Integrating Activities for Advanced Communities

D2.7 - Pocket guide on how to reduce CO_2 emissions from Arctic science

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Author: Svenja Holste

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PP	Restricted to other programme participants (including the Commission Services)	
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Publishable Executive Summary

Our travel, work and other personal activities leave a trail of greenhouse gas emissions. They therefore contribute to global warming. Researchers working in the polar realms try to explore the climate change effects on the Polar Regions and its inhabitants by understanding the physical, chemical, biological and atmospheric cues. Many of the researchers living or working in the Arctic have directly experienced Climate Change and its impacts in their region of study, e.g. sea-ice retreat, increase of rain-on-snow events, glacier mass balance records, permafrost thaw and its consequences on infrastructure, changes in species distributions, socio-economic development, changes in geopolitics, and adaptation actions by the people inhabiting the Arctic.

The polar scientific community is engaged in various types of fieldwork, conferences, training and collaborations, which all come with a significant carbon footprint. Many are concerned about climate change and its impact on the environment. This may especially be true for those working in the Arctic, an area warming three times as quickly as the rest of the world, and where the impact of climate change is clearly visible.

While many environmental impacts are systemic and thus beyond the control of the individual, there are numerous opportunities to reduce CO_2 emissions that are within the capacity of both institutions and researchers alike. This report (later published as a handbook) attempts both to summarize and to offer solutions for researchers who want to reduce CO_2 emissions related to their research activities. One of the biggest areas under individual control is travel, which is the focus of the forthcoming chapters.

We believe that the scientific community must act responsibly in relation to the changes that we see – hopefully setting an example for others to follow. The report focuses on researchers engaged in arctic science. However, much of the material is also applicable to others who are looking to reduce their environmental impact in other research activities.

The *first chapter* gives a brief outline of facts about greenhouse gas emissions, specifying what is called sustainable travel and the CO_2 emissions in Arctic Science. *Chapter two* discusses what is understood as the carbon footprint, calculation methods and various tools, with a short reference to individual carbon footprint. As the core of this book, *chapter three* gives an overview of fieldwork and related CO_2 emissions. Another important aspect covered in *chapter four* is on the CO_2 emissions associated with travel to meetings, conferences etc. The following part, *chapter five*, focuses on the role of arctic research institutions, and how they could embrace their responsibilities for contribution to main sources of global CO_2 emissions. Although this handbook is dedicated to CO_2 reduction while traveling, the general picture is completed by alternative strategies such as carbon compensation or offsetting in *chapter six*. To acknowledge the complexity of the topic, *chapter seven* focuses on the question of how to conduct science in the future. Finally, recommendations reducing travel-related emissions for scientists, conference organisers and institutions are presented.

The report will after submission (and a layout in accordance with other INTERACT Handbooks) be published as an INTERACT Guidebook both in real book format and as a pdf. The report will then be included in the library of INTERACT books being freely available to the public.

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Preface

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About this guidebook

This handbook focuses on researchers engaged in arctic science. However, much of the material is also applicable to others who are looking to reduce their environmental impact in other research activities. In this respect, INTERACT has made a valuable contribution by publishing a handbook on *Reducing the Environmental Impacts of Arctic Fieldwork* in 2021.

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1. Facts about Greenhouse gas emissions

1.1 Global warming

It is now widely acknowledged that global warming of anthropogenic origin has reached approximately 1 °C above pre-industrial levels, and many regions have experienced warming rates above the global average (IPCC, 2018). In particular, the Arctic surface air temperature has increased three times as fast as the global average between 1971 and 2019 (AMAP, 2021). One of the contributors to the Arctic amplification are the sea-ice and snow albedo feedbacks (Serreze and Barry, 2011). Both the arctic sea ice thickness and extent have decreased and are likely to continue to do so with increased warming. The glacial extent and snow on land has also diminished and presumably it will continue to decline in the Arctic, and the mass of the glaciers is expected to decrease as well. Of particular concern is the projected loss of permafrost due to rising temperatures, since it may lead to significant release of greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4) to the atmosphere, thus contributing to additional warming. Even if the concentration of GHGs in the atmosphere stabilises, the cryosphere and the ocean are expected to undergo a long-term change given their long response times (IPCC, 2019).

Climate change, which refers to long-term changes in temperatures and weather patterns, has already started to affect human societies (e.g., food production, livelihoods, infrastructure stability, education, health). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C (2018) stated that global warming will increase the frequency and severity of extreme weather such as heavy precipitation and droughts. In addition, climate projections indicate that a global warming of 1.5 °C would lead to a global mean sea level rise of 0.26 – 0.77 m by 2100 relative to 1986 – 2005; in the case of a 2°C warming the sea level rise would be 0.04 – 0.16 m higher.

Given these facts, there is no doubt that actions must be taken to minimize the multidimensional damage caused by a changing climate. One of the key responses is climate change mitigation, which consists of undertaking actions to decrease the warming rate through reducing our GHG emissions.

1.2 Towards an international recognition of global warming

As a result of the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, the United Nations Framework Convention on Climate Changes (UNFCCC) was adopted the same year and entered into force in 1994. While embracing the reality of global warming at the international level, this treaty recognized a common responsibility for all states, while differentiated, for the global emissions of GHGs. The conference of the parties (COP) to the UNFCCC have since then gathered governmental delegations and members of the civil society as observers to address global warming, fed by continuously updated scientific information provided by the IPCC (see Box 1.3).

The *Paris Agreement* (2015, entered into force in 2020), adopted at the COP21, is a legally binding international treaty with the objective to keep global warming to "well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" (Article 2, paragraph 1a). To achieve this ambitious goal, each Party commits to reaching peak GHG emissions as soon as possible, and then undertake a rapid decrease in GHG emissions in order to attain *net zero emissions* in the second half of this century. *Carbon neutrality* or *net zero emissions* refer to a balance between GHG emission to the atmosphere and GHG absorption from the atmosphere. The agreement imposes the developed countries to meet with their goals while encouraging the developing countries to continue their mitigation efforts with the support of the most advanced countries. The Paris Agreement also establishes the goal to strengthen adaptation efforts and resilience, and requires countries to prepare and implement adaptation plans (UNFCCC, n.d.) (see Box 1.1).

Box 1.1: Nationally Determined Contributions (NDCs)

Under the *Paris Agreement* (United Nations, 2015, Article 4, paragraph 2), all Parties are required to prepare and report on their NDCs, which are the actions defined by governments to achieve their respective long-term goals in terms of GHG emissions reduction. For more equity, countries will achieve differentiated goals according to their capabilities, economy, history, development issues and other peculiarities. The first NDCs were asked to be submitted in 2020 and must be submitted every five years to the United Nations Framework Convention on Climate Change secretariat. Each NDC must be more ambitious than the previous ones so the governments' commitment to climate change mitigation will be enhanced during the process (UNFCCC, n.d.).

NDCs can be either unconditional or conditional. As the name suggests, unconditional NDCs are those that can be implemented without any further requirement, whereas conditional NDCs are those that can only be implemented when certain conditions are fulfilled (e.g. international financial and technical support). Note that emissions from international aviation and shipping are not covered by the NDCs (UNEP, 2020).

1.3 GHG emissions

The main GHGs whose concentrations have increased due to human activities are CO_2, CH_4 and nitrous oxide (N_2O). In order to compare the contribution of each gas to global warming, the emissions of gases other than CO_2 are normalised to the mass of CO_2 to obtain the mass of CO_2 equivalent (see Box 1.2). The contribution of each gas to climate change depends on its concentration in the atmosphere and its global warming potential (GWP). Although the GWP of CH_4 and N_2O are higher than that of CO_2, the emission of the latter is much larger, making it the most significant contributor to global warming.

