also international aviation emissions to the transport sector, 9.06 % of the total transport greenhouse gas emissions in Austria arise from international aviation (2.34 Mt CO_2eq). Domestic aviation, however, represents only 0.02 % of the transport sector including international aviation. Austria's total greenhouse gas emissions of 82.02 Mt CO_2eq include six sectors: fossil fuel combustion, agriculture, waste, industrial processes and solvent use, indirect CO_2 and international aviation. Regarding the total greenhouse gas emissions, international aviation contributes to 2.85 % (EU Commission, 2018).

Concerning business trips, Statistik Austria (2018) states that 1.3 million people (age over 15) in Austria did at least one business trip in 2017. Compared to the total population in Austria, this is 17.2 %. In total, 3.5 million business trips were done in Austria in 2017, which is a decline of 10.2 % compared to the total number of business trips in 2016.

Figure 3 shows the development of the number of several-day business tips in Austria. In general, the development is rather stable and amounts to 3-5 Mio. Business trips per year. Between 2004 and 2007, the number of business trips increased but began to decline in 2007. This decrease is possibly connected to the global financial crisis and its impacts in that period. In 2010, the number reached a temporary low level and began to grow afterwards. We see an overall decrease over the last years beginning in 2014.

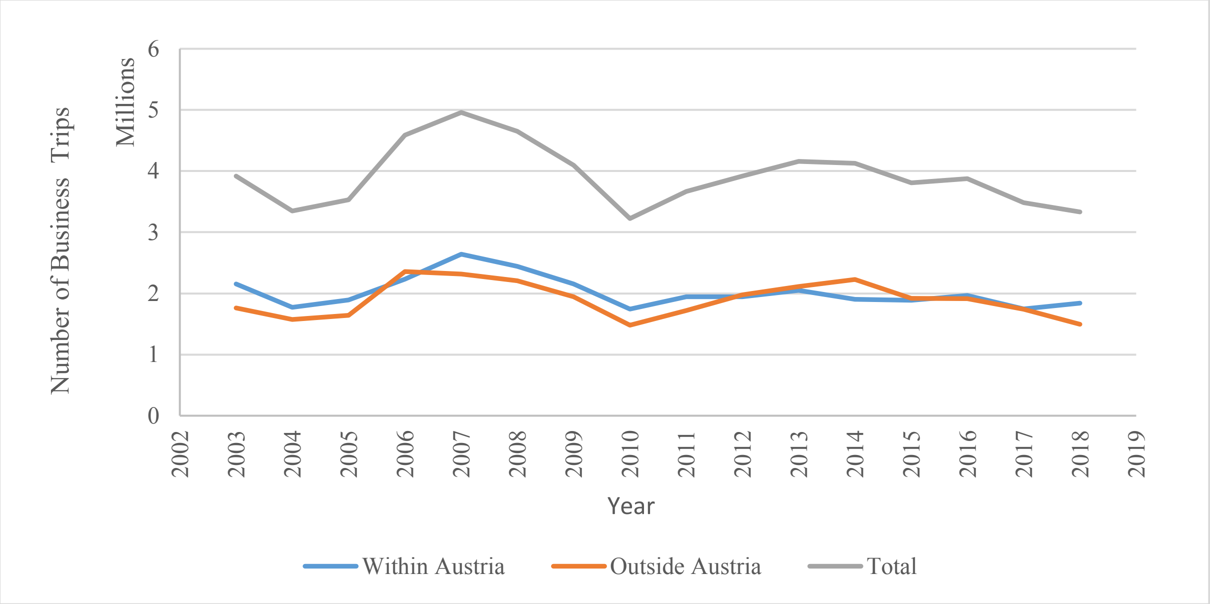

Figure 3: Number of Business Trips Within Austria and Abroad from 2003 to 2018;
Data Source: Statistik Austria, 2019a; Graphic: Own Representation

Statistik Austria (2018 and 2019a) gives the following information on the destinations. The destination of about half of the business trips lies within Austria, the other half is abroad. The relation between trips abroad and domestic trips is remaining almost stable over the last 15 years, which we see in Figure 4. Concerning trips abroad, European destinations represented 91.4 %. From that, more than the half are trips to Germany, Italy and Switzerland. The remaining 8.6 % were intercontinental business trips.

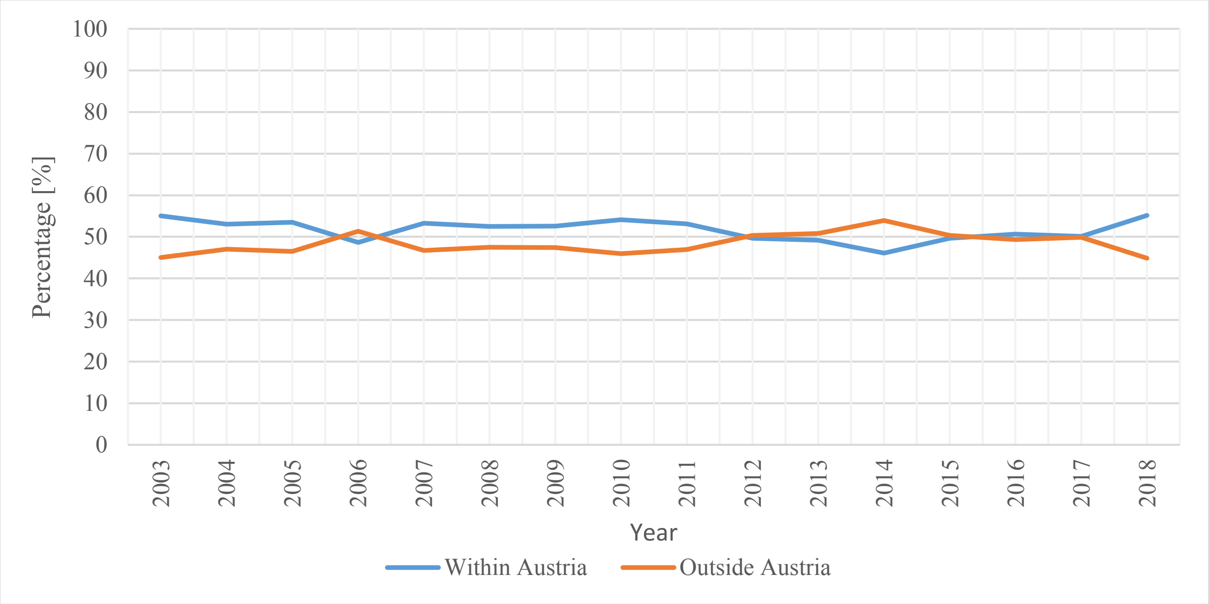

Figure 4: Percentage of Business Trips Within Austria and Abroad from 2003 to 2018; Data Source: Statistik Austria, 2019a; Graphic: Own Representation

According to Statistik Austria (2018), the chosen transport mode depends on the destination and the duration of the trip. There is a difference in the used mode of transportation for international trips and domestic trips. The farther away the destination and the longer the duration of the business trip, the more likely it is that the traveller uses an airplane, which we see in Figure 5 and Figure 6. Airplanes represent the majority of the used transportation modes in international trips (51.0 %), whereas in domestic trips within Austria cars are the majority (65.0 %). For trips abroad, the car plays still a significant part with 33.8 %. This is mainly due to the fact, that the main international destinations for business trips (Germany, Italy and Switzerland) are neighbouring countries of Austria. Conversely, domestic flights are only 1.5 % of the transportation mode in domestic trips. Train travel is still a minor part in both international and domestic destinations. While rail travel is 23.2 % of domestic business trips, it is only 7.8 % in trips abroad. Coaches represent even a smaller part. The data are based on the year 2017.

Statistik Austria (2018) gives the quantity of international flights for business trips in 2017. It is 887,300 flight trips. As 91.4 % of the trips abroad are taking place within Europe, it corresponds to 810,992 European flight trips and 73,308 intercontinental flight trips.

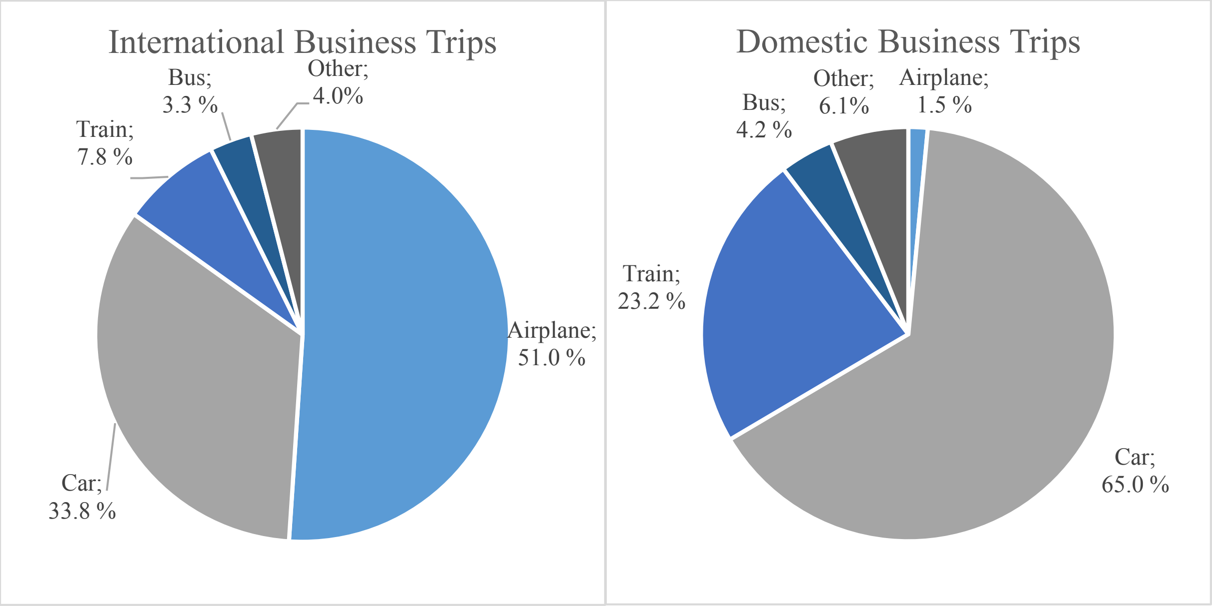

Figure 5: Comparison of Transportation Modes for International and Domestic Business Trips in Austria in 2017; Data Source: Statistik Austria, 2018; Graphics: Own Representation

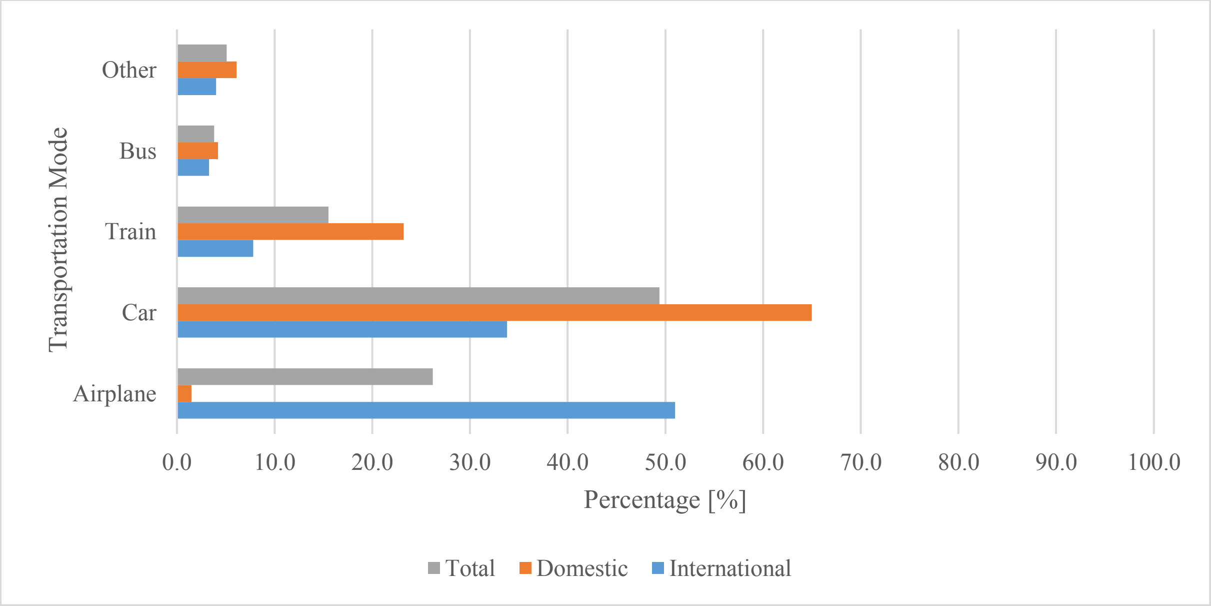

Figure 6: Comparison of Transportation Modes for International and Domestic Business Trips in Austria in 2017; Data Source: Statistik Austria, 2018; Graphics: Own Representation

Figure 7 compares the development of the number of business trips and vacation trips in Austria. We see that the trend in the number of business trips (several-day trips) per year is quite stable, while the number of vacation trips of persons that did at least one vacation trip per year is increasing.

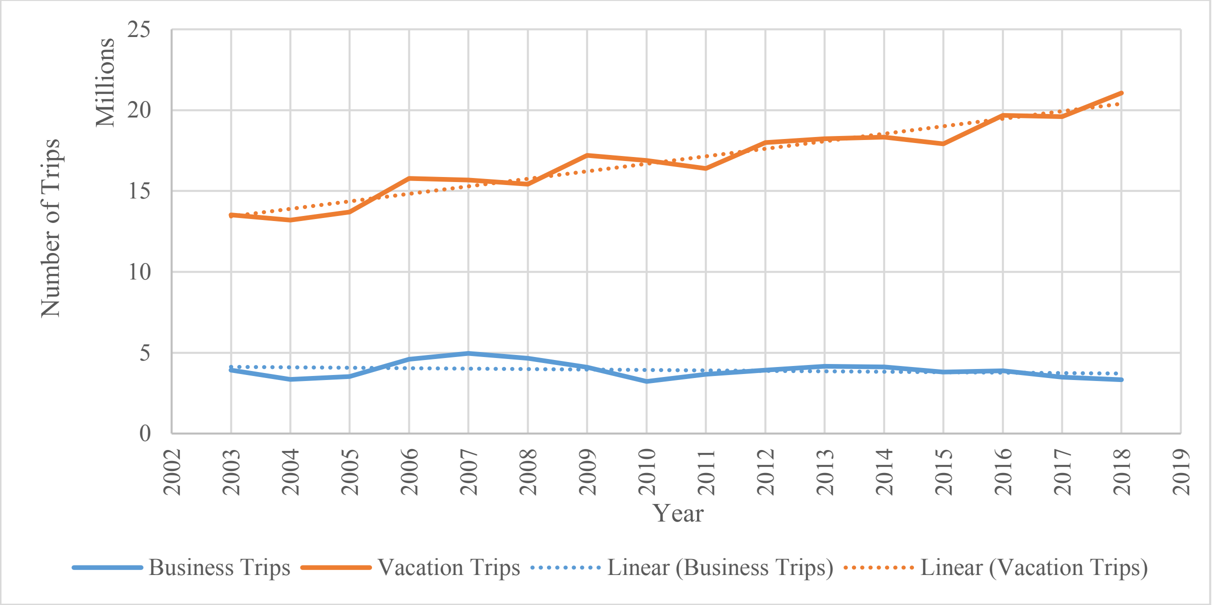

Figure 7: Development of Number of Vacation Trips and Business Trips in Austria from 2003 to 2018; Data Source: Statistik Austria, 2019b; Graphics: Own Representation

3. First Main Part: Recent Past Emissions 2013 - 2018

The first main part deals with the development of greenhouse gas emissions of the Wegener Center Graz with focus on its international scientific travels in the context of the total greenhouse gas emissions in the past. The time horizon for this part are the years from 2013 to 2018.

We explain what emission factors are and why they are necessary in our study. We have a closer look on the special case air travel and its emissions. Additionally, we give explanations and comparisons of emission factors provided by different institutions and motivate our decision for using the emission factors of Mobitool (2017).

3.1. International Scientific Travel

3.1.1 Comparison and Validation of Emission Factors of Passenger Transport

This chapter uses emission factors provided by five different institutions. The institutions are the Environmental Protection Agency (EPA, 2018), the European Environmental Agency (EEA, 2014; EEA, 2018), the Department for Business, Energy & Industrial Strategy and the Department for Environment, Food & Rural Affairs from the UK government (Defra) (UK government, 2018), the Swiss Mobitool (Mobitool, 2017) and also the Austrian Federal environment office "Umweltbundesamt" (UBA, 2018a). Although all these organizations calculate emission factors for passenger transport, the values differ. This is due to the different approaches the institutions calculate the respective emission factors. This means, the decision which variables to include or exclude is crucial for answering our research question.

This chapter gives an overview of comparable values and explains how the respective organisation calculates the emission factors. We examine advantages and disadvantages of the different methods and compare the outcomes. On this basis, we decide which emission factors we use for our study.

Emission factors are needed to estimate the environmental impacts investigating the amounts of greenhouse gases of different travel modes, in this case especially coming from flight travel and train travel used in international scientific travel. There are different ways to calculate the factor, depending on what life stages of the vehicle are included or, respectively, excluded. One possibility is to compute the emissions that come directly from the combustion of the fuel itself, but the fuel consumption is not equal for every train or airplane. The used amount of fuel is determined by several aspects, such as the weight of the vehicle, its velocity, its aerodynamic form or the number of passengers. Hence, all these different aspects should be included as they influence the resulting amount of greenhouse gas emissions. Furthermore, not only the use of a transport mode itself leads to greenhouse gas emissions, but also upstream processes related to the vehicle production, the energy provision and the transport cause environmental impacts. We should also keep these influences in mind and consider to which amount they should be included.

The calculation of emission factors is done as the following paragraphs describe. According to the Greenhouse Gas Protocol Corporate Standard (GHG Protocol, 2019), a greenhouse gas inventory incorporates seven greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PCFs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

The GHG Protocol (2015) gives three scopes that categorise the emissions for a particular activity, in this case transport modes for passenger transport. The scopes refer to the generation of greenhouse gas emissions. Scope 1 emissions sum up all direct emissions that the company, which generates the inventory, can control. For transport, it is e.g. the combustion of fuel during operation. Scope 2 emissions are indirect emissions coming from the electricity the company uses. For transport modes, electrified rail transports show scope 2 greenhouse gas emissions due to its electricity need. The used technology of electricity generation is responsible for the production of the scope 2 greenhouse gas emissions. Emissions that occur during the electricity production are allocated here. Nevertheless, the connection between a company and scope 2 emissions comes from the electricity use of the company and the resulting emissions. Scope 3 emissions are other indirect emissions occurring along the total value chain. It means the used materials produce the greenhouse gas emissions during their extraction, transport and use.

The emission factor is a quantity that gives the greenhouse gas emissions relating to a suitable reference value. For passenger transport, this may be greenhouse gas emissions per kilogram fuel or per passenger kilometer. Emission factors give the possibility to compare the resulting emissions for different transport modes and for one passenger. Therefore, you add the activity, which is the travelled distance in kilometer, and you get the amount of emissions for your travel with a specific transport mode. We are able to compare the impact of different travel modes.

To obtain the emission factors for passenger transport modes, scope 1 and scope 2 emissions have to be calculated. Different organizations deal with scope 3 emissions in a different way. Some institutions include indirect emissions coming from upstream processes along the value chain. Others exclude scope 3. This may depend on the purpose, on the background of the institution or on the available data.

Using only direct emissions may be easier in order to calculate the emission factor. For passenger transport, direct emissions are connected with the fuel consumption and combustion. The emissions are derived by a chemical equation describing the combustion process. However, they give only a limited overview about the greenhouse gas emissions that the chosen transport mode generates.

The approach of an attributional life cycle assessment is more complex. It is not easy to obtain required data because they may not be available. Estimations can help in such a case. This approach is more extensive and gives a better overview about the emissions concerning the whole life cycle of the chosen transport mode. It includes also the construction of the vehicle and the needed infrastructure, the maintenance and disposal. The difficulty in data acquisition is also a source of possible errors and uncertainties regarding the final emission factor.

It is important that the chosen process boundaries remain consistent in the course of the inventory. Only emission factors that used the same scope can be compared directly. It leads to large differences, whether the emission factor considers upstream processes or not.

As there are different types and sizes of the transport mode, either one representative vehicle is used in the calculations to symbolise the whole category (e.g. a specific train type for the whole rail transport category) or different examples are used to build an average value.

The reference value for the emission factors in passenger transport is “passenger kilometer” resulting in amount of greenhouse gases per passenger kilometer. There are different possibilities to derive this value. One option is to calculate the total national passenger kilometers during a specific period and apply them to the transport mode category in the respective country. This leads to a more general solution and a mean value for all the same transport modes (e.g. train, aviation) in a country. The amount of national passenger kilometers is the number of persons transported along the total quantity of kilometers in a specific time, usually a year or a month. Another possibility is to use the available seats in a specific type of transport mode or over an average of different types. If the loading factor is available, it should be included, too. The loading factor is the typical number of occupied seats given as a percentage. The higher the loading factor is, the lower the greenhouse gas emissions per passenger become.

Greenhouse Gas Emissions from Aviation:

The aviation sector is a special case concerning greenhouse gas emissions. This is due to different aspects that have to be considered in the calculation of its greenhouse gas emissions. Lee et al. (2010) state that as aircrafts operate in large heights, they emit greenhouse gas emissions directly into the upper troposphere and into the lower stratosphere. Other transport modes such as rail transport or cars are operating on ground level. Consequently, also the emitted greenhouse gas emissions occur there. The gases and aerosols change the composition of the atmosphere, which leads to climate change and depletion of ozone.

According to the Intergovernmental Panel on Climate Change IPCC (1999), greenhouse gas emissions emitted directly in high altitudes act differently than on ground level. Their atmospheric lifetime can vary with the altitude. An example are nitrogen oxide NO_X emissions. Their lifetime increases at atmospheric conditions, which again has an influence on how it reacts in the atmosphere and how it effects the climate (IPCC, 1999). It is different with the lifetime of carbon dioxide (CO_2).

The IPCC (1999) and Lee et al. (2010) state that CO_2 has a long lifetime and causes therefore long-term effects. As it does not degrade fast and has a long residence time in the atmosphere, it is transported over wide ranges. CO_2 emissions remain over hundreds of years in the atmosphere. Other emissions from aviation cause short-term effects that occur mainly on the flight routes, which is a more regional level. Emissions with a short residence time are water vapour, aerosols and nitrogen oxides.

The International Civil Aviation Organization ICAO (2016) and Lee et al. (2010) describe that the main emissions produced by aviation traffic are coming from the combustion process of the fuel in the engine. Kerosene is the most commonly used fuel, but also aviation gasoline is available. Both have the chemical composition of "C_nH_m", where n represents the number of carbon atoms C, m the number of hydrogen atoms H in the molecule. Sulphur is also present in the fuel and is therefore part of the emissions.

ICAO (2016) explains the ideal and the real combustion in aviation the following way. The combustion process uses the fuel and air, which is mainly nitrogen (N_2) and oxygen (O_2). It produces carbon dioxide (CO_2) and water vapour (H_2O) through the oxidation process as main products. N_2 and O_2 coming from the combustion air are also products. Due to the sulphur content in the fuel, the oxidation process leads to sulphur dioxide (SO_2). These products correspond to an ideal combustion without by-products, which takes place only if a perfect ratio between oxygen, nitrogen and aviation fuel is available. However, a real combustion occurring in the aviation process produces also other chemical compounds. Besides CO_2, H_2O and SO_2, also nitrous oxides (NO_x) and additional sulphur oxides (SO_x) arise. Due to an incomplete combustion, carbon monoxide (CO), hydrocarbons (HC) and soot or black carbon (BC) occur.

According to Lee et al. (2010) the process is more ineffective at "lower power conditions", which leads to a higher amount of CO and HC. Especially HCs depend on the engine power but also on the ambient temperature. With increasing thrust, the amount of HC declines.

Due to its long residence time in the atmosphere, CO_2 has long-term effects, while non-CO_2 emissions show shorter-term effects (Lee et al., 2010). The radiative forcing (RF) can describe the different impacts from greenhouse gas emissions.

Fuglestvedt et al. (2010) describe that the radiative forcing expresses the quantitative (in mW/m^2) and qualitative (positive or negative) change in temperature in reference to pre-industrial times caused by a greenhouse gas. Therefore, the radiative forcing depends on the past development of former emissions. A positive radiative forcing represents a warming effect, while a negative one characterises a cooling impact.

CO_2 has a warming effect and leads to a positive radiative forcing, as it is infrared active and absorbs outgoing longwave radiation from the earth (Lee et al., 2010).

NO_x emissions sum up nitrogen monoxide (NO) and nitrogen dioxide (NO_2) (Lee et al., 2010). According to Wormhoudt et al. (2007), the composition of NO_x depends on the engine power. At low powers, NO_2 represents 80 % of NO_x emissions, while at high thrust conditions it decreases to 7 %. The reaction of NO and NO_2 with hydroxyl radicals (OH) forms small amounts of nitrous acid (HNO_2) and nitric acid (HNO_3) (Lee et al., 2010).

NO_x reacts in different ways in a tropospheric surrounding. On the one hand, it leads to a warming effect, as it is responsible for ozone production due to chemical processes. The production of ozone from NO depends on the NO_x background concentration (Lee et al., 2010). IPCC (1999b, pages 122 – 123 therein) describes the atmospheric reactions of NO_2 leading to ozone formation in detail.

The ozone, which results from the NO_x reactions, has a warming effect on the climate and a positive radiative forcing. On the other hand, NO_x produces hydroxyl radicals (OH). This causes reactions that reduce the methane concentration, which leads to a cooling effect and a negative radiative forcing. As already mentioned, the NO_x chemistry depends on the altitude. Dessens et al. (2014) and Lee et al. (2009) state that above 20 km NO_x leads to ozone destruction instead of generation. Despite the two different impacts, the overall effect of NO_x emissions is warming. Both processes are photochemical reactions.

In addition, NO_x promotes the production of aerosols. SO_x and hydrocarbons have the same effect, while soot is already an aerosol itself (ICAO, 2016). Water vapour converts sulphur trioxide (SO_3) to sulphuric acid (H_2SO_4), which is a very important aerosol precursor and causes the production of aerosols (Dessens et al., 2014; Lee et al., 2010). The fraction of sulphur dioxide (SO_2) that is converted to SO_3 depends on the temperature and the pressure in the engine (Lee et al., 2010). Aerosols may cause the formation of clouds and influence the climate and climate change (ICAO, 2016). Sulphur oxides have the capability to reflect incoming shortwave radiation and hence have a cooling effect, while black carbon absorbs both solar shortwave radiation and longwave radiation coming from the earth. Soot has therefore a warming effect on the climate (Dessens et al., 2014; Gettelman and Chen, 2013; Lee et al., 2010). The amount of soot emissions decreases with the altitude, which means they are higher at landing and take-off cycles (Hendricks et al., 2004). In addition, it depends on the engine type and the power conditions (Petzold et al., 2003).

According to ICAO (2016), water vapour is another problematic emission that is the “counterpart” of aerosols and lead therefore to similar impacts. With aerosols from background concentration or emitted by aviation, water vapour forms contrails under specific circumstances. The contrails are persistent, when the ambient temperature is low and the humidity high. In this case, they increase cloudiness.

There are also other species among the greenhouse gas emissions from aircraft containing hydrogen: hydrocarbons (HC), hydroxyl radicals (OH), perhydroxyl radicals (HO_2), hydrogen peroxide (H_2O_2) and hydrogen (H_2) (Lee et al., 2010).

Concerning the lifetime of chemicals, ICAO (2016) summarises that the types of greenhouse gas emissions from the aviation sector have different atmospheric lifetimes. Therefore, they have influences on a broad range of timescales and corresponding spatial scales, too. We see special patterns on global level, regional level or in the areas where aviation activities take place. The physical and chemical processes are various and complex due to the different interactions and feedback loops. Additionally, “meteorological conditions in the upper troposphere and in the lower stratosphere” influence the processes (ICAO, 2016).

Summing up, the extent of the climate forcing due to a specific pollutant is not always depending on the same factors. According to Dessens et al. (2014), CO_2 emissions are proportional to the amount of fuel burnt during the flight. The influence of NO_x on the climate change depends on the geographical location and the height where the flight process emits the NO_x. The major part of greenhouse gas emissions from aviation is emitted in altitudes of 8 – 12 km. This high, NO_x has a higher lifetime. Therefore, the impact on ozone formation is larger than the one from NO_x pollution on ground levels. The flown distance is decisive for the induced cloudiness. Moreover, there are warming effects that cause a positive change in the radiative forcing and there are cooling ones reducing the radiative forcing. Warming greenhouse gas emissions from aviation are CO_2 and NO_x due to the formation of ozone and black carbon aerosols by forming contrails and cloudiness. In contrast, the reduction of CH_4 due to and the reflecting solar radiation through SO_x particles lead to a negative impact on radiative forcing.

Fuglestvedt et al. (2010) created a "cause and effect chain" that describe the impacts of greenhouse gas emissions from aviation on the climate system. The chain contains six parameters in a linear chain where the previous parameter is the cause for the next, and the subsequent one is the effect from the previous. It starts with the greenhouse gas emissions from aviation that have an impact on the atmospheric concentration of the pollutants. The alteration in atmospheric concentration leads to a change of the radiative forcing of the greenhouse gas, which in return induces climate change. Climate change has impacts on different areas concerning society. They vary from effects on agriculture and forestry to social impacts and ultimately cause damages. The further down we go in the chain the higher gets the uncertainty of the respective parameter.

Greenhouse Gas Emissions during LTO Phase and CCD Phase:

Depending on the institution that calculates the emission factors, they assess different phases in the flight in a different way.

ICAO (2011) divides the flight stages into the landing and take-off cycle (LTO) and the climb, cruise and descent cycle (CCD). According to its definition, the LTO cycle includes four stages of the flight operation. It contains the approach, the taxi, the take-off and the climb phases "up to 915 m (3,000 ft.) above ground level".

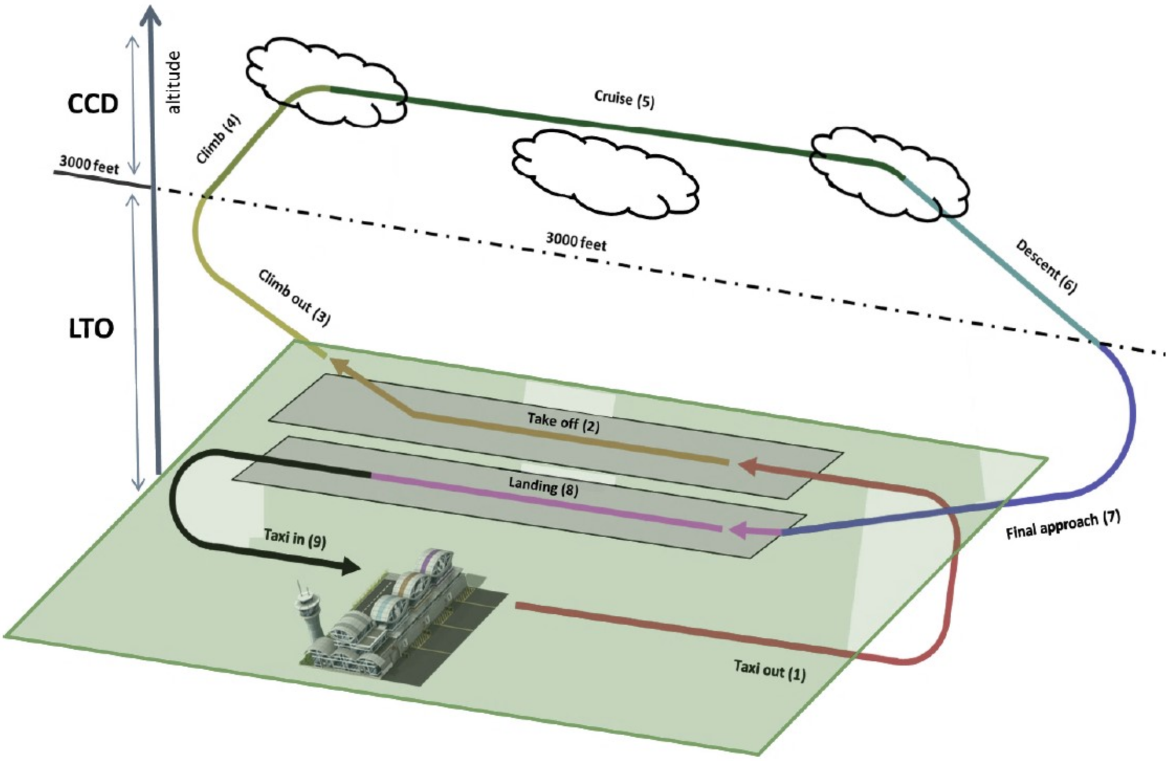

Figure 8: Representation of Flight Stages: LTO up to 3,000 ft., CCD beginning with 3,000 ft.; Source: Eurocontrol (2016), page 15 therein.

Figure 8 (adapted from Eurocontrol, 2016) shows the different stages during a flight operation. Eurocontrol (2016) defines the different stages as follows. The LTO phase includes all processes below an altitude of 3,000 ft. (915 m). This contains the "taxi out", which covers the way from the parking space to the start of the runway, and accordingly the "taxi in". Additionally, it includes the take-off and landing phase. Take-off describes the movement from the starting point of the runway to the moment the aircraft flies, while landing refers to the movements when the aircraft is again on the ground up to the moment where "taxi in" begins. LTO includes also the "climb out" following the take-off up to 3,000 ft. and the "final approach" from 3,000 ft. to the landing. All operations occurring above the altitude of 3,000 ft. are part of the climb, cruise and descent (CCD) phase. The "climb" is the movement of increasing altitude beginning at 3,000 ft. until the aircraft reached its optimum flight level. "Cruise" refers to the operation at the optimum flight level. During the "descent" phase the altitude of the aircraft decreases again from its optimum flight level to 3,000 ft. These three are the CCD phase, or in the interest of simplification "cruise phase".

According to the European Energy Agency (EEA, 2016), the optimum flight level depends on different aspects. The type of the aircraft is crucial. In addition, the operating weight is central. Therefore, the optimum flight level may vary during a long flight, as the weight decreases due to the loss of the weight of the consumed fuel. Hence, the length of the flight is influencing the optimum flight level, too.

According to Frischknecht et al. (2016), Mobitool (2017) assumes that the landing and take-off phase of a flight operation consumes more fuel than the cruise phase. This is due to the higher energy demand that the thrust requires to lift the aircraft. The energy demand is smaller, once the aircraft reached its optimum flight level and the cruise phase began. This is comparable to the acceleration and braking phases of rail or car traffic. These stages are more energy intensive than the cruise phase, therefore consume more fuel and, consequently, lead to a higher amount of greenhouse gas emissions. Mobitool (2017) considers this aspect, which we can see in the difference between short haul and long haul flights. The share of the LTO phase of the total flight operation is higher, the shorter the total flight distance is. This leads to the consequence that the LTO phase has a higher impact on regional, short or medium haul flights than it has on international or long haul flights. Therefore, the greenhouse gas emissions per passenger kilometer are higher for short haul flights.

Other institutions, such as the Environmental Protection Agency (EPA, 2018) and the UK government (UK Government, 2018), treat the influence of the LTO cycle differently. The different treatment of its impact is not obvious in the difference between short haul flights (distance shorter than 483 km) and medium haul flights (distance between 483 and 3,700 km). From short to medium haul flights the greenhouse gas emissions per passenger kilometer decrease. With the larger distance, the percentage of the energy intensive LTO phase decreases. Hence, the emission factor per passenger kilometer decreases, too. This is similar to the development of the emission factors from Mobitool (2017) that decrease from European (further named medium haul) to intercontinental (further named long haul) flights. This is not the case for the difference from medium to long haul flights (distance longer than 3,700 km) in EPA (2018) and UK Government (2018) emission factors. For long haul flights, the distance is crucial. The total fuel consumption due to the long distance is responsible for an increase of the amount of greenhouse gas emissions per passenger kilometer. The impact of the long distance is more relevant than its smaller percentage of the LTO phase compared to the whole distance. Therefore, the emission factor increases from medium to long haul flights (EPA, 2018; UK Government, 2018).

Accounting for Additional Radiative Forcing:

According to Bonizafi et al. (2018), besides CO_2eq, represented by CO_2, CH_4 and N_2O, there exist other types of aviation emissions that contribute to global warming. Water vapour, NO_x

or the formation of contrails are examples for such further aspects. In addition, greenhouse gases emitted directly into the upper troposphere and lower stratosphere act differently than on ground level. A possibility to take non-CO_2eq emissions and the height into account is to use a multiplier. The multiplier is applied to the direct CO_2 emissions, i.e. to the exhaust gas emissions. This indicates that the non-CO_2 emissions are directly connected to the produced CO_2, which is not necessarily the case.