Box 1.2: Measuring GHG emissions: CO_2-equivalent

The **equivalent CO_2 emission (CO_2e)** is the "*amount of carbon dioxide emission that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a greenhouse gas or a mixture of greenhouse gases*" (IPCC, 2013: 1453).

The integrated radiative forcing of a greenhouse gas over a certain period of time depends on its lifetime and its effectiveness in causing radiative forcing. The GWP is an index that measures "*the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide*" (IPCC, 2013: 1455). The choice of time horizon has an important impact on the GWP values.

The following table shows the lifetime of some GHGs as well as their GWP for a 20-year period (GWP_{20}) and for a 100-year period (GWP_{100}):

	Lifetime (years)	**GWP_{20}**	**GWP_{100}**
CO_2	No single lifetime can be given	1	1
CH_4	12.4	84	28
N_2O	121	264	265
CFC-11	45	6900	4660
CF_4	50,000	4880	6630

Table 1.1: Information about some GHGs: lifetime, GWP for a 20-year period (GWP_{20}), and GWP for a 100-year period (GWP_{100}). (Myhre et al., 2013)

The CO_2e of a given greenhouse gas is computed by multiplying the emission of the gas by its GWP for a certain time horizon. The CO_2e of a mix of GHGs is equal to the sum of the CO_2e emission of each gas.

In 2019, the global GHG emissions, including land-use change (LUC) emissions, reached 59.1 $GtCO_2$e (UNEP, 2020). The main component of these GHG emissions, excluding LUC, was fossil CO_2 emissions (38 $GtCO_2$e), followed by CH_4 (9.8 $GtCO_2$e), N_2O (2.8 $GtCO_2$e) and fluorinated gases (1.7 $GtCO_2$e) (idemUNEP, 2020).

The global per capita average of fossil CO_2 emission was 4.93 tCO_2, with varying emissions per capita depending on the region. For instance, it was 6.47 tCO_2/capita for the European Union and the United-Kingdom taken together. The main activity sector responsible for the fossil CO_2 emission was the power industry, followed by other industrial combustion, transport and buildings (Crippa et al., 2020).

Relevant for the topic of this book is that the shipping and aviation sectors together currently account for approximately 5% of global CO_2 emissions. The emissions from these two sectors have been increasing during the last decades and are projected to significantly increase in the future (UNEP, 2020).

Box 1.3: The Intergovernmental Panel on Climate Change (IPCC)

Created in 1988 on the initiative of the Group of Seven (G7), the IPCC is linked to the World Meteorological Organization and the United Nations Environment Program. It aims at conducting an objective scientific assessment necessary to provide a better understanding of the risks related to anthropogenic global warming, to identify the potential consequences of this change and to provide guidelines for stakeholders to outline strategies of adaptation and mitigation. Up to 2021, six *Assessment Reports* have been released in respectively 1990, 1995, 2001, 2007, 2014 and 2021 (the first part of the *6th Assessment Report* was published in August 2021, the whole report will be released in 2022). In its *1st Assessment Report*, the IPCC established 4 scenarios of future GHG emissions. According to scenario A, the IPCC was expecting a temperature rise of 3 °C by 2100, while in its more optimistic scenario D, it was expecting a temperature rise of only 1 °C in the course of the 21st century. In its *2nd Assessment Report*, the IPCC acknowledged the anthropogenic origin of global warming and stated that climate changes represent a danger for Mankind. The responsibility of human societies was more underlined in the following report. Indeed, *the 3rd Assessment Report* of the IPCC made new climate predictions, i.e. up to a 5,8 °C temperature increase between 1990 and 2100, and conveyed a much more alarming message. By contrast, *the 5th Assessment Report* focused on potential mitigation strategies, which might limit the temperature rise.

1.4 Where are we now

Although, global fossil CO_2 emissions plunged 5.4% in 2020 as a result of the COVID-19 pandemic, the concentration of GHG in the atmosphere is expected to continue an increasing trend under the current policy scenario (Figure 1.1).

As of 30 September 2021, 120 countries that are responsible for just over half of GHG emission have submitted either updated or new NDCs. Of those NDCs, 49% are more ambitious than the previous NDC, 18% are less ambitious, and it is not possible to assess how ambitious the remaining 33% are. The G20 members, who are responsible for approximately 80% of global GHG emissions, are not on track to collectively meet neither their previous nor their new unconditional NDCs for 2030 (UNEP, 2021).

The *emission gap* is large.

The *emission gap* is the difference between the projected global GHG emissions assuming that the NDCs are implemented and the emission under the least-cost pathways that are consistent with limiting global warming to well below 2 °C above pre-industrial levels (UNEP, 2021).

For a 2 °C (1.5 °C) global warming, annual GHG emissions by 2030 need to be around 13 $GtCO_2e$ (28 $GtCO_2e$) lower than those implied by the unconditional NDCs (UNEP, 2021). If current conditional and unconditional NDCs are implemented, global warming is estimated to reach 2.6 °C at the end of this century (Figure 1.1).

On a more positive note, as of September 2021, 49 countries and the EU27 have formally adopted or announced net-zero emission goals, most of them for 2050. The full implementation of the net-zero emission pledges in addition to the NDCs would lead to a global warming of around 2.2°C at the end of the century (UNEP, 2021). More actions are, however, still needed on a global scale to limit global warming to below 2^{o}C.

International summits and national policies may also have a positive social impact. They have given global warming more visibility within societies and they have resulted in more funding opportunities within the academic sector for studying climate change and its impacts, and to identify and develop mitigation measures. Researchers therefore have an important role to play to influence the political decisions at the national and international levels but also in their own scientific institutions.