As there does not exist a more appropriate climate metric for greenhouse gas emissions from aviation, the multiplier is an acceptable approach. Defra (UK Government, 2018) uses a multiplier of 1.9. The TRADEOFF project (2000) developed the value. It is the ratio of the total estimated radiative forcing without the one from cirrus coming from aviation (47.8 mW/m^2) to the radiative forcing from its CO_2 emissions alone (25.3 mW/m^2). Therefore, the multiplier is applied only to the direct CO_2 emissions, not the CH_4 and N_2O emissions. The multiplier includes impacts of ozone, methane, water vapour, contrails, direct sulphate and soot (Bonifazi et al., 2018).

The Federal Environmental Agency Germany "Umweltbundesamt" (2012) defines the radiative forcing index (RFI) as the factor that gives the relation between the radiative forcing of the overall flight emissions to the radiative forcing of the CO_2 emissions alone. Overall emissions cover CO_2 emissions as well as non-CO_2 emissions. Non-CO_2 emissions include the effects of the greenhouse gases described above: NO_x emissions, water vapour, sulphate aerosols, soot, and contrails. Induced cirrus clouds are afflicted with a high uncertainty and are therefore not included in non-CO_2 emissions.

The impact of greenhouse gas emissions other than CO_2 is not easy to assess, especially for short-lived species (Fuglestvedt et al., 2010). Therefore, the multiplier entails a certain amount of uncertainty. IPCC (1999) provides an uplift factor for the additional radiative forcing that is much higher than the one derived from TRADEOFF (2000). IPCC (1999) derives the multiplier in the same way as TRADEOFF (2000), dividing the total radiative forcing by the radiative forcing from CO_2 alone. The difference is that the radiative forcing of CO_2 emissions from IPCC (1999) is lower (18 mW/m^2) than in TRADEOFF (2000) (25.3 mW/m^2), while the total radiative forcing is very similar: 48.5 mW/m^2 in IPCC (1999) and 47.8 mW/m^2 in TRADEOFF (2000) (Sausen et al., 2005). Dividing the total radiative forcing by the one from CO_2-alone emissions, IPCC (1999) gets a higher ratio (Bonifazi et al., 2018).

The radiative forcing index from the IPCC (1999) is therefore 2.7. IPCC (1999) gives an uncertainty of ± 1.5, which leads to a range between 1.2 and 4.2. The TRADEOFF (2000) radiative forcing index lies in the lower third of this range. Sausen et al. (2005) as well as Lee et al. (2009) estimate a value of 3 to 5. Mobitool (2017) uses an average RFI for aviation of 1.35 (Frischknecht et al., 2016). This is relatively low compared to Sausen et al. (2005) or Lee at al. (2009b) but lies in the range of uncertainty given by IPCC (1999).

To emphasise the significance of the effect of greenhouse gas emissions emitted from aviation, we want to derive a value that gives the additional radiative forcing from flights as amount of CO_2 equivalents. We are able to add this value to the greenhouse gas emissions given by the emission factor. In this way, we estimate the total impact of a flight trip. To calculate the value we use the data and information from the UK Government (2018) and their methodology papers (Bramwell, Harris and Hill, 2017; Bonifazi et al., 2018) and Mobitool (2017) described by Frischknecht et al. (2016). We want to calculate CO_2eq values for short haul, medium haul and long haul flights that account for the radiative forcing at flights heights. This way, we are able to add the value to the respective emission from a specific seat class and distance category to receive the total amount of greenhouse gas emissions from air traffic per passenger kilometer.

In the "UK Government GHG Conversion Factors for Company Reporting, version 1.01" (UK Government, 2018), Defra provides the direct emissions from air traffic in form of an excel sheet. Direct emissions arise during the flight operation. They include an uplift factor (UF) of 8 % that takes into account all additional flight ways as circling and delays (UK Government, 2018).

The real distance of a flight is longer than the great circle distance (GDC) because in addition to the GDC, the airplane covers the distance from ground level to its flight height in a certain angle. As greenhouse gas emissions act differently in flight heights than on ground level, the additional radiative forcing has to be considered only at flight height, not on ground level. Therefore, we exclude the 8 % uplift factor in a first step, as they do not represent emissions in the direct cruise phase but we consider them to represent the covered distance in the LTO phase. They are additional to the emissions associated with the great circle distance. To exclude the uplift factor, we multiply direct CO_2 emissions with 0.92 (see Equation 1; excluding the uplift factor of 8 %).

$$\mathrm{CO}_{2,\mathrm{without\ UF}} = \mathrm{CO}_{2,\mathrm{with\ UF}} * 0.92 \tag{1}$$

In the next calculation step, we multiply the CO_2 emissions emitted directly in the GCD ($CO_{2,\ \mathrm{without\ UF}}$) with 0.9. This value derives from the "1.9" radiative forcing uplift factor. As 1.9 is the RFI that the UK Government (2018) uses, it means that the CO_2 emissions, representing 100 %, lead to an additional amount of 90 % greenhouse gas emissions referring to the CO_2 alone value ($CO_{2,\text{ without UF}}$). We only want to have the amount of additional greenhouse gas emissions accounting for radiative forcing, not the total ones.

The original direct CO_2 emissions represent the factor “1”. To provide 190 %, 90 % of them are added additionally. 190 % of the CO_2 emissions correspond to the multiplier of 1.9. As Defra applies the multiplier only to CO_2 emissions, we also multiply the factor to provide the additional impact on radiative forcing (0.9) only to CO_2 emissions. It accounts then for the absolute amount of additional non-CO_2 emissions (in g CO_2eq/pkm) and their radiative forcing (see Equation 2; calculation of g CO_2eq/pkm accounting for the additional radiative forcing in flight height).

$$\mathrm{CO}_{2,\text{with RF}} = \mathrm{CO}_{2,\text{without UF}} * 0.9 \tag{2}$$

Equation 2 gives the additional amount of greenhouse gas emissions, which we can add as the radiative forcing for flights. With the given data, we receive an emission value per passenger kilometer for short haul, medium haul and long haul air travel and for every seat class considered. We can add the value to the provided emission factors from the UK government (2018) and Mobitool (2017), to get not only the amount of CO_2 emissions emitted in the flight, but also the additional effects of other greenhouse gas emissions and their radiative forcing. The obtained value corresponds to the additional effects in the cruise phase.

The UK government (2018) provides two tables of emission factors. One table represents the emission factors without additional radiative forcing. The other table includes additional radiative forcing. The UK government (2018) does not exclude the 8 % uplift factor for the additional radiative forcing, but applies it to the 108 % CO_2 emissions. This means, that the additional radiative forcing is calculated as taking place over the whole flight phases.

As the effect that includes additional radiative forcing (multiplier of 1.9) is almost doubled comparing to the amount of emissions ignoring it, it is crucial to show also the large impact of non-CO_2 emissions and exhaust gases that are emitted directly at high altitudes.

As the factor 1.9 is still low compared to the area 3 - 5 that Lee et al. (2009) and Sausen et al. (2005) suggest, we decide to include Mobitool’s (2017) radiative forcing index, too. Mobitool (2017) includes an average radiative forcing index of 1.35 (Frischknecht et al., 2016). In the table representing all emission factors from the different organisations, we show the base value representing a factor of 1.00. Therefore, we divide Mobitool’s (2017) aviation emission factors by 1.35. In a next step, we calculate the 35 % as an absolute value in g CO_2eq/pkm. We sum up the 35 % referred to Mobitool's base value and the (little less than) 90 % referring to UK Government's (2018) base value and receive our additional greenhouse gas emissions in g CO_2eq/pkm for aviation.

Different Institutions Providing Emission Factors:

Mobitool Platform

One possible tool providing emission factors is the Swiss Mobitool (2017), collectively developed with the support of five institutions. The following description of the Mobitool (2017) emission factors follows the background report from Frischknecht et al. (2016). Mobitool (2017) offers emission factors for 150 different modes of transport. For our study, emission factors for rail, bus and aviation are important. Mobitool (2017) concentrates on Switzerland but provides also emission factors for neighbour countries (France, Italy, Germany and Austria) for rail traffic. The aviation sector includes emission factors for European and intercontinental flights. Mobitool's (2017) eco-balance contains different transport phases in all their life stages. This means that it does not only assess greenhouse gas emissions that come from the direct use of the transport mode. In addition, Mobitool (2017) analyses and calculates greenhouse gas emissions from energy provision, production, maintenance and removal of the vehicle. Another step producing greenhouse gas emissions and included in the emission factors from Mobitool (2017) is the construction of infrastructure (e.g. rails and roads) itself (Frischknecht et al., 2016).

Mobitool (2017) includes all these stages in the attributional life cycle assessment (LCA). The attributional LCA involves steps from the beginning to the end of the process (Frischknecht et al., 2016).

The Mobitool (2017) uses a reference value, which is the environmental impact, produced by a certain distance the vehicle drives and by one passenger, which results in emitted grams of greenhouse gases per passenger kilometer (g CO_2eq/pkm). The emission factor expresses how many emissions correspond to a passenger that the vehicle transports over the distance of one kilometer. Hence, the more passengers use one vehicle, the less emissions are counted per person, as the whole impact of the vehicle is divided to more people. To get this reference value, Mobitool (2017) uses typical passenger loading factors (Frischknecht et al., 2016).

Concerning rail travel, Mobitool (2017) distinguishes between national (5-200 km) and international (> 200 km) travel. International train travel considers trains in Switzerland, Germany, France, Italy and Austria. For each country, Mobitool (2017) divides the specific haul capacity (passenger kilometer) by the overall train-kilometers of the country to get the typical passenger load (Frischknecht et al., 2016).

For the emission factors of passenger transport via airplane, Mobitool (2017) distinguishes different travel distances and travel classes. It differentiates between intercontinental flights and flights within Europe. In addition, there are the classifications economy class, business class and, for intercontinental flights, first class. As classes that are more comfortable provide more space for the passenger, the emissions per capita are higher in business (and first class) than the ones for passengers in economy class (Frischknecht et al., 2016).

For Mobitool's (2017) calculation of the emissions originating in the construction process, two different types of airplanes represent aircrafts for intercontinental travels and travels taking place within Europe. For intercontinental flights, "Airbus A3400-600" is used. It offers 380 seats. The empty weight is 178 tonnes. "Airbus A320" represents the European flights with 150 seats and an empty weight of 61 tonnes. As every passenger has also luggage, Mobitool (2017) splits the emissions per kilometer between the weight of the passengers, their luggage and the infrastructure, resulting to 160 kg per passenger for intercontinental and 166 kg per passenger for European, flights (Frischknecht et al., 2016).

As Mobitool (2017) established their emission factors on a basis of an attributional lifecycle assessment, not only airplane construction but also its maintenance is included in the resulting greenhouse gas emissions. Maintenance is calculated as 5 % of the effort of the construction (Frischknecht et al., 2016).

Comparing the two differentiations of distances, European flights have a higher fuel consumption per passenger kilometer, because the share of the take-off and landing phases (LTO) to the overall flight distance is higher than in intercontinental flights. The LTO phase needs more kerosene than the cruise phase, which is a similar characteristic as for automobiles or rail traffic. The difference in the emission factors reflect this consideration (Frischknecht et al., 2016).

Hence, kerosene consumption per passenger kilometer varies between 46 g and 72 g for national flights and between 25 g and 81 g for intercontinental ones, depending on the chosen class (Frischknecht et al., 2016).

Mobitool (2017) considers the additional effect of greenhouse gas emissions that are emitted directly in flight height. According to Frischknecht et al. (2016), Mobitool (2017) uses an average radiative forcing index of 1.35 kg CO_2eq/kg. It divides the fuel consumption and the resulting emissions into LTO and cruise phase according to the moment when the fuel is burnt. For short haul flights, the cruise phase is responsible for 86 % of the total greenhouse gas emissions, while for long haul flights it is 96 %. In addition, Mobitool (2017) divides the cruise phase emissions into emissions arising in the troposphere and emissions occurring in the stratosphere. Short haul flights emit 43 % of their total emissions in the stratosphere, long haul flights even 75 %. The part in the stratosphere is responsible for the additional greenhouse effect of greenhouse gas emissions of aviation. Therefore, Mobitool (2017) uses a factor of 1.50 kg CO_2eq/kg for the CO_2 emitted in the stratosphere. As an average over the whole flight, Mobitool (2017) uses the value of 1.35 kg CO_2eq/kg (Frischknecht et al, 2016).

European Environment Agency EEA

Also the European Environment Agency (EEA, 2016) provides pollutant amounts for five sources of greenhouse gas emissions: energy, industrial processes and product use, agriculture, waste, and other. Each sector offers categories and subsectors. Emission factors for the transport sector are found in the section “energy” (EEA, 2016).

Concerning aviation, Winther and Rypdal (2017) describe that EEA (2016) takes two classifications. On the one hand, it distinguishes between landing and take-off cycles (LTO) and the cruise phase. On the other hand, EEA (2016) differentiates between domestic and international traffic, which concerns the country of the take-off and landing airports. If departure and arrival take place in the same country, it is a domestic flight. Otherwise, it refers to international flight traffic. Furthermore, military aviation is another category. EEA (2016) does not include fuel that is used for transportation on the ground, this part is calculated separately (Winther & Rypdal, 2017).

EEA (2016) provides emission data for different emission species produced in the combustion process of the aviation fuel: carbon dioxide CO_2, carbon monoxide CO, water vapour H_2O, hydrocarbons HC, nitrous oxides NO_x, sulphur oxides SO_x, the fuel consumption itself and total suspended particulates TSP. The data concerning these emission types are calculated and offered for 29 aircraft types for international LTO-cycles and for 29 aircraft types for civil aviation or domestic LTO. This method describes the “Tier 2 methodology” that bases its calculation of emissions on the fuel consumption of LTOs and the aircraft type. Altogether, there a three Tier approaches possible. According to EEA (2016), the fuel consumption is enough data to calculate CO_2, SO_2 and heavy metals, as these emissions are not reliant on the technology but are dependent on the fuel.

Therefore, EEA (2016) calculates the amount of pollutants per LTO cycle by multiplying the fuel consumption with an emission factor. The emission factor that EEA (2016) uses for carbon dioxide is 3.15 kg CO_2 per kg burnt fuel, which arises from the chemical equation for the fuel combustion (EEA, 2016).

As EEA (2016) uses the value of 3.15 kg CO_2 per kg fuel, the fuel consumption of a specific engine or aircraft type determines the amount of pollutants. The aircraft type indirectly includes other factors, such as its weight and aerodynamics, which have an influence on the fuel consumption and subsequently the emissions. In this case, different aspects are not included in the emission factor but are calculated concerning the aircraft type. The difference of the aircraft type results in different amounts of fuel burnt in the LTO phase. This in turn changes the CO_2 emissions, as they are directly connected to the combustion fuel.

The chapter “1.A.3.c Railways” in EEA’s (2016) air pollutant emission inventory guidebook from Norris and Ntziachristos (2018) only consider rails operating with diesel. In this category, there are three types of locomotives: shunting locomotives, rail-cars and line-haul locomotives.

As we do not need emission factors for specific types of airplanes or rails, we use data given by the TERM 2014 report to compare them with the emission factors from other institutions. In the TERM 2014 report, EEA (2014) provides emission factors for freight and passenger transport as gram pollutants per passenger kilometer. The passenger transport section lists ten transport modes. The table shows nine different pollution species and gives the most climate relevant greenhouse gases. They are CO_2, CH_4 and N_2O due to their amount and long residence time in the atmosphere. The other listed pollutants are carbon monoxide CO, non-methane volatile organic compounds NMVOC, nitrous oxides NO_x, particulate matter with an average diameter under 10 microns PM_{10}, sulphur dioxide SO_2 and volatile organic compounds VOC. To derive values for CO_2eq, we use Formula 4. EEA (2014) gets the values from the TRACCS database 2013 (EEA, 2014).

Environmental Protection Agency EPA

The US Environmental Protection Agency (EPA, 2018) provides emission factors for transport modes in the United States. They list the values in the “Emission Factors for Greenhouse Gas Inventories” from 2018 (EPA, 2018, p. 4). There is a separate table offering emission factors for business travel (EPA, 2018).

In rail traffic, EPA (2018) distinguishes between intercity rail, commuter rail and transit rail. We do not considered transit rail in this work, as it represents rails within urban centres and are not relevant for international scientific travel. An intercity rail – similar to the ones in Europe – connects long distances between large cities. According to EPA (2018), the commuter rail operates between a city and its surrounding area. To get the emission factors for rail traffic, EPA (2018) uses fuel consumption data and passenger-miles data, which are provided in the "Transportation Energy Data Book: Edition 35" from Boundy et al. (2016) (Table 2.12, page 69, 2-19). Together with electricity emission factors from EPA eGRID 2016, EPA (2018) provides then kg CO_2 per passenger-mile, g CH_4 per passenger-mile and g N_2O per passenger-mile (EPA, 2018).

Also EPA (2018) distinguishes between three different flight distances in aviation. There are short haul, medium haul and long haul flights. The limitation between short and medium haul is set at 483 km. Is the flight distance beyond 3,700 km, it is a long haul flight (EPA, 2018).

Bramwell et al. (2017) state that EPA (2018) uses data from Defra, but does not state how it converted the data to their own use, as there are some differences. Defra uses average load factors and a variety of representative aircrafts to calculate emission factors. Furthermore, it uses "domestic flights", additionally to short haul, long haul and international flights. Defra considers seating classes in these air passenger modes, as they influence the greenhouse gas emissions per passenger kilometer. EPA (2018) does not include seating classes in the table, where the emission factors are listed. As the United States do not usually use the metric system, the reference unit for the emission factors is "passenger-mile". EPA (2018) provides emission factors separately for CO_2, CH_4 and N_2O emissions. To compare these emission factors with the others, we convert them into CO_2eq per passenger kilometer.

UK Government

The UK "Department for Business, Energy & Industrial Strategy" provides emission factors for eight different sectors divided again into subsectors. It assesses direct emissions as well as indirect or "wheel-to-tank" (WTT) emissions (Bonifazi et al., 2018).

The subsequent description of the emission factors from the UK government (2018) follows the background report from Bonifazi et al. (2018). The direct greenhouse gas emissions for passenger rail include international rail (Eurostar), national rail, light rail and London Underground. We do not consider the last two for our purpose. The emission factor for international rails is based on five routes with the start point in the UK, the end point in France or in Belgium. Eurostar offers the emission factor. It uses three main factors for their calculation: the electricity consumption for the trains, the passenger numbers and consequently passenger kilometer data and CO_2 emission factors for the used electricity. It estimates CH_4 and

N_2O emissions in relation to the CO_2 emission factor. National rail on the contrary does not only use electricity for the energy demand of trains, but also diesel fuel. The emission factor consists of the emission factors for the consumed electricity and diesel and data about the passenger kilometers. Again, Defra estimates CH_4 and N_2O proportional to the CO_2 emission factors (Bonifazi et al., 2018).

Indirect or wheel-to-tank (WTT) emissions for international rail traffic come from the electricity, while for national rail they are based on the mixture of emissions from electricity and diesel. They include estimations on relative passenger kilometer shares for diesel and electricity rails. The UK Government (2018) calculates the CO_2eq together with the global warming potentials (GWPs) from the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (Bonifazi et al., 2018).

We sum up the direct and indirect emission factors to compare them with the ones from EPA (2018), Mobitool (2017) and UBA (2018).

Also for air travel, the UK Government (2018) provides the emission factors for direct and indirect processes. First, the UK Government (2018) calculates direct CO_2 emission factors. According to Bonizafi et al. (2018), they include different types of airplanes used in certain regions as well as loading factors, derived from Department for Transport data, “EUROCONTROL small emitters tool” and IATA data. With the “EUROCONTROL small emitters tool”, the UK Government (2018) calculates the direct CO_2 emissions for an aircraft type based on the specific fuel consumption. Then, it includes further data: the seating capacities, load factors and the share of passenger kilometers by the aircraft types. These data come from the UK Civil Aviation. Due to the information on aircraft type used in specific regions, they group air transport into domestic flights, short haul flights and long haul flights.

Bonifazi et al. (2018) describe the differences of domestic, short haul and long haul flights. For domestic flights, the UK Government (2018) uses 14 aircraft types for the calculation of emission factors. Domestic flights have an average of 361 km flight distance and an average seat capacity of 136. The average load factor is 74 %. A domestic flight emits 11.2 kg CO_2 per vehicle kilometer (vkm). Start and end point of domestic flights are in the United Kingdom. Short haul flights (average over 18 aircraft types) show the same emission factor (11.2 kg CO_2/vkm), although seat capacity (180 seats), load factor (80 %) and average flight length (1,677 km) are higher. Short haul flights correspond to European flights with a maximum flight distance of 3,700 km. Long haul flights have the longest average flight distance with 6,523 km. Therefore, the 19 aircraft types are flying to non-European or intercontinental destinations with a distance longer than 3,700 km. The average load factor is 74 % with 324 seats. The emission factor per vehicle kilometer is the highest for long haul flights (27.2 kg CO_2/vkm), as it is based on the fuel consumption.

To refer the emission factors on passenger kilometer, the passengers and their luggage are included. Furthermore, there are three allocation methods to take into account passengers and freight. The UK Government (2018) uses the most comprehensive one, “Freight Weighing Option 2”, which includes passengers, luggage and the equipment such as seats and galleys. The UK Government (2018) uses 100 kg for the weight of a passenger and its luggage and adds then the weight for passenger services to this value (Bonifazi et al., 2018).

The UK Government (2018) distinguishes between economy and first/business class for short haul flights. For long haul flights, it differentiates between economy, economy+, business and first class (Bonifazi et al., 2018). For reasons of comparison with other emission factors, we do not consider the economy+ class in this work. The more comfortable the seat class is the less number of seats are available in this class, and the emission factor per passenger kilometer increases.

Using information on direct CH_4 and N_2O emissions for domestic and international aviation, the UK Government (2018) calculates the CH_4 and N_2O emissions per passenger kilometer in reference to the consistent CO_2 emission factor (Bonifazi et al., 2018).

Concerning indirect or WTT emissions, the emission factors include the production and distribution from the fuel, resulting directly from the fuel lifecycle. To derive the final emission factor, the UK Government (2018) includes an uplift factor of 8 % to the great circle distance accounting for the real flight distance, i.e. it considers delays and circling (Bonifazi et al., 2018).

As already mentioned, the UK Government (2018) provides their emission factors for flights in two ways: one table gives them without the additional radiative forcing, another table includes the additional radiative forcing with the help of a multiplier of 1.9.

Umweltbundesamt UBA

The Austrian Federal Environment Office „Umweltbundesamt“ (UBA, 2018a) provides emission factors for tree passenger transport categories: street, rail and flight traffic. UBA (2018a) includes 18 traffic modes in total and gives the emission factor in two different ways: as amount of greenhouse gas emissions per vehicle and as amount of greenhouse gas emissions per passenger-kilometer or tonne-kilometer.

UBA (2018a) accounts for direct as well as indirect emissions and provides the total greenhouse gas emissions. Direct greenhouse gas emissions come from the fuel combustion. UBA (2018a) uses information on direct greenhouse gas emissions from the Austrian air pollution inventory 2017 (original: "Österreichische Luftschadstoffinventur 2017"). Data concerning indirect greenhouse gas emissions come from the Austrian database "GEMIS Österreich 4.94" (UBA, 2018a). The indirect emissions include greenhouse gas emissions from the vehicle production and the energy provision (UBA, 2018b). The table containing the emission factors offers CO_2 emissions, NO_x emissions, particulate matter PM_{10} and CO_2 equivalents.

For the emissions from a coach, UBA (2018b) makes different assumptions. It calculates the emission factor using an average traffic situation derived from rides on highways, in towns, out of towns, etc. The data are based on the year 2016. The fuel consumption of a coach is 33.6 litres for 100 kilometers and during its lifetime of 15 years, it drives 58,900 km (UBA, 2018b). The occupancy rate of a coach is 18.8 passengers (UBA, 2018a).

For passenger traffic via rail, UBA (2018a) uses a fuel mix of 14.2 % diesel and 85.8 % electricity, whereby the traction current is a specific electricity mix. The federal railway "Österreichische Bundesbahnen" (ÖBB) provides data for the year 2016. The load factor for rails in Austria in 2016 is 110 passengers (UBA, 2018a; UBA, 2018b).

Flight traffic distinguishes between national and international flights and gives the average. UBA (2018a) uses two types of aircrafts. With 30 years, the average lifetime is the same for both types. The aircraft weight on the other hand is different. An aircraft for short haul flights is considered to weigh 18 tonnes, one for long haul flights 40 tonnes (UBA, 2018b). Furthermore, the load factor differs: national flights transport an average of 33.10 passengers, while international flights carry 87.87 passengers, while the average between national and international flights is 86.64 passengers (UBA, 2018a). This average load factor is very similar to the one from international flights, which is an indicator that international flights represent the majority of Austrians flight activities. The fuel for both national and international flights is kerosene (UBA, 2018b).

A significant characteristic of the UBA (2018a) emission factors from aviation is that they use a radiative forcing index (RFI) of 2.7 (UBA, 2018a). The RFI contributes to other greenhouse gas emissions than CO_2 emitted in high altitudes and is the "ratio of total radiative forcing to that from CO_2 emissions alone" (IPCC, 1999b, page 419). According to IPCC (1999b), the value refers to the year 1992 and has an uncertainty of ±1.5. The RFI represents how much higher the effects on the climate are in comparison to CO_2 emissions alone. In Table 2, we divide the emission factors from aviation by the factor 2.7 to receive CO_2 emissions in order to compare them with values from Mobitool (2017), UK Government (2018), EPA (2018) and EEA (2014).

The original emission factor for national aviation (including RFI of 2.7) is nearly twice as high as the one for international flights. This indicates that UBA (2018a) evaluates the landing and take-off phase to have a large impact on the resulting greenhouse gas emissions. The LTO phase in national flights clearly constitutes a higher part concerning the total flight than it has in international flights. Due to the higher energy requirement in the LTO phase, it burns more fuel. Consequently, the LTO phase produces more greenhouse gas emissions. On a flight with short distance, the greenhouse gas emissions from the LTO phase contribute more to the total greenhouse gas emissions, which leads to a higher amount per passenger kilometer.

Comparison of Emission Factors:

Due to the above analysis on how emission factors are developed, we are able to compare the emission factors of different travel modes within one study.

According to the International Energy Agency (2017), in Europe, electricity provides the bulk energy for train service (67.6 % in 2015). Oil and coal products contribute to 32 %. The remaining part comes from biomass (IEA - UIC, 2017). Mobitool (2017) uses for their calculations the traction power of the country’s railway service – if available – otherwise it uses the typical electricity mix of the respective country (Frischknecht et al., 2016).

According to Frischknecht et al. (2016), rail transport in Switzerland uses mainly (96 %) renewable electricity from hydropower plants. Considering only the operation mode, hydropower plants are CO_2-neutral. The residual electricity originates from nuclear power plants. The traction power of Austria is similar, with 89 % electricity from hydropower plants. Wind and solar power plants, biomass and petroleum gas (7.5 %) generate the remaining part. German rail transport uses more fossil fuels: 43 % of the traction power is coming from coal and gas. 16 % come from nuclear power, the rest is electricity coming from renewable sources (wind energy, hydropower, solar power and biomass). Mobitool (2017) assumes the traction power in France and Italy to coincide with the national electricity mix. Within rail travel, high-speed trains have higher loads than regional traffic. Hence, “Intercity Express” (ICE) in Germany, “train à grand vitesse” (TGV) in France and “Frecciarossa” in Italy have all a passenger load of 55 %, whereas the national rail service in Switzerland has loading factors between 23 and 30 %. As Mobitool (2017) provides the data in an interactive excel sheet, the loading factor can be adopted individually by adjusting the capacity (potential number of passengers or tonnes for freight transport) and the load (actual number of passengers or tons). In addition, long distance rails drive with high velocity. Therefore, the air resistance is higher and the train needs more fuel. This increases the emission factors. However, due to longer distances, there are fewer brake and acceleration phases. The reduction of braking and acceleration processes causes a decrease of fuel consumption compared to traffic with shorter distances.

The differences in the emission factors for train travel in different countries arise mainly from the respective type of energy provision and differences in their passenger load. Therefore, due to a relatively high amount of used fossil fuels, German trains have comparably high emission factors. Higher emission factors result only for Italy, because more than half of Italy's produced electricity originates from non-renewable sources (Frischknecht et al., 2016; elettricità future, 2019). Owing to a large percentage of hydropower, Switzerland shows the lowest emission factors. Also the emission factors of France are relatively low, which is due to the electricity generated by nuclear power plants (Frischknecht et al., 2016). According to RTE (2015) These represent a share of 77 % of France's electricity. Additionally, almost 18 % are coming from other renewable sources (hydropower, wind power, photovoltaic). Consequently, fossil fuels generates only 5 % (RTE, 2015).

A comparison between Mobitool (2017) for the aviation sector shows that the emission factor for the economy class in flights within Europe (163.3 g CO_2/pkm) is significantly higher than the emission factor for intercontinental flights in the same class (94.4 g CO_2/pkm). Here, the high ratio from LTO phase to cruise phase contributes to a large difference in emission factors. Concerning the business class, the difference is not that high. However, flights within Europe still have a higher emission factor than intercontinental flights. Substitute intercontinental flights by train travel is not possible for scientific travels, whereas for flights with a distance shorter than 1,000 km it is possible.

Without the additional amount of greenhouse gas emissions for aviation, which the grey areas in Figure 9 represent, the travel emissions for a European flight travel per person are about five times the emissions per person from the same travel by an average intercity rail. Considering the additional greenhouse gas emissions due to their relevance in the upper troposphere and lower stratosphere, the difference between flight and train travel emissions is even more significant.

We see that the use of rails saves high amounts of greenhouse gas emissions compared to a travel done by flights. The emission factor for commuter rails is valid for Switzerland. Due to the source of the traction current, the emission factors for commuter rails are considerably higher in other European countries. Nevertheless, a travel using intercity or commuter rails instead of aviation saves a substantial amount of greenhouse gas emissions (see Figure 9).

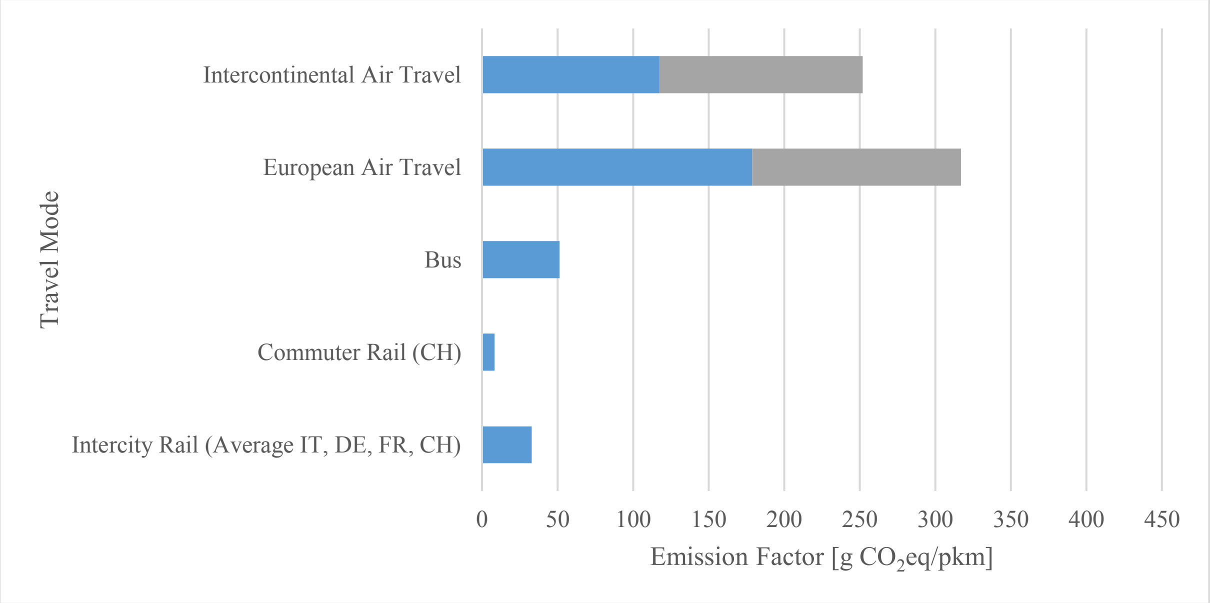

Figure 9: Comparing Mobitool's Emission Factors for Different Travel Modes. The blue bars represent the emission factors in g CO_2eq*/pkm for different modes of transport. In the case of air travel, they characterise the greenhouse gases without the additional amount coming from non-*CO_2 *emissions and their effects in flight heights. The grey parts in air travel emission factors represent the additional amount of greenhouse gas emissions for aviation. For intercontinental and European Air Travel we use the weighted average of economy and business class for the emission factors and the additional amount of greenhouse gas emissions for aviation;*
Data Source: Mobitool, 2017; UK Government, 2018; Graphic: Own Representation

The TERM Report (EEA, 2014) provides emission factors for three travel modes. The emission factor for intercity rails is the lowest, while aviation's emission factor is about 20 times higher. This means that travelling by train instead of flying saves a considerable amount of greenhouse gas emissions. Aviation is responsible for almost 20 times the greenhouse gas emissions of a rail travel for the same distance. A scientist could do 10 round trips using rails until he/she caused the same amount of greenhouse gas emissions a one-way trip with an aircraft would produce. In addition, considering the produced greenhouse gas emissions rail travel is the better option compared to a bus travel. Despite a relatively big difference between rail and bus emission factors, aviation still produces about four times the emissions of a bus travel (see Figure 10).

TERM (EEA, 2014) does not define "aviation" further. Therefore, we are not able to add the amount of additional greenhouse gas emissions in aviation, as they depend on the flight distance (see Figure 10).

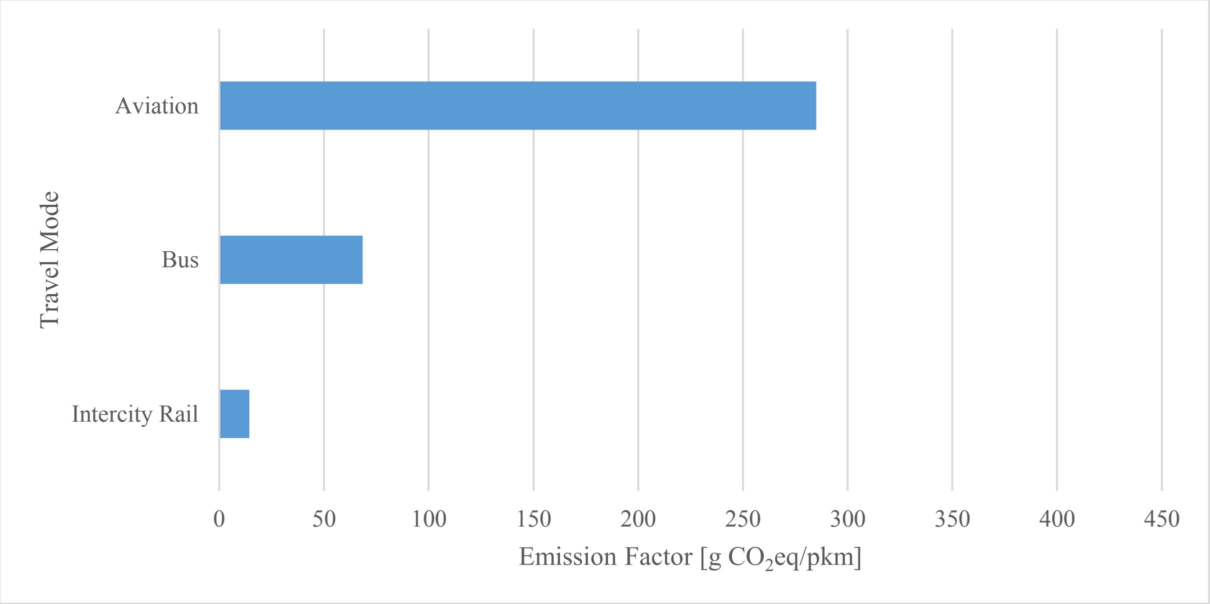

Figure 10: Comparing TERM's (EEA, 2014) Emission Factors for Different Travel Modes, The blue bars represent the emission factors in g CO_2eq/pkm for different modes of transport;
Data Source: EEA, 2014; EEA, 2019; Graphic: Own Representation

Concerning rail travel in EPA (2018), intercity-rails emit less CO_2eq per passenger kilometer than a commuter rail does. This is due to the higher energy intensity of the commuter rail. Intercity-rails need approximately the half amount of bitumen per vehicle-mile: 44,934 Btu per vehicle-mile, whereas commuter rails use 85,564 Btu per vehicle-mile (Boundy et al., 2016). Concerning Btu per passenger-mile, the values are not that far apart, though (2,816 for intercity, 2,708 for commuter rail), where the smaller difference comes from a higher amount of passenger-miles and higher load factor for commuter rail (Boundy et al., 2016).

According to EPA (2018) data, buses lead to the lowest amount of greenhouse gas emissions. Both intercity and commuter rails have higher emission factors than a bus. Without our additional amount of greenhouse gas emissions for aviation (grey part in Figure 11), the emission factors from intercity and commuter rails are even higher than the one for air travel with distances between 483 km and 3,700 km. This is because the US energy mix for railways consists to the major part of oil products (IEA - UIC, 2017). In 2015, 94 % of the energy mix was diesel (IEA - UIC, 2017). Adding the additional amount of greenhouse gas emissions for aviation, a flight between 483 and 3,700 km produces 2.5 times more greenhouse gas emissions than the same trip using an intercity rail.

Compared to medium haul flights (85.8 g CO_2eq/pkm), the emission factor for short haul flights (141.4 g CO_2eq/pkm) is high. This is due to the larger part of the LTO phase considering the whole flight. Considering medium haul flights, the cruise phase represents a higher percentage of the total flight, which leads to a lower emission factor per passenger kilometer. From medium to long haul flights, EPA (2018) increases the emission factor again. This shows that with higher distance, the aircraft may be larger. It leads to more weight concerning the airplane itself but also the passenger and luggage weight, as the bigger airplane transports more passengers.

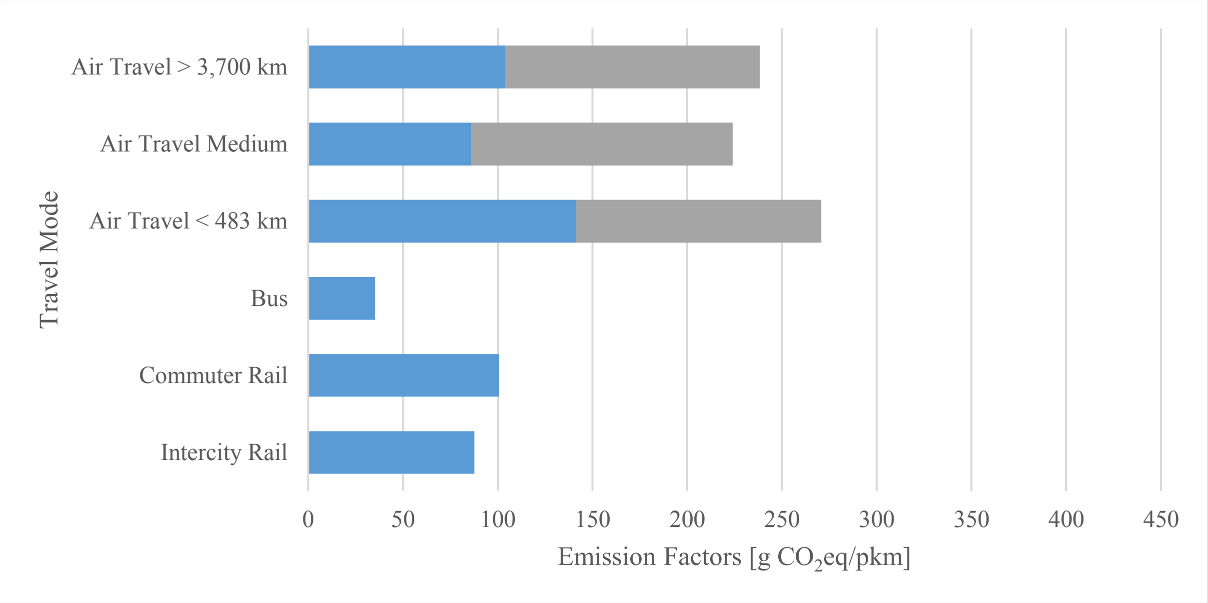

Figure 11: Comparing EPA's Emission Factors for Different Travel Modes. The blue bars represent the emission factors in g CO_2eq/pkm for different modes of transport. In the case of air travel, they characterise the greenhouse gases without the additional amount coming from non-CO_2 emissions and their effects in flight heights. The grey parts in air travel emission factors represent the additional amount of greenhouse gas emissions for aviation. As EPA does not distinguish seating classes, we add the average of business and economy class for the additional amount of greenhouse gas emissions for aviation;
Data Source: EPA, 2018; Mobitool, 2017; UK Government, 2018; Graphic: Own Representation

To compare UK Government's (2018) emission factors with the ones from the other institutions, we use the emission factors without radiative forcing but add our amount for additional greenhouse gas emissions for aviation. We sum up direct and indirect emission factors. In addition, we build the average over long haul (to/from UK) and international (to/from non-UK) flights and use them for "Long Haul > 3,700 km", as Defra states that both categories have average distances over 3,700 km.

Within the data from the UK Government (2018), domestic flights show a high emission factor. It decreases in short haul flights. In addition, the average long haul flight emission factor is lower, despite the fact that business and first class have higher values. The average passenger in international flights has also a lower emission factor than the one in domestic flights. However, there are big differences within the seating classes. The emission factor for the business class is almost three times higher than for the economy class, the one for the first class is four times higher.

Figure 12 illustrates the significant differences in greenhouse gas emissions that a chosen travel mode causes according to the UK Government (2018). We see that high-speed rails produce the smallest amount of greenhouse gas emissions. This is due to the high electrification rate and the renewable electricity generation of railways. Commuter rails on the other hand lead to a higher amount of greenhouse gas emissions. They represent national rails in Great Britain, which use a mix of electricity and diesel fuel for their traction power (Bonifazi et al., 2018).

A medium haul air travel (without the additional amount of greenhouse gas emissions for aviation) causes eight times the greenhouse gas emissions of a high-speed train for the same distance. Adding also the 138.1 g CO_2eq/pkm for the effect in the upper troposphere and lower stratosphere, the difference is even higher. Short distance flights (< 483 km) produce the highest amount of greenhouse gas emissions. Especially for this distance, it is possible to substitute flight travels by rail travels, which save a notable amount of greenhouse gas emissions. A striking example is the following fictional situation: instead of flying one round trip below 483 km, one could travel to the same destination and back home on every weekday (5 days a week) for one month by train until the trips caused the same amount of greenhouse gas emissions.

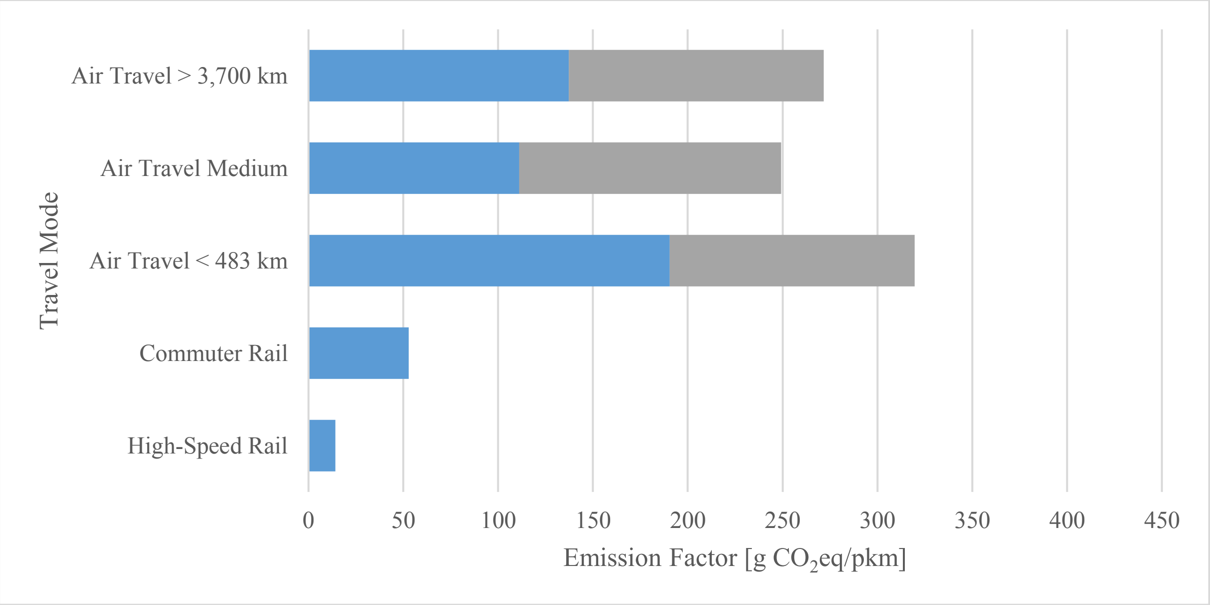

Figure 12: Comparing UK Government's (2018) Emission Factors for Different Travel Modes. The blue bars represent the emission factors in g CO_2eq/pkm for different modes of transport. In the case of air travel, they characterise the greenhouse gases without the additional amount coming from non-CO_2 emissions and their effects in flight heights. The grey parts in air travel emission factors represent the additional amount of greenhouse gas emissions for aviation. For medium haul and long haul flights we use the weighted average of economy and business class for the emission factors and the additional amount of greenhouse gas emissions for aviation;
Data Source: Mobitool, 2017; UK Government, 2018; Graphic: Own Representation

When comparing the UBA (2018a) emission factors from the three different transport modes train, bus and airplane it is obvious that the aviation sector produces by far the highest greenhouse gas emissions (see Figure 13). Due to our determination, the scientists can do all travels by train within Austria, as the distances in one direction do not exceed 1,000 km. If a researcher used Austrian national aircraft traffic, it would lead to 30 times higher greenhouse gas emissions than the same travel by train causes. This means that flying a national route one time causes the same amount of emissions as using 30 times the train for the same directions. As an example, we could take a look on a travel to Vienna. A researcher could use the train from Graz to Vienna and back every day for a whole month and would produce the same amount of greenhouse gas emissions that another scientist would cause using national aviation for the same round trip one time.

Also international aviation produces a significantly higher amount of greenhouse gas emissions than train travels. The train emissions are very low. This is due to the electricity mix that Austria's railways use. According to ÖBB (2019a), 100 % of its electricity demand comes from renewable sources. The electricity is a mix of hydro, wind and solar power generation. The use of this electricity is CO_2 free, but the upstream processes cause greenhouse gas emissions. Currently, ÖBB does not compensate them yet but it is one of ÖBB's aims to pay off upstream greenhouse gas emissions from the electricity production (ÖBB, 2109b).

The emissions per passenger kilometer of a coach are four times higher than the ones from the same travel by rail. This is a relatively big difference, but small compared to flights emissions. The higher emission factor comes from the different energy provision. While the amount of electrified rail traffic is high, coaches use fossil fuels.

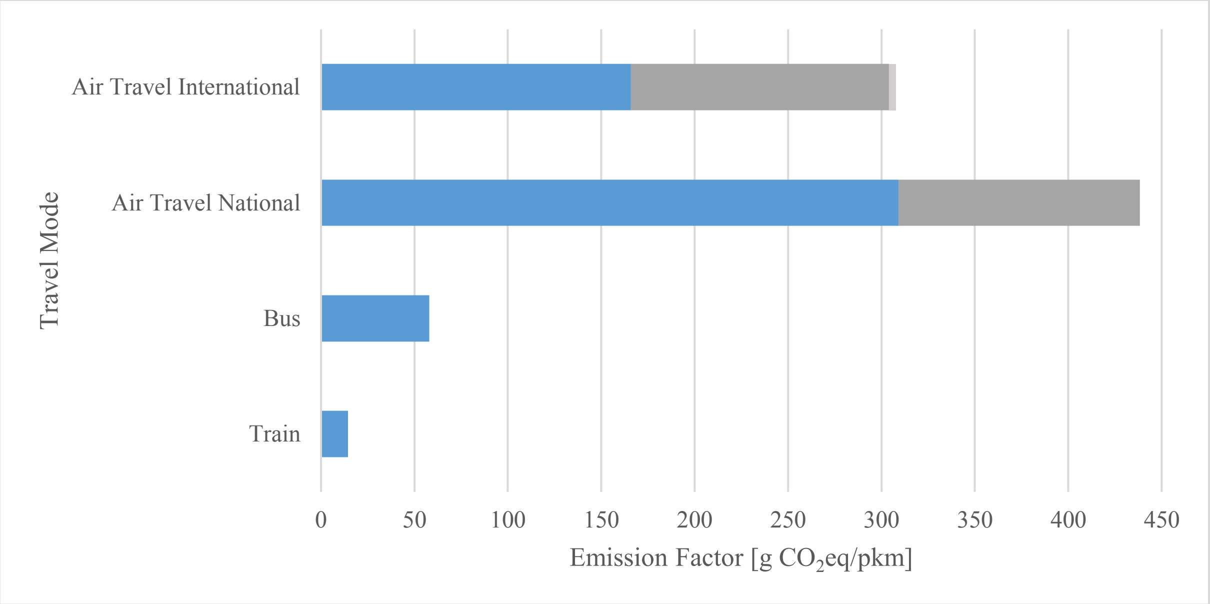

Figure 13: Comparing UBA's (2018a) emission factors for Different Travel Modes. The blue bars represent the emission factors in g CO_2eq/pkm for different modes of transport. The grey parts in air travel emission factors represent the additional amount of greenhouse gas emissions for aviation. As Air Travel International is not further distinguished between medium and long haul flights, we add the additional amount of greenhouse gas emissions for aviation of both categories: the dark bar represents the one for medium haul flights, the light grey bar shows the additional amount from medium haul flights to long haul flights. The sum of the dark and the lighter bar gives the additional amount for long haul flights. We use the weighted average of economy and business class for the emission factors and the additional amount of greenhouse gas emissions for aviation;
Data Source: Mobitool, 2017;UBA 2018a; UK Government, 2018; Graphic: Own Representation

Table 2 compares the emission factors across the studies. All columns include typical passenger load factors for the respective country. The number of occupied seats is usually smaller than the number of available ones. The commuter rail described in the columns of Mobitool (2017) refers to the regional trains in Switzerland.

We divide air travel into sections with three different flight distances: short, medium and long haul flights. We use Mobitool's (2017) emission factors from European air travel as "Medium Haul Flights", which describe lengths from 483 km to 3,700 km. In addition, we associate Mobitool's (2017) emission factors for intercontinental flights to "Air Travel > 3,700 km".

EEA (2014) does not distinguish between different travel distances for flights. It does not differentiate passenger train between high-speed rail or commuter rail. We calculate their emission factors from the TERM 2014 report (given on page 104) according to Formula 4.

EPA (2018) provides their emission factors separately for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are the most relevant greenhouse gas emissions. We first convert the unit kg emission per person and mile (kg/pmi) for CO_2, respectively g/pmi for CH_4 and N_2O, into kg/pkm, respectively g/pkm, to allow a comparison with data from the other institutions. As one mile corresponds to 1.61 km, we divide the original data by that factor (see Equation 3). We do the calculation for CH_4 and N_2O in the same way.

Table 2: Comparison of Emission Factors,
Data Sources: a) Mobitool, 2017; b) UK Government, 2018; c) UBA, 2018a; d) EEA, 2014; e) EEA, 2019; f) EPA, 2018; IPCC, 2007; Table: *Own Representation*

			Mobitool[a)]	**UK GHGI**[b)]	**UBA AT**[c)]	**Additional for flight RF**[a), b)]	**EEA**[d), e)]	**EPA**[f)]
			CO_2eq [g/pkm]	**CO_2eq** [g/pkm]	**CO_2eq** [g/pkm]	**CO_2** [g/pkm]	**CO_2eq** [g/pkm]	**CO_2eq** [g/pkm]
Rail	**Intercity (Average High-Speed)**		32.7		14.4		14.3	87.7
	High-Speed	Germany	49.9	14.1				
		France	16.9					
		Italy	57.0					
		Switzerland	6.9					
	Average Intercity-Commuter	Germany	59.6					
		France	17.1					
		Italy	65.6					
		Austria	21.2					
		Switzerland	7.3					
	Commuter Rail		8.4	52.8				100.7

Bus	**Bus**	Coach	58.2		57.9		68.4	35.2
		Remote Bus	44.6					

Air Travel	**Long Haul Flights < 483 km**		(same as Air Travel Medium)	190.4	309.1	129.3	285.0	141.4
	Medium Haul Flights	Economy	163.3	101.9	165.9	126.4		85.8
		Business	249.8	152.9		191.3		
		Average[1]	178.9	111.1		138.1		
	Long Haul Flights > 3,700 km	Economy	94.4	96.6		98.7		104.0
		Business	194.5	280.2		258.4		
		First	299.5	386.5		367.4		
		Average[2]	117.5	137.3		134.4		

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[1] We built the weighted average based on data from Mobitool (2017). The economy class represents 0.82, while the business class is 0.18 of the airplane's seats.
CO_2eq (Average) = 0.82 * CO_2eq Economy + 0.18 * CO_2eq Business

[2] We built the weighted average based on data from Mobitool (2017). The economy class represents 0.79, while the business class is 0.19 and the first class 0.02 of the airplane's seats.
CO_2eq (Average) = 0.79 * CO_2eq Economy + 0.19 * CO_2eq Business + 0.02 * CO_2eq First

UBA (2018a) gives their emission factors in a similar way as EPA (2018). They do not further define rail traffic. For the aviation sector, they give no seat classes (see Equation 3; conversion of pmi into pkm).

$$\frac{\text{kg CO}_2}{\text{pkm}} = \frac{\text{kg CO}_2/\text{ pmi}}{1{,}60934 \text{ km}} \tag{3}$$

If the organizations give separate amounts for the three main greenhouse gases, we convert them into CO_2 equivalents (CO_2eq). To receive CO_2 equivalents, we multiply the amounts of CH_4 and N_2O with their Global Warming Potential (GWP). The GWP compares their impact over a certain time period (100 years) in respect to CO_2, which has a GWP of 1. The GWP of CH_4 is 25, the GWP from N_2O is 298 (IPCC, 2007). Then, we sum up the three greenhouse gases, the conversion of kg CO_2 into g CO_2 is included (see Equation 4; calculation of CO_2eq).

$$\frac{\text{g CO}_2\text{eq}}{\text{pkm}} = \frac{\text{kg CO}_2}{\text{pkm}} * 10^3 + \left(\frac{\text{g CH}_4}{\text{pkm}} * \text{GWP}_{\text{CH}_4}\right) + \left(\frac{\text{g N}_2\text{O}}{\text{pkm}} * \text{GWP}_{\text{N}_2\text{O}}\right) \tag{4}$$

To compare the different emission factors it is important that they represent the same unit. We converted all the values in Table 2 in a way that they express gram of greenhouse gas emissions per passenger kilometer. The emission factor refers to one passenger and one kilometer. To obtain the total greenhouse gas emissions for the international scientific trip of a researcher we multiply the emission factor for the chosen travel mode with the travel distance. It is crucial for a comparison to know how the organizations derived their values. Knowing the differences, we are able to interpret the variations in the final emission factors and to choose the ones that suit the most to our purpose.

As we do not know how the TERM study (EEA, 2014) obtained the given values, the comparison of the resulting CO_2eq with the ones from Mobitool (2017), UBA (2018), the UK Government (2018) and EPA (2018) must be taken with caution. Nevertheless, the scale of the different CO_2eq values is matching. For passenger rail, the 14.3 g CO_2eq/pkm are in the same range as the values provided by Mobitool (2017), UBA (2018a) and the UK Government (2018). It is obvious that the pollution amount is very similar to the one from the UK government (2018), which is 14.1 g CO_2eq/pkm, and the one from UBA (2018a) with 14.4 CO_2eq/pkm. This indicates that the values are derived in a comparable way. For rail transport, the electricity mix is crucial for the resulting emissions. According to IEA and UIC (2017), the railway energy fuel mix in 2015 in the EU-28 consists of 67.6 % electricity. This relatively high share of electricity is one aspect leading to the low emission value.

Another important factor influencing the g CO_2eq/pkm of rail travel is the number of passengers per train. The more people use the train, the lower becomes the value of emissions per passenger kilometer. TRACCS calculates 156 passengers per train in the TERM 2014 report (EEA, 2014). This is again similar to the absolute number of passengers per ton used from Mobitool (2017) in the intercity rails. There, the load (passengers per ton) varies between a maximum of 235 in Germany, France and Italy (55 % load factor) and a minimum of 107 passengers per ton in Austria, which corresponds to a load factor 37 %. The numbers of passengers per ton for regional trains is smaller (Frischknecht et al., 2016). UBA (2018a) uses 110 passengers.

Mobitool (2017), EEA (2014) and the UK Government (2018) show similar scales of aviation emission factors. EEA (2014) provides an amount of 285 g CO_2eq/pkm. Mobitool (2017) offers nearly 242 g CO_2eq/pkm for the average over economy and business class for air travel medium (Frischknecht et al., 2016). The emission factor from EEA (2014) lies between the one for the business and the first class in Mobitool (2017). UK Government's (2018) long haul emission factor for the business class is very similar, too. The UK Government (2018) shows lower emission factors than Mobitool (2017) for almost every distance and seating class. Therefore, UK Government's (2018) and EEA's (2014) values differ more. With UK Government's (2018) emission factors for medium haul flights of 101.9 g CO_2eq/pkm and 152.9 g CO_2eq/pkm (economy and business class), the 285.0 g CO_2eq/pkm from EEA (2014) are twice as high. Comparing this value to the emission factor for short haul flights from the UK Government (2018) (190 g CO_2eq / pkm), the values are more similar but there is still a big difference. We find the best accordance in the long haul category.

The similar magnitude of the air travel emission factors from Mobitool (2017), the UK Government (2018) and EEA (2014) shows that the institutions may have used similar assumptions and data basis, such as loading factor, aircraft type or assessment of the LTO cycle. In addition, Mobitool (2017) provides an attributional life cycle assessment including greenhouse gas emissions from upstream processes. Also the UK Government (2018) and UBA (2018a) offer amounts of direct and indirect greenhouse gas emissions.

Comparing the load factor used in EPA (2018) with the ones used in Mobitool (2017) it is obvious that the relationship is different in Europe. In Europe, high-speed trains show higher load factors than regional trains, which is opposite in EPA (2018) data.

Furthermore, the emission factors for rail traffic are higher in EPA (2018) than in Mobitool (2017), UBA (2018a) or from the UK Government (2018), which means they are higher in the USA. In 2015, rail transport accounted for only 0.1% of the total passenger transport activity (in passenger kilometers) in the USA, while it accounted for 7.9 % in Europe (IEA - UIC, 2017). Moreover, the share of diesel as rail fuel is quite different in the two continents. Still in 2015, the US fuel mix for rail traffic used 94.0 % diesel, whereas in Europe only 31.8 % of the energy mix was diesel (IEA - UIC, 2017). That is why rail traffic in the USA emitted 41 $MtCO_2$ (2.4 % of US transport sector CO_2), while it was 26.64 $MtCO_2$ (2.9 % of European transport sector CO_2) in Europe (IEA - UIC, 2017).

As mentioned, we sum up the direct and indirect emission factors from the UK Government (2018) and UBA (2018a) to compare them with the emission factors from EPA (2018) and Mobitool (2017). UK Government's (2018) emission factor for high-speed or international rail is relatively low. It is similar to the one from France in Mobitool (2017). This seems logical, as Eurostar includes routes to France and Belgium and therefore the respective energy mix. The calculated electricity emissions come from the United Kingdom, France and Belgium. France uses 77 % of its electricity from "CO_2-neutral" nuclear power plants (RTE, 2015). Germany and Italy have significantly higher rail emission factors, which is also due to the respective electricity provision.

The situation is different for national or commuter rails. Here, the UK Government (2018) uses a mix of electricity and diesel trains. Therefore, the emission factor per passenger kilometer is much higher than the one for Switzerland using mainly hydropower. The emission factors in the USA are nearly twice as high, because of the high amount of diesel used in the energy provision for commuter rails.

Aviation factors from the UK Government (2018) and EPA (2018) show a similar development: the emission factors increase from medium to long haul flights. In Mobitool (2017) the emission factor decreases from European (= medium haul) to intercontinental (= long haul) flights. Comparing the EPA (2018) emission factor for medium haul flights with the other emission factors, it is the lowest value, regarding other short haul emission factors, but also considering all emission factors in the comparing table. Only the emission factors for the economy class in long haul flights provided by the UK Government (2018) is in the same range. Moreover, it is visible that all emission factors from EPA (2018) have the lowest value in their respective class (short, medium, long haul).

In Europe, aviation accounted for 9.9 % of pkm in the year 2015. In the same year, the share of aviation as transport mode was higher in the US: 12.5 % of total pkm (IEA - UIC, 2017).

Mobitool's (2017) emission factors are higher for medium air travel than for air travel > 3,700 km, whereas in EPA (2018) and the UK Government (2018) the emission factor increases with the increasing distance. Therefore, the average emission factor over all seat classes for intercontinental air travel is higher in the data from the UK Government (2018) than in Mobitool (2017). Nevertheless, the range of the values is similar.

The reverse is true for air travel medium: here, Mobitool's (2017) emission factors are higher than the ones from the UK Government (2018). Mobitool's (2017) emission factors for economy and business class are higher as the ones from the UK Government (2018). This is due to the fact, that Mobitool (2017) accounts LTO phases and cruise phase. The share of LTO to the whole flight is larger in short distances than in long ones. Therefore, LTO accounts to a higher amount of greenhouse gas emissions per passenger kilometer in "air travel medium". As the cruise phase has a higher part in air travel above 3,700 km, the emission factor per passenger kilometer decreases. Defra does not mention a differentiation between LTO and cruise phase. Therefore, its emission factors increase with increasing distance (from medium to long haul flights).

Another cause for the big difference in Mobitool's (2017) emission factors is the fact that Mobitool (2017) uses higher amounts of kerosene consumption for medium distances than for long distances. Airbus A340-600 represents intercontinental flights and needs between 25 to 81 g kerosene per passenger kilometer. Mobitool (2017) uses the Airbus A320 for short haul flights, which consumes between 46 and 72 g kerosene/pkm. The maximum consumption is higher concerning long haul flights, but the minimum amount of needed kerosene is higher for European/medium flights. The higher minimum consumption results again from the higher share of the LTO phase (Frischknecht et al., 2016).

In addition, Mobitool (2017) uses "scope 3" emissions, which means it includes emissions developed in upstream processes, too. The UK Government (2018) includes in the indirect emissions only emissions from fuel production and distribution, but not the construction or maintenance of the airplane. UBA (2018a) on the other hand includes greenhouse gas emissions arising from the airplane construction and the energy provision.

An additional difference in the emission factors from Mobitool (2017) and the UK Government (2018) is the ratio between different seating classes. In medium air travels, economy to business class seats have a ratio of 1:1.5 for both sources. However, it is different for long haul flights. Mobitool (2017) uses a ratio of approximately 1:2:3 for economy : business : first class. The difference between the seating classes is higher in the values provided by the UK Government (2018). Here, the ratio of economy to business to first class is approximately 1:3:4. EEA (2014), EPA (2018) and UBA (2018a) do not provide emission factors for different seating classes.

Comparing the values from UBA (2018a) with the ones from Mobitool (2017) and the UK Government (2018), we see that the range of emission factor for rail travel is similar to the others. UK high-speed trains have the same amount of greenhouse gas emissions per passenger-kilometer, which means the electricity mix is very similar. In addition, load factors and type of train may be similar, but for rail traffic the energy provision is crucial for the resulting greenhouse gas emissions. Mobitool's (2017) values for France and Switzerland are comparable to UBA's (2018a), too. France and Switzerland use electricity coming from renewable sources. The emission factor for a coach is nearly the same as the ones from Mobitool (2017). This seems logic as they use the same fossil fuel, gasoline or diesel, and have a comparable size.

Mobitool (2017) and the UK Government (2018) use similar aircraft types for long haul flights. Mobitool (2017) uses the Airbus A340-600 for international air travel. The UK Government (2018) uses the average over 19 types of airbus and Boeing aircraft types. For medium air travel, Mobitool (2017) uses again an Airbus (A320) (Frischknecht et al., 2016), whereas the UK Government (2018) uses the average over 18 aircraft types, consisting not only of Airbus and Boeing types but also additional ones (Bonifazi et al., 2018).

Table 3 compares the aviation emission factors from Mobitool (2017) and the UK Government (2018). "Total CO_2eq" indicates that the value accounting for additional radiative forcing is added to the initial emission factor. The table shows also the factor that is applied to the initial value to account for the additional amount of greenhouse gases in flight heights. The original factor used from the UK Government (2018) is 1.9, the one from Mobitool (2017) 1.35. We see that the additional "90 %" and "35%" used in the original calculations are altered due to our modifications described previously. We see that the resulting RFI varies between 1.7 and 2.3.

Table 3: Comparing Emission Factors provided by Mobitool (2017) and UK Government (2018) with and without additional Radiative Forcing;
Data Sources: Mobitool, 2017; UK Government, 2018, Table: *Own Representation*

		Mobitool			**UK GHG Inventory**		
		CO_2eq without RF	**Total CO_2eq**	**Factor**	**CO_2eq without RF**	**Total CO_2eq**	**Factor**
		[g/pkm]	[g/pkm]		[g/pkm]	[g/pkm]	
Air Travel < 483 km					190.4	319.7	1.7
Air Travel Medium	Economy	163.3	289.7	1.8	127.4	197.8	2.2
	Business	249.8	441.1	1.8	101.9	171.2	2.3
	Average	178.9	317.0	1.8	152.9	256.8	2.2
Air Travel > 3,700 km	Economy	94.4	193.1	2.0	254.4	427.3	2.0
	Business	194.5	453.0	2.3	96.6	162.3	1.9
	First	299.5	666.9	2.2	280.2	470.5	2.0
	Average	117.5	252.0	2.1	386.5	649.2	2.0

Air traffic emission factors from UBA (2018a) show differences to the ones from Mobitool (2017) and the UK Government (2018). The difference in national or short haul flights (distance shorter than 483 km) is very large. Austrian national flights have a relative high emission factor. UK Government's (2018) emission factor is 2/3 of UBA's (2018a). Mobitool (2017) does not provide emission factors for air travel below 483 km, but for European flights and intercontinental flights. We use European flights for air travel below 3,700 km. European flight emission factors are therefore valid for air travel medium and air travel shorter than 483 km. We see that the UBA (2018a) emission factor for national flights lies in the range of Mobitool's (2017) emission factors for a distance shorter than 3,700 km. This indicates that the UBA (2018a) values assess the impact of the LTO phase similarly as Mobitool (2017). The percentage of the LTO phase is higher in short flights, which leads to higher emission factors per passenger kilometer. Regarding UBA's (2018a) emission factor for air travel medium and air travel longer than 3,700 km, it is in-between the economy and business class from Mobitool (2017) and UK Government's (2018).

We conclude that every emission factor has its own advantages and disadvantages due to the way they were generated. In this master thesis, we use Mobitool's (2017) emission factors due to different reasons. On the one hand, the composition of the emission factors is transparent, comprehensive and detailed. In addition, Mobitool (2017) generates an attributional life cycle assessment. Not only exhaust gases from direct operations are included, but also greenhouse gas emissions from upstream processes. On the other hand, Mobitool (2017) provides different emission factors for rail activities with a disaggregation for different European countries. One of the dimensions we consider in our study is the travel distance. There is regional travel with a circumference of 1,000 km around Graz and long distance travel. We set the boundary at the limit where the possibility to substitute air traffic with rail traffic exists. Most of the rail travels considered take place within 1,000 km around Graz. The disaggregation of the emission factors for Germany, France, Italy, Austria, and Switzerland is therefore suitable for our purpose. The travel data show that there are some train travels to other European countries that we do not consider in Table 4. In such a case, we decide the emission factor based on the one from one of its neighbouring countries with comparable energy provision.

Table 4: Final Emission Factors[g CO_2eq/pkm] for Our Calculation in this Study; Data Source: Mobitool, 2017; Table: Own Representation

Travel Mode	**Destination**	**Seat Class**	**Emission Factor** [g CO_2eq/pkm]
Rail	Austria		21.2
	Germany		49.9
	Switzerland		7.3
	Italy		57.0
	France		16.9
	Eastern European Countries		59.6
Air Travel	National Flights		438.4
	European Flights	Economy	289.7
		Business	441.1
	International Flights	Economy	193.1
		Business	453.0

As Graz is located near eastern European countries, we add an emission factor for these countries. Due to similar energy provision, we allocate the German emission factor for the average of intercity and commuter rails to eastern European countries. As already mentioned, the emission factor for rails is highly depending on the source of its traction power. Germany's electricity mix arises mostly from coal-fired power stations. The one in Eastern Europe countries is similar. For travels to Germany, France, and Italy we use the emission factors representing high-speed trains, as we assume the destinations to be major cities connected to a high-speed rail net.

As all our rail travels start in Graz, the train passes Austria before crossing a border. Within Austria, it uses the Austrian electricity mix. Over the national border, the electricity supply of the train changes. With the different electricity mix, the emission factors change. Therefore, we separate international train trips into a part within Austria and a part outside of Austria. As the main part of the trips with rail are going to its neighbouring countries Germany, Italy, Switzerland and to France, we define four standard routes from Graz to one of the borders. From Graz to one of the four specific points, we use the emission factor given for Austria. From that specific point to the target destination, we use the emission factor of the respective country. The difference of the overall distance to the distance from Graz to the defined point near the border gives the distance, for which we use the emission factor of the respective country.

Specifically, we define the routes from Graz to Salzburg for trips to Germany, Graz to Villach for trips to Italy, Graz to Feldkirch for trips to Switzerland. For trips to France, we use Austria's emission factor for the distance Graz-Feldkirch and the one from Switzerland for the route Feldkirch to Basel. In this way, we assume that all international rail trips take place via Salzburg, Villach, Feldkirch and Basel. This may not correspond to the real driving routes in all cases, but it allows us to automatise the calculation process (see Equation 5; distance of standard routes).

As the real rail travel distance differs from the great circle distance (GCD), we use the adjustment factor of 1.1 to correct the distance. The adjustment factor increases the given GCD by 10 %. The resulting distance corresponds better to the realistic distance a rail drives. We apply the factor to the overall distance as well as the standard route and, consequently, the part without the standard route (see Equation 5). For aviation, we do not use the adjustment factor, as the actual flight route is more similar to the GCD. In addition, the uplift factor of 1.08 already includes circling and delays.

d … distance in km
$x \rightarrow y$ … from country "x" to country "y"
z … via country "z"
a - b … from point "a" to point "b"
AF … Adjustment Factor for Train Travel (1.1)

$$d_{x\rightarrow y}^{z} = d\ (\mathrm{a}-\mathrm{b}) * AF \tag{5}$$

$$d_{AT\rightarrow DE}^{AT} = d\ (\mathrm{Graz}-\mathrm{Salzburg}) * AF = 218\ \mathrm{km}$$

$$d_{AT\rightarrow IT}^{AT} = d\ (\mathrm{Graz}-\mathrm{Villach}) * AF = 144\ \mathrm{km}$$

$$d_{AT\rightarrow CH}^{AT} = d\ (\mathrm{Graz}-\mathrm{Feldkirch}) * AF = 486\ \mathrm{km}$$

$$d_{AT\rightarrow FR}^{CH} = d\ (\mathrm{Feldkirch}-\mathrm{Zurich}-\mathrm{Basel}) * AF = 172\ \mathrm{km}$$

$$d_{AT\rightarrow FR}^{AT\&CH} = d\ (\mathrm{Graz}-\mathrm{Basel}) * AF = 658\ \mathrm{km}$$

We get the emissions of a specific trip by multiplying the emission factor of the neighbouring country with the difference of the overall distance to the standard route for the specific country plus the emission factor for Austria multiplied with the standard distance to the respective border (see Equation 6; calculation of GHG emissions for a rail trip).

$$Amount_{\mathrm{CO_2eq_{Rail}}}[\mathrm{g\ CO_2eq}] = EF_{Neighbouring\ Country} * (d_{overall} - d_{standard\ route}) + EF_{AT} * d_{standard\ route} \tag{6}$$

Regarding air travel, we use the emission factors from Mobitool (2017) and add the amount for additional radiative forcing that we calculated.

Concerning "National Flights", Mobitool (2017) does not give a value for this distance category but uses different values for international flights and flights within Europe. As short flights have higher emission factors as the landing and take-off phase represents a larger part of the overall flight, we add the category "National Flights". For this category, we adapt the emission factor for national flights provided by UBA (2018a). Also for this emission factor, we add the amount of additional radiative forcing. We do not distinguish seat classes in national flights, but we consider economy and business class for European and international flights. The first class is not important, as none of Wegener Center's personnel travelled first class.