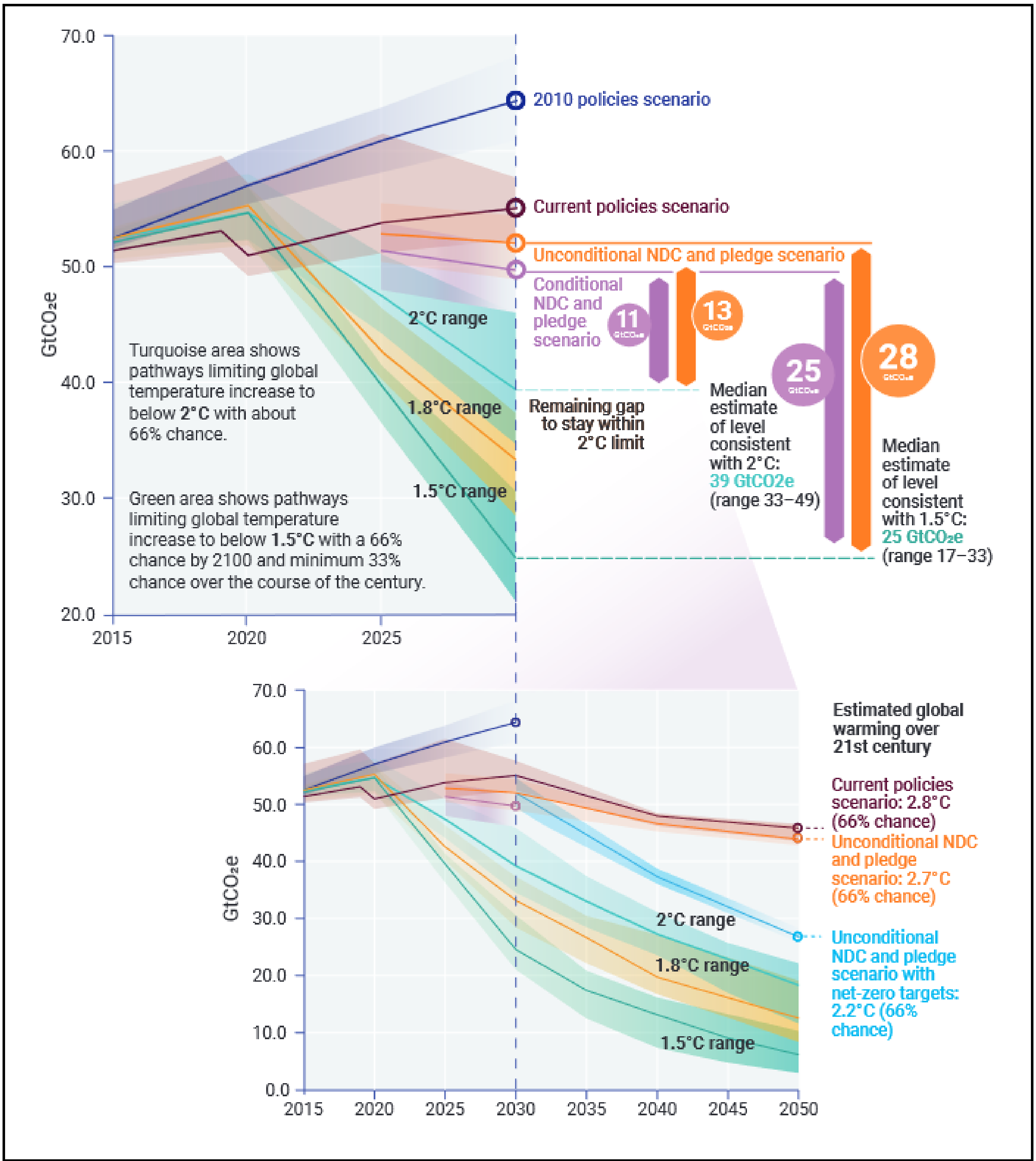


Figure 1.1. Global greenhouse gas emissions under different scenarios and the emission gap in 2030 (median estimate and tenth to ninetieth percentile range) (Reference: UNEP Emission Gap Report 2021: 35).

2. The Carbon footprint

2.1 Definition

The ***carbon footprint*** refers to the quantity of GHG emissions caused by the activities of a person or an organisation. Although the word "carbon" is used, the computation of the carbon footprint includes all GHGs (CO_2, N_2O, CH_4, O_3). In carbon footprint analysis, the unit of measurement typically used is tonnes of mass of CO_2 equivalent (tCO_2e; see Box 1.2) emitted per year for a given activity, process or product (Franchetti & Apul, 2013).

2.2 Carbon footprint and travel emissions

The computation of the total carbon footprint per capita is useful to compare the GHG emissions of different countries or regions. The carbon footprint per capita can also be computed for a given activity sector in order to analyse the most important sources of GHG emissions in a given country or region. As an example, the carbon footprint of the European Union was 6.7 tCO_2e per capita in 2019, of which 1.6 tCO_2e were directly emitted by households due to the burning of fossil fuels and 5.1 tCO_2e were indirectly emitted along the production chains (Eurostat, 2021a).

In order to limit global warming to 1.5 °C, we must reduce our carbon footprint to around 2 - 2.5 tCO_2e/year per capita by 2030, and to 0.7 tCO_2 by 2050 (UNEP, 2020).

Calculating our carbon footprint can help us pinpoint which of our activities are the most carbon intensive. With this knowledge, we can then identify the most high-impact actions both at the individual and institutional level for Climate Change mitigation.

When comparing carbon footprints of different product groups in the EU-27 (2019), transport has a small, albeit still significant contribution (6%) (Eurostat, 2021b).
Globally speaking, transport in 2018 constitutes around one quarter (24%) of CO_2 emissions if only CO_2 emissions are considered from energy (Ritchie, 2020a) and in some countries transport represents one of the greatest segments of an individual's carbon footprint (Ritchie, 2020b). As shown in figure 2.1, in 2018, road transport accounted for 74.5% of transport emissions, aviation for 11.6% and shipping for 10.6%. Rail transport had a significantly small share of only 1% (Ritchie, 2020a).

On an individual level, the most high-impact actions are living car-free, which could save 2.4 tCO_2e per year, and avoiding air travel, which could save 1.6 tCO_2e per transatlantic roundtrip flight (Wynes and Nicholas, 2017). In practice, the reduction in GHG emissions from high-impact actions are often replaced by actions, with lower emission levels (e.g., using public transport to replace car travel). To reach required reduction aims for our carbon footprint, we may therefore need to look across all our activities to identify actions that can lower our total carbon footprint.

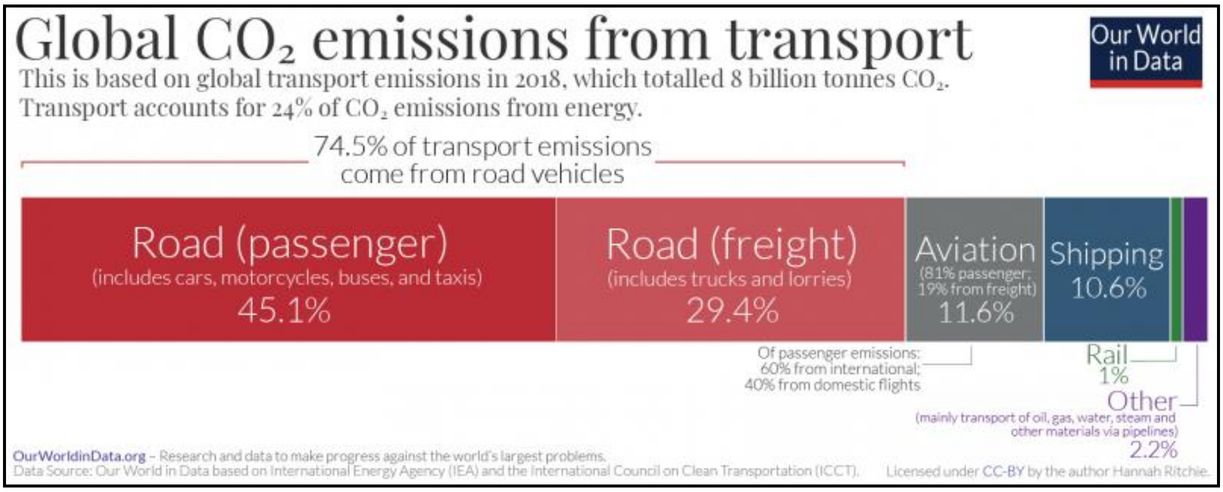


Figure 2.1: Global CO_2 emissions from transport. (Ritchie, 2020a. Our World in Data based on data from International Energy Agency (IEA) and the International Council on Clean Transportation (ICCT)).

2.3 The individual carbon footprint

The term 'individual carbon footprint', which relates to the amount of CO_2 emitted from the daily activities of individuals, has increased its visibility during the past decade. At the individual level, one can try to assess one's daily carbon footprint by using information provided by different databases. For some activities, you may need to feed the calculation tool with the amount of energy consumed for the given activity.