We make the assumption that every flight has a layover in Vienna, Zurich, Munich or Frankfurt. Similar to the standard routes for international train travel, we calculate a standard route for flights. For this purpose, we use the average great circle distance from Graz to each of the four cities, which is 395 km. This corresponds to European flights, which is why we use the European emission factor for the standard route. Each flight travel is then composed of the standard route, representing the distance from Graz to one of the four connecting airports, and the remaining distance to the destination. We get the remaining distance by subtracting the 395 km from the total distance Graz – destination. Equation 7 (Calculation of Resulting Greenhouse Gas Emissions from Flight Travels) gives the amount of greenhouse gas emissions from a specific flight travel.

$$Amount_{\mathrm{CO_2eq_{Air}}}[\mathrm{g\ CO_2eq}] = EF_{EU} * \text{standard route}_{\text{aviation}} + EF * (\text{total distance} - \text{standard route}_{\text{aviation}}) \tag{7}$$

Which emission factor (European or international) we use for the remaining part depends on the remaining distance itself. If the total distance without the standard distance is shorter than

3,700 km, we use the emission factor for flights within Europe, otherwise the one for international flights.

3.1.2 International Scientific Travels of the Wegener Center

The focus in this subsection lies on the question how different starting situations influence the emissions of the institute coming from international scientific travels. Besides international scientific travel, we also consider national scientific travel within Austria. Moreover, we consider three dimensions to examine possible differences in travel emissions. They concern the reference group (scientists) doing the travels, the travel mode and the travel distance. In each dimension, a disaggregation takes place.

The number of travellers in the Wegener Center corresponds to the number of its scientists. The number of employees as well as the number of full time equivalents (FTE) is changing each year (see Table 5 and Table 6). The more scientists there are, the higher we expect the greenhouse gas emissions coming from international scientific travels to be, as the Wegener Center hosts also more travelling employees.

We adapted the number of senior scientists to the real one, as well as its full time equivalents (FTE), because senior scientists have a 40-hour week. One FTE corresponds to one senior scientist. In the list that we have, this is not true for every senior scientist, therefore we adjusted the number and the FTEs. In 2017, one senior scientist began working in the Wegener Center in October. As there were left three months of the year, we add one quarter of the year, and therefore 0.25 "scientist" and FTE. For post-doc scientists, the number of scientists and the FTEs coincide as well.

Table 5: Number of Wegener Center's Employees 2013 to 2018

Number of Employees								
		2013	**2014**	**2015**	**2016**	**2017**	**2018**	**Average**
Travelling Employees = Scientists	Senior Scientists	6	6	6	7	8.25	9	7.04
	Post-Doc Scientists	8	9	9	13	10	10	9.83
	Prae-Doc Scientists	15	14	26	25	24	19	20.50
	Sum	29	29	41	45	42.25	38	37.38
Non-Travelling Employees	Others	18	15	15	14	11	12	14.17
Sum	Total	47	44	56	59	53.25	50	51.54

Table 6: Number of Wegener Center's Full Time Equivalents 2013 to 2018

Full Time Equivalents								
		2013	**2014**	**2015**	**2016**	**2017**	**2018**	**Average**
Travelling Employees = Scientists	Senior Scientists	6.0	6.0	6.0	7.0	8.25	9.0	7.04
	Post-Doc Scientists	8.0	9.0	9.0	13.0	10.0	10.0	9.83
	Prae-Doc Scientists	11.75	12.5	14.75	13.5	15.5	16.25	14.04
	Sum	25.75	27.5	29.75	33.5	33.75	35.25	30.92
Non-Travelling Employees	Others	5.0	5.25	5.25	5.5	5.5	5.0	5.25
Sum	Total	30.75	32.75	35.0	39.0	39.25	40.25	36.17

The results for international and national scientific travels from Wegener Center's personnel show that the average travel emissions per scientist and year is about one tonne CO_2 equivalents (see Table 7). For individual years in our sample, travel emissions per persons are subject to strong fluctuations. We therefor focus on the average value of the observed period, which begins with 2013 and ends with 2018. One of the most important results is the predominance of emissions coming from international scientific travel. We see another significant outcome concerning the travel mode in Figure 14, where flights account for the majority of the greenhouse gas emissions.

The major part of the travel greenhouse gas emissions come from international scientific travel. On average, they cover 99.1 % of the total travel emissions per year. National scientific travel is therefore responsible for less than 1 % of Wegener Center's average travel emissions per year. However, the count of national travels (301 between 2013 and 2018) is higher than the number of international travels (248). Thus, scientific trips within Austria represent 54.8 % of the total number of scientific trips in the years from 2013 to 2018. Accordingly, the major part of Wegener Center's travel emissions come from a small number of scientific trips, which is due to the fact that international scientific trips are more intensive concerning its greenhouse gas emissions. The extreme difference between the amounts of greenhouse gas emissions from the two categories has different reasons. On the one hand, international scientific travels consist of longer distances. The higher count of kilometers per trip causes more greenhouse gas emissions. On the other hand, the travel mode is the most decisive cause. While train travel is the only travel mode in national trips, 71.8 % of the international trips are flight travels. The major part of the greenhouse gas emissions from international scientific travels is therefore coming from aviation.

Table 7: Results of greenhouse gas emissions [t CO_2eq] as total, per full time equivalent [t CO_2eq/FTE] and per scientist [t $CO_2eq/scientist$] coming from Wegener Center's scientific trips, from its international scientific trips and from its national scientific trips 2013 to 2018

	All Travels			**Destination**	
Year	**Total Travel Emissions** [t CO_2eq]	**Travel Emissions per Full Time Equivalent** [t CO_2eq/FTE]	**Travel Emissions per Scientist** [t $CO_2eq/scientist$]	**International Travel Emissions** [t CO_2eq]	**National Travel Emissions** [t CO_2eq]
2013	9.96	0.39	0.34	9.71	0.25
2014	32.46	1.18	1.12	32.13	0.32
2015	24.48	0.82	0.60	24.20	0.28
2016	51.73	1.54	1.15	51.33	0.39
2017	68.45	2.03	1.62	67.92	0.53
2018	43.60	1.24	1.15	43.25	0.35
Average	38.45	1.24	1.03	38.09	0.35

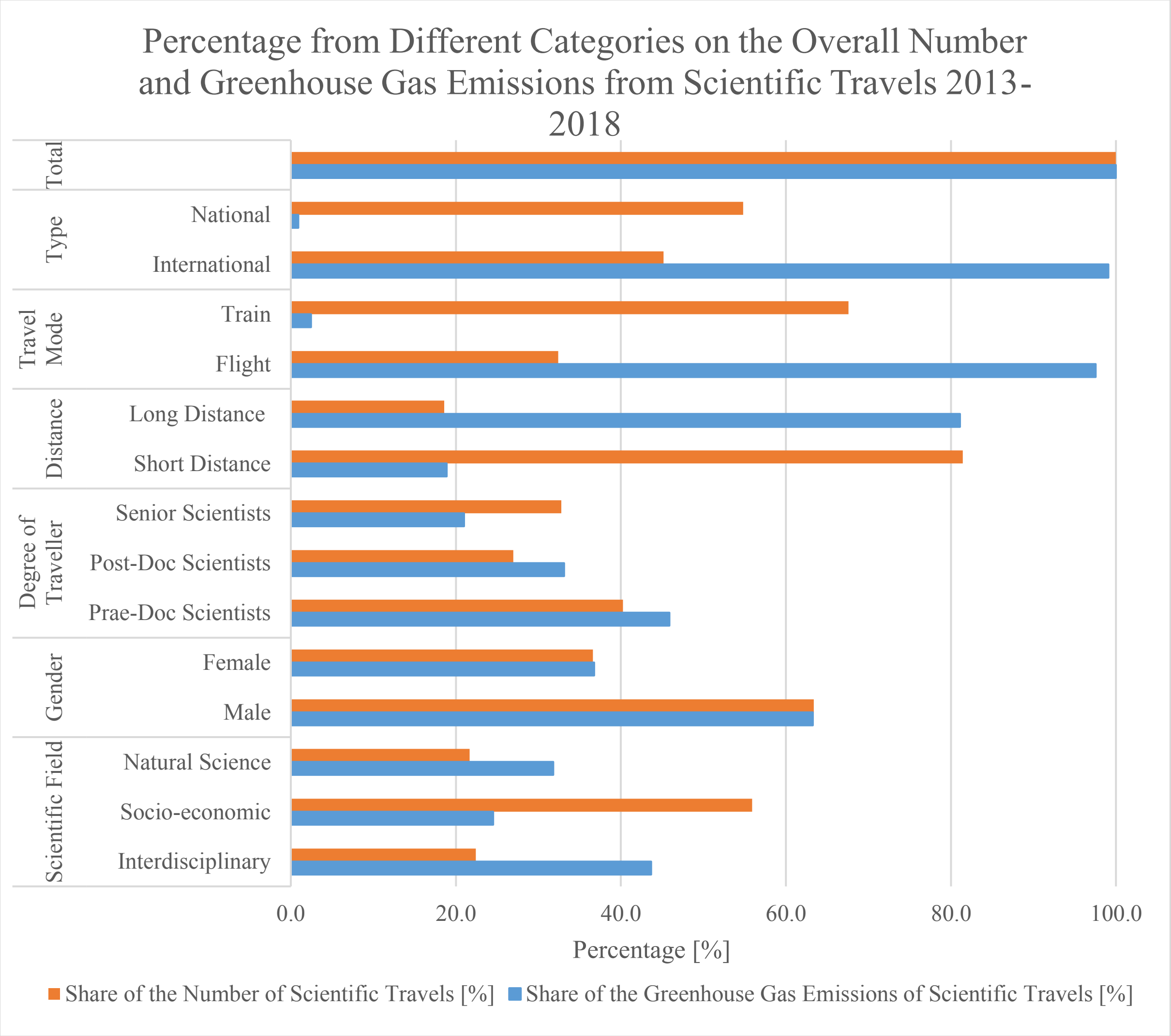

Figure 14: Percentage [%] of the Number of Travels per Category as Average from 2013 to 2018 and Percentage [%] of Resulting Greenhouse Gas Emissions [t CO_2eq] per Category coming from Wegener Center's Scientific Travels as Average of the Years from 2013 to 2018

Table 8: Results as Absolute [t CO_2eq] and Relative [%] Greenhouse Gas Emissions per Year Grouped per Categories as Average from 2013 to 2018, with the exception "Scientific Field", where the average is calculated from 2015 to 2018, as the interdisciplinary department was founded in the late 2014 with its travel activity starting in 2015

			2013	**2014**	**2015**	**2016**	**2017**	**2018**	**Average**
Total		**absolute** [t CO_2eq]	9.96	32.46	24.48	52.35	68.45	44.36	38.68
		relative *[%]*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
Travel Type	**National**	**absolute** [t CO_2eq]	0.25	0.32	0.28	0.39	0.53	0.35	0.35
		relative *[%]*	*2.5*	*1.0*	*1.1*	*0.8*	*0.8*	*0.8*	*0.9*
	International	**absolute** [t CO_2eq]	9.71	32.13	24.20	51.96	67.92	44.01	38.32
		relative *[%]*	*97.5*	*99.0*	*98.9*	*99.2*	*99.2*	*99.2*	*99.1*
Travel Mode	**Train**	**absolute** [t CO_2eq]	0.50	0.65	0.91	1.16	1.66	1.17	1.01
		relative *[%]*	*5.0*	*2.0*	*3.7*	*2.2*	*2.4*	*2.6*	*2.6*
	Flight	**absolute** [t CO_2eq]	9.46	31.81	23.58	51.19	66.97	43.19	37.70
		relative *[%]*	*95.0*	*98.0*	*96.3*	*97.8*	*97.8*	*97.4*	*97.5*
Travel Distance	**Long Distance**	**absolute** [t CO_2eq]	7.26	28.75	13.93	45.81	57.82	34.75	31.39
		relative *[%]*	*73.0*	*88.6*	*56.9*	*87.5*	*84.5*	*78.3*	*81.2*
	Short Distance	**absolute** [t CO_2eq]	2.69	3.70	10.55	6.54	10.45	9.62	7.26
		relative *[%]*	*27.0*	*11.4*	*43.1*	*12.5*	*15.3*	*21.7*	*18.8*
Gender of Traveller	**Female**	**absolute** [t CO_2eq]	2.43	15.05	9.85	19.25	24.78	13.32	14.11
		relative *[%]*	*24.5*	*46.4*	*40.2*	*36.8*	*36.2*	*30.0*	*36.5*
	Male	**absolute** [t CO_2eq]	7.52	17.41	14.63	33.11	43.49	31.05	24.53
		relative *[%]*	*75.5*	*53.6*	*59.8*	*63.2*	*63.5*	*70.0*	*63.4*
Scientific Seniority of Traveller	**Senior Scientists**	**absolute** [t CO_2eq]	3.31	6.66	6.65	10.32	8.16	10.26	7.56
		relative *[%]*	*33.3*	*20.5*	*27.2*	*19.7*	*11.9*	*23.1*	*19.6*
	Post-Doc Scientists	**absolute** [t CO_2eq]	6.59	24.00	8.27	9.90	17.15	11.74	12.94
		relative *[%]*	*66.2*	*73.9*	*33.8*	*18.9*	*25.1*	*26.5*	*33.5*
	Prae-Doc Scientists	**absolute** [t CO_2eq]	0.05	1.80	9.57	32.16	43.68	22.35	18.27
		relative *[%]*	*0.5*	*5.5*	*39.1*	*61.4*	*63.8*	*50.4*	*47.2*
Scientific Field of Traveller (average 2015-2018)	**Natural Science**	**absolute** [t CO_2eq]	5.54	27.26	7.17	9.82	14.15	10.08	10.31
		relative *[%]*	*55.7*	*84.0*	*29.3*	*18.8*	*20.7*	*22.7*	*21.7*
	Socio-economic	**absolute** [t CO_2eq]	4.41	5.18	9.31	10.76	9.51	14.68	11.07
		relative *[%]*	*44.3*	*16.0*	*38.0*	*20.6*	*13.9*	*33.1*	*23.3*
	Inter-disciplinary	**absolute** [t CO_2eq]	0.00	0.02	8.00	31.77	45.33	19.60	26.18
		relative *[%]*	*0.0*	*0.1*	*32.7*	*60.7*	*66.2*	*44.2*	*55.1*

Table 9: Results as Absolute [t CO_2eq/scientist] and Relative [%] Greenhouse Gas Emissions per Year and Scientist Grouped per Categories as Average from 2013 to 2018, with the exception "Scientific Field", where the average is calculated from 2015 to 2018, as the interdisciplinary department was founded in the late 2014 with its travel activity starting in 2015

			2013	**2014**	**2015**	**2016**	**2017**	**2018**	**Average**
Total		**absolute** [t CO_2eq/scientist]	0.34	1.12	0.60	1.16	1.62	1.17	1.03
		relative *[%]*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
Travel Type	**National**	**absolute** [t CO_2eq/scientist]	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		relative *[%]*	*2.5*	*1.0*	*1.1*	*0.8*	*0.8*	*0.8*	*0.9*
	International	**absolute** [t CO_2eq/scientist]	0.33	1.11	0.59	1.15	1.61	1.16	1.03
		relative *[%]*	*97.5*	*99.0*	*98.9*	*99.2*	*99.2*	*99.2*	*99.1*
Travel Mode	**Train**	**absolute** [t CO_2eq/scientist]	0.02	0.02	0.02	0.03	0.04	0.03	0.03
		relative *[%]*	*5.0*	*2.0*	*3.7*	*2.2*	*2.4*	*2.6*	*2.6*
	Flight	**absolute** [t CO_2eq/scientist]	0.33	1.10	0.58	1.14	1.59	1.14	1.01
		relative *[%]*	*95.0*	*98.0*	*96.3*	*97.8*	*97.8*	*97.4*	*97.5*
Travel Distance	**Long Distance**	**absolute** [t CO_2eq/scientist]	0.25	0.99	0.34	1.02	1.37	0.91	0.84
		relative *[%]*	*73.0*	*88.6*	*56.9*	*87.5*	*84.5*	*78.3*	*81.2*
	Short Distance	**absolute** [t CO_2eq/scientist]	0.09	0.13	0.26	0.15	0.25	0.25	0.19
		relative *[%]*	*27.0*	*11.4*	*43.1*	*12.5*	*15.3*	*21.7*	*18.8*
Gender of Traveller	**Female**	**absolute** [t CO_2eq/scientist]	0.27	1.67	1.09	1.48	1.91	1.11	1.30
		relative *[%]*	*41.8*	*65.8*	*70.5*	*58.9*	*56.2*	*48.2*	*58.5*
	Male	**absolute** [t CO_2eq/scientist]	0.38	0.87	0.46	1.03	1.49	1.19	0.92
		relative *[%]*	*58.2*	*34.2*	*29.5*	*41.1*	*43.8*	*51.8*	*41.5*
Scientific Seniority of Traveller	**Senior Scientists**	**absolute** [t CO_2eq/scientist]	0.55	1.11	1.11	1.47	0.99	1.14	1.07
		relative *[%]*	*40.0*	*28.4*	*46.3*	*41.9*	*21.9*	*32.7*	*32.7*
	Post-Doc Scientists	**absolute** [t CO_2eq/scientist]	0.82	2.67	0.92	0.76	1.72	1.17	1.32
		relative *[%]*	*59.7*	*68.3*	*38.4*	*21.6*	*37.9*	*33.6*	*40.1*
	Prae-Doc Scientists	**absolute** [t CO_2eq/scientist]	0.00	0.13	0.37	1.29	1.82	1.18	0.89
		relative *[%]*	*0.2*	*3.3*	*15.4*	*36.5*	*40.2*	*33.7*	*27.2*
Scientific Field of Traveller (average 2015-2018)	**Natural Science**	**absolute** [t CO_2eq/scientist]	0.29	1.60	0.33	0.39	0.70	0.56	0.49
		relative *[%]*	*39.8*	*71.1*	*14.7*	*8.8*	*12.3*	*12.5*	*11.7*
	Socio-economic	**absolute** [t CO_2eq/scientist]	0.44	0.65	1.16	1.20	0.86	1.13	1.09
		relative *[%]*	*60.2*	*28.7*	*52.5*	*26.7*	*15.2*	*25.2*	*25.8*
	Inter-disciplinary	**absolute** [t CO_2eq/scientist]	0.00	0.01	0.73	2.89	4.12	2.80	2.63
		relative *[%]*	*0.0*	*0.2*	*32.8*	*64.5*	*72.5*	*62.4*	*62.5*

Travel Mode:

The travel mode considers train travels and flight travels. Bus travels are negligible for international scientific travels. They cannot substitute train or flight travels because the travel time from point A to point B would be too long in the most cases.

We assume each trip to be a round trip, because different travel modes for the outward journey and the return journey are not usual. The data set from the travel management department gives the destination point. The data set does not give the starting point specifically, but as the Wegener Center is located in Graz, we set all starting points to be Graz.

Flight Travel

Concerning flight travels, there is a difference in emissions per scientist between the business and the economy class. This is due to two aspects. In the business class, on the one hand the seats are bigger so that the passenger has more space. On the other hand, it is usual that only every second seat in the business class is occupied to guarantee a certain comfort for the client. Consequently, a smaller number of passengers needs more space, or reversely, in the economy class more passengers use the same space.

On average, the economy class locates two times more people than the business class, which leads to a proportion of 1:2 (business to economy). Occupying more space, the emissions per person are higher in the business class because less persons split the resulting emissions.

Required data for this part are the travel data of the personnel from Wegener Center and the emission factors of flights. Due to the new General Data Protection Regulation (GDPR) it is difficult to get data concerning the destination, travel mode and date of Wegener Center personnel's business trips.

We differentiate national, European and international flights in our emission factors for the aviation category. National flights are the ones from Graz to a destination within Austria. In the period from 2013 to 2018, there is no such flight in our data. We distinguish European and international flights according to their distance, rather than the destination country. European aviation correspond to (non-Austrian) flights with a distance shorter than 3,700 km from Graz. Above 3,700 km distance, we encode the travel as an international flight. Therefore, the emission factors differ. For the calculations, we consider that every flight has a layover, which has the average distance of 395 km from Graz. For this destination, we apply the corresponding European emission factor. The emission factor for the second part of the flight depends on the remaining distance.

It is to mention that there are some underestimations concerning the resulting amounts of CO_2eq. The data set does not give information whether there is a layover for a specific flight and, consequently, a connecting flight. Layovers separate the overall distance into two (or more) shorter distances. If the flight was a European one and was divided into more flights, the emission factor would remain the same. The situation changes, if the destination was international but the layover reduces at least one of the new distances to under 3,700 km. In such a case, at least one of the emission factors would change from the international to the European category and, therefore, increase. This leads to a higher amount of CO_2eq, as more LTO phases occur on a travel. As we do not have information on layovers, we consider each flight to have a layover in Vienna, Munich, Frankfurt or Zurich resulting in the average distance of 395 km from Graz.

In addition, the data set does not distinguish different seat classes. Knowing that only an insignificant number of the flights from Wegener Center's personnel are business flights, we assume all aviation travels to be economy flights. Hence, we do not consider business flights, which again may lead to small underestimations.

Every flight is connected to an additional journey to and from the airport. We have no information about the real take-off and landing airports. We determine the airport of Graz to be the take-off airport. The uplift factor 1.08 covers the distance from Graz to its airport and from the landing airport to the final destination.

In the year 2016, there is one trip with destination "Shanghai". In this individual case, we know how this international scientific trip took place. The journey there and back did not cover the same route, which would be Graz-Shanghai and Shanghai-Graz. In reality, this trip consists of seven flights to different cities. The specific route was Graz-Vienna, Vienna-Shanghai, Shanghai-Wuhan, Wuhan-Shanghai, Shanghai-Peking, Peking-Munich, and Munich-Graz. We eliminate one of the underestimations by calculating the greenhouse gas emissions from all seven flights and allocate them to the IST with destination Shanghai. The distance is 2,181 km longer than the round trip distance Graz-Shanghai-Graz. Consequently, the resulting greenhouse gas emissions from the real trip are 0.65 t CO_2eq higher compared to the round trip Graz-Shanghai-Graz. This amount represents about 16 % of the greenhouse gas emissions from the real trip.

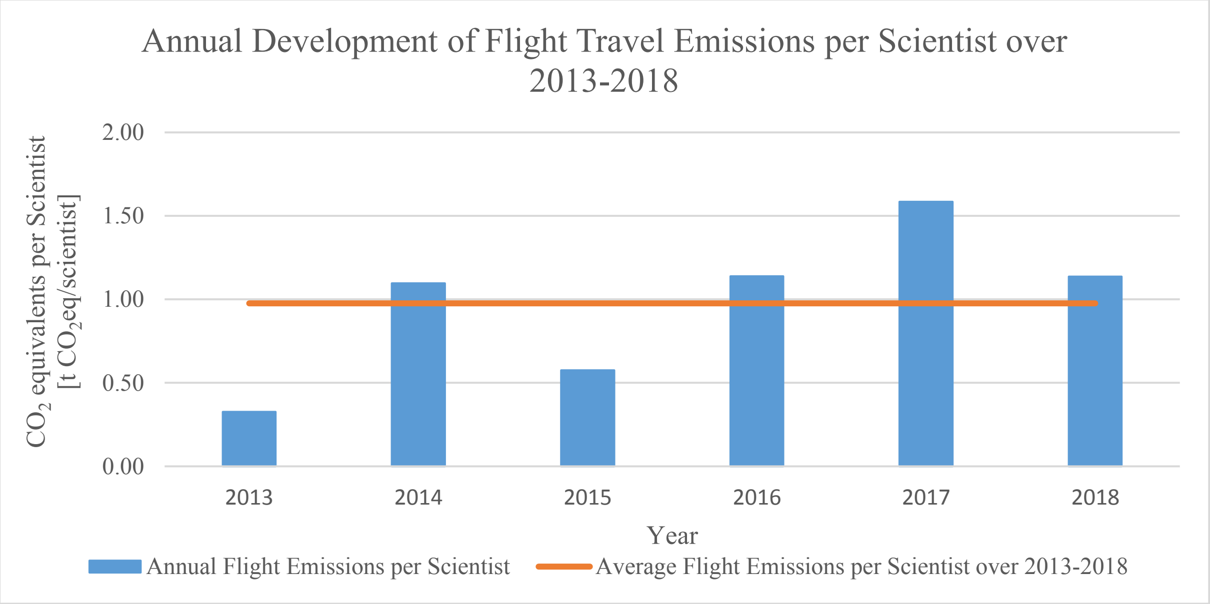

Figure 15: Past Annual Development of Flight Travel Emissions per Scientist [t CO$_2$eq/scientist] with Its Average from 2013 to 2018

Figure 15 shows the development of flight travel emissions per scientist. The average amount of greenhouse gas emissions per scientist and year caused by flight travel is 0.98 t CO$_2$eq/scientist. The amounts per year do not show a clear up or downwards trend. The resulting greenhouse gas emissions per year are strongly dependent on the number of international conferences the scientists attend in the respective year.

The number of flight travels represents one third of the total travels. As there are no national flights, all flight trips are European or intercontinental flights and are therefore considered international scientific travels. In this category, they represent almost 72 % of the number of travels and caused 98.4 % of Wegener Center's greenhouse gas emissions from international scientific travel from 2013 to 2018. Moreover, flight travel dominates the resulting greenhouse gas emissions from all Wegener Center's travel emissions, causing 97.5 % of the average travel emissions per year. They cause the vast majority of the greenhouse gas emissions due to the higher emission factors and the longer distances. Half of the flight travels from 2013 to 2018 are long distance flights with a distance of at least 1,000 km, resulting in 82 % of the flight travel emissions.

Train Travel

Also with trains, there is a difference between first and second class regarding the seat space and therefore the emissions per capita. Another important segregation is the use of a regular compartment, a sleeping compartment or a multi-person sleeping compartment. In a regular compartment, there are six persons in the second class and four in the first class. The sleeping car offers place for one to two persons, while the couchette accommodates four to six passengers.

The required data are equivalent to the ones concerning flight travel, which means travel data of Wegener Center personnel from the past and emission factors of trains. The data that we receive do not include the type of train travel. Furthermore, neither Mobitool (2017) nor other institutions do provide emission factors concerning seat classes for rail traffic.

The standard routes for international train travel considers trips to Germany, Italy, Switzerland and France. In the data set, there are train trips to seven other European countries as well. These countries are Great Britain (GB), Slovenia (SI), Poland (PL), the Czech Republic (CZ), Denmark (DK), Belgium (BE), and Spain (ES). For each country, we consider the real train travel route and find the border crossing points, where the emission factors change. Applying the suitable emission factor to the distance from one border crossing point to the next and summing up all parts, we obtain the greenhouse gas emissions per person kilometer for the trip. To choose an appropriate emission factor, we compare the energy provision of the seven countries to the ones from the standard route countries.

Table 10: Train Emission Factors for GB, SI, PL, CZ, DK, BE, ES and the Train Route (Border Crossing Points), where Emission Factors Change

Country	**Country of the chosen Emission Factor**	**Emission Factor** [g CO_2eq/pkm]	**Route**
Great Britain	Eastern European Countries	59.6	Graz-Salzburg (AT) –Karlsruhe (DE)-Lille (FR)-GB
Slovenia	Eastern European Countries	59.6	Graz-Spielfeld (AT) -SI
Poland	Eastern European Countries	59.6	Graz-Bernhardsthal (AT)-CZ
Czech Republic	Eastern European Countries	59.6	Graz-Bernhardsthal (AT)-Ostrava (CZ)-PL
Denmark	Germany	49.9	Graz-Salzburg (AT)-Fehmarn (DE)-DK
Belgium	Germany	49.9	Graz-Salzburg (AT)-Aachen-BE
Spain	Eastern European Countries	59.6	Graz-Salzburg (AT)-Karlsruhe (DE)-Porté-Puymorens (FR)-ES

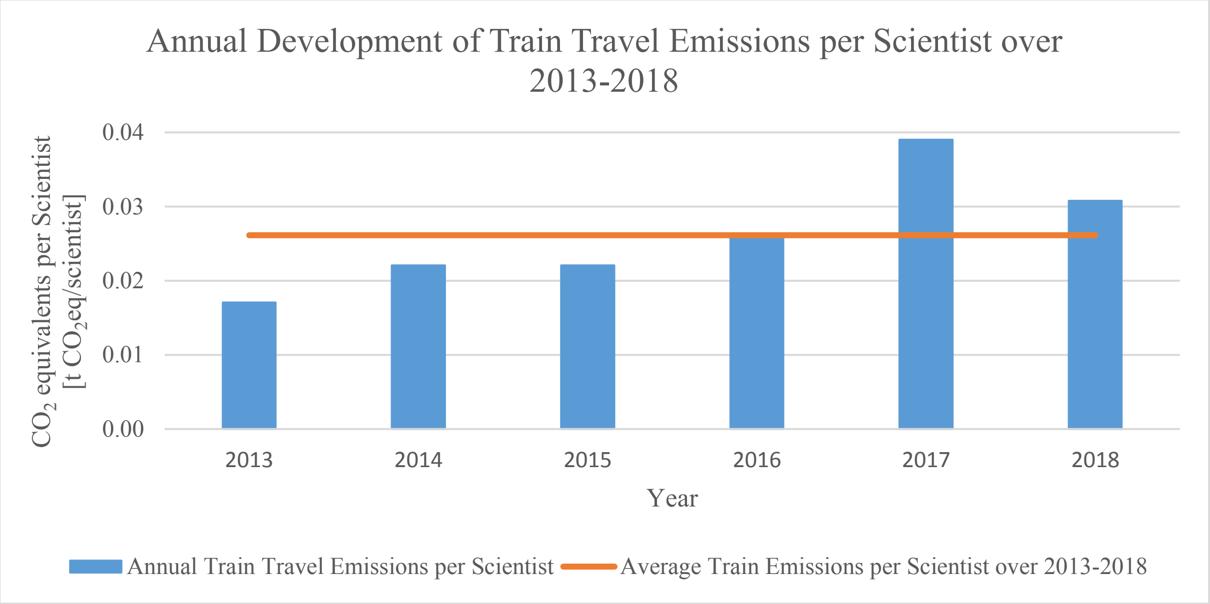

Figure 16: Past Annual Development of Train Travel Emissions per Scientist [t CO_2eq/scientist] with Its Average from 2013 to 2018

Train travel is the only travel mode used in national scientific travels. Therefore, train travel causes all national greenhouse gas emission. In international scientific travels, train trips cover 28 % of the number of travels, but are responsible for only 1.6 % of its emissions. The major part of international scientific train travel is short distance travel (81 %), the remaining part (19 %) covers distances of at least 1,000 km. As seen in the emission factors, train travel in other countries causes different amounts of greenhouse gas emissions. Compared to Austria, all emission factors from other countries are higher, except the one in Switzerland. This leads to the fact that the longer the trip will be, the more emissions it causes not only due to the higher amount of kilometers but also due to the higher emission factors per passenger kilometer in other countries. This is why long distance train travel is responsible for more than one third of the greenhouse gas emissions caused by international scientific train travel.

The average emissions per scientist and year caused by train travel lies between 0.02 and 0.03 t CO_2eq/scientist/year. The development of the past emissions per scientist and year shows that the train emissions per scientist increased over the years (see Figure 16).

Comparing Flight and Train Travel

Comparing the resulting emissions over the years 2013 to 2018, we see that the clear majority from Wegener Center’s scientific travel emissions come from trips using aviation as travel mode. The number of train trips was higher than the number of flight travels, though. The greenhouse gas emissions from national travels, which is the same as national train travel, represent only 0.9 % of the total travel emissions. Aviation as travel mode occurs only in international scientific travels. There, it represents the vast majority (98.4 %) of the greenhouse gas emissions. Accordingly, train travel causes a minor part of the emissions from international scientific travel. In international scientific travels, the share of the number of flight and train trips changes. The share is now one train trip compared to two and a half flight trips. Besides the higher emission factors (g CO_2eq/pkm) of flight travels, the proportion is another reason why the major part of emissions from international scientific travel comes from aviation. Summing up, international scientific travel is responsible for 99.1 % of Wegener Center’s greenhouse gas emissions coming from scientific travels. In addition, the majority comes from aviation, summing up to 97.5 % of Wegener Center’s past travel emissions (see Figure 17, Figure 18).

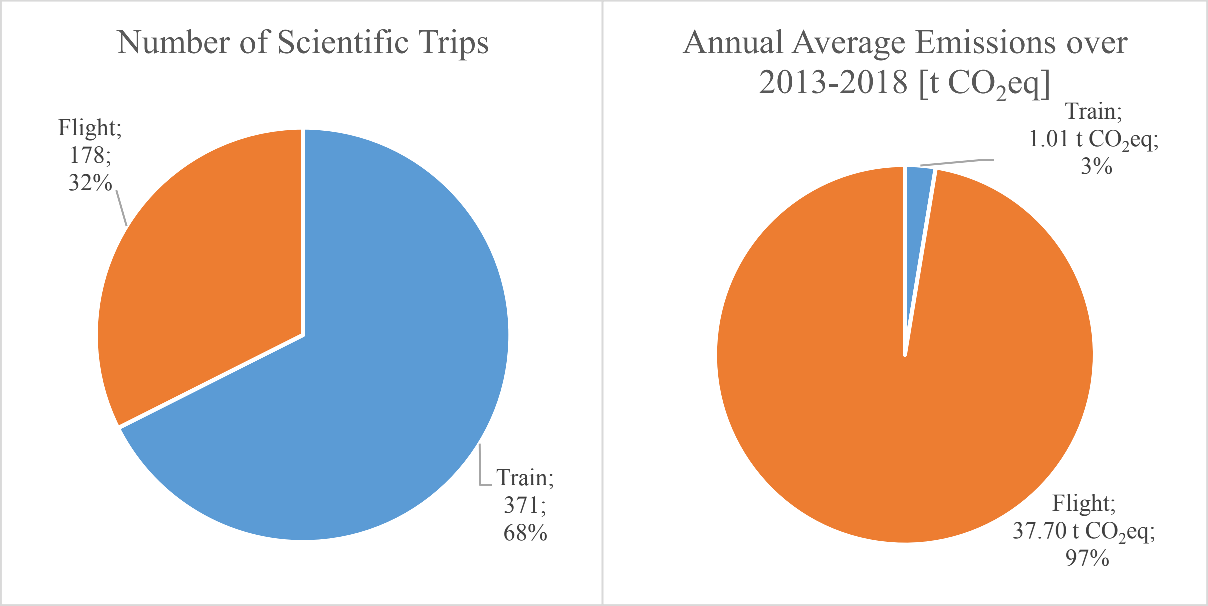

Figure 17: Comparison of Wegener Center's Scientific Travel Emissions by Travel Mode: Number of Total Travels in the Period from 2013 to 2018 and Average Annual Travel Emissions over 2013 to 2018 from Flight and Train Trips

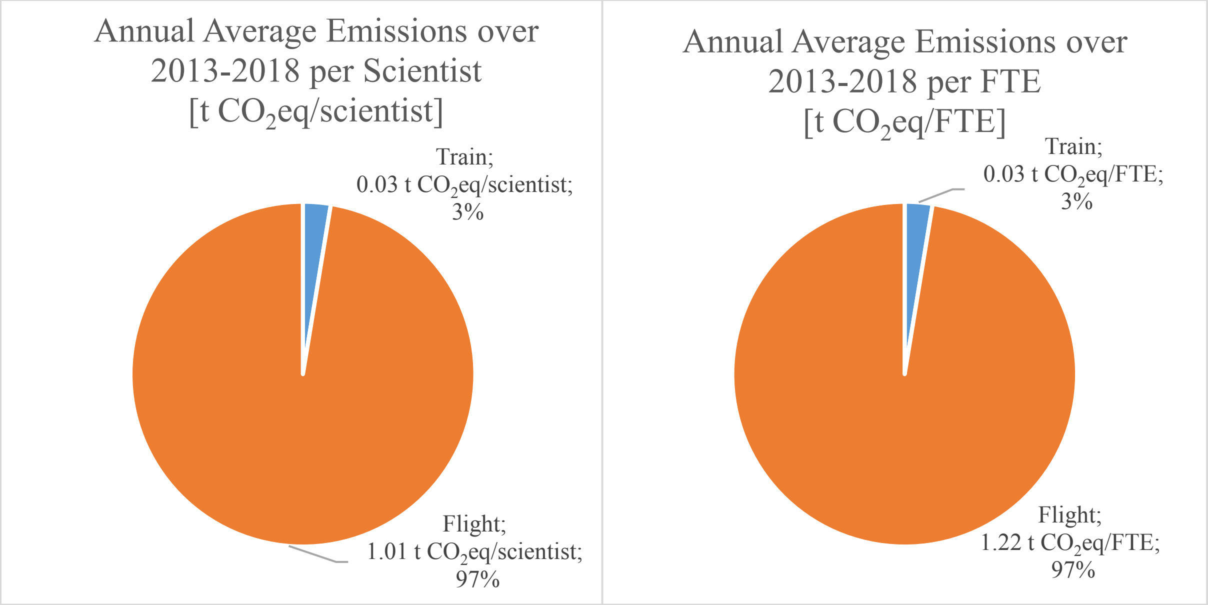

Figure 18: Comparison of Wegener Center's Scientific Travel Emissions by Travel Mode: Average Travel Emissions per Scientist and Average Travel Emissions per FTE over 2013 to 2018 from Flight and Train Trips

Travel Distance:

Considering the travel distance we define two areas. On the one hand, there is short or regional distance travel, on the other hand we define long distance travel. As boundary for the two parts serves the possibility for substitution of train travel for flight travel. Therefore, we choose the distance of 1,000 km from Graz. We consider all points B that lay in a circumference of 1,000 km from Graz as short distance travels.