In general, online calculators are available for e.g. transport/travel, household/workplace, products, food consumption and lifestyle (see Tip: Carbon footprint calculators). While a significant number of datasets may be open access, not all of them focus on transport services and few include all lifecycle stages of a given product or service (e.g. emissions from production, use and disposal). While some providers offer to compute the individual carbon footprint over a certain period of time (e.g. one year), travel calculators estimate the carbon footprint for a chosen journey.

2.3.1 Methodologies applied by carbon footprint calculation tools

The literature identifies two methodological approaches for calculating the carbon footprint of products. They are known as the process model and the input-output model (Barnett et al., 2012).
The ***process model*** takes into account all processes in the product life-cycle, from production to disposal of the product and because of this, it is assumed to be the most accurate model. The method requires detailed information on the entire life cycle of the product, making it very expensive in terms of time and computation. A major issue with the process model is that the detailed data required is often not available causing reductions in accuracy.

Life-cycle assessments can be used to evaluate the environmental impacts not only of products, but also processes or activities. This includes the extraction of raw materials, the manufacturing process, product transport and distribution as well as the use, reuse, maintenance, recycling and disposal of the product (EPA, 2010).

The ***input-output model*** uses carbon intensities, measured in kilograms of CO_2 per unit of a specific currency spent, to assign footprint to a product based on the price of the product. The system is fully automated and costs very little in terms of both computation and time. It also requires little information about the production of the product itself (only price, description and unit of measure). Because the model is based on sector averages, it cannot handle any product specific data such as low carbon sourcing.

Box 2.1: The lifecycle of electronic devices

While the footprint of transportation or power supply may be obvious, there are other sources of CO_2 emissions which appear more hidden and harder to quantify. Computers, smartphones, GPS, sensors and other electrical devices affect the environment in several ways and contribute to global warming. This consideration is particularly important as technology is often celebrated as the solution to numerous societal challenges. Since most electronic devices consist of different components from many suppliers, the GHGs associated with the manufacture and the transport of electronic devices represent only a part of the emissions of the lifetime of each piece. The lifecycle of electronics can be summarized in four major phases which are all energy-demanding: the manufacturing process, the transport and distribution, the use phase (i.e., the operational phase) and the end-of-life treatment.

In the competitive context of the publication race, GHG reduction policies related to scientific equipment and instruments can be a sensitive topic as it can be perceived as a threat to the quality of the research.

2.3.2 Tools for footprint calculation of travel

Often, when booking a particular journey, the carbon footprint is provided by e.g. the airline at time of booking, sometimes allowing for the option of carbon offset for an additional fee.

When comparing online tools for travel related emissions, and in particular aviation, it is noticeable that calculators are using different methods and emission factors. Sometimes carbon footprint estimations by different data providers for the same flying distance (all economy seating) differ by up to a factor of five (Barret, 2020). Figure 2.2 illustrates these differences between widely-used tools by offsetting providers, national governmental agencies and the aviation industry. The different numbers can be explained by different ways of accounting for non-CO_2 effects, e.g. whether radiative forcing is included in the method (Barret, 2020). Barret (2020) further identifies a number of emission related parameters that have to be taken into account when calculating carbon footprint from air travel:

- Actual fuel consumption per aircraft kilometer
- Fleet

- Correction for deviations from the great circle distance
- Assumed seating configuration and weighting by seating class
- Passenger load factor
- Fraction of the fuel burnt allocated to the freight
- Aircraft related emissions (incl. refinery and transport of the fuel used, fabrication, maintenance, disposal)
- Airport infrastructure

So far, no standardized nor commonly accepted method for computing flight related emissions exists. But with an increasing aviation industry there is a clear need for more transparency and regulation/standardization (Barret, 2020).

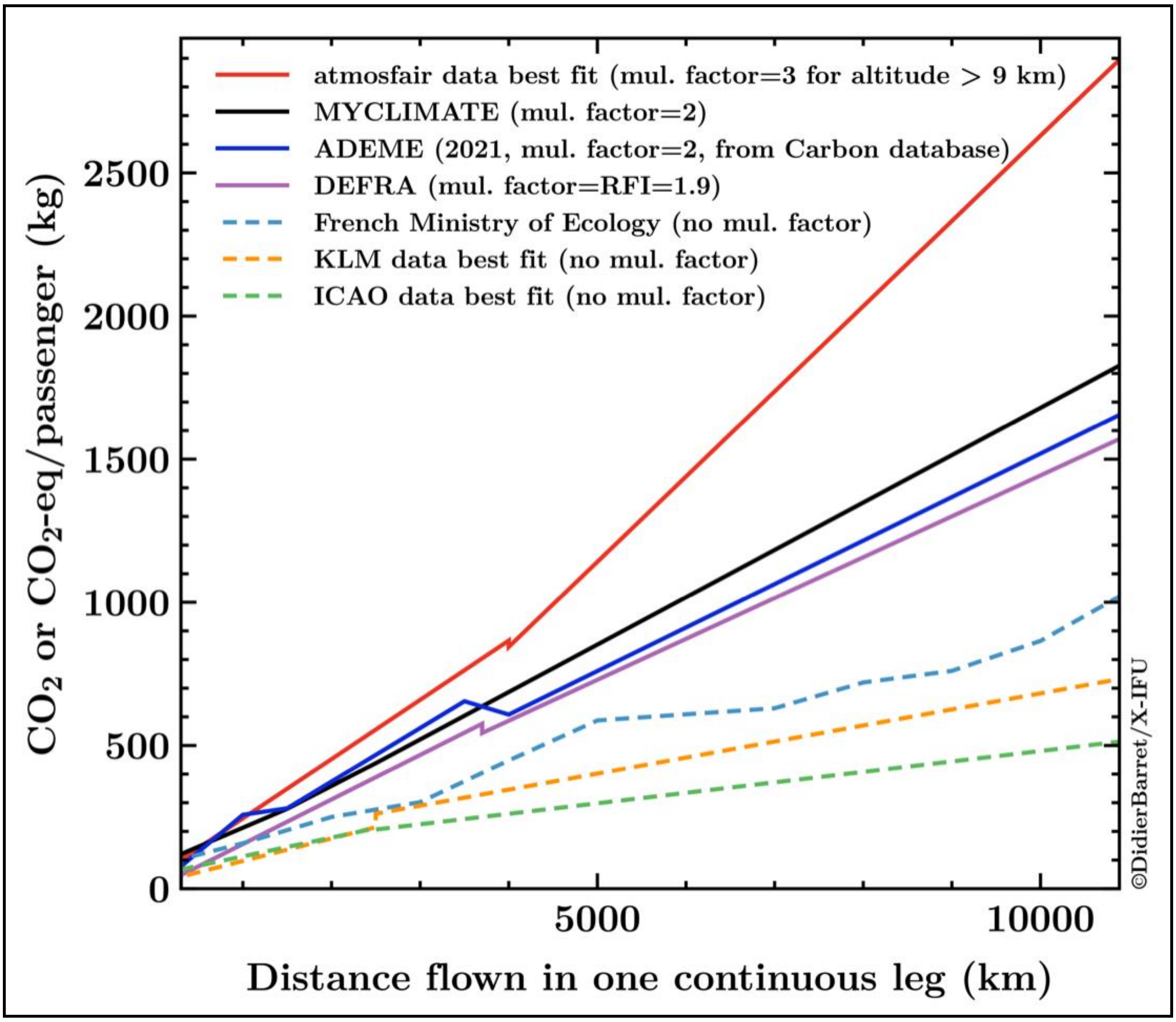


Figure 2.2. Emission factors (CO_2 in dashed lines, or CO_2e in continuous lines, per passenger in kg) as a function of the distance flown in one continuous leg (km) as derived from the seven data sources used by X-IFU calculator. The emission is computed assuming economy seating. Jumps in the functions are related to boundaries of interval distances over which the first is applied or the mean emission factors defined (Barret, 2020: 189)

Box 2.2: The online Travel Simulator by Labos 1point5

Labos 1point5 is an official research group based in France and supported by the French national research council and the Ecological Transition Agency. It takes the carbon footprint as object of study and intends to measure and better define the carbon footprint of public research in France (in terms of GHGs). Labos 1point5 offers an online tool that allows the user to simulate a professional trip. Drawing on the town of departure, the town of destination and the mode of transportation at each step of the travel, the simulator calculates the total distance and the carbon footprint (in CO_2e) of the travel.

From Paris, France, to Tromsø, Norway, a trip of 2,573 km, the simulator calculates emissions of 263 ± 26 kg CO_2e while from Paris to Resolute, Canada (5,121 km) it gives 425 ± 42 kg CO_2e. Although this simulator is useful to assess the footprint of flights, trains, ferries and other urban modes of transportation, it has limits due to the specific travel conditions in the arctic region.
Access: https://labos1point5.org/travels-simulator

TIP: Examples of carbon footprint calculators that includes transport components

- **Atmosfair** (for flights): https://www.atmosfair.de/en/offset/flight/
- **My Climate** (for flights, car, cruise, individual footprint, project, household, event, company): https://www.myclimate.org/
- **Ecopassenger** (for comparison between car, railway, air traffic): http://www.ecopassenger.org/bin/query.exe/en?L=vs_uic
- **Ecotree** (for flights, car, train, home, internet): https://ecotree.green/en/calculate-train-co2
- https://casestudy.chooose.today/
- **The Engineer ToolBox**: (for trains): https://www.engineeringtoolbox.com/CO2-emissions-transport-car-plane-train-bus-d_2000.html

3. Necessity and impacts of fieldwork related travel

Fieldwork and field trips represent a decisive component and an exciting side of scientific research and academic learning in the Arctic. From marine biology to anthropology, or from archaeology to glaciology, the access to the field ensures data gathering and is the foundation of knowledge production and development of scientific skills in most disciplines within arctic science.

With the rise of climate change, we need to seek alternative ways of acquiring this knowledge and the skills to reduce contributions to Climate Change without compromising scientific results. For a long time, these trips have been an integral part of arctic science and education programs with relatively minimal self-reflection on how fieldwork may impact Climate Change and the natural environment. Whilst methodological articles and manuals have had little focus on the environmental impact of science, it is currently becoming more and more obvious among students and researchers to pay attention to how fieldwork and other research related activities can be done in a more environmentally friendly manner.

Box 3.1: Sustainable travel

The concept of *sustainability* has become common in the context of nearly everything that is done or used each day. Sustainability can be defined as meeting the needs of the present without compromising the future of other generations to meet theirs. This concept is often divided into three pillars: Economic, Environmental and Social (United Nations World Commission on Environment and Development, 1987). Global initiatives such as the United Nations' Agenda 2030, including the Sustainable Development Goals (2015), present a variety of objectives within the concept of sustainability.

Sustainable travel broadly means travelling in a way that minimises our environmental footprint. This includes minimising emissions from travel, taking care not to harm or commodify the destination's cultural and natural environments. Being a sustainable traveller helps us to continue exploring and taking enjoyment from the planet while preserving its beauty, healthy ecosystems and diverse communities.

3.1 Travel to the Arctic

Travelling to the Arctic needs careful planning and often different modes of transport are used until the final destination is reached. To compare these modes of transport in terms of CO_2 emissions is not an easy task when going into details, because various factors are to be considered: selection of transport means, choice of route, use of capacity, source of energy (renewables, nuclear plant, fossil fuel power plant) and infrastructure.

3.1.1 Air transport

Flying constitutes one of the most climate-polluting activities at the individual level. For instance, a researcher flying a roundtrip between London and New York to attend a scientific event generates almost the same quantity of CO_2 as an average person heating their home for a whole year in the EU (Langsdale, 2019). According to the aviation tracking report by the International Energy Agency

(IEA) the rapid rise of CO_2 emissions from aviation over the past two decades resulted in nearly 1 Gt in 2019, which is about 2.8% of the global CO_2 emission from fossil fuel combustion (IEA 2020b). However, this global estimation does not cover the impact due to the release of emissions at high altitudes, which can affect climate change by radiative forcing. Studies indicate that radiative forcing might double or even triple the impact flying has on climate change (Lee et al. 2020). In addition, aviation-related emissions, such as airplane manufacturing or energy costs for operating airports are not included in these numbers (Eriksson et al. 2020). Taken all this together, a revised estimate results in aviation more probably being responsible for alone 5% of impacts of global anthropogenic Climate Change (Eriksson et al. 2020: 18). However, decarbonizing aviation is challenged by, i.e. robust demand growth, industry structure and the physics of flight (IEA 2020b).

Box 3.2: EU for a 'Clean Sky'

The *'Clean Sky'* initiative, part of the *EU Horizon 2020 research and innovation programme*, aims at developing cutting-edge technologies to reduce CO_2 gas emissions, NO_x emissions and noise levels. The European Commission and the European aeronautics industry have started a public-private partnership, the *Clean Sky 2 Joint Undertaking* to develop cleaner air transport technologies "capable of reducing CO_2, NO_x and noise emissions by 20 to 30% compared to 'state-of-the-art' aircrafts entering into service as of 2014" (Clean Sky 2, 2020: 4).

By sending students and researchers on field trips, the scientific institutions make a significant contribution to CO_2 emissions. **When comparing carbon footprint per capita, it is noticeable that scientists and academia have a higher carbon footprint than the average population** (Fardet et al., 2020; Klöwer et al., 2020; Stevens et al., 2020).

Box 3.3: Carbon footprints in academia

In their study on the GHG emissions of Max Planck Institute for Astronomy in Heidelberg, Germany, Jahnke et al. (2020) calculated an amount of 18.1 tCO_2e per researcher in 2018, compared to 6.8 tCO_2e per person for the German climate target of 2030. Academic flights accounted for the largest share of carbon-intensive activities (47%) followed by electricity (26%) and heating (16%) (Jahnke et al., 2020: 813).

While long-haul flights often represent the primary and major cause of CO_2 emissions at institutions (e.g. Langsdale, 2019), the *carbon intensity* remains high for even short flight distances of less than 1,000 km (Figure 3.1). *Carbon intensity* describes the emission rate of a given pollutant relative to the intensity of a specific activity (e.g. the number of grams of carbon dioxide (CO_2) that it takes to make one unit of electricity a kilowatt per hour).
This demonstrates the importance for scientific institutions and scientists to develop strategies for minimising the impacts of both long-haul and short-haul flights.