We assume the average velocity of a train to be 100 km/h. This means that the train needs 10 hours for the 1,000 km. A longer travel time is not reasonable for ISTs. For longer distances, we generally consider flight travels to be not substitutable by train travels.

Figure 19 and Figure 20 lead to one of the core contributions of the assessment of Wegener Center's recent-past travel emissions. The majority, 448 out of 549 (81.6 %), of Wegener Center's scientific trips had a destination point with a distance shorter than 1,000 km from Graz. Nevertheless, the remaining 18.4 % long distance travels caused more than 80 % of the greenhouse gas emissions coming from scientific travels. As the maximum length from Graz to a destination within Austria is shorter than 1,000 km, all long distance trips are international scientific travels.

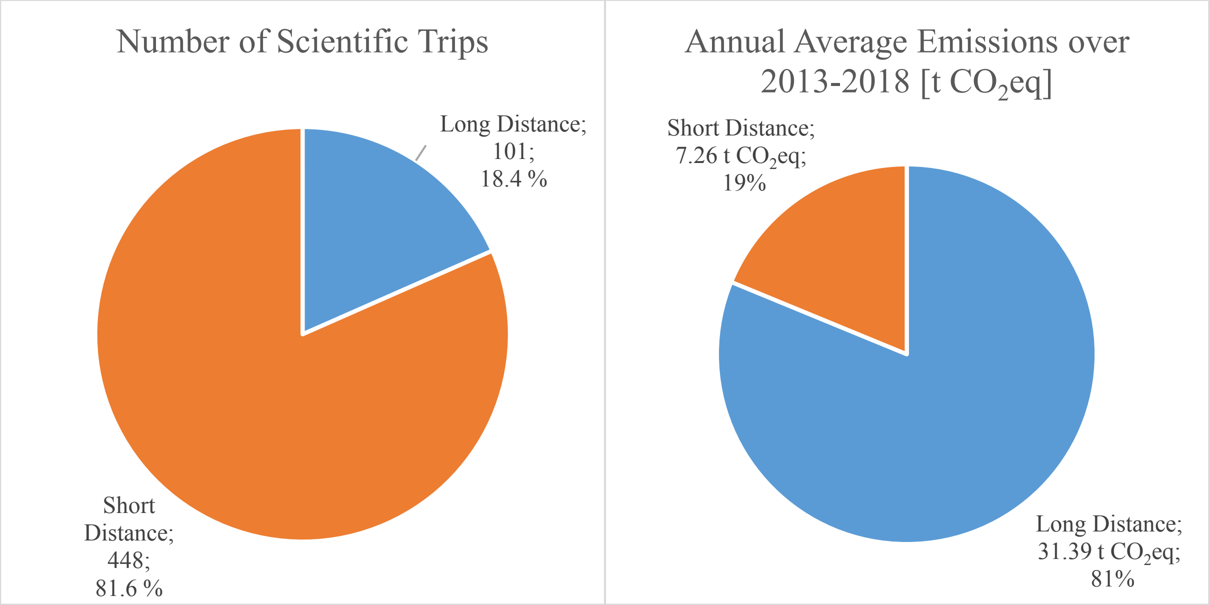

Figure 19: Comparison of Wegener Center's Scientific Travel Emissions by Travel Distance: Number of Total Travels in the Period from 2013 to 2018 and Average Travel Emissions from Short Distance (< 1,000 km) and Long Distance (≥ 1,000 km) from 2013 to 2018

Concerning the travel mode, there are the same number of long distance flights and short distance flights in the period from 2013 to 2018. Nevertheless, long distance flights cause 82 % of the flight emissions, while the same number of short distance flights is responsible for the remaining 18 % of flight emissions.

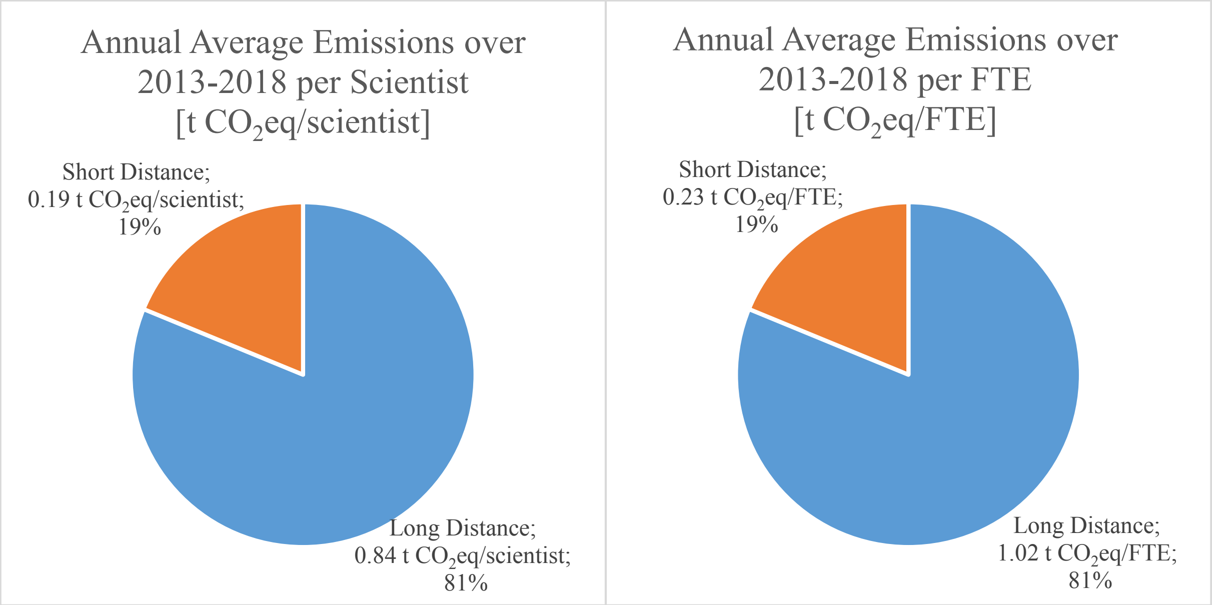

Figure 20: Comparison of Wegener Center's Scientific Travel Emissions by Travel Distance: Average Travel Emissions per Scientist and Average Travel Emissions per FTE over 2013 to 2018 from Long Distance (< 1,000 km) and Short Distance (≥ 1,000 km) Travel

In average, each long distance flight caused 2.09 t CO_2 equivalents. On the other hand, an average short distance flight produced 0.44 t CO_2 equivalents. Although the emission factor (economy class) for international flights (distance ≥ 3,700 km) is lower than the one for

European flights, the elongated distance of long distance flights leads to higher greenhouse gas emissions in this category.

Seen as percentage, long distance travel shows a lower share of train travels than the category short distance. Only 13 of the 101 (12.8 %) long distance trips are train travels. The destinations cover different European countries: France, Denmark, Great Britain, Spain and Belgium. Train travel contributes to less than 1 % of long distance greenhouse gas emissions, while more than 99 % are coming from flight travel emissions.

For short distance trips, the relationship is different. Here, train travel represents about 80 % (358 of 448) of the scientific travels. Although the number of short distance train travels is high compared to short distance flights, the latter is still responsible for 90 % of the greenhouse gas emissions of short distance travels.

Regarding the development over the years from 2013 to 2018, in both long and short distance travel the last two years lie above their average annual greenhouse gas emissions per scientist. In the contrary, we see a difference in the year 2015. While the emissions from long distance travel in 2015 are far below its average of 0.81 t CO_2eq/year/scientist, the greenhouse gas emissions from short distance travels reach their highest value (see Figure 21, Figure 22).

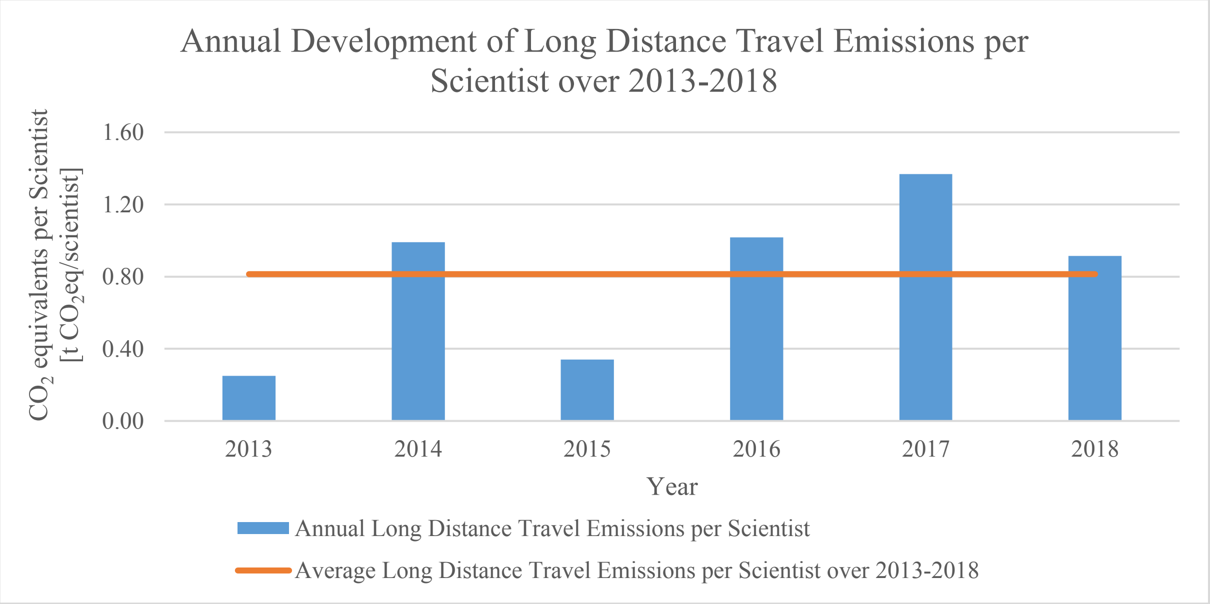

Figure 21: Past Annual Development of Long Distance Scientific Travel Emissions per Scientist with Its Average from 2013 to 2018

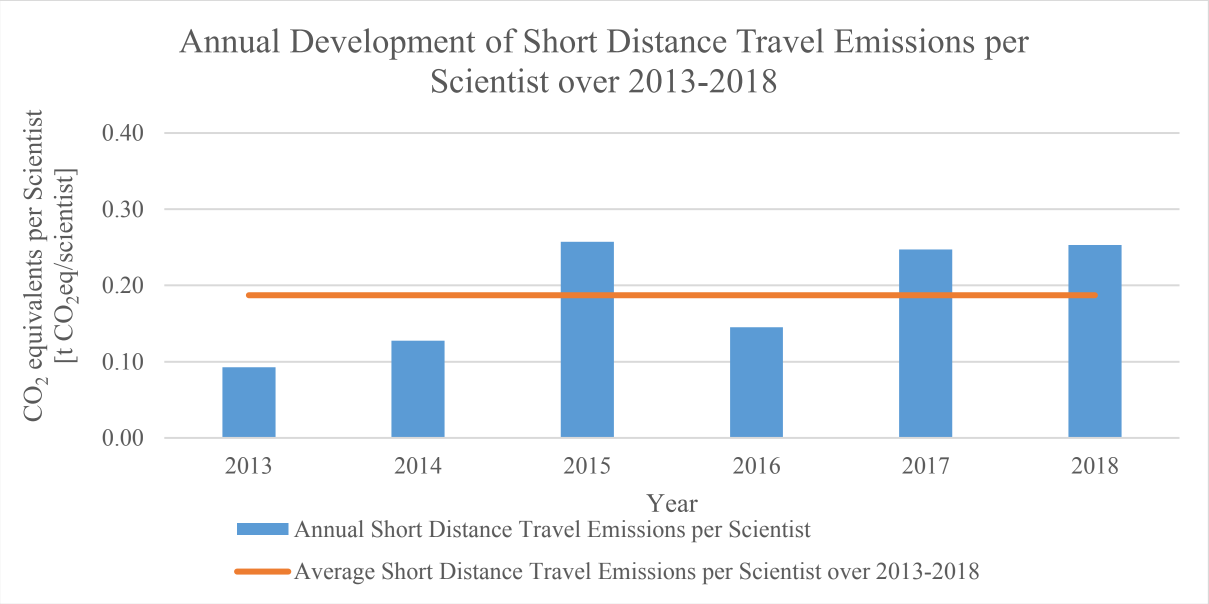

Figure 22: Past Annual Development of Short Distance Scientific Travel Emissions per Scientist with Its Average from 2013 to 2018

Reference Group:

Depending on different aspects, we expect the resulting emissions to differ from group to group. Therefore, we disaggregate the reference group into three sub-dimensions. The number of travellers in the Wegener Center corresponds to the number of its scientists.

Gender of Traveller

The first differentiation of the reference group is the one of the gender. A further differentiation capturing Wegener Center staff with LGBTQ orientation is not possible with our data set. In Table 11, we see the number and the FTEs of female and male scientists for the period from 2013 to 2018. The share of female and male scientists remains relatively constant over the years.

Table 11: Number of Female and Male Scientists and Number of FTEs staffed by Female and Male Scientists 2013 to 2018

	Gender of Traveller							
	Female Travellers				**Male Travellers**			
	Scientists		**FTE**		**Scientists**		**FTE**	
	Number	Percentage [%]	FTE	Percentage [%]	Number	Percentage [%]	Number	Percentage [%]
2013	9	31	8.00	31	20	69	17.75	69
2014	9	31	8.50	31	20	69	19.00	69
2015	9	22	6.50	22	32	78	23.25	78
2016	13	29	9.75	29	32	71	23.75	71
2017	13	31	10.50	31	29.25	69	23.25	69
2018	12	32	11.25	32	26	68	24.00	68

Although the group of male scientists dominates both the number of scientific travels and the average amount of greenhouse gas emissions, it is different when seen per scientist or FTE (see Figure 32). The amount of CO_2 equivalents per female scientist is higher than the one of its male colleagues in four of the six years. The same is true for CO_2 equivalents per FTE. The average amount of scientific travel greenhouse gas emissions is 1.30 t CO_2 equivalents per female scientist, while for male scientists it is 0.91 t CO_2 equivalents per scientist.

The share of flight to train travels is similar for Wegener Center's female scientists and for its male ones. In both cases, about one third of the travels are flight travels. Consequently, the percentage of scientific travel emissions per travel mode is comparable. While flight travels account for 98.0 % of the total travel emissions for female scientists, they are responsible for 97.2 % of male scientist's travel emissions.

Male scientists have a slightly higher amount of long distance travel, covering 19.5 % of their scientific travels. The number of long distance travel for female scientists is 16.4 %.

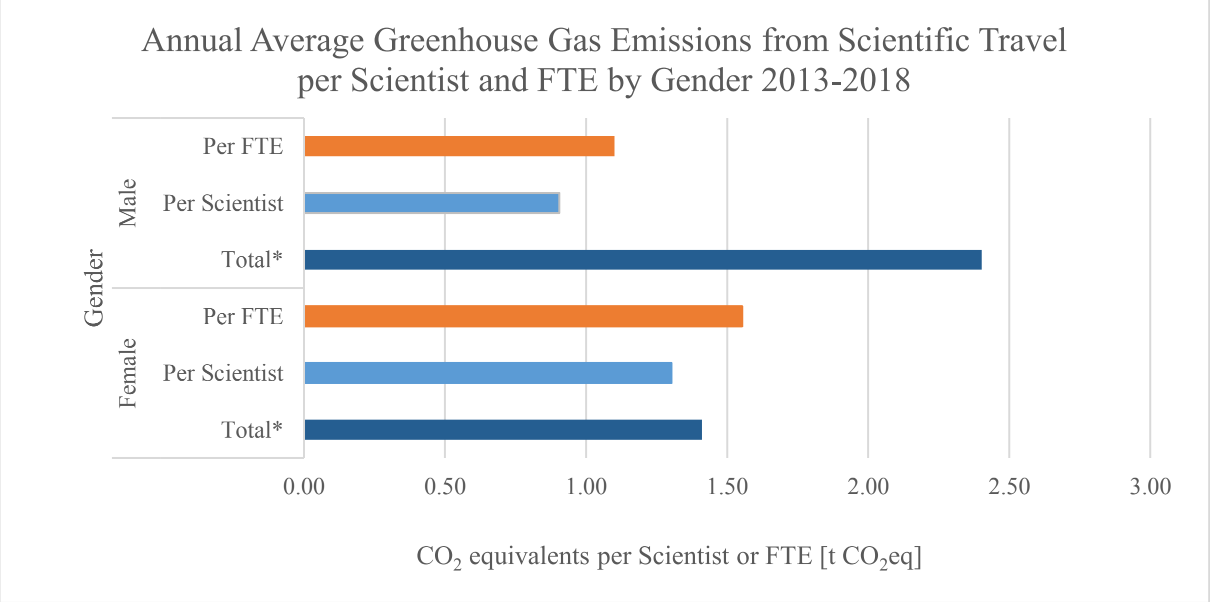

Figure 23: Annual Average Greenhouse Gas Emissions per Scientist and FTE by Female and Male Scientists 2013-2018.
**: The magnitude for the total amounts is *10^1 t CO2eq, in order to provide a clearer representation*

Scientific Seniority of Traveller

There are differences in Wegener Center's scientists concerning their scientific seniority. We distinguish "prae-doc scientists", "post-doc scientists" and "senior scientists". Various remits may lead to different scientific travel activities. Prae-doc scientists are currently working on their doctoral degree, while post-docs already finished it.

The group of the prae-doc scientists accounts for the highest number of trips (221 out of 549) in the period from 2103 to 2018. As prae-doc scientists represent the biggest group of the three, their high share on the number of travels is reasonable. Summing up to almost 47 %, prae-doc scientists also contribute to the largest part of the average scientific travel greenhouse gas emissions per year, which follows from the high number of scientific travels. The situation changes regarding greenhouse gas emissions per scientist or per FTE.

Post-doc scientists perform the fewest scientific travels but their trips contribute to a higher amount of greenhouse gas emissions than the scientific travels from Senior Scientists. This leads to the expectation that post-doc scientists may have a higher share of flight to train travels than senior scientists do. About 38 % of post-doc scientist's travels are flight travels. In the category senior scientists, flight trips account for about 26 %. Concerning prae-docs, 33.5 % of their travels are flight travels (see Figure 23).

For all of the three groups, long distance travel is accountable for the bigger part of the greenhouse gas emissions. Short distance travel emissions have the highest proportion in the group of senior scientists. There, long distance travel accounts for 69 % of senior scientist's total travel emissions. In the groups of prae-doc scientists and post-doc scientists, long distance travel accounts for more than 80 % of the greenhouse gas emissions.

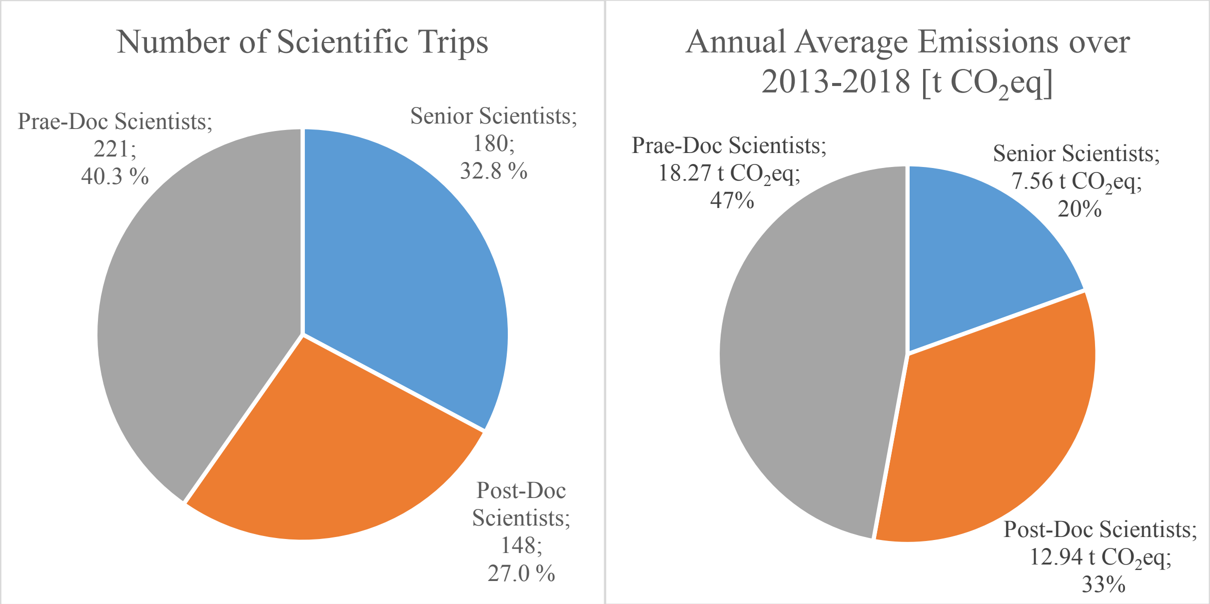

Figure 24: Comparison of Wegener Center's Scientific Travel Emissions by Scientist's Scientific Seniority: Number of Total Travels in the Period from 2013 to 2018 and Average Travel Emissions from 2013 to 2018 from Senior Scientists, Post-Doc Scientists and Prae-Doc Scientists

Although the group of prae-doc scientists is responsible for the biggest part of travel emissions, they have the lowest emissions per scientist. Regarding greenhouse gas emissions per year and

FTE, the three groups show relatively similar amounts, while referring to emissions per year and scientist, the amounts vary more between the groups (see Figure 25).

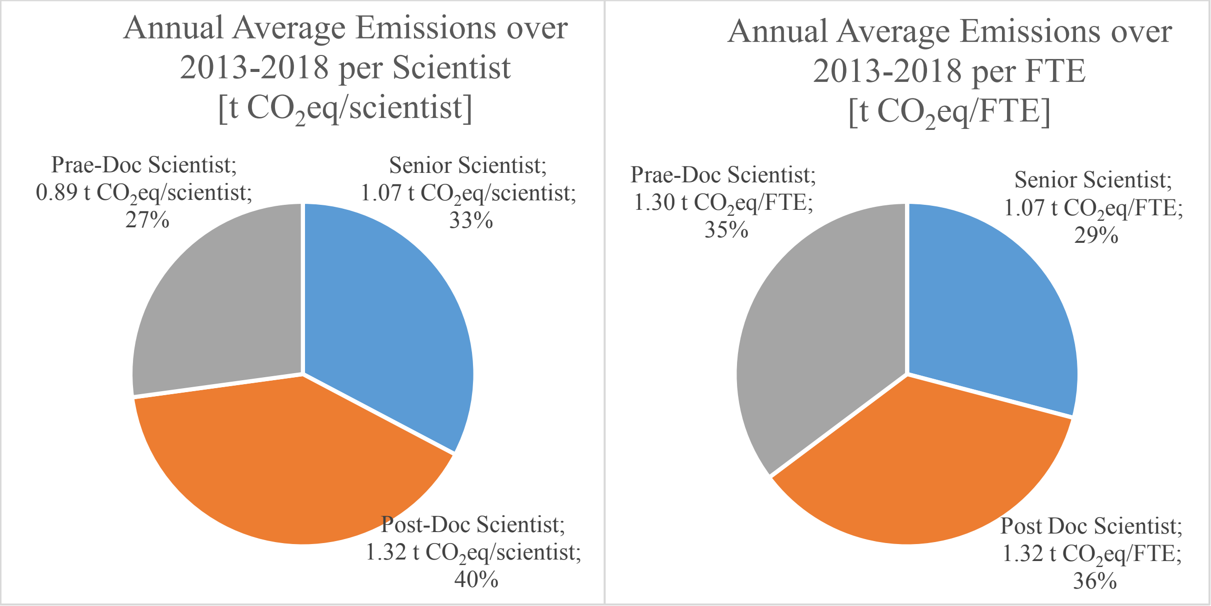

Figure 25: Annual Scientific Travel Emissions per Scientist and FTE as Average from 2013 to 2018. The average amount of greenhouse gas emissions from Senior Scientists is divided by the average number of Senior Scientists working in the Wegener Center. For post- doc scientists and prae-doc scientists the same calculation step is done. For Senior Scientists and Post-Doc Scientists the amount of greenhouse gas per scientist corresponds to the amount of greenhouse gas emissions per Full Time Equivalent (FTE). For Prae-Doc Scientists, the amount changes from 0.89 t CO₂eq/scientist to 1.30 t CO₂eq/FTE.

Scientific Field of Traveller

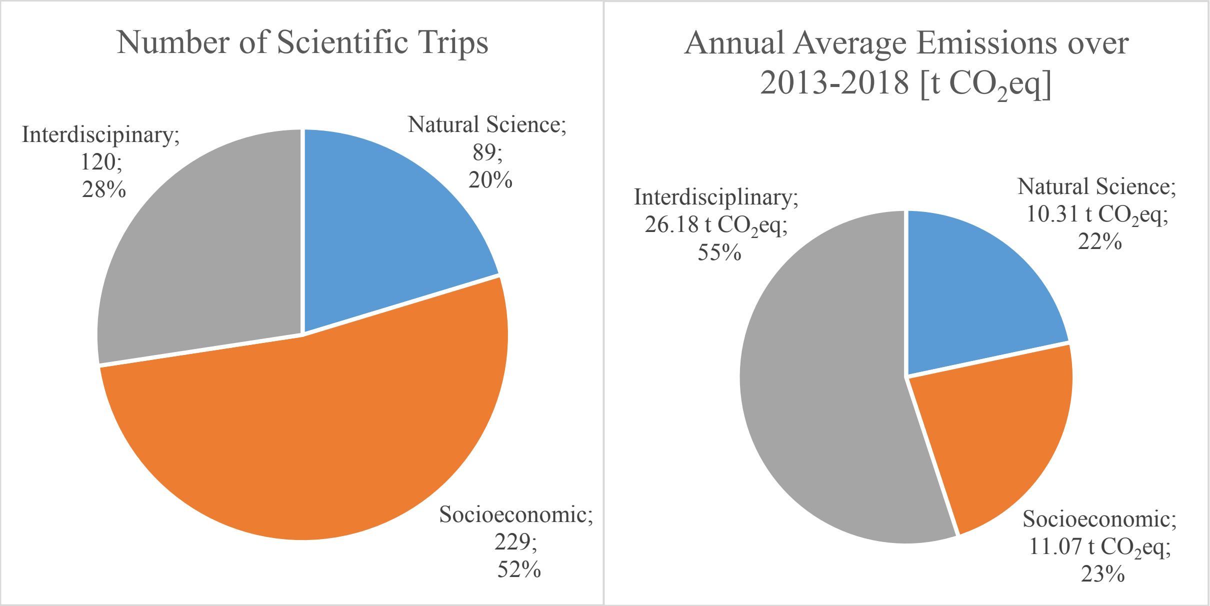

Figure 26: Comparison of Wegener Center's Scientific Travel Emissions by Scientist's Scientific Field: Number of Total Travels in the Period from 2013 to 2018 and Average Travel Emissions from 2015 to 2018 from Natural Science, Socioeconomic and Interdisciplinary Scientists

As the Wegener Center is working in different scientific fields, there are variations in travel emissions regarding natural scientists, socioeconomic scientists and interdisciplinary scientists (see Figure 26). The interdisciplinary field exists since the end of 2014, with its travel activity starting in 2015. It hosts mainly prae-doc scientists, which is why we see an increase of prae-docs in 2015.

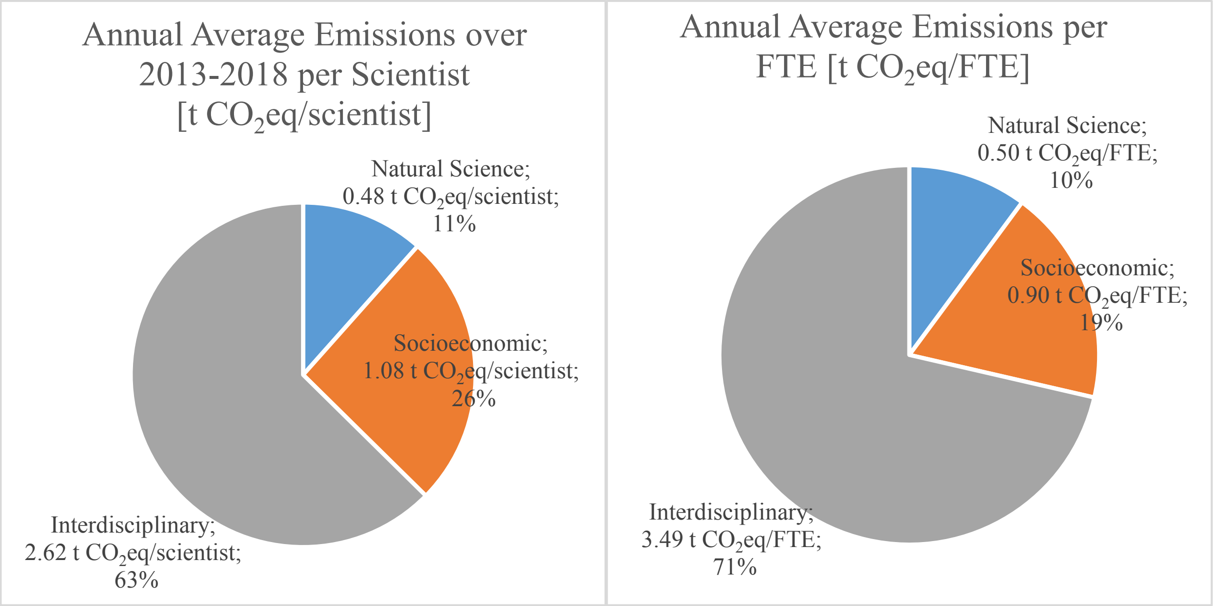

Figure 27: Annual Scientific Travel Emissions per Scientist and FTE as Average from 2015 to 2018. The average amount of greenhouse gas emissions from Natural Scientists is divided by the average number of Natural Scientists working in the Wegener Center. For Socioeconomic and Interdisciplinary Scientists the same calculation step is done. As the department containing interdisciplinary scientists was founded at the end of 2014, scientific travels took place beginning with 2015. Therefore, the we use the average over 2015 to 2018.

Socioeconomic scientists did the majority of the number of scientific travels between 2015 and 2018. A quarter of their travels are flight travels. Natural scientists did the smallest number of travels. However, they show a higher share of flight travels (38 %). Converting the travels into their produced greenhouse gas emissions, we see that the natural science part is the smallest, while interdisciplinary scientists are responsible for the largest part (55 %). This is mainly because about half of interdisciplinary travels are flight travels. Additionally, the major part of the flights (69.5 %) were long distance flights. Greenhouse gas emissions from the interdisciplinary field were much higher in the last three years than the ones from socioeconomics and natural science. One reason for this difference could be the young age of the interdisciplinary department of the Wegener Center. Its scientists may build new connections through attending, for instance, in conferences or summer schools. In addition, the average amount of greenhouse gas emissions per scientist and per FTE is the highest for the interdisciplinary group, which is probably because of higher funding (see Figure 27, Figure 28, Figure 29).

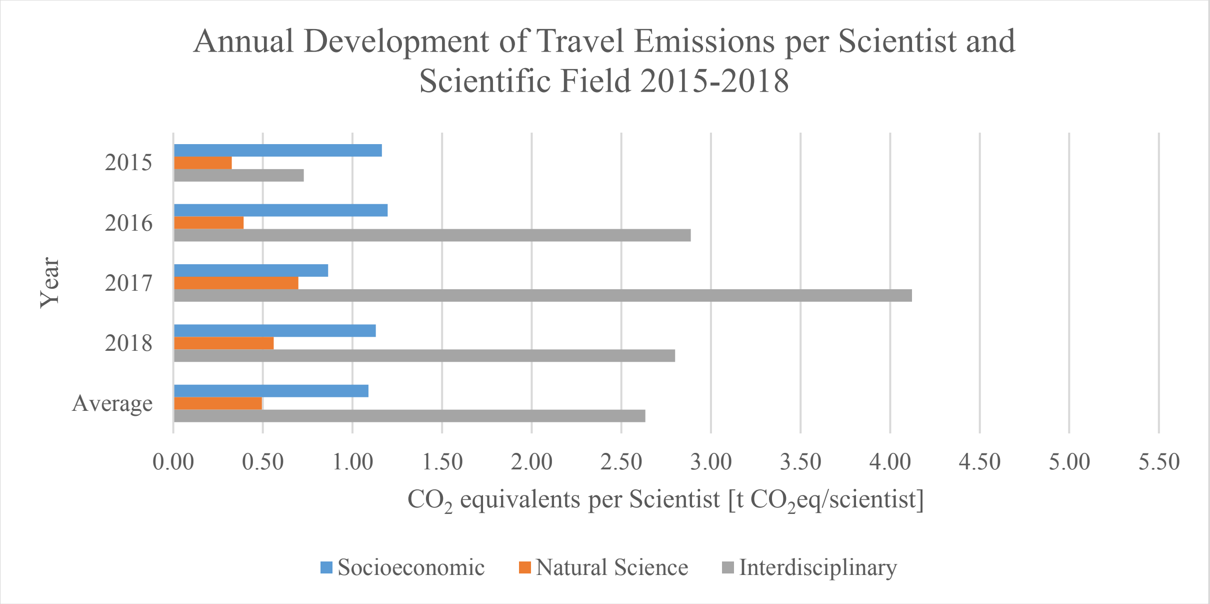

Figure 28: Comparison of the Development of Annual Travel Greenhouse Gas Emissions per Scientist Accounted by Scientists of Different Scientific Fields 2015-2018

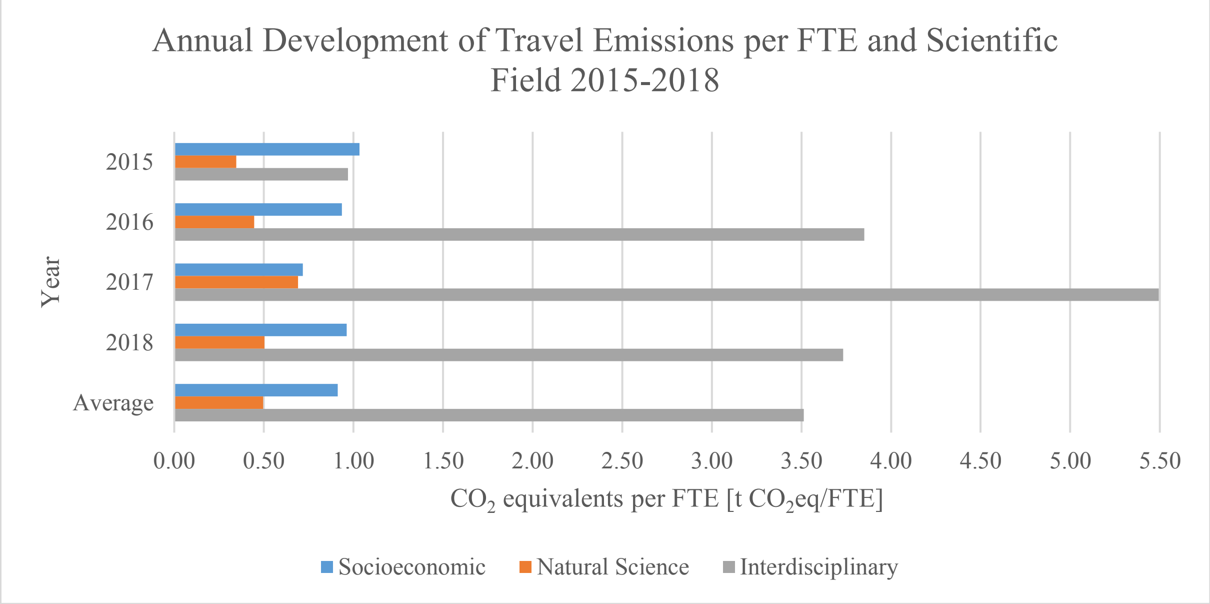

Figure 29: Comparison of the Development of Annual Travel Greenhouse Gas Emissions per FTE Accounted by Scientists of Different Scientific Fields 2015-2018

The average (2015-2018) travel greenhouse gas emissions per socioeconomic scientist and year is 1.09 t CO_2eq/scientist/year. The last three years the values show a slight decrease. The average greenhouse gases per interdisciplinary scientist with 2.63 t CO_2eq/scientist/year is high compared to a socioeconomic researcher. Moreover, they are about five times the average travel emissions coming from a natural scientist (0.49 t CO_2eq/scientist/year). In both groups, the average travel greenhouse gas emissions increased from 2015 to 2017 and decreased in the following year.

As mentioned, the main reason for the significantly higher amount of resulting travel emissions from interdisciplinary scientists is probably the own funding they have. The higher amount of aid money and the associated obligation of presence, for instance in conferences, leads to international scientific travels. As we saw in the evaluation of the greenhouse gas emissions from interdisciplinary scientists, the high CO_2 equivalents per scientist or per FTE (see Figure 30, Figure 31, Figure 32) arises from the chosen travel mode, which is also connected to the destination. In the period from 2015 to 2018, about the half of the travels of interdisciplinary scientists are flight travels (49 %), while 69.5 % thereof are long distance flights with a distance longer than 1,000 km. These long distance flights caused about 91 % of the total travel emissions from interdisciplinary scientists from 2015 to 2018.

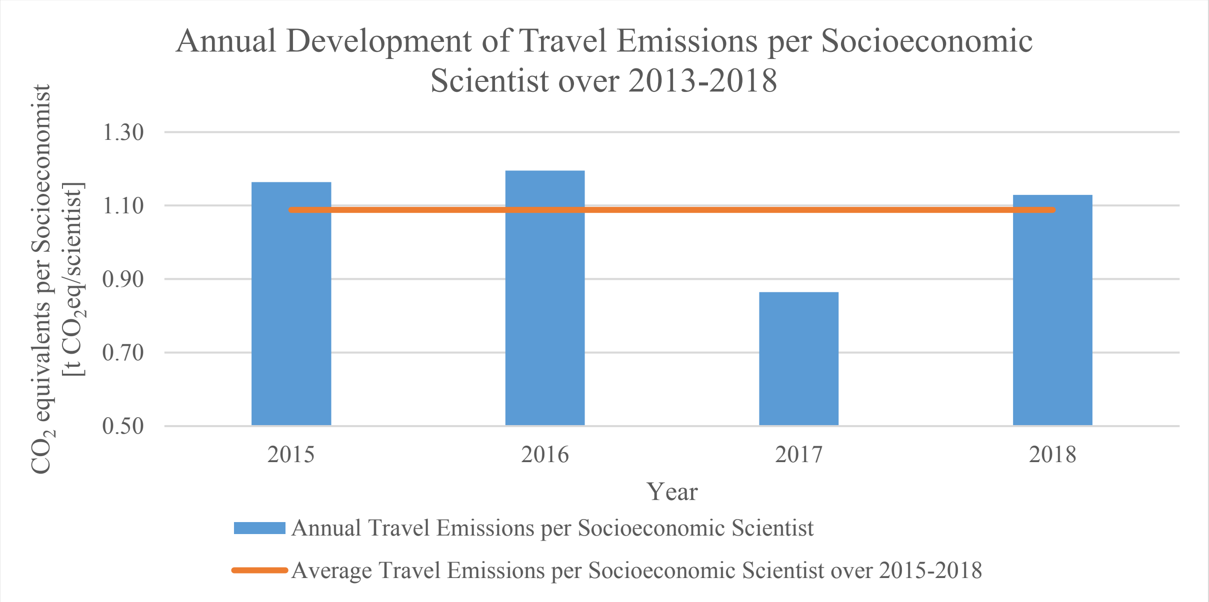

Figure 30: Past Annual Development of Travel Greenhouse Gas Emissions per Socioeconomic Scientist with its Average from 2015 to 2018

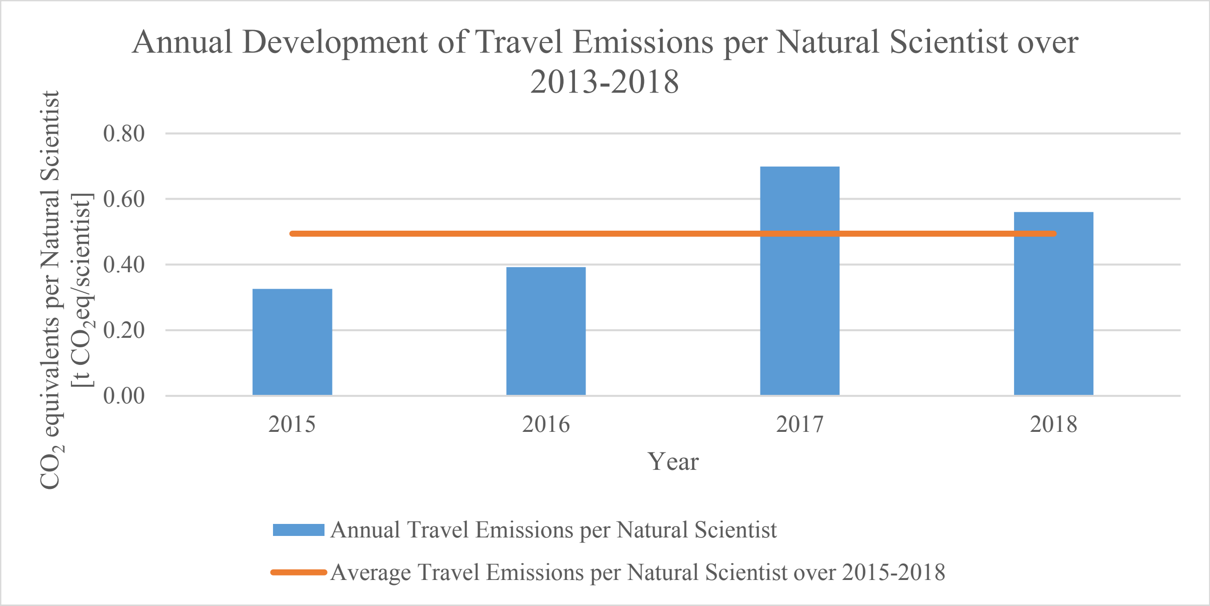

Figure 31: Past Annual Development of Travel Greenhouse Gas Emissions per Natural Scientist with its Average from 2015 to 2018

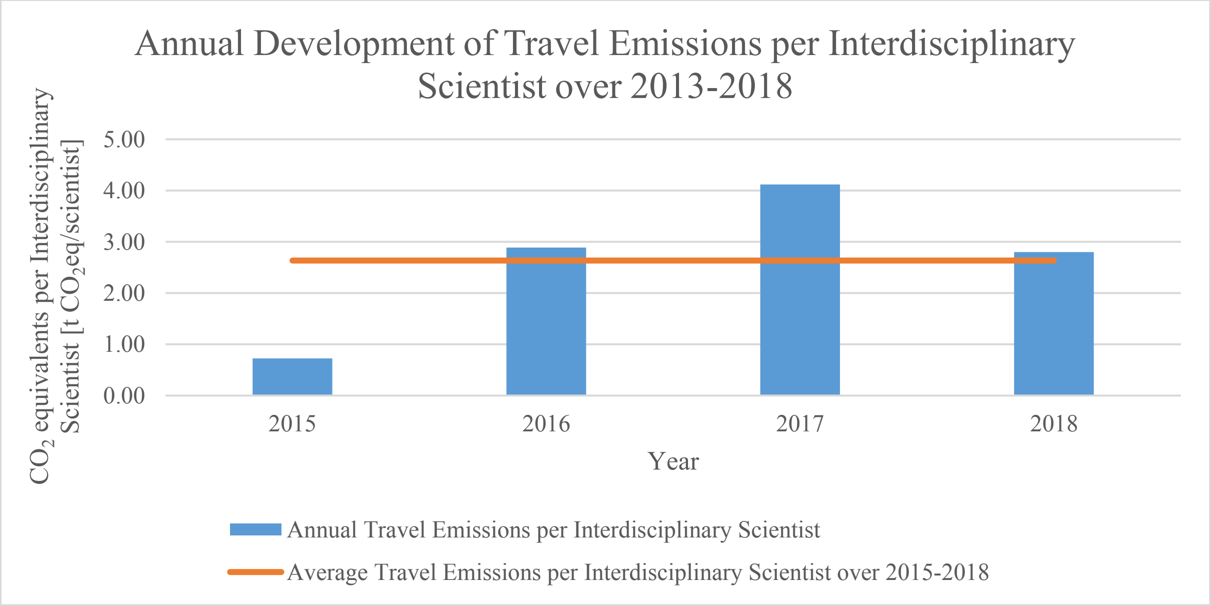

Figure 32: Past Annual Development of Travel Greenhouse Gas Emissions per Interdisciplinary Scientist with its Average from 2015 to 2018

3.2. Non-Travel Emissions from the Institute

This part considers all non-travel emissions produced by the work of the Wegener Center. These include the main causes of such a facility: heating, illumination, IT infrastructure, et cetera. We explore the data as emissions per year starting from the year 2013 as an annual balance should be established. To define a clear system boundary, we use the building of the Wegener Center.

3.2.1 Electricity and Heating

Table 12: Wegener Center's Amount of Electricity and Heating in Kilowatt Hour[kWh] per Year

		2013	**2014**	**2015**	**2016**	**2017**	**2018**
Electricity	**kWh**	31,158.4	33,074.0	25,306.0	29,942.0	32,387.0	35,083.0
Heating	**kWh**	105,938.6	105,938.6	105,938.6	105,938.6	105,938.6	105,938.6

Electricity:

According to the environmental statement (University of Graz, 2017), all of the electricity the University of Graz uses comes from 100 % renewable resources. More specifically, the electric power comes from hydropower plants from the network operator "Stromnetz Graz GmbH". The total amount of electricity used from personnel and from active students was 20,852,997 kWh in 2016. One source for the use of electricity are the IT facilities for teaching and research, on working places from the personnel as well as working places used from students. Also electric lightning demands electricity, as well as it is used in conference rooms, social rooms and for other devices. In addition, technical building equipment and toilets contribute to the electricity consumption (University of Graz, 2017). In the Wegener Center, the IT facilities and the lightning cause the main electricity demand.

We derive the emission factor for the electricity used in the University of Graz from data available in the environmental statement 2017. In 2016, the generation of 20,852,997 kWh electricity led to greenhouse gas emissions of 5,807,560 kg CO_2eq (University of Graz, 2017). This means that the resulting emission factor is 278.5 g CO_2eq/kWh.

The emission factor corresponds to the value provided by the Umweltbundesamt (Gemis 4.9) (as cited in "Climcalc_edu_v1_0_Bilanzierungstool" from the University of Natural Resources and Life Sciences, Vienna (BOKU), the University of Klagenfurt (AAU) and the Umweltbundesamt (UBA), 2017). 87 % of the total amount of greenhouse gases per kWh electricity are direct emissions. At the same time, they are scope 2 emissions. The remaining part, 13 % of the 278.5 g CO_2eq/kWh, are upstream emissions or scope 3 emissions.

Although the electricity that the University of Graz uses comes from 100 % renewable resources (University of Graz, 2017), the used emission factor correspond to the Austrian electricity mix. This is because the consumed electricity was not yet certified with the "Österreichisches Umweltzeichen" in the period from 2013 to 2018. Therefore, Umweltbundesamt (Gemis 4.9) (as cited in BOKU, AAU, UBA, 2017) has the convention that the emission factor for Austria's overall electricity is to be used. Only electricity with the Austrian “UZ46” certificate has the lower emission factor of 30.3 g CO_2eq/kWh.

Concerning electricity production, Austria produced 78 % of its electricity from renewable energies in 2016 (BMNT, 2018).

Dones et al. (2004) and Knight, Steinhurst and Schultz (2012) state that the development of greenhouse gas emissions in a hydropower plant occurs in different life stages.

For hydropower plants, the construction and production of the dam contributes to the largest part of its greenhouse gas emissions because it needs huge amounts of concrete (Dones et al., 2004; Knight et al., 2012; Weisser D., 2006).

According to Dones et al. (2004), the amount of indirect emissions depend on plant and site features, e.g. the location, the capacity, the type of dam, etc. In addition, the type of hydropower plant influences its resulting greenhouse gas emissions. Pumped-storage plants usually show higher overall emissions than run-of-river hydropower plants. Pumped-storage plants rely on the electricity mix, which they need to pump the water back to a specific height.

Barros et al. (2011) as well as Knight et al. (2012) explain the production of direct emissions in hydropower plants the following way. Direct emissions from the operation come from the decomposition of the flooded biomass, which leads to the production of carbon dioxide CO_2 and methane CH_4. The decay slows down with the age of the plant, as the amount of flooded biomass decreases due to decomposition. This means that in the initial phase of the plant more greenhouse gas emissions arise than in a later life stage. The more years the plant operates, the less emissions are produced due to bacterial activity.

The decomposition and oxidation of organic matter depends on different aspects. Examples are the climate and the climate zone (Barros et al., 2011; Dones et al., 2004; Knight et al., 2012; Weisser D., 2007), the size of the plant (Weisser D., 2007), the type and amount of the flooded biomass (Barros et al., 2011; Dones et al. 2004; Knight et al., 2012; Weisser D., 2007) and the the depth of the reservoir, as bottom water and sediments are anoxic and CH_4 is produced (Barros et al., 2011; Dones et al., 2004; Weisser D., 2007).

Hertwich (2013) describes N_2O as another greenhouse gas arising in hydropower plants. Additional to the oxidation of biomass, which leads to CO_2 and CH_4, denitrification of bound nitrogen produces nitrous oxide N_2O. Methane has a better solubility in great depths, as they provide favorable conditions with low temperatures and high pressure. Together with water, methane floods through the turbines. As the gas leaves the turbines, temperature and pressure change, the solubility of the gas decreases and CH_4 is released (Hertwich, 2013).

We receive a table containing Wegener Center's electricity consumption for the years 2014 to 2018 from the Department of Building and Technology University of Graz (Mr. Raimund Klöckl[3]). Table 13 shows the development of the used electricity and its resulting greenhouse gas emissions in numbers. We calculate the emissions by multiplying the amount of kWh electricity per year with the emission factor (0.2785) in kg CO_2eq/kWh.

For the year 2013, we use the average kWh of the five following years.

Table 13: Electricity Consumption and Resulting Greenhouse Gas Emissions of the Wegener Center from 2013 to 2018

Year	**Consumption** [kWh]	**GHG Emissions** [t CO_2eq]
2018	35,083.0	9.8
2017	32,387.0	9.0
2016	29,942.0	8.3
2015	25,306.0	7.1
2014	33,074.0	9.2
2013[4]	31,158.4	8.7

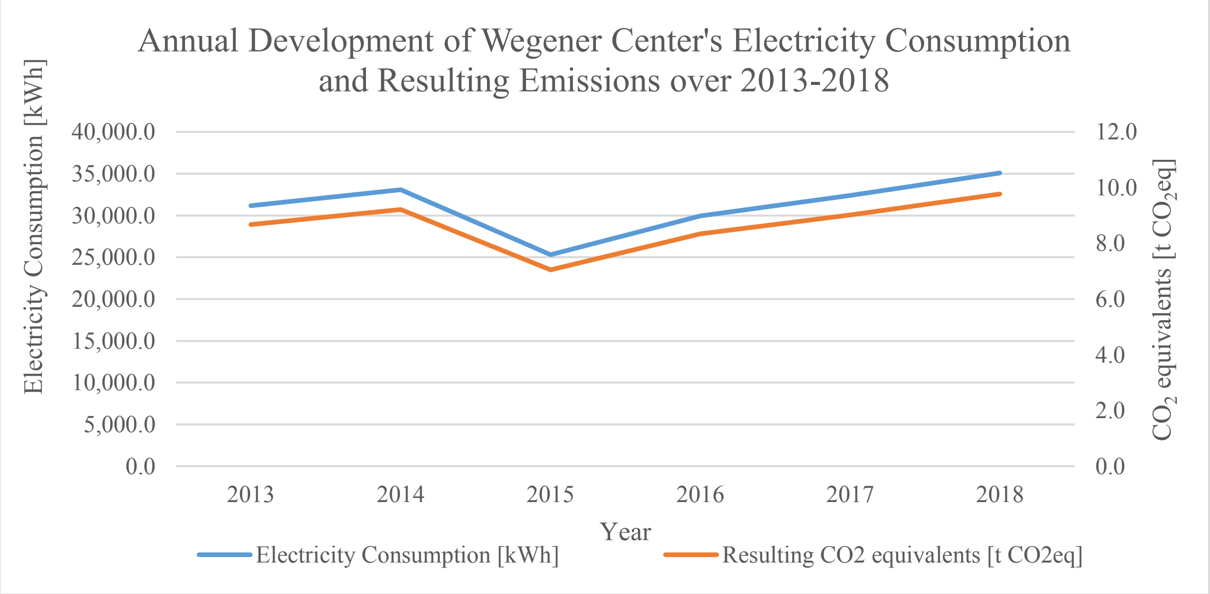

Figure 33: Chronological Development of Electricity Consumption in kWh and its Resulting Greenhouse Gas Emissions in t CO_2eq from 2013 to 2018

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[3] Department of Building and Technology University of Graz, assistant of the head of department. Original: Abteilung Gebäude und Technik, Assistent der Abteilungsleitung

[4] The values for the year 2013 represent the average of the years 2014 to 2018

Figure 33 shows the development of Wegener Center's electricity consumption and the resulting emissions. The upper, blue line represents the electricity consumption in kWh in the specific year. The lower, orange line shows the GHG emissions resulting from the electricity. The developing of the two lines is the same, i.e. the lines are parallel. This arises from the fact that the emissions are directly coming from the electricity by a multiplication with a constant value. The year 2014 shows a high amount of consumed electricity compared to the other years, which is only higher in 2018. From 2014 to 2015, we see a decrease of almost 25 %. Table 9 shows that the number of employees increased sharply. For the following three years, the amount increases again.

Heating:

According to the environmental statement 2017 ("Umwelterlärung") (University of Graz, 2017), in the year 2016, the University of Graz consumed 20,834,652 kWh heat, from which the majority (20,412,734 kWh) came from district heat. Less than 3 % came from other sources such as solar plants. The district heating grid is provided by the city of Graz, the power stations are located in and around Graz. The district heat that the University of Graz uses consists mainly of heat coming from coal-fired district heating power plants or district heating power plants using heating oil and are located around Graz. A small part comes from solar systems and waste heat from a nearby steel and rolling mill. More than the half of the used heat comes from the district heating power station "Mellach".

The environmental statement 2017 ("Umwelterklärung") (University of Graz, 2017) gives the direct greenhouse gas emissions but also greenhouse gas emissions resulting from the production of the energy for the used district heat. In 2016, the CO_2eq emissions caused by the heat consumption of the University of Graz were 6,579,024 kg CO_2eq.

Combining the total amount of greenhouse gas emissions that comes from heating with the amount of consumed heat in kWh in 2016, we obtain an emission factor of 322 g CO_2eq/kWh. While the electricity's emission factor depends on the electricity mix, the one for district heat has a higher winter and a lower summer share, resulting in an average emission factor per year.

The emission factor for heating (322 g CO_2eq/kWh) that the University of Graz uses corresponds again with the one given by Umweltbundesamt (Gemis 4.9) (as cited in BOKU, AAU, UBA, 2017). Here, the emission factor is distributed into 84.5 % direct or scope 2 emissions, while 15.5 % are upstream or scope 3 emissions.

The resulting emissions from district heat are depending on the energy provision of the power plant that provides the heat. Krenn et al. (2014) states that in a coal-fired power plant, greenhouse gas emissions arise due to the combustion process of fossil resources. Carbon dioxide is the main product of the combustion process, but also sulphur dioxide and nitrogen oxides arise due to the presence of sulphur and nitrogen species in the coal. Power plants use denitrification plants to get rid of the nitrogen oxides. A by-product of such denitrification plants is nitrous oxide, which is therefore another greenhouse gas emission occurring at coal-fired power plant. The combustion process produces methane if it is incomplete.

District heat can also come from solar systems. Fraunhofer ISE (2019) describes that solar systems do not produce carbon dioxide during the operation, but the production of solar panels leads to carbon dioxide emissions. Depending on how the production takes place, also nitrogen trifluoride (NF_3) is used. Residual NF_3 is released into the atmosphere. It has a global warming potential of 17,200. Depending on the type of panels, they contain toxic substances, which may be released into the environment and be able to reach the groundwater if the panel is not treated properly after disposal.

As an example, we take a closer look on the district heat power plant “Mellach”. According to the Verbund AG (2019) it uses lignite that comes mainly from Poland for the firing. The fuel demand is 400,000 tonnes per year. The power plant operates from September until May and provides up to 230 MW district heat.

The Federal Environment Agency Austria (“Umweltbundesamt”) (Böhmer & Gössl, 2009) states that the operation during summer shows higher network losses due to the lower heat consumption. The average losses in the grid of “Energie Graz” are with 10 % relatively low, but the net between Mellach and Graz shows additional 2.5 % losses (Böhmer & Gössl, 2009). We want to mention that this information is based on the year 2003.

To calculate the greenhouse gas emissions that the Wegener Center was responsible for due to its heat consumption, we need to have information on the amount of heat used per year. Different departments of the University of Graz do not have the required data. The building management communicated on our request that we are not allowed to get the specific data. Therefore, we went for a different approach and asked for the energy certificate of the building from the Department of Building and Technology of the University of Graz. The energy certificate gives the specific heating requirement is 81 kWh/m^{2}a (DI Jörg Jandl GmbH, 2011). However, the specific final energy demand is higher: 113.69 kWh/m^{2}a (DI Jörg Jandl GmbH, 2011). The specific final energy demand is the amount of energy that the energy system consumes for the heating of the building, the water heating and all auxiliary operations during a standard use of the building (DI Jörg Jandl GmbH, 2011). According to the rental contract, the area of the Wegener Center covers 931.82 m^2.

3.2.2 Product-related Emissions

Other non-travel emissions cover smaller amounts of greenhouse gas emissions that arise due to the work of the personnel of the Wegener Center apart from heating, electricity, and scientific travel. We consider IT-devices and the amount of used paper for copies and printouts that accumulate over the year.

Table 14: Wegener Center's Amount of IT Devices and Paper per Year over 2013-2018

			2013	2014	2015	2016	2017	2018
New Bought IT Device	**PCs**	number	11	8	6	0	6	0
	Monitors	number	18	8	0	6	10	0
	Notebook	number	2	1	1	2	1	2
	Printer	number	2	0	1	0	1	1
Paper	**Paper**	kg	76.00	68.25	64.42	87.29	105.54	77.56

Paper Use:

According to austropapier (2018), the production of paper in Austria was 4.86 million tonnes in 2017. Moreover, Austria produced 2.1 million tons of pulp in the same year. Due to different measures, the paper industry is a circular economy. One aspect is the very high recycling rate of paper in Europe. The recycling rate of paper in Europe is 72.5 %, while the one in Austria is slightly higher with 73.5 %. The paper industry is able to recycle paper several times, before the fibres get too short and the paper is delivered to thermal utilization. Other industries use waste materials from paper mills such as sludge, ashes or tree bark for material or thermal utilization. 1.9 % of the waste material is disposed as there is no other possibility to use them. The paper industry clarifies the used water in wastewater treatment plants and uses it again. In addition, the production facilities use the heat that the production process develops. The paper industry is an energy intensive industry. It requires heat and electricity. In 2017, Austria' paper industry consumed 15,680 GWh, of which 1/3 was electricity and 2/3 heat. Therefore, the paper production in Austria is responsible for 5.7 million tonnes of CO_2 per year. The major part of it (4.1 million tonnes) are biogenic carbon emissions, the smaller one (1.6 million tonnes) are fossil carbon emissions. With an amount of 4.86 million tonnes of produces paper (austropapier, 2018), this leads to 1.16 kg CO_2 emissions per kg of paper.

The institute for energy and environmental research Heidelberg (IFEU, 2006) gives similar values for the amount of greenhouse gas emissions per amount of paper. A difference in the resulting greenhouse gas emissions comes from the different European regions where the paper comes from. Paper fibres from northern regions are responsible for a smaller amount of greenhouse gas emissions, because the transportation route to Germany is not as far as the one from southern regions. IFEU (2006) calculates 1,117 kg CO_2eq per tonne paper with fibres from northern regions, while fibres from southern regions lead to 1,288 kg CO_2eq per tonne paper. Recycled paper has again shorter transportation routes, which directs to 933 kg CO_2eq per tonne paper (IFEU, 2006).

The Wegener Center uses five laser printers in 2019 that are available for the personnel's use. One of the printers is a colour printer, but Wegener Center recommends making black and white printouts. For saving sheets, it also suggests to print double-sided.

As the number of used sheets is not available, we use the costs of prints and copies per year and calculate the amount of paper used. A black and white print costs 0.035 €, while a colour print costs 0.11 €. The number of A3 printouts is comparably small, which is why we neglect them and assume all printouts to have A4 format. We assume that 80 % of the prints are black and white prints. 20 % are colour prints, respectively. This ratio has an impact on the overall costs. In addition, we suppose the relationship between one-sided and double-sided prints to be 80 % double-sided and 20 % one-sided. With these data, we are able to calculate the number of sheets used in a year. The Wegener Center uses three types of recycling paper for their printers. They all have a specific weight of 80 g/m^2. As the measures of an A4 sheet are 210 and 297 mm, its area is 62,370 mm^2. Therefore, one sheet weighs 4.9896 g, a package containing 500 sheets 2,494.8 g. We use this information together with the number of sheets to calculate the weight of the paper that was used in one specific year from the personnel of the Wegener Center.

The following steps describe the calculations for Table 15:

1. We sum up the costs per month to get costs per year (see "sum per year")
2. We calculate 80 % of the costs of "sum per year", which are then the costs for black and white printouts per year. Then, we calculate the remaining 20 % to get the costs for colour printouts in the same year.
3. For both categories, we calculate the costs of the double-sided prints, which are 80 %, and the costs for one-sided printouts, which are the remaining 20 %.
4. We calculate the sheets of paper for all of the four categories by dividing the overall costs of the category by the price per copy. Black and white prints cost 0.035 €, coloured

ones 0.11 €. We have to consider that the price is per copy, not per sheet. A double-sided printout costs therefore two times the price, which is 0.07 € and 0.22 €.

5. We multiply the number of sheets with the weight per sheet (4.9896 g) and convert it into kg.

Table 15: Paper Use Calculations per Year over 2013-2018

			2013	**2014**	**2015**	**2016**	**2017**	**2018**
Sum per year	**total**	**costs** [€]	888.57	797.91	753.17	1020.54	1233.83	906.75
Black and white printouts	**total**	**costs** [€]	710.86	638.33	602.54	816.43	987.06	725.40
	one-sided	**costs** [€]	142.17	127.67	120.51	163.29	197.41	145.08
		Sheets	4,062	3,648	3,443	4,665	5,640	4,145
		weight [kg]	20.27	18.20	17.18	23.28	28.14	20.68
	double-sided	**costs** [€]	568.68	510.66	482.03	653.15	789.65	580.32
		sheets	8,124	7,295	6,886	9,331	11,281	8,290
		weight [kg]	40.54	36.40	34.36	46.56	56.29	41.37
Colour printouts	**total**	**costs** [€]	177.71	159.58	150.63	204.11	246.77	181.35
	one-sided	**costs** [€]	35.54	31.92	30.13	40.82	49.35	36.27
		sheets	323	290	274	371	449	330
		weight [kg]	1.61	1.45	1.37	1.85	2.24	1.65
	double-sided	**costs** [€]	142.17	127.67	120.51	163.29	197.41	145.08
		sheets	646	580	548	742	897	659
		weight [kg]	3.22	2.90	2.73	3.70	4.48	3.29
Sum per year	**total**	**sheets**	13,155	11,813	11,151	15,109	18,267	13,425
		weight [kg]	65.64	58.94	55.64	75.39	91.15	66.98

We obtain the weight of the paper that the Wegener Center used in the period from 2013 to 2018 per year as result. We use this information together with the emission factor of 1.16 kg CO_2eq per kg paper and determine the greenhouse gas emissions deriving from Wegener Center's paper use in the period from 2013 to 2018.

IT Devices:

According to the European Commission (2007), the material extraction, the production, transport and end-of-life treatment of IT devices cause release of greenhouse gas emissions. Besides different materials and water, also energy is required in the different steps. The major part of the greenhouse gas emissions concerning production, transport, use and end-of-life treatment comes from the operation. For a desktop PC in an office, the use contributes to 78 % of the total greenhouse gas emissions, for a notebook it is 74 %.

In our data, the greenhouse gas emissions from the used electricity cover already the operation mode of laptops, PCs and printers. Therefore, we only consider the production, distribution and end-of-life phase in the calculation concerning the greenhouse gas emissions coming from IT devices.

We use emission factors provided by the European Commission (2007). A computer consists of the central process unit, input devices and a display screen (European Commission, 2007). As we have separate numbers of PCs and monitors, we divide the given emission factor by two. Therefore, we allocate half of the amount of greenhouse gas emissions to the LCA based emissions without operation of a personal computer and the other half to the ones of a desktop. The production, distribution and end-of-life treatment of a unit consisting of a PC and a desktop lead to 165 kg CO_2eq (European Commission, 2007). We divide it into two parts to get separate values for desktops and PCs. We obtain 82.5 kg CO_2eq for a monitor and 82.5 kg CO_2eq for a PC. For notebooks, the EU commission gives 90 kg CO_2eq that arise in its production, distribution and disposal or recycling steps (European Commission, 2007). We have also the number of printers that the Wegener Center bought in the years between 2013 and 2018. As the EU Commission (2007) does not provide emission factors for printers, we use the amount given for a PC and desktop as a unit for the LCA based greenhouse gas emissions without operation for a printer, which is 165 kg CO_2eq.

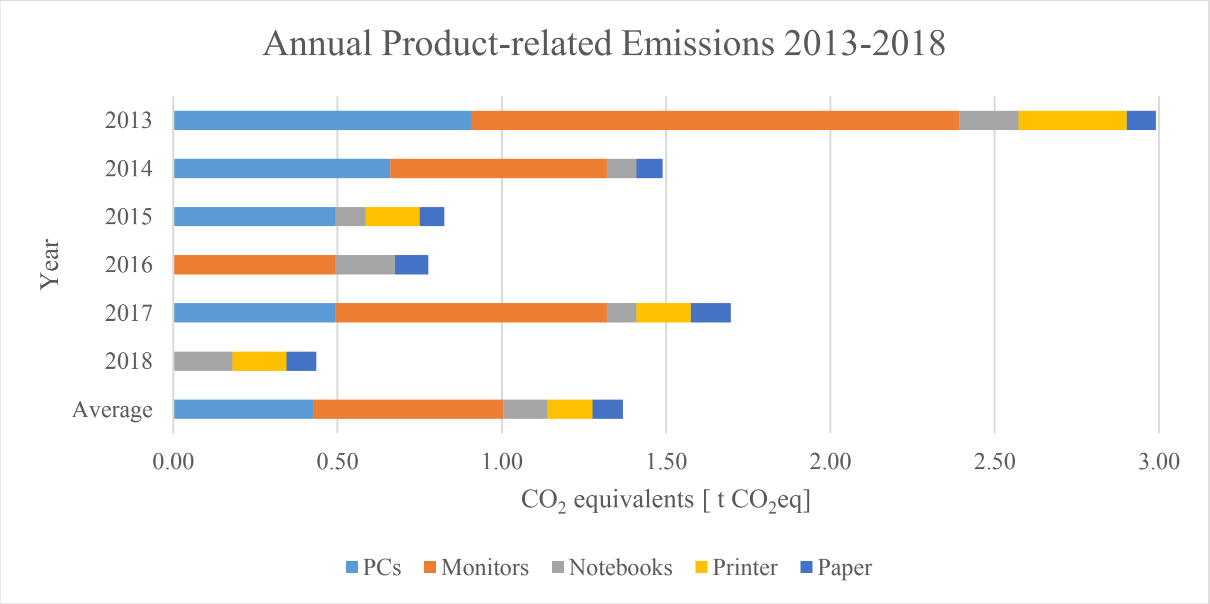

Figure 34: Annual Product-related Emissions from IT Devices and Paper Use

Figure 34 shows the development and composition of non-travel related greenhouse gas emissions without considering heating and electricity. We see that the amount of the greenhouse gas emissions in this category depends on the acquisition of IT devices rather than on paper consumption. The resulting greenhouse gas emissions from IT devices are irregularly distributed over the considered period. This is comprehensible as they arise at the Wegener Center the same moment when the institute buys a PC, a monitor, a notebook or a printer. In the first year, the Wegener Center moved into the current building. In that year, the emissions from IT devices were the highest compared to the following years, as the Wegener Center bought new equipment. We see that the paper contributes only to small parts of the non-travel emissions and is relatively constant compared to the emissions coming from IT devices. Regarding the greenhouse gas emissions from paper alone, they were the lowest in the year 2015, which is similar to the development of the greenhouse gas emissions from Wegener Center's electricity.

The overall context emissions are put together from the production, provision and use of electricity and heating, of the IT devices that the Wegener Center bought over the years and the use of paper.

Summarizing, we use the following emission factors to convert the data into amounts of greenhouse gas emissions: The overall energy consumption (OEC) is 113.69 kWh/m²a (DI Jörg Jandl GmbH, 2011) with Wegener Center's area of 931.82 m². For the electricity coming from hydropower and for the district heat we use emission factors from the environmental statement of the University of Graz. They are 278.5 g CO2eq/kWh for electricity and 322.3 g CO2eq/kWh for heating (University of Graz, 2017). The emissions from paper production and transport are 1.16 kg CO2eq/kg (Austropapier, 2018; ifeu, 2016). For the combination of PC and monitor the EU commission gives 165 kg CO2eq (EU Commission, 2007). As we have the number of PCs and monitors separately, we divide the value and use the half for the production and transportation of a monitor and a PC, which results in 82.5 kg CO2eq per monitor and PC. For printers, we do not find emission values, therefore we compare it to the unity of PC and monitor and use its emission factor 165 kg CO2eq. For notebooks we use 90 kg CO2eq (EU Commission, 2007).

In Table 16 we see the conclusive amounts of non-travel greenhouse gas emissions of the Wegener Center listed in source categories and years. Figure 35 shows their corresponding development from 2013 to 2018. The dominating part are the greenhouse gas emissions coming from heating. As the required energy (kWh) per year and square metre as well as the area of the Wegener Center remain constant, the amount of emissions coming from heating is the same amount for every year. Reducing their amount would be the most effective act concerning non-travel emissions. However, the Wegener Center as institute is not able to change this parameter.

The building is an old building, the walls are thick but the windows are not isolating well. A second aspect is the heat itself. The University of Graz uses district heating, which comes mainly from coal-fired power plant (University of Graz, 2017). The change from fossil fuel based heat to heat from renewable sources could reduce the amount of greenhouse gas emissions coming from heating. With the closure of the coal-fired district heating power plant Mellach and a switch to carbon neutral energy sources such a decrease seems possible.

Table 16: Annual Development of Non-Travel Greenhouse Gas Emissions in t CO$_2$eq in the period from 2013 to 2018

				2013	**2014**	**2015**	**2016**	**2017**	**2018**
Energy related	**Electricity**		t CO$_2$eq	8.68	9.21	7.05	8.34	9.02	9.77
	Heating		t CO$_2$eq	34.14	34.14	34.14	34.14	34.14	34.14
Others	**IT Devices**	**PCs**	t CO$_2$eq	0.91	0.66	0.50	0.00	0.50	0.00
		Monitors	t CO$_2$eq	1.49	0.66	0.00	0.50	0.83	0.00
		Notebooks	t CO$_2$eq	0.18	0.09	0.09	0.18	0.09	0.18
		Printer	t CO$_2$eq	0.33	0.00	0.17	0.00	0.17	0.17
	Paper	**Paper**	t CO$_2$eq	0.09	0.08	0.07	0.10	0.12	0.09
	Sum		t CO$_2$eq	2.99	1.49	0.82	0.78	1.70	0.43
Sum			t CO$_2$eq	***45.81***	***44.84***	***42.02***	***43.26***	***44.86***	***44.35***

The electricity contributes to the second largest part of the non-travel greenhouse gases from the Wegener Center. In the year 2015, we see a clear decline of the use of electricity and therefore the resulting amount of greenhouse gas emissions. A logical explanation would be a technical change in the institute. In the following three years, the electricity related greenhouse gas emissions increase again. Nevertheless, compared to the greenhouse gas emissions from heating, the ones from electricity are about a third.