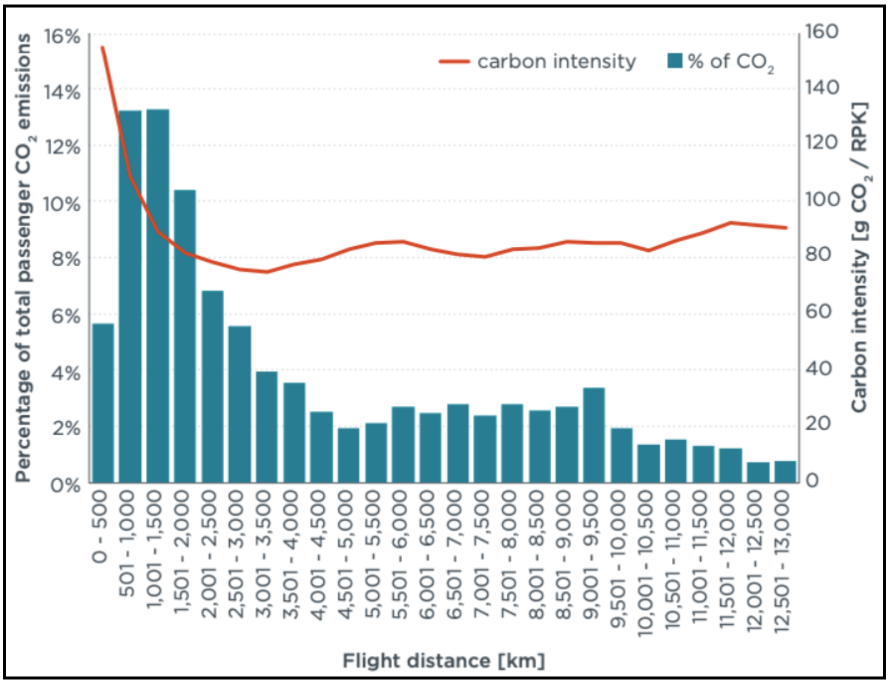


Figure 3.1. Share of passenger CO_2 emissions and carbon intensity in 2018, by flight distance (Graver et al., 2019: 8). RPK (Revenue Passenger Kilometre) is the number of kilometres travelled by paying passengers (Number of revenue passenger x total travel distance).

TIP: Air transport will always include a large amount of CO_2 emission. However, it is still possible to reduce emissions a little by "fine tuning of flights" (Eriksson et al. 2020: 22-23). Here are some little choices that help to reduce the carbon footprint:

- Choose direct flights - Most fuel is needed with take-off and landing
- Choose airlines with newer and more fuel-efficient planes
- Choose airlines with alternative non-fossil fuels with low environmental impacts (see e.g. box 3.2)
- Fly economy instead of business or first class (transport more people per emission)
- Choose scheduled flights instead of charter flights (where possible)
- Pack light - The heavier the plane, there more fuel is needed
- Choose daytime flights when it is possible

Box 3.4: The rise of biofuel: The example of Scandinavian Airlines

Scandinavian Airlines (SAS) turns regular flights customers into 'sustainable travellers' by encouraging passengers to buy blocks of biofuel that cover, either partially or fully, the flight time. SAS aircrafts are certified to be able to use up to 50 percent biofuel together with fossil fuel. When booking a trip with SAS, one can purchase 20-minute blocks of biofuel (10 euros per block) directly on the website. According to SAS, biofuel can reduce CO_2 emissions by up to 80%, compared to conventional jet fuel. The biofuel purchased by a passenger might be used for another flight than the one the traveller has bought a ticket for. Still, every passenger can contribute to the SAS environmental goal to use 17% biofuel in 2030.

Note, however, that biofuel may have land use implication and impacts on local societies and environment. Certified biofuels may ensure that such impacts are minimised.

3.1.2 Land transport

The Arctic may not be renowned for its land transport infrastructure (roads and rails), but the increasing urbanisation of the region and the use of motorised vehicles, even at remote research stations, highlight the need to reflect on land transport (Dybbroe, 2008; Laruelle, 2019).

Road transport (e.g. cars, trucks, buses, ATVs and two- and three-wheelers) is considered the greatest emitter of GHGs among the transport sector, representing approximately three quarters of the emissions (IEA, 2020a). While numbers of electric cars are increasing and despite the progress being made in electrification, there is an increasing growth of emissions from road transport (IEA, 2020a).

Reindeer crossing street in Northern Norway. [Credits: Svenja Holste, 2017]

In Finland, Iceland, Sweden and mainland Norway, the road network is considerably denser than in other parts of the Arctic. However, roads are still connecting southern and northern settlements in sparsely populated regions like Alaska (USA), the Northwest Territories and the Yukon (Canada) and Russian arctic. Winter ice roads across frozen ground, lakes, rivers and swampy areas connect remote and small communities in some arctic regions. Due to climate change, these are likely to become increasingly inaccessible. Few railroads are connecting the southern cities with destinations above the Arctic Circle. Vast areas of Greenland, Nunavut, Nunavik and Labrador (Canada) have no land transport infrastructure, only exemptions being road segments connecting nearby settlements. Here, most transport between settlements is with aircraft, helicopter or boat (Figure 3.2).