The greenhouse gas emissions from the IT devices depend on the acquisition of new units, as the operation is included in the electricity. In the year 2013, the most new IT devices were bought, which is because the Wegener Center moved to the current building. The production and transportation of the used paper contributes to a small part of the overall non-travel emissions. Saving paper is therefore desirable in order to save its energy and greenhouse gas emissions coming from the transport of paper, as well as to save resources such as trees, which bind emissions in return. However, emissions from Wegener Center's paper use are the smallest part of its non-travel emissions. Compared to the greenhouse gas emissions from heating and electricity, the IT devices and the paper cause a negligible amount of greenhouse gases.

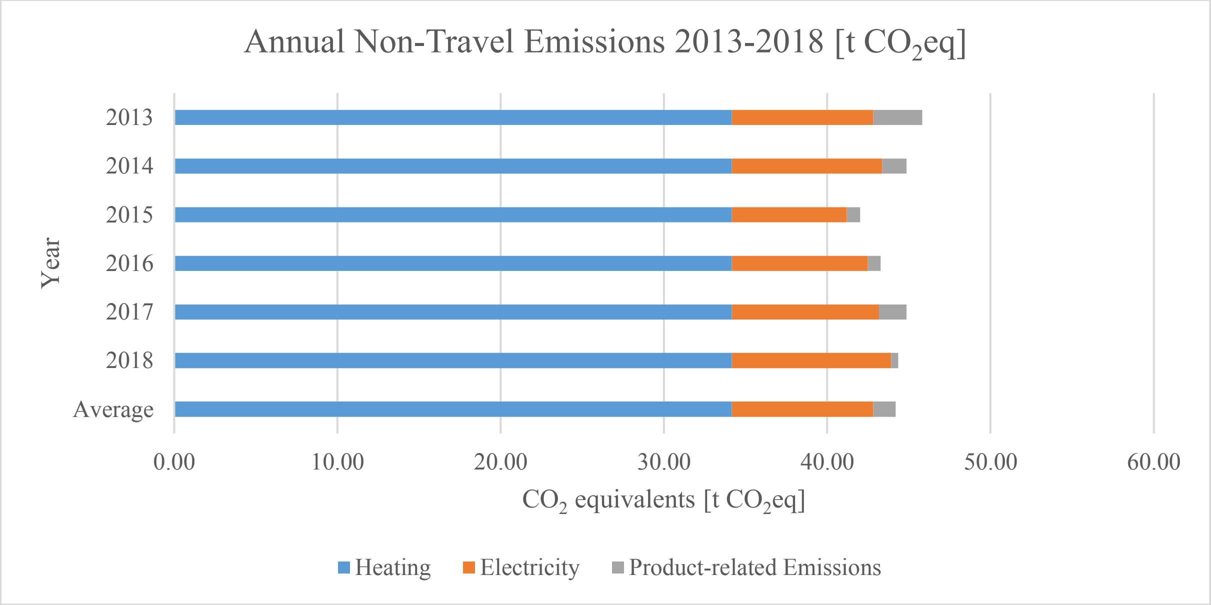

Figure 35: Annual Development of Non-Travel Greenhouse Gas Emissions 2013-2018 [t CO₂eq]

As mentioned, Figure 35 shows that the overall amount of Wegener Center's non-travel emissions remain quite stable over the period from 2013 until 2018. In average, heating emissions are responsible for 77 % of all non-travel emissions, the amount in t CO_2eq is the same for every year. In Figure 36 we see that the heating greenhouse gases per FTE are decreasing every year. This is related to the fact that the number of FTEs on the Wegener Center increases since 2013. As the number of employees and the number of FTEs do not correspond, the development of heating emissions per scientist is different and does not show a downwards trend (see Figure 36, Figure 37).

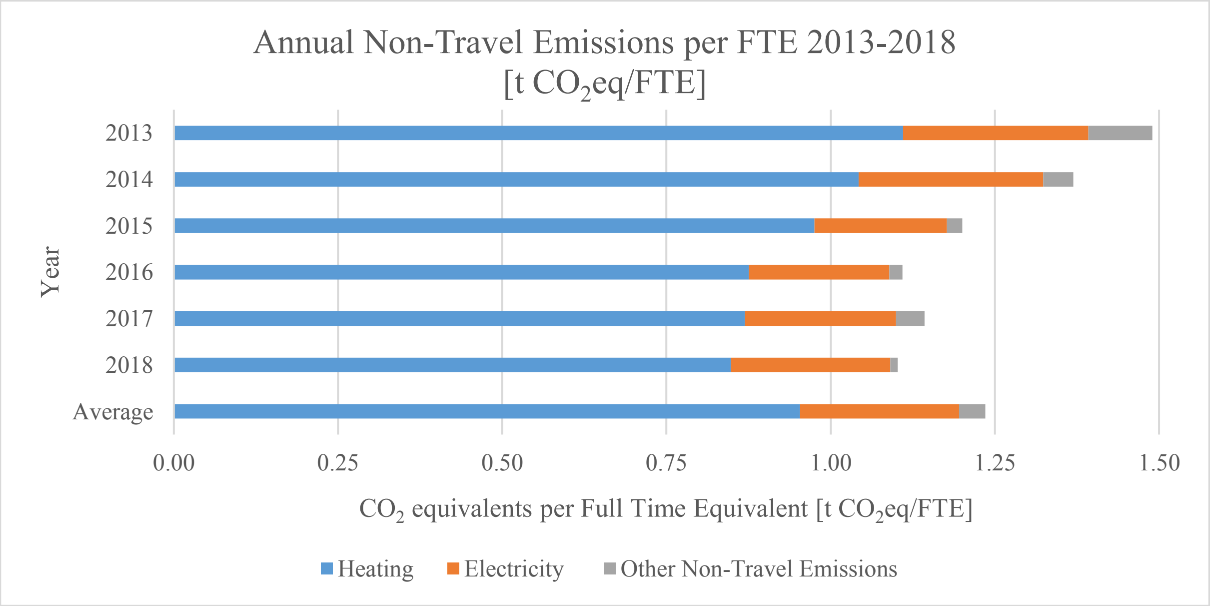

Figure 36: Annual Development of Non-Travel Greenhouse Gas Emissions per Full Time Equivalent 2013-2018 [t CO₂eq/FTE]

The average amount of greenhouse gases from electricity corresponds to nearly 20 % of non-travel emissions, product related emissions from IT-devices and paper use account for 3 %. Figure 38 shows the relation between the average of annual emissions coming from heating, electricity and product use.

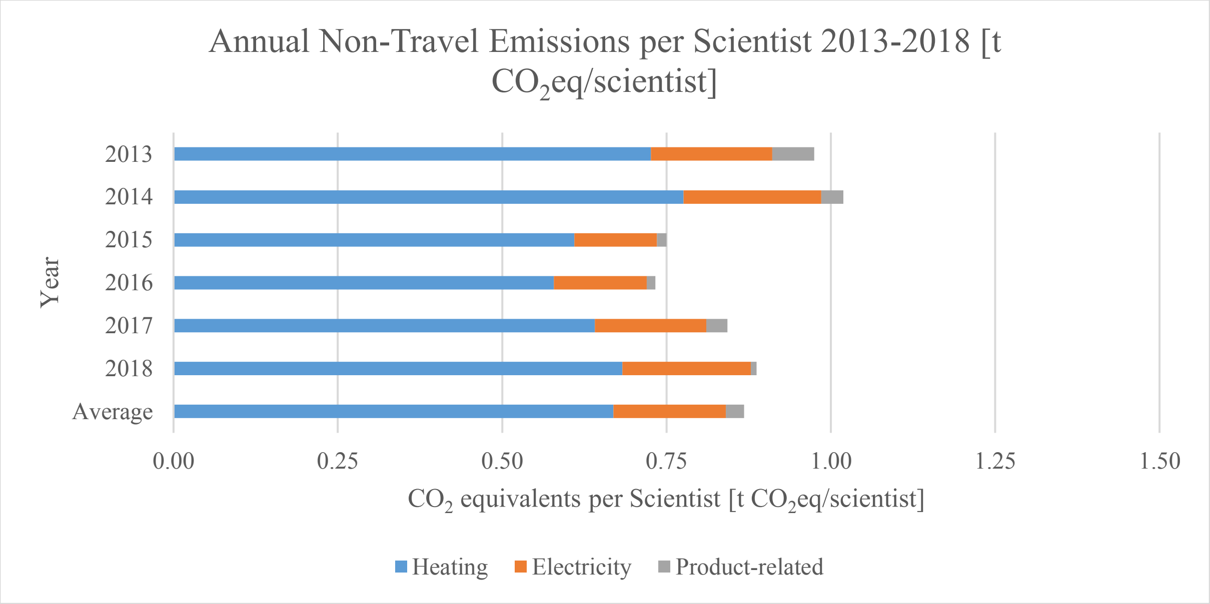

Figure 37: Annual Development of Non-Travel Greenhouse Gas Emissions per Scientist [t CO$_2$eq/scientist]

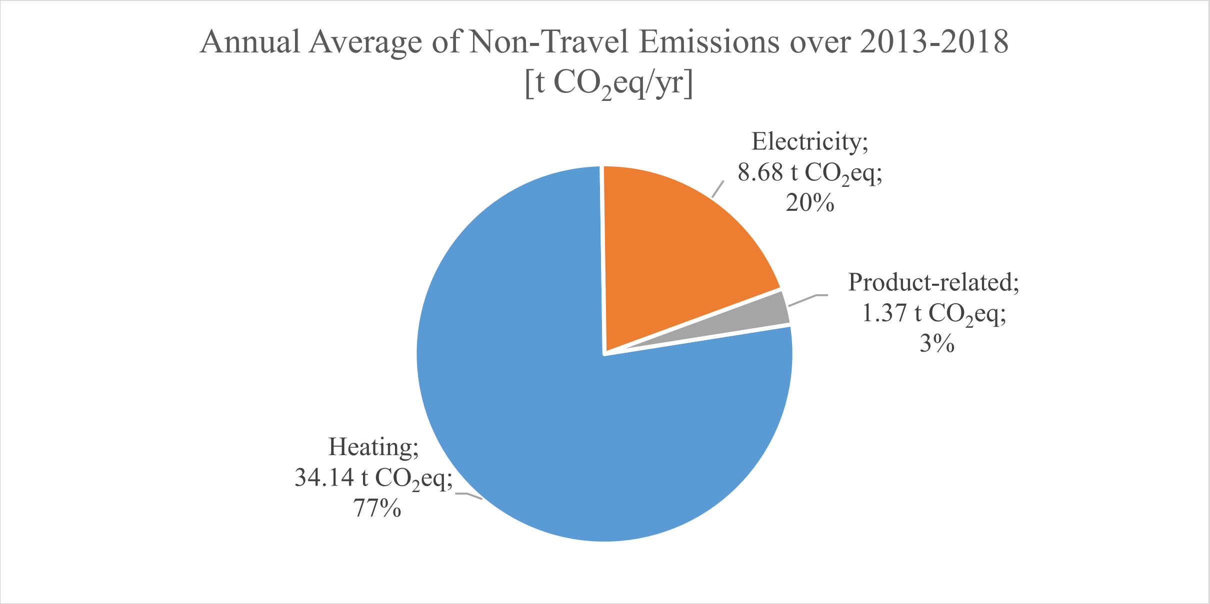

Figure 38: Annual Average of Non-Travel Greenhouse Gas Emissions Consisting of Heating, Electricity and Other Non-Travel Product-Related Emissions (IT-Devices, Paper Use)

As the resources heat, electricity, IT devices and paper are not only used by Wegener Center's scientists but from the total employees, we use the number of the total employees and the respective FTEs as a base.

3.3. Comparison: Emissions from Travel as Part of the Total Past Emissions

We expect the greenhouse gas emissions from international scientific trips to be a big part of the full emission budget. To show the relation, a descriptive data analysis takes place. We show aggregations and frequencies and do a stocktaking. To visualise the development of the past, we use pie charts and diagrams showing the development in time in all three dimensions mentioned in section 3.1. With these, we picture also the portion of international travel emissions to the total emissions.

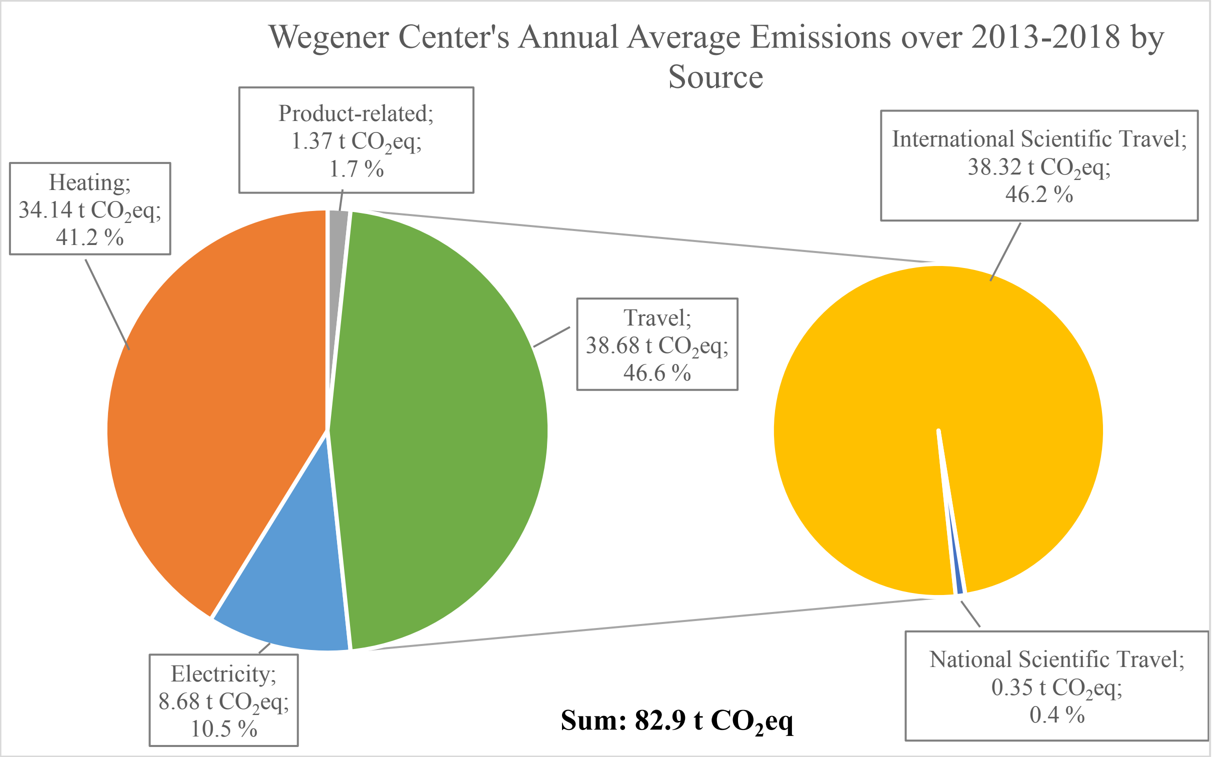

Figure 39: Wegener Center's Total Annual Greenhouse Gas Emissions [t CO_2eq] by Sources as Average Value from 2013 to 2018

We see that the major part of Wegener Center's average greenhouse gas emissions per year come from scientific travels (Figure 39, Figure 41). They contribute to 46.6 % of the total amount. Moreover, international scientific travel represents the vast majority of the travel emissions, summing up to 46.2 % of the total amount of Wegener Center's greenhouse gas emissions. National scientific travel on the other hand contributes to the smallest part. Heating is responsible for the second biggest part of greenhouse gas emissions. It covers 41.2 %. In contrast to travel, heating is less controllable by the Wegener Center itself but depends more on external factors such as the energy supply of power plants. However, the University can choose to switch to different energy providers or to produce energy (partly) on its own (e.g. solar-based electricity and heat).

Also the contribution of electricity is not negligible, as its contribution to the overall greenhouse gas emissions accounts for 10.5 %. Product-related emissions account for a small fraction.

As we allocated the travel emissions to scientists only, the non-travel emissions to all employees, the relative share of travel emissions per scientist is even higher (see Figure 40, Figure 42). The amount of non-travel emissions per employee corresponds to the amount of non-travel emissions per scientist because non-scientists and scientists use the same amount of resources in the building of the Wegener Center. Therefore, we are able to represent the annual emissions of a scientist. Per scientist, travel emissions cover more than the half of the overall greenhouse gas emissions (53.6 %). Again, they almost correspond to the emissions coming from international scientific travel. The percentage decrease for the heating emissions per scientist can be attributed to the fact that the overall amount is allocated to more persons compared to the travel part.

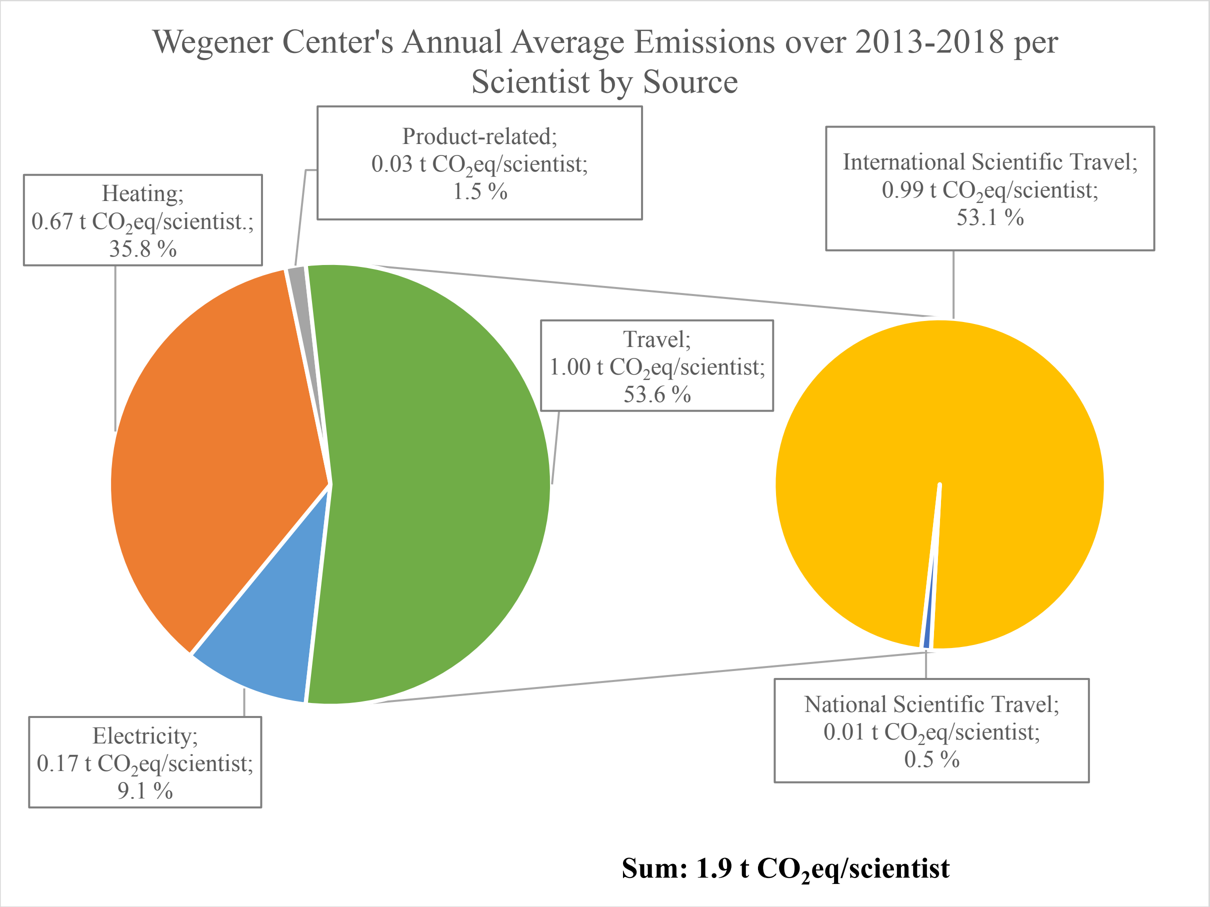

Figure 40: Wegener Center's Annual Greenhouse Gas Emissions per Scientist [t CO_2eq/scientist] 2013 to 2018 with its Average

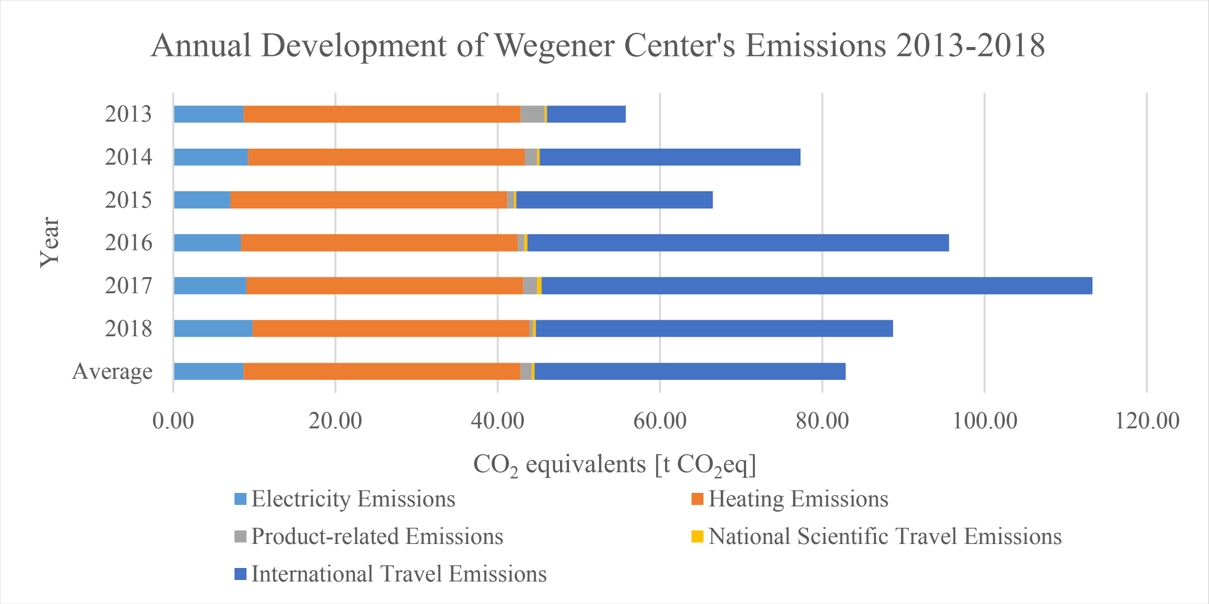

Figure 41: Wegener Center's Annual Greenhouse Gas Emissions [t CO_2eq] 2013 to 2018 with its Average

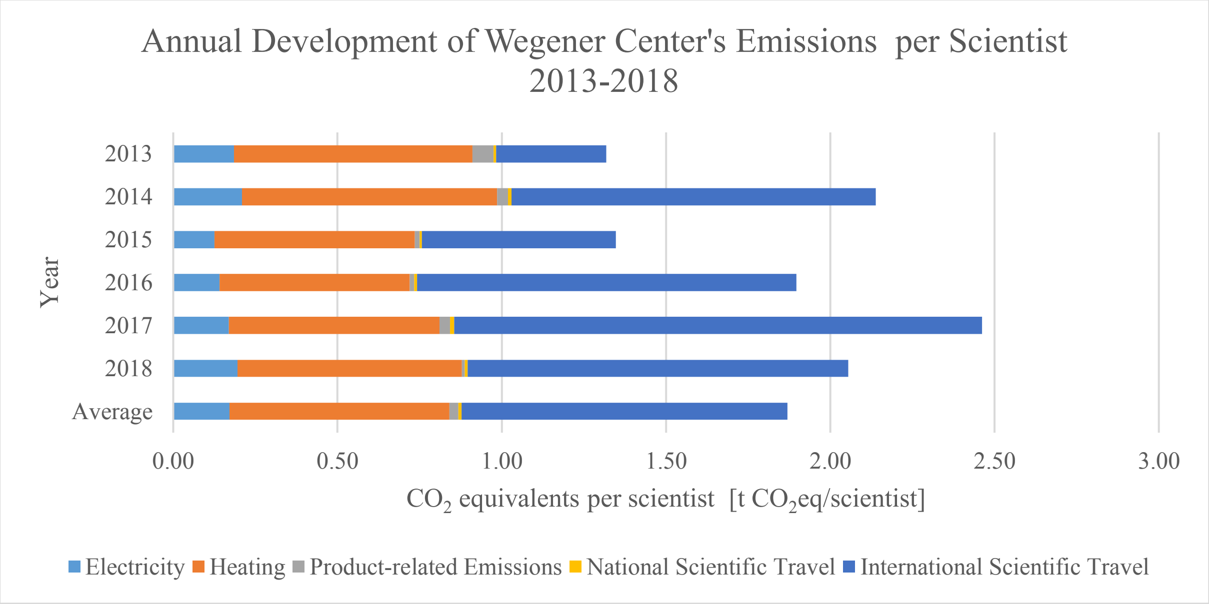

Figure 42: Wegener Center's Annual Greenhouse Gas Emissions per Scientist [t CO_2eq/scientist] 2013 to 2018 with its Average

3.3.1 International Scientific Travels of the Wegener Center

As we already expected as our first hypothesis, the greenhouse gas emissions coming from international scientific travel represent the major part of Wegener Center's past emissions. In average, they are responsible for 46.2 % of the annual overall emissions. Considering the emissions per scientist, they account for over the half of a scientist's annual emissions. Due to the high share of greenhouse gas emissions from international scientific travel, this category represents a field with a high possibility to reduce its emissions and consequently the overall greenhouse gas emissions of the institute.

Table 17 represents detailed results for greenhouse gas emissions from international scientific travels in the period from 2013 to 2018 as absolute amount per year [t CO_2eq], amount per FTE [t CO_2eq/FTE] and amount per scientist [t CO_2eq/scientist].

Table 17: Detailed Results for International Scientific Travel Emissions per Year and Average over 2013 to 2018 in t CO_2eq, t CO_2eq/FTE and t CO_2eq/scientist

Year	**International Scientific Travel Emissions** [t CO_2eq]	**International Scientific Travel Emissions per Full Time Equivalent** [t CO_2eq/FTE]	**International Scientific Travel Emissions per Scientist** [t CO_2eq/scientist]
2013	9.71	0.38	0.33
2014	32.13	1.17	1.11
2015	24.20	0.81	0.59
2016	51.96	1.55	1.15
2017	67.92	2.01	1.61
2018	44.01	1.25	1.16
Average	38.32	1.20	0.99

The development of the emissions from international scientific travel shows that they are varying with the years. The year 2013 shows an exceptionally low amount of greenhouse gases. Although it is the year with the lowest amount of full time equivalents, it is not the one with the least number of employees. It is possible that the data set does not cover all travels from 2013.

98.4 % of the annual greenhouse gases from international scientific trips are coming from flight travels, leaving the comparably small amount of 1.6 % train travel emissions. The huge difference is due to different reasons. One cause is that the average number of international flight travels per year is higher than the one of international train travels. Furthermore, the average flight distance differs from the average distance travelled by train. Longer distances cause higher amounts of greenhouse gases per trip. The average distance of an international flight trip of a Wegener Center scientist is 2,882 km. In contrast, an international train trip has the average distance of 752 km. Another decisive factor are the emission factors.

As described in section 3.1, the emission factors per person kilometer vary significantly depending on the chosen travel mode. While the emission factors for train travel in European countries lie between 7.3 and 59.6 g CO_2eq/pkm (depending on the source of the country's traction power), the ones for flight travels lie between 193.1 and 453.0 g CO_2eq/pkm (depending on the flown distance and the seating class). We see a clear distribution also concerning the distances of the travels. Long distance travels cause 81.6 % of the IST emissions per year, while short distance travels lead to the remaining 18.4 %. The major part of long distance travels (87 %) are flight travels, which leads together with the long distances to over 4/5 of the emissions regarding the classification of the travel distance.

In the period from 2013 to 2018, the destinations of international scientific travels lie in 30 different countries. The five countries with the highest number of ISTs are the following: Germany (DE), the United States of America (USA), Switzerland (CH), Italy (IT) and Great Britain (GB). The destination points in one of these neighbouring countries of Austria, i.e. Germany, Switzerland and Italy, represent short distance trips with a distance smaller than 1,000 km. All scientific trips to the USA and to Great Britain are long distance trips.

Concerning the travel mode, with the differentiation between train and flight it is obvious that all of the business trips to the US are flight trips. Considering the international scientific trips to Great Britain, about 78 % of the trips are flight trips, causing 96.4 % of the travel emissions from trips to Great Britain.

Table 18: Results for the Most Frequently Visited Countries Disaggregated by the Travel Mode.

	Flight		**Train**	
	Number [%]	**Resulting GHG Emissions** [%]	**Number** [%]	**Resulting GHG Emissions** [%]
DE	68	91.0	32	9.0
USA	100	100.0	0	0.0
CH	23	80.7	77	19.3
IT	22	70.5	78	29.5
GB	78	96.4	22	3.6

3.3.2 Outlook to Upscaling to University of Graz

The University of Graz occupies 4,325 employees of which 2,990 are scientific employees (University of Graz, 2019). Upscaling the results from the Wegener Center personnel to the scientific employees from the Universities of Graz may lead to huge uncertainties. Due to different scientific fields and task areas, departments may show different travel behaviour. Moreover, there are institutes that show a higher energy demand due to the operations in laboratories and similar. Compared to departments that host only book sciences, the energy demand in form of heat and electricity is significantly higher in the ones with laboratories. Concerning the heating of the buildings themselves, the energy demand per year depends on the way of construction, the size and the location, amongst others. Compared to the building of the Wegener Center, newer buildings may show a smaller specific final energy demand.

Another factor that influences the amount of all types of greenhouse gas emissions of the University are its students. In the winter semester 2018/2019, about 31,000 students are enrolled in the University of Graz (University of Graz, 2019). The more people use the facilities of a building, the higher gets its energy demand. In the Wegener Center there is only small student's activity, which does not influence the electricity demand. In our calculations and the data situation, the heating does not depend on the number of people in the building.

All in all, the differences between the structural organisation of the Wegener Center and the whole University of Graz may lead to large uncertainties, which do not allow to provide a direct upscaling using Wegener Center's values for its greenhouse gas emissions.

The University of Graz plans to address its greenhouse gas emissions by introducing a so-called Institutional Carbon Management (ICM). The ICM aims to manage the greenhouse gas emissions of an institution, in this case the University of Graz. Similar to the work we did in this research for the Wegener Center, the first step of the ICM is to develop a CO_2eq balance sheet that lists the recent-past amounts of greenhouse gas emissions and their sources that originated within the defined system boundaries of the University. The definition of the system boundaries is therefore crucial and classifies which sources are included, respectively excluded. The University-intern implementation of the ICM follows the guidance of the so-called "Verbrauch die Hälfte" rule, meaning "Consume just Half" by 2030. Planned reference time for the recent-past emissions is the period between 2015 and 2019. ICM aims to develop and implement measures that are able to reduce the average amount of greenhouse gas emissions, referred to the reference time, by 50 % at least, with a target of 55 % until 2030.

There will be CO_2eq emissions that the institutes can influence directly as well as parts that are more general and not to be affected directly by the institutes. Incentive mechanisms such as monetary incentives are able to take effects only if there is a scope of action for the institutes. The institute has not a high influence on the heating of the building where it is located. The scope of action concerning greenhouse gas emissions coming from heating is therefore very small. The situation is similar for electricity. The operation of an office workplace takes a certain amount of energy, so does the standard operation of other workplaces such as laboratories. The scope of action regarding the use of electricity is limited, too. The field which institutes have the most influence on is scientific travel. In addition, the number of travels and the resulting greenhouse gas emissions are assignable to a specific institute or department. The assignability is more difficult for energy related sources, as there are cases where different institutes share the same buildings. Therefore, assignability and the own possibility of action make scientific travel the field where incentive mechanisms are effective.

4. Second Main Part: Future More Sustainable Pathways to 2030

The second main part of this Master's thesis critically reflects possible future development of travel emissions of the Wegener Center as well as opportunities to reduce them. Using the development of the past as our basis, we explore future trends from 2020 until 2030. First, we construct a business as usual estimate (Section 4.1), which serves as benchmark for developments under carbon-reduction policy options (Section 4.2).

4.1. Business as Usual Estimates

The analysis of the past greenhouse gas emissions coming from the work of the Wegner Center shows that scientific travel is responsible for about half of the total emissions per year (46.6 %) and represents even a higher part (53.6 %) of Wegener Center's emissions per scientist.

We assume the growth of the Wegener Center to be 25 % until 2030 based on the year 2020. For the years 2019 and 2020, we use the average amount of greenhouse gas emissions from 2013 to 2018, which on average have been around 38 t CO_2eq (Figure 43). As we expect the number of employees and FTEs to increase by 25 %, the scientific travels will expand to the same extent. Such an increase would lead to an additional absolute amount of 9.67 t CO_2eq. The major part of it will consist of international scientific travel, whereas national scientific travel corresponds to a very small part of it.

We also consider that the efficiency of technologies increases. Different measurements such as the reduction of the drag and the weight of airplanes may contribute to a technology efficiency increase. Also for non-travel emissions, such as heating and electricity, we expect technology improvements. Based on 2019 and 2020, we assume a technology efficiency increase of 25 % in 2030. In this way, the savings due to the higher efficiency of airplanes balance the additional greenhouse gas emissions from Wegener Center's growth of personnel.

Considering also non-travel-emissions, we have to distinguish heating from electricity and product-related emissions. The electricity consumption as well as the IT-devices and paper use will grow according to the growth of Wegener Center's personnel. At the same time, we expect the efficiency of both categories to increase as well. This is why we assume that the sum of the resulting greenhouse gas emissions from electricity and products to remain constant. The situation is different for heating. As we do not have the real heating data for the years from 2013 to 2018, we used the specific final energy demand in kWh/m^2a. This is a constant value and is not depending on the number of employees of the Wegener Center. In reality, the heat demand depends slightly on the number of persons present in the building. On the one hand, their body heat has an impact. The more people there are the more body heat sums up in one room. We can use this effect by first occupying all working spaces of a shared office instead of occupying different offices with less people and leaving unoccupied working spaces. If an office stays empty in this way, the room has not to be heated, which saves again energy and therefore greenhouse gas emissions. However, as long as we do not have further information on the real heating data and as long as the source for the heat does not change, also the amount of resulting greenhouse gas emissions remains the same. Nevertheless, we can expect a technology efficiency increase also in the heating sector.

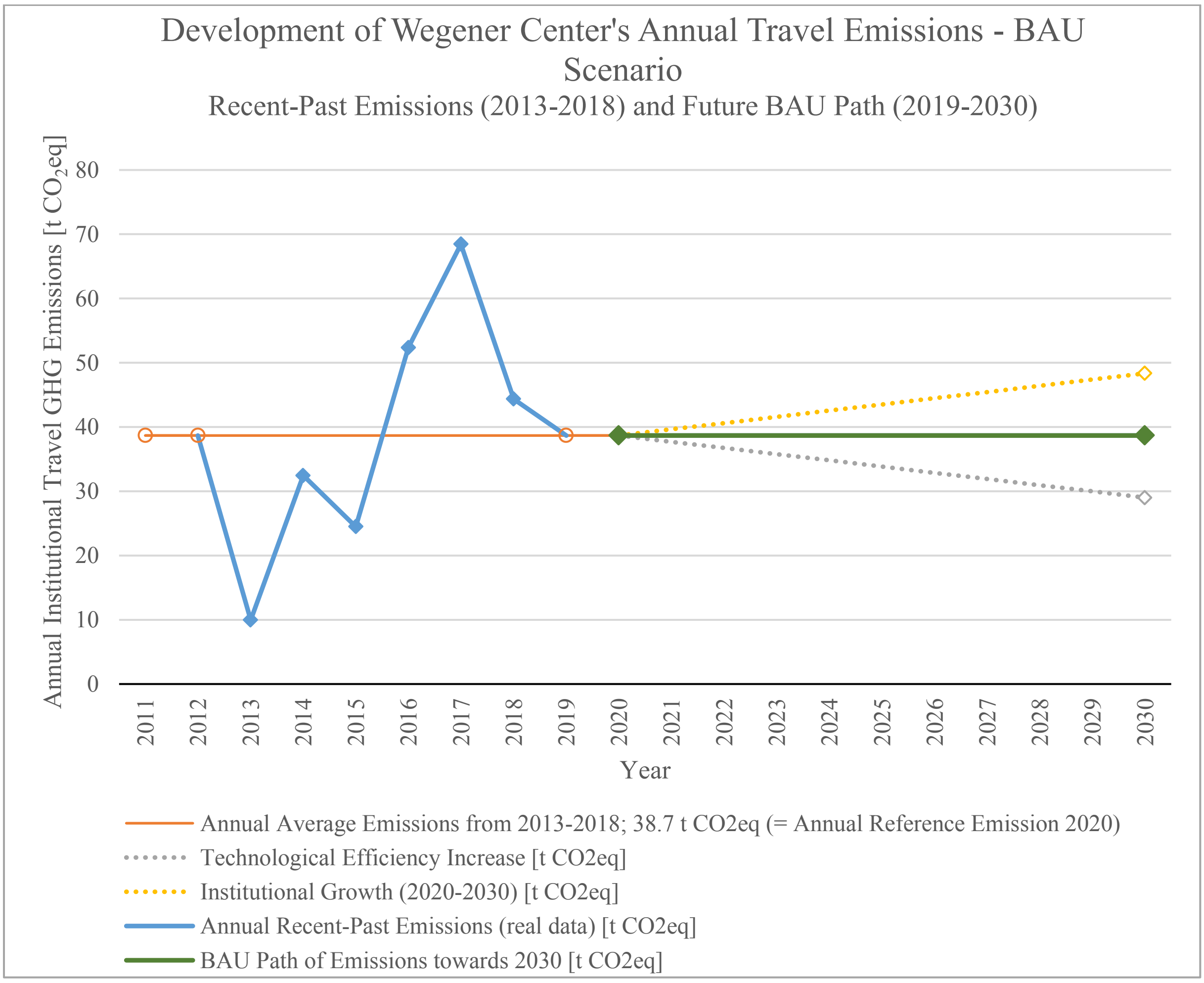

Figure 43: Development of Wegener Center's Annual Travel Emissions – Business As Usual (BAU) Scenario. The emission increase due to Wegener Center's growth and the emission decrease due to efficiency improve balance each other and the overall travel emissions remain constant. The future development is based on the year 2020, which represents the average value of greenhouse gas emissions from the Wegener Center based on the period 2013 to 2018

The Business as Usual (BAU) scenario is relatively optimistic, as the efficiency gain of the aviation sector balances all additional greenhouse gas emissions arising from our institutional growth. In the BAU scenario, the Wegener Center is able to maintain the level of its travel greenhouse gas emissions. Hence, the amount of greenhouse gas emissions in the years from 2021 to 2030 correspond to the average amount of 2013 to 2018, which is 38.67 t CO2eq/yr.

4.2. Carbon Reduction Policy Options

In the framework of the Institutional Carbon Management ICM55, the Wegener Center pursues the goal of reducing its institutional greenhouse gas emissions by 55 % compared to the base year 2020. To achieve this goal, policy measures are unavoidable.

Creutzig et al. (2018) suggest measures coming from the demand-side. To structure different policies for the transport sector, they use the “avoid-shift-improve” concept. This structure describes the objective the policy measures should follow.

4.2.1 Emission Avoidance Options with Example

The first step to reduce greenhouse gas emissions from transport is to avoid the necessity of the travel itself (Creutzig et al., 2018).

In our case, the Wegener Center introduces ICM55 and reduces its institutional greenhouse gas emissions from the transport sector by avoiding scientific travels. The analysis of the past-recent years (2013-2018) shows that the biggest part from the average travel emissions per year comes from international scientific travel (99.1 %). The savings potential of international scientific travels is accordingly high. Therefore, IST is a reasonable point to take measures. Concerning the travel mode, flight travels account for 97.5 % of the average travel emissions of greenhouse gases per year. In addition, the categories – IST and flight travels – are related as flight travel emissions represent the major part of international scientific travel. By avoiding the need to fly, we create the possibility to save institutional greenhouse gas emissions. Avoiding the need of scientific train travels safes greenhouse gas emissions, too, but their absolute amount of saved t CO_2eq is much smaller and almost insignificant compared to flight emissions. The same observation is valid for national scientific travels. Again, train travel and national scientific travels are closely related, as the later consists exclusively of train travels. Due to the longer distances of international scientific travel and the higher emission factor for train travel in other countries, avoidance of train travel with international destinations is more effective than avoiding national train trips. As the average total train emissions per year account for 2.5 % of the total travel emissions, the major savings potential still lies in the avoidance of flight travels.

As scientific travels help to transfer knowledge, build up collaborations, strengthen cooperation, they are part of a scientist's job. A direct alternative to international scientific travels are online meetings and telecommunication. Both possibilities show advantages as well as disadvantages, which have to be weighed up for the specific cases.

Telecommunication itself is not emission free. Greenhouse gases arise during the life cycle use of the needed technical tools. This includes their manufacturing and disposal as well as the energy needed for the operation. Mobitool (2017) gives emission factors for virtual mobility. The factor describes the greenhouse gases that arise due to the telecommunication work per person and hour (Mobitool, 2017). It covers a notebook including a video camera and the microphone, internet access and the power of the used servers and routers (Frischknecht et al., 2016). The resulting emissions for a videoconference depend on the source of the used electricity (Mobitool, 2017). Therefore, the emission factor slightly differs according to the use of either green electricity or a country specific electricity mix: 37.03 g CO_2eq/h/participant for the green electricity mix in Switzerland and 40.27 g CO_2eq/h/participant if the Swiss standard electricity mix is used (Mobitool, 2017).

According to Clausen, Schramm and Hintemann (2019), the amount of saved greenhouse gases depends on the distance, the travel mode and the IT facilities.

The increased use of online meetings and telecommunication could avoid the need of scientific travel. Nevertheless, there are disadvantages to be considered.

In their study about videoconferencing, Denstadli, Julsrud and Hjorthol (2012) state that the decision whether to use videoconferencing depends on the purpose of the meeting. The more complex the purpose the more probable are face-to-face meetings. The most common purposes for which videoconferencing is used are project works and information exchange.

Le Quéré et al. (2015) demonstrate advantages and disadvantages. According to the working paper, face-to-face meetings as well as online alternatives may lead to a generation of new ideas, as different views come together. However, face-to-face meetings have a higher possibility to build trust and connections between researchers. According to Le Quéré et al. (2015), the participants have the possibility to get to know each other also on a personal level, which is important for their connection and therefore their teamwork. This leads to the conclusion, that online meetings can substitute face-to-face meetings, once the researches know each other already.

Le Quéré et al. (2015) state that online alternatives and meetings are less cost-intensive. International scientific meetings have to be organised, which is connected to economical efforts. In addition, physical attendance of a scientist requires financial support, which may restrict the attendance for some conferences or young researchers. If telecommunication methods substitute physical travel, the costs for transportation, accommodation and provisioning vanish. Therefore, telecommunication gives also researchers with a low budget the possibility to attend at international meetings. This concerns young researchers or institutions in developing countries. According to the Austrian Business Travel Association (abta, 2017), the most expensive aspect of the main costs of one-day and several-day business travels is the transport (45.5 % of the total costs for the trip). The accommodation is also a large share of total costs (31.5 %). Provisioning and other services are responsible for the remaining costs.

The physical attendance at an international meeting is also connected to a time aspect. According to abta (2017), Austrian companies carried out 8,462,000 business trips in 2015, from which 3,807,900 (45 %) were several-day trips with an average duration of 3.5 nights within Austria and 4.6 nights abroad (abta, 2017, pages 8, 10, 12). The trip is therefore time intensive and has to be coordinated with the occupational activity and with the private commitments of the researcher. According to Denstadli, Julsrud and Hjorthol (2012), participants of videoconferences appreciate that as well as the planning time as the meeting is shorter in virtual conferences compared to face-to-face meetings.

Furthermore, due to different time zones, online meeting may be difficult to arrange depending on where the different researchers come from. Finding a suitable time for all participants gets the more difficult, the more researchers from different regions of the world attend at the meeting.

Besides social concerns, technical problems such as poor video and audio quality or the stability of the internet connection are other reasons why physical attendance is preferred in some cases (Le Quéré et al., 2015).

Summing up, the possibility of virtual conference has to be checked for different cases. As a real case study, we examine the greenhouse gas emissions resulting from the virtual participation at an international conference that took place in Barcelona (ES) in July 2019. According to the consensus of the conference, physical attendance should exclusively proceed if avoiding flight travel is possible. Therefore, the event provided the possibility to participate online for participants who – for various reasons – could not be present physically. According to our calculations, a round trip from Graz to Barcelona via train causes about 0.2 t CO_2

equivalents per scientist. The online participation on the 5-hour long conference leads to 0.2 kg CO_2 equivalents per scientist, using the higher emission factor given by Mobitool (2017). When we compare the greenhouse gases resulting from the train trip with the ones from the participation via videoconference, the positive effect of saving emissions via online participation becomes obvious. The greenhouse gas emissions that the scientist produced due to his/her virtual presence represent 0.1 % of the travel emissions. Regarding exclusively greenhouse gases from the travel to the conference and the ones from the online participation, telecommunication is a helpful way to avoid the need to travel and, consequently, greenhouse gas emissions from scientific travel.

To demonstrate the potential of the first step "avoid" for the future development of the Wegener Center, we create an ICM55 scenario considering Wegener Center's travel emissions. As baseline we use the value from 2020, which corresponds to the average greenhouse gas emissions from 2013 to 2018. It is our goal to avoid half of the long distance flights by the year 2030. As the measure is not likely to be implemented to 100 % already with the beginning of the ICM55 period, we set the annual realisation to be 10 % regarding the baseline value. In this way, we create a linear reduction path. By the end of the ICM55 period, which is 2030, we implemented the full measure and avoid every second long distance flight. The savings potential for the year 2030 is 15.30 t CO_2eq per year or 39.6 % compared to the baseline. We see the huge potential of avoiding international scientific travel by aviation. Implementing this measure, we are already able to realise 72.0 % of the ICM55 goal and 79.2 % of the marginal ICM50 goal.

4.2.2 Emission Substitution Options with Examples

According to Creutzig et al. (2018), the next step is to "shift" the travel mode for travels that are not avoidable to a lower carbon-intensive form of mobility. This goal can be achieved, for instance, by changing from car travels to public transport services or, in the best case, to cycling or walking.

For the Wegener Center, shifting to cycling or walking is not possible due to the large distances of the travel destinations. However, there are possibilities for the substitution step. The data show that there are flight travels with a distance shorter than 1,000 km in the years from 2013 to 2018. We set the maximum distance within reason that a scientist can reach by train at 1,000 km. If we estimate the average velocity of an intercity train to be 100 km/h, a distance of 1,000 km takes 10 hours. Longer travel times are not reasonable for a scientific trip. Due to this convention, all flight travels shorter than 1,000 km can be deemed to be substituted by train travels. As the feasibility of a business trip up to 1,000 km by train depends also on the train connections, there will be exceptions to this rule.

As a real case study for the second step, which is the substitution of flight travels, we have a look at the international business trips Graz-Milan (IT) and Graz-Frankfurt (DE), which took place in 2019 by a Wegener Center scientist. Other scientists did the same travels by flights in the period from 2013 to 2018. The great circle distance from Graz to Milan is 513 km, the one from Graz to Frankfurt is 601 km. Including the factor 1.1 that accounts for the distance by train travel, they expand to 564 km and 661 km. According to the Austrian federal railways ÖBB (2019c), the fastest train connection Graz-Frankfurt is an option through Vienna during daytime and takes about 9 hours.

To take advantage of the time, it may be more efficient for the scientist to travel at night and sleep in the train but she can also be productive while on the train. Connections that go at night have the disadvantages of either having more changes, requiring longer time or even both. The fastest train connection by night to Frankfurt takes about 12 hours with at least one change (ÖBB, 2019c). The difference of greenhouse gas emissions on basis of the travel mode is obvious: while a round trip flight Graz-Frankfurt causes 0.35 t CO_2eq/scientist, the travel by train leads to 0.05 t CO_2eq/scientist, a reduction of 85 % in emissions (see Figure 44).

The fastest train connection from Graz to Milan via Klagenfurt and Venice Mestre is during daytime and takes about 8 hours (ÖBB, 2019c). The connection by night is more difficult, as more changes and more time is required (ÖBB, 2019c). Although the distance Graz-Milan is about 100 km shorter than Graz-Frankfurt, the resulting greenhouse gas emissions for the travels are similar. The round trip to Milan produces 0.30 t CO_2eq/scientist by airplane and 0.05 t CO_2eq/scientist by train, a reduction in emissions of around 83 % (see Figure 44).

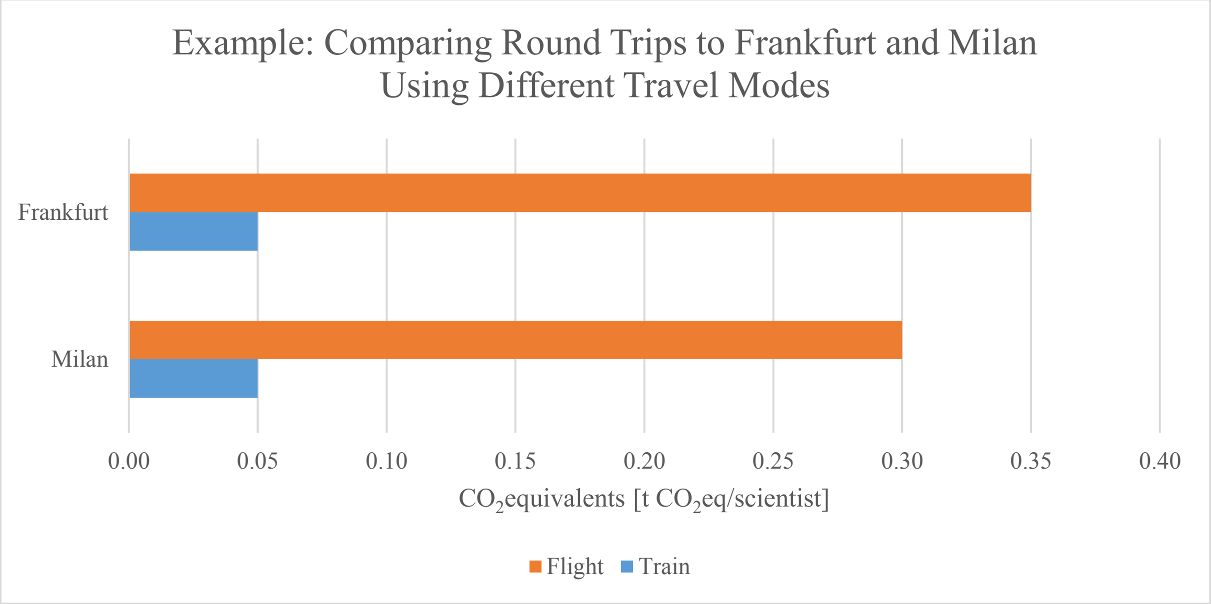

Figure 44: Comparing the Resulting Greenhouse Gas Emissions for the Round Trips from Graz to Frankfurt and from Graz to Milan by Travel Mode [t CO_2eq/scientist]

For ICM55, we create another scenario considering Wegener Center's travel emissions with the baseline value from 2020. It is our goal to substitute all flight travels shorter than 1,000 km with train travels by the year 2030. Every year, our measure shifts 10 % of the initial short distance flights to train travel. After 10 years, which matches the year 2030, we shift 100 % of the short distance flights to train travels. In the last year, the savings potential lies at 3.10 t CO_2eq (see dotted blue line in Figure 45). This corresponds to 8.0 % savings based on the average value of travel greenhouse gas emissions from 2013 to 2018. Regarding the ICM55 goal, which tries to save 55 % of travel emissions by 2030, the savings due to substitution correlates to 14.5 % of the goal and to 16 % of the marginal goal (saving at least 50 %).

A possibility to combine the measures avoid and substitute is the possibility of holding a semi-virtual, multi-hub conference instead of an international conference, where participants may use CO_2-intensive intercontinental flight travels to attend to the meeting. Multi-hub refers to different locations around the world, if the event is intercontinental, where parts of the participants meet simultaneously. Every contributor travels to the hub with the nearest distance. The hubs communicate via videoconference with each other. The multi-hub conference is an example where the structure of the meeting itself already supports the implementation of the first step, which is the avoidance of greenhouse gas emissions by scientific travels.

The report "About: 15th International Conference on Music Perception and Cognition and 10th triennial conference of the European Society for the Cognitive Sciences of Music" from the University of Graz (2020) describes the structure of the stated conference. It took place as a simultaneous conference in four hubs on different continents, where the live talk was transmitted to the other three locations. The hubs were Montréal (Canada), La Plata (Argentina), Sydney (Australia) and Graz (Austria). Participants were asked to travel to the nearest hub, which to the one hand supports the involvement of scientists with financially weak background and on the other hand leads to the reduction of greenhouse gases due to long travel distances.

With "avoid" and "substitute" we refer to the activity itself, which is the act of travelling. Making the classification, we orient on the objective we want to achieve. This is why, for example, we consider telecommunication as a measure to avoid scientific travelling, instead of substituting the trip. The functionality of the trip is the activity, hence the attendance in conferences, meetings, etc. It is the scientist's goal to be visible and present in an international context and to educate oneself internationally.

4.2.3 Improvement Options and Substitution & Avoidance Options

Creutzig et al. (2018) suggest "improve" as the third and last step to reduce the negative consequences of the transport sector on anthropogenic climate forcing. Improve refers to the technological side of transport. Vehicles can be improved in order to be more efficient and the fuel can be chosen according to a low carbon-intensity. Electric vehicles as well as small and light vehicles reduce the direct emissions of greenhouse gases compared to fossil fuel based, heavy vehicles.

Indirect GHG emissions and other non-intended consequences of e-mobility (e.g. recycling of batteries) many undermine the effectiveness of such "improve" strategies.

We include the improve approach in the business as usual (BAU) scenario and consequently in the value of the base line, which represents the BAU scenario. We assume that technological efficiency improves by 25 % in the year 2030 compared to 2020. The savings potential of "improve" is already compensating the future growth of the Wegener Center.

Regarding the term "improve", we can think about improving the structure of a scientific travel. If external factors allow it, scientific travels to similar destinations could be merged timely in order to reduce the amount of travels. Instead of travelling two or more times to the same or a similar destination the scientist could merge various scientific meetings in order to travel only once. Concerning flight travels, the travel to the airport which brings the scientist to an international destination should be done by train instead of using a connection flight from Graz. Furthermore, flights with transfers should be avoided.

Aside from the improvement of the transport sector itself, we can improve the organization of scientific business trips. The first consideration should include the decision if advantages of the physical attendance on the scientific trip outweigh the negative impacts concerning greenhouse gas emissions of the travel.

Figure 45 shows the development of Wegener Center's travel emissions with consideration of substitution and avoidance. The dotted blue line represents the possible savings of emissions under the substitution measure. There, all flights with a distance shorter than 1,000 km are substituted by train travels until 2030. Concerning the baseline of 38.68 t CO_2eq, the substitution leads to a reduction of 8.0 % in 2030. The dotted red line symbolises the possible reduction of travel emissions compared to the baseline (orange), if every second long distance flight is avoided in 2030. This avoidance saves 39.6 % of the average travel emissions. The two measures together lead to a reduction of 47.6 % travel emissions compared to the baseline emissions. The bright thick green line shows the sum of the measures. We see that with substitution and avoidance, the goal of a reduction by 55 % compared to the baseline is almost achievable.

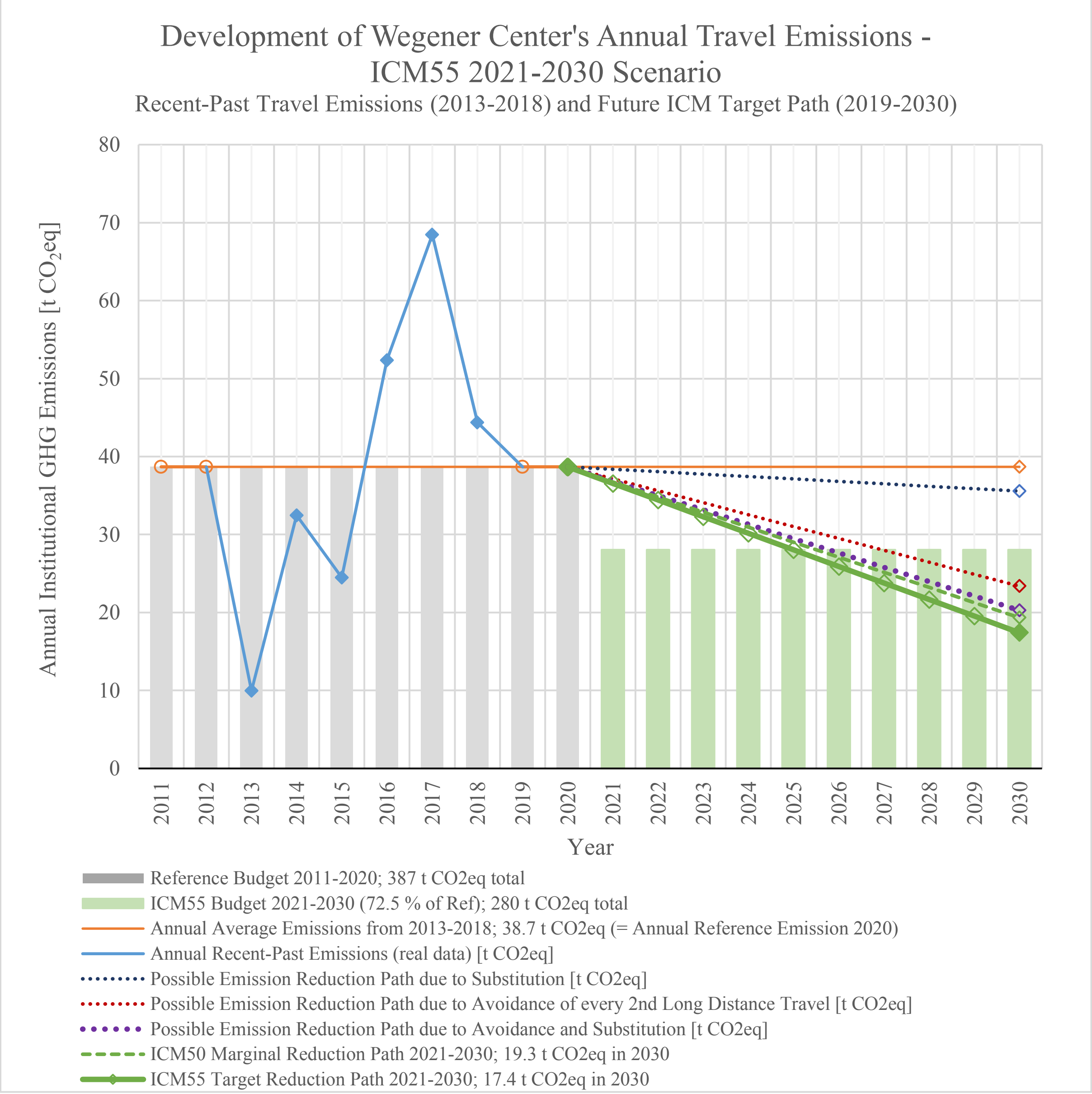

Figure 45: Development of Wegener Center's Annual Travel Emissions under the Institutional Carbon Management 55 (ICM55) 2011 to 2030. ICM55 aims to reduce the institutional greenhouse gas emissions by 55 % until 2030 (solid green line), with a marginal goal of 50 % (dashed green line). The future development is based on the year 2020, which represents the average value of greenhouse gas emissions from the Wegener Center based on the period 2013 to 2018 (solid orange line). The dotted blue line shows the possible reduction of greenhouse gas emissions, if every flight with a distance under 1,000 km was substituted by train travels until 2030. We see that substitution alone fulfils only a small part of the ICM55 goal. The dotted red line represents the possible emission reduction due to avoidance of every second long distance flight. Avoidance is the essential tool to achieve a meaningful reduction. The dotted violet line symbolises the possible emission reduction due to both avoidance and substitution.

4.2.4 Comparison to Policy Options from ETH Zurich

A case study for an academic institution that takes measures concerning its flight emissions is the Swiss Federal Institute of Technology (ETH) Zurich. According to Althaus and Graf (2019), ETH calculates the greenhouse gas emissions arising from the business trips of its personnel already for several years. In addition to train and flight travels, ETH considers also car travels. In 2018, flight travels caused 92.7 % of the greenhouse gas emissions (in t CO_2eq) coming from business trips. 5.0 % came from car travel, while train travel produced 2.2 %. In emissions per

FTE, this is 1.81 t CO_2eq/FTE from flights, 0.10 t CO_2eq/FTE from cars and 0.04 t CO_2eq/FTE from train travels.

Althaus and Cox (2019) describe the approaches used to compute the emissions of the ETH flights. The calculation follows three steps. First, ETH collects detailed data about a flight, including also the flight number. Then, an external organisation gathers more information about the specific flight using the collected information from ETH. It calculates the great circle distance and the part of the flight that takes place over 9,000 meters above sea level, corresponding to the cruise phase of the flight. Combining all the information, the fuel consumption per passenger is derived, from which the organisation determines greenhouse gas emissions and GWP100. For the cruise phase an emission weighting factor of 2 is used. In a third step, post-processing takes place, which includes amongst other steps the calculation of the emissions from fuel production.

Görlinger (2018) describes that ETH started a program in 2017 with the aim to reduce its greenhouse gas emissions from flight business trips without restricting scientific excellence and scientist's career chances. The path provides an 11 % reduction of emissions per FTE until 2025 based on the average value of the years 2016 to 2018. Görlinger (2018) states that ETH considers not only flight emissions from its employees but also from guests, that the ETH invites, and from students within the scope of their study. To achieve the goal, different departments listed various measures such as increased use of telecommunication, a sustainable planning of the business trips, introduction of decision tools and an internal carbon tax.

Kreil (2019) lists measures that help reduce flight travels. Kreil (2019) divides them into six levels referring to the target person or organisational unit that implement the measures and allocates the measures to categories. Kreil (2019) structures the six levels from the smallest to the largest unit. The levels are the individual researcher, teams, conference organisers, institutions/associations, group of institutions and academia "as a whole". For each unit, Kreil (2019) lists possible measures that the unit ("level") can follow to reach a reduction of flight travels. She lists additional six measures relevant at different levels.

We see that the ETH has similar procedures and aims. First, they monitor the greenhouse gas emissions from their scientific travels. The way of monitoring differs slightly from our method, as the input data vary, too. Nevertheless, the results represent the same. In the next step, both ETH and the Wegener Center pursue a goal reducing their institutional emissions and establish measures to achieve the aim.

5. Conclusions and Recommendations

As discussed in Section 3, the results support our hypothesis of high relevance of travel emissions. The analysis of the recent past greenhouse gas emissions of the Wegener Center show that international scientific travels (IST) of Wegener Center's scientists dominate the resulting annual emissions of greenhouse gases of the institute. Summing up to 46.2 %, they represent the largest part of the average annual emissions. From a look on the details of Wegener Center's IST emissions, we derive that 98.4 % of these emissions come from flight trips, while only 1.6 % originate from train travels, correspondingly. In overall terms, international flight travels represent 45.5 % of Wegener Center's total average annual greenhouse gas emissions over 2013 to 2018.

When we consider the differentiation between long distance (> 3,700 km) and short (regional, European) distance (< 3,700 km) trips, long distance travels are responsible for over 80 % (81.6 %) of the IST emissions. The significance of the IST emission portion becomes even more apparent when expressing the resulting emissions as per-person amounts of CO_2 equivalents per scientist. Here, IST emissions represent more than half (53.1 %) of a scientist's total average annual emissions over 2013 to 2018. National scientific travels, on the other hand, which are completely based on train travels, lead to a very small part of emissions per year (0.4 %).

The evaluation of the greenhouse gas emissions of the scientific trips suggest that a large savings potential lies in the reduction of flight travels, in particular long distance travels, or combining travel purposes in a remote region for less long distance flights. Measures that successfully achieve an emission reduction should follow the "avoid-substitute-improve" principle. Avoiding a certain number of long distance flights is the most effective measure to save a comparably large amount of greenhouse gases. As the career of scientists and the international work of the Wegener Center shall not be restricted, we have to think of partial replacements, such as online alternatives. Substituting flight travels with train travels for trips with a reasonably short distance or trip destination (e.g. under 1,000 km or 10 hours) is another possibility to reduce institutional carbon emissions.

Nevertheless, the possible amount that substitution saves is about one fifth only compared to emission reductions through avoidance of every second long distance flight, which highlights the significance of partial avoidance. The measure "improve" can support to reduce travel emissions already due to the way of planning the trip. Scientists can choose necessary flights by preferring direct flights over flights with transfers as more LTO phases lead to higher amounts of greenhouse gas emissions. In addition, they can use trains to reach a larger airport (e.g. Graz to Vienna trains) from which they take the direct flight.

The amount of the calculated greenhouse gas emissions from IST strongly depends on the chosen emission factors. The evaluation and the understanding of the emission factors is hence crucial. Furthermore, to achieve reliable outcomes, the quality and completeness of the data set listing scientific trips of the recent past years is decisive. Due to the European General Data Protection Regulation, receiving personal data concerning the IST trips of Wegener Center's scientists posed a difficulty. To comply with the regulation, and to properly protect person rights of the personnel, we solved the problems by elaborating a contract with the University of Graz, which allowed us to receive data that are anonymised to the greatest possible and then sufficient extend. These two points, emission factors and personnel data acquisition, highlight possible difficulties in the course of the evaluation process and involve uncertainties to be accounted for in interpretation.

Next to travel-related emissions, the remaining greenhouse gas emissions that arise due to the work in the Wegener Center come from heating, electricity, and product-use. The resulting emissions from the heating of the building represent the largest part of non-travel emissions over 2013 to 2018. They constitute 41.2 % of the overall institute emissions, or 35.8 % on a per-scientist basis. External factors such as the source of district heating in Graz, the contract of the house owner with the University of Graz, or the building's specific heat energy demand are essentially beyond control of the Wegener Center. It is hence not apt to develop measures to this end at institute level; it is a topic at University level.

The consumed electricity comes from renewable resources. It sums up to 10.5 % of Wegener Center's annual emissions 2013-2018, or to 9.1 % on a per scientist basis. The smallest part of the institutional greenhouse gases originates from product use, namely IT devices and paper (1.7 % of annual Wegener Center emissions or 1.5 % on a per scientist basis). These latter resource-use related emissions are biased somewhat low, since the source inventory is incomplete; still it will be only a few percent also in reality.

Overall the results clearly show the dominance of IST emissions as part of the total emissions of the Wegener Center. A so-called Institutional Carbon Management with focus on IST emission reduction options, is therefore unavoidable to reduce the amount of CO_2eq emissions significantly and to reach more sustainable international travel. Management tools for organising scientific travels should integrate the request for the data needed to calculate travel-related greenhouse gas emissions. The University and institutes should work out a clear list of possible measures, which the institute follows subsequently for organising its scientific travels. Additionally, the scientists themselves should be able to track their emissions of greenhouse gases from scientific travelling and to follow a list of options that enable them to reduce their academic carbon footprint.

We conclude that international scientific travels cause the major part of annual greenhouse gas emissions of the Wegener Center, and likely in other scientific institutes at University of Graz and beyond as well. Seen from another action-oriented perspective, international travel as the main cause poses also the best possibility to save a significant amount of greenhouse gas emissions. It thus represents a substantial opportunity to help mitigate increasing atmospheric CO_2 concentrations and the resulting global climate change and its consequences.

Appendix: Information on Data Collection

We require the travel data of the Wegener Center personnel from the recent past years (2013 to 2018) as well as information about the consumption of heating, electricity, IT infrastructure and paper use from the University of Graz. We do a meaningful segregation depending on the data availability.

Due to the General Data Protection Regulation, we are not allowed to get data that enable the identification of an individual person. To avoid this problem, the staff department providing the data anonymises the travel data by garbling the name of the traveller and the exact travel date. The needed information about the travel are gender of traveller, the scientific seniority and function level of traveller, and the scientific field of traveller, the destination point B, the month and year of the trip and the travel mode (flight or train travel). The administrative department of the University of Graz providing these data is the "Amt der Universität und Reisemanagement"; we collaborate with Mag. Ralph Duschek and Claudia Knoll. Dr. Manuela Postl from the legal department of the University took part in our negotiations and guided the elaboration of a contract that regulates the dealing with the data.

For the data about the non-travel emissions, we collaborate mainly with the Department of Building and Technology of the University of Graz ("Gebäude und Technik"). To get these data, the support of Mrs. Sabine Tschürtz and Mrs. Bettina Schlager (both Wegener Center) was necessary, as they are in regular contact with the respective sections. We checked which data are available, which form they have and in which time period we could obtain them.

Regarding Wegener Center's electricity, our contact person is Mr. Raimund Klöckl ("Gebäude und Technik"), who sent us an Excel sheet containing electricity consumption data of the Wegener Center (in units kWh). The building management is responsible for the heating but is not allowed to give us information on the energy consumption (external house owner). Therefore, we used the energy performance certificate for the house, provided by Mag. Ralph Zettl ("Direktion für Ressourcen und Planung"), and the area (m^2) occupied by the Wegener Center. Mrs. Bettina Schlager compiled a table containing the price of the paper copies and print-outs per year, while Mr. Wim De Geeter provided lists of the IT devices per year. Both are employees of the Wegener Center.

Other required data are emission factors (kg CO_2eq/km) for the different travel modes and other CO_2eq conversion factors. There are emission factors for different travel modes provided by "Mobitool" from ecoinvent (Mobitool, 2017). Other CO_2eq conversion factors are based on various literature sources as described in the text.

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Abstract:
In this study, we analyse the greenhouse gas emissions of the Wegener Center, an institute of the University of Graz in the field of "Climate, Environmental, and Global Change". Considering the overall emissions of the institute itself, we explore emissions coming from the heating, electricity and resource use (paper use, etc). However, our focus lies on the part coming from international scientific travels (IST) of the personnel of the Wegener Center. We find that these IST emissions account for the biggest part (about half) of the total emissions of the institute and examine the development over 2013 to 2018, taking into account flight and train travels that went beyond the borders of Austria and distinguishing between long distance and short/regional distance travels. Additionally, we take a closer look on three levels of differentiation across travellers, which are gender, scientific seniority level, and scientific field examining possible systematic differences in IST behaviour and the resulting GHG emissions. A core task of the analysis is to come up with robust estimations of emission factors, which vary with modes of transport. We use literature research as well as basic descriptive data analysis. Based on the analysis of the development of the recent years, we discuss possible future pathways up to 2030 and options to decrease greenhouse gas emissions to reach more sustainable IST.

Zum Inhalt:
Diese Arbeit beschäftigt sich mit der Analyse der Treibhausgasemissionen des Wegener Centers, ein Institut der Universität Graz, das im Bereich „Klima und Globaler Wandel“ arbeitet. Bezogen auf die Emissionen, welche am Institut selbst anfallen, werden jene aus dem Wärmebedarf, der Elektrizität und Produktnutzungen untersucht. Der Fokus liegt jedoch auf jenen Emissionen, welche von internationalen Reisen des wissenschaftlichen Personals stammen. Wir finden, dass diese für den größten Anteil (rund die Hälfte) der Treibhausgasemissionen des Instituts verantwortlich sind. Unter Berücksichtigung von Flug- und Zugreisen, wobei zwischen Lang- und Kurzstrecken unterschieden wird, wird die Entwicklung der internationalen Reiseemissionen im Zeitraum von 2013 bis 2018 untersucht. Zusätzlich wird die Gruppe der Reisenden mittels der drei Kriterien Geschlecht, akademische Seniorität und wissenschaftliches Feld differenziert, um eventuelle systematische Unterschiede im Reiseverhalten und den daraus resultierenden Emissionen aufzudecken. Eine Kernaufgabe der Untersuchung ist die Entwicklung von stabilen Schätzungen von Emissionsfaktoren, welche vom gewählten Verkehrsmittel abhängen. Es werden sowohl Literaturrecherche als auch grundlegende deskriptive Datenauswertung angewandt. Basierend auf der Untersuchung der Entwicklung der letzten Jahre werden mögliche zukünftige Pfade bis 2030 und Optionen aufgezeigt, Treibhausgasemissionen zu reduzieren, um ein nachhaltigeres wissenschaftliches Reisen zu ermöglichen.

Wegener Center for Climate and Global Change
University of Graz
Brandhofgasse 5
A-8010 Graz, Austria
www.wegcenter.at
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