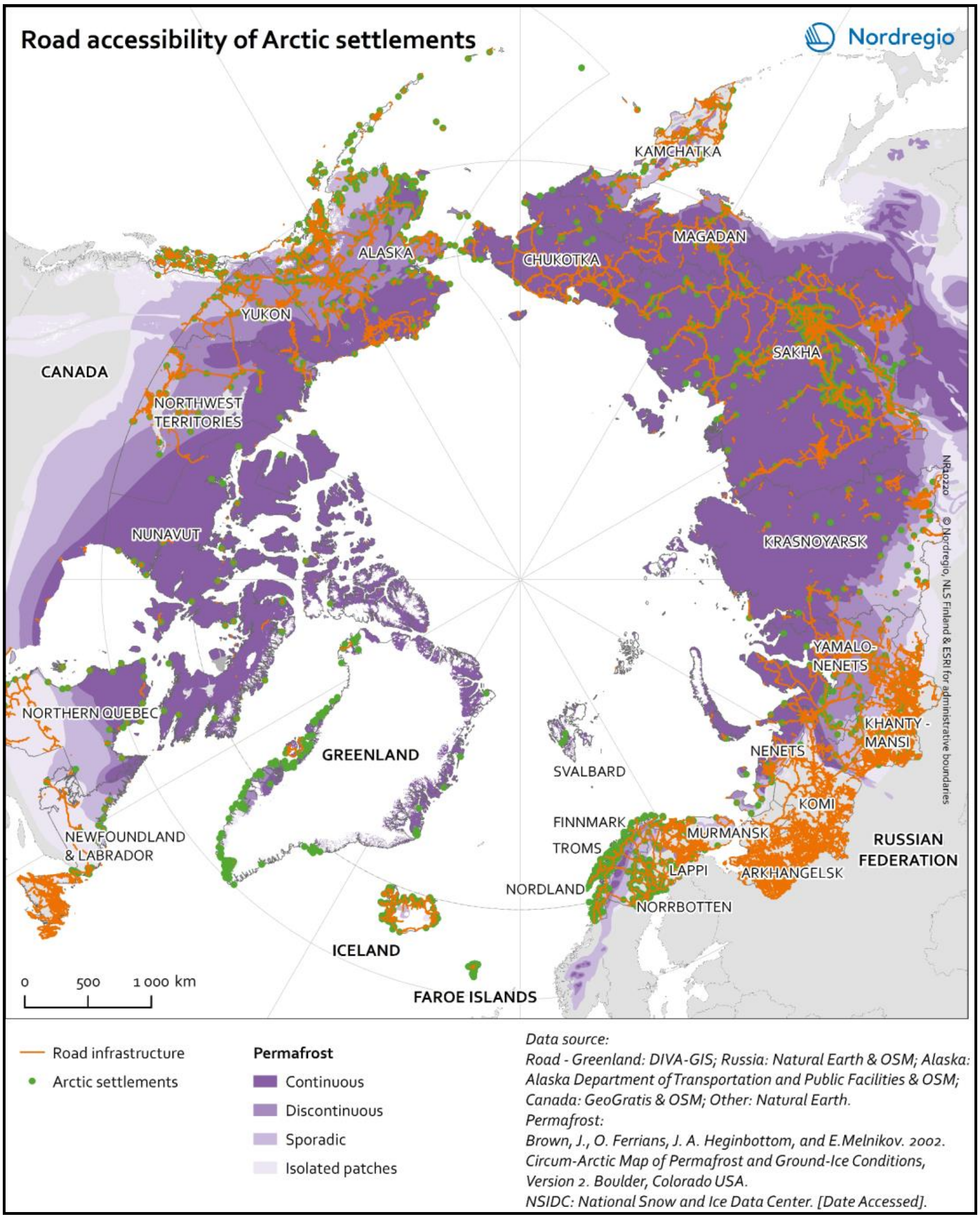


Figure 3.2. Road accessibility of Arctic settlements. [Designer/Cartographer Eeva Turunen, 2019]. (Nordregio, 2019) Note: This map includes small roads in towns, and hence settlements with no connection to other settlements may appear orange. It is the authors impression that at least for Greenland, the information gathered for the map might be insufficient.

3.1.3 Shipping

As a result of Climate Change, sea ice thickness and spatio-temporal distribution also change. Changing ice conditions have implications for local transport on ice (e.g. dog sledge and snowmobile), while changes in sea ice cover facilitates an increase in shipping activities both locally and through the Arctic Ocean that connects the Atlantic and Pacific Ocean. However, due to harsh environmental conditions and rare SAR infrastructure, passages will remain difficult in the near future. The 2009 Arctic Marine Shipping Assessment (AMSA) Report by the Protection of Arctic Marine Environment Working Group of the Arctic Council report that the number of ships in the Polar Code Area has increased by 25% from 2013 – 2019. The majority of these vessels were fishing vessels (41% in 2019) (PAME 2020a) and 47 out of the 1,725 ships listed were research vessels (PAME 2020b).

Box 3.5: Polar Code

The *Polar Code* or International Code for Ships Operating in Polar Waters (in force since 2017) is a legally binding catalogue of rules for ships operating in Arctic waters north of 60°N. It applies to member states of the International Maritime Organization. One stated objective is not only to make shipping in polar waters safer, but also to mitigate its impacts on the arctic environment (Polar Code, 2017).

Ships do not only emit CO_2, but also black carbon (BC), when burning fossil fuels such as heavy fuel oil (HFO) (Figure 3.3). Black carbon is a solid particle or aerosol rather than a gas, but it also contributes to warming of the atmosphere. BC can be about 3,200 times more powerful as a climate forcer than CO_2 over a 20-year time horizon (Comer and Olmer, 2016). According to The International Council on Clean Transportation (ICCT) global shipping emissions inventory (2013-2015), BC accounts for more than 20% of CO_2e emissions from ships over a 20-year timeframe, making it a significant climate warming contributor (Olmer et al., 2017).

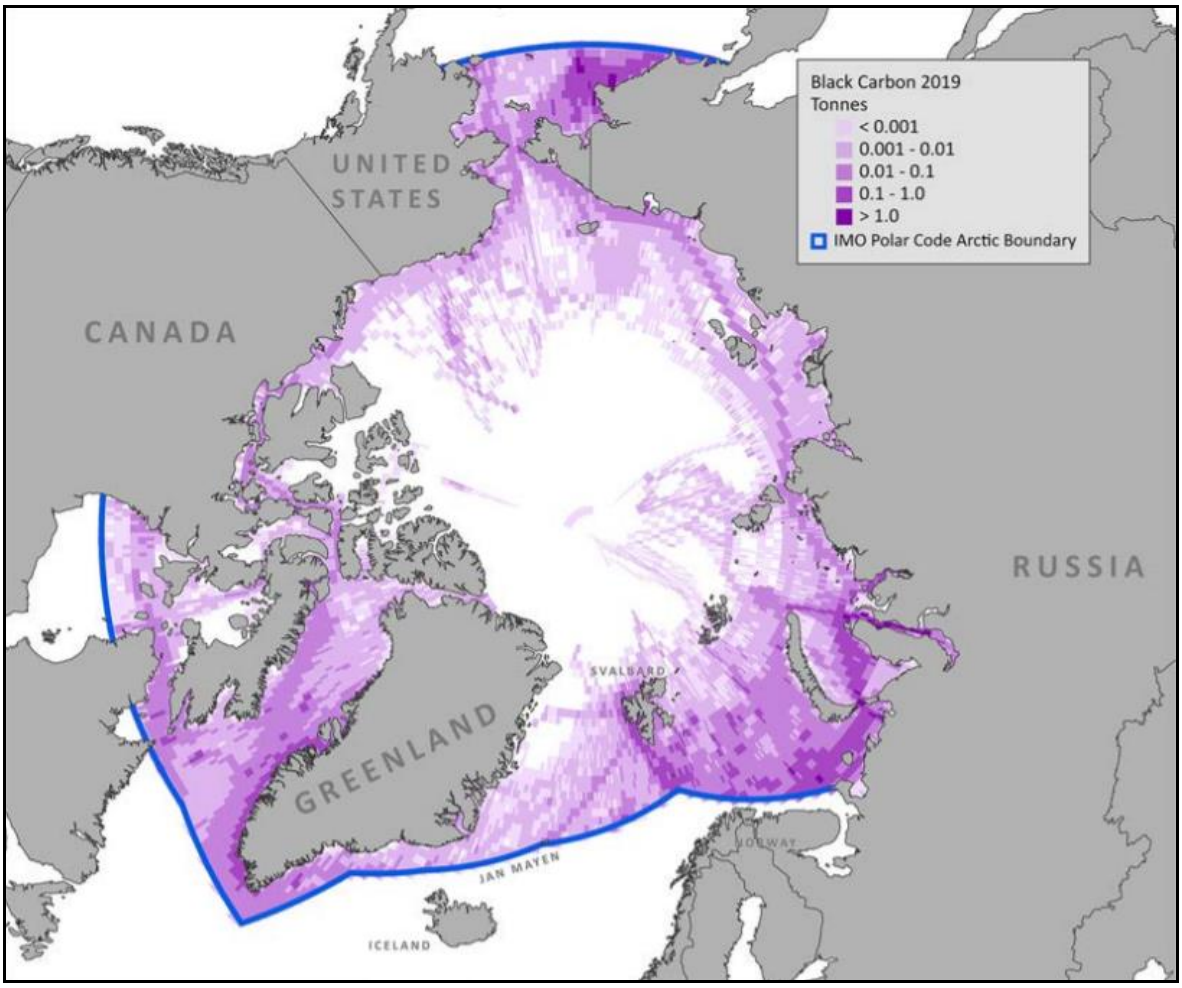


Figure 3.3. Black carbon emissions from Arctic shipping (all fuels) in 2019 (Comer et al., 2020:8)

Cargo vessels transport goods, like engines, samples, or equipment, from and to the Arctic. ***Icebreakers***, ***ice-strengthened vessels*** or ***normal cargo/passenger ships*** are mainly used for long distance travel or expeditions (e.g. oceanography, marine biology, geology). For expeditions collecting samples at sea for weeks, or even months, scientific vessels of a significant size with specific research facilities, embarking large crew and scientific teams, are often required. Emissions vary depending on shipping operation at port, at sea or when manoeuvring.

In Arctic waters, ships are often using different types or combinations of fuel, depending on factors such as type, size, operation, logistics, chartering, legal requirements or costs. In 2019, the Arctic Ship Traffic Data (ASTD) system was launched by the Protection of the Arctic Marine Environment (PAME) Working Group to monitor shipping activities in the Arctic. According to their data, distillate marine fuel (MGO/MDO) is most commonly used in the Arctic. Other types are residual marine fuel, heavy fuel oil (HFO), hybrid oils, or liquified natural gas (LNG) or battery powered ships. In the near future, international regulations are expected to change the use of marine fuels in the Arctic, with major benefits for health and environment. In 2020, the IMO introduced a global limit for sulphur in fuel oil. In 2029, a potential ban on HFO might be adopted. In addition, the IMO strategy for 2050 envisions a reduction of GHG emissions from ships by 50% by 2050 relative to 2008 (PAME, 2020b).

Box 3.6: MOSAiC expedition and the research vessel (RV) Polarstern

The MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) expedition was designed and supported by a consortium of polar research institutions led by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Germany.

Taking inspiration from Nansen's Fram expedition (1893-1986), *RV Polarstern* drifted with the ice across the central Arctic from October 2019 to October 2020. A distributed regional network of observational sites was set up across the sea ice within a ~50 km radius of *RV Polarstern*. Research teams made *in-situ* observations of the climate processes related to atmosphere, ocean, sea ice, biogeochemistry and ecosystems. The results from MOSAiC will greatly strengthen our understanding of the regional and global implications of Arctic climate change and sea-ice loss, while improving weather and climate predictions around the world.

During the 357 days of natural ice drift, diesel consumption of *Polarstern* was only estimated to be 15 tonnes per day, due to heating and electricity generation. *Polarstern* runs on low-sulphur marine diesel (DMA), which burns more cleanly than heavy fuel oil. The journeys to the Arctic and return (33 days in total) through ice and water have been calculated with an average of 54 tonnes diesel per day. As one tonne of diesel produces around 3.1 tonnes of CO_2 emissions, it has been estimated that in total ca. 22100 tonnes of CO_2 will be produced at the end of the expedition. (AWI, 2019)

The new hybrid-driven boat MS Bard operated by Hurtigruten Svalbard in Isfjorden, during its first maritime season, on the route to Pyramiden, a former Russian settlement on Svalbard, Norway [Credits: Sophie Duveau, 2021].

3.2 Local transport in the Arctic and field site access

3.2.1 Local air transport

For remote areas and difficult terrain, aircrafts often provide the only option for personnel transport, supplies or logistics. In the Arctic, their use is also indispensable in emergency situations (Search and Rescue operations).

For all use of aircrafts (i.e. helicopters and fixed winged aircrafts), there is a potential for reducing fuel emission (and costs) significantly by cooperation among as many projects as possible. When an aircraft is mobilised to a very remote site, it is beneficial to use it as much as possible before demobilising it again. Therefore, a coordination of projects to make more focussed campaigns including many different projects is of utmost importance in remote arctic areas – to keep the CO_2 emission and the costs down. Further, while on site, it is worth to make a detailed planning of all flights (e.g. of scientists and equipment to small field sites) with the purpose of reducing the amount of flight time and to fill the aircraft as much as possible on each flight. If, for example two projects both are working far from the base camp but relatively close to each other, it might be considered to use the same flight out of base camp to bring payload (weight of passengers and cargo) to the one site and to bring payload back to camp from the other site. Calculations of how to make such coordination of flights with the purpose of reducing the duty hour of the aircrafts is a task for professional logisticians – but can still easily reduce the duty hours of aircrafts and their fuel consumption with at least 50%. For bigger campaigns, it is therefore advisable to include professional logisticians to take care of flight coordination.

Helicopters in the Arctic can be ship-based, (mainly on icebreakers, military ships or research vessels, which have a landing platform and a hangar for maintenance) or land-based. In some cases, helicopters are chartered and brought in either by sea or by air. Although this mean of transportation allows researchers to reach remote areas and fly above their study sites, it has a very high environmental footprint. Fuel provision is particularly challenging in some remote regions and needs careful planning way ahead to ensure good and sufficient fuel positioning. Although depending on the power type (i.e. piston, turbine), helicopters are generally using more fuel than fixed-wing aircrafts and are therefore expensive tools. Flying low with helicopters are known to disturb wildlife (Hoang, 2013).

Helicopter used to spot and retrieve gliders lost in a wide geographical area, in Qikiqtarjuaq, Nunavut, Canada. [Credits: Gwenaëlle Gremion, 2018]

The burn rate of ***small fixed winged aircrafts*** is dependent upon a number of factors such as size, speed, altitude, weather, empty weight, amount of payload, amount of fuel during operation, position of load (in sling-net versus in cabin) etc. While efforts are put in place to replace those planes with electric-powered aircrafts in the future, the difficulty of battery autonomy in cold regions, and the questionable fact of the origin of battery elements and end-of-life recycling has to be considered. However, during the last years a new type of battery driven helicopters, i.e. drones, have proven to be able to take over much of the activities (especially in relation to remote sensing), previously being carried out sole by manned helicopters of different sizes.

Balloons and non-motorised airborne apparatuses represent a low-carbon option to collect observations that are relevant in some scientific fields such as atmospheric sciences (e.g. weather balloons that carry radiosondes). It should be noted, however, that the launch of latex balloons has an impact on the environment as well as on human societies, as around 1,300 locations around the globe do routine releases, two or four times daily (WMO, 2021). The fact that personnel are sometimes requested to find and bring back the radiosondes is rather counterproductive as the mode of transport used to search for the instrument emit CO_2.

3.2.2 Local land transport

Snowmobiles are commonly used for recreational activities, for hunting and fishing, for rescue operations and by scientists to access the field sites as well as installations and instruments. While they may facilitate scientific activities during the snow season, they still emit substantially more CO_2 emission than cars.

The type and condition of the snowmobile will determine the extent of the environmental effect. Having a well-running engine, changing filters, ongoing maintenance and ensuring the quality of fuel can make a substantial difference in reducing emissions. For example, snowmobiles running on two-stroke engines are known to emit high quantities of carbon monoxide and particulate matter, as compared to four-stroke engines. Consequently, snowmobiles can have a significant impact on the environment, yet the extent of this can be partly mitigated by utilising newer and higher quality machinery. However, buying new snowmobiles while the old ones are still working is pushing over-consumption and increasing industrial waste.

Attention should also be paid to other kinds of pollution resulting from snowmobiling. In a recently published study, the highest polycyclic aromatic compounds concentrations observed in spring in Longyearbyen, Svalbard, are attributed to local snowmobiling emissions (Drotikova et al., 2021). Moreover, snowmobile traffic can affect the local fauna. For instance, on the same archipelago, a comparative analysis of the Arctic Fox behaviour in two areas, one control area with low snowmobile traffic and one experimental area with high snowmobile traffic, also reveals that snowmobiles affect the diurnal activity patterns of these animals (Fuglei et al. 2017). Although there is a lack of literature focusing on CO_2 emissions, the negative effects of snowmobiles on the environment have already been acknowledged and even led to tightened management measures within sensitive nature and cultural heritages (Svalbard Environmental Protection Act, 2001). However, snowmobile impacts differ from one place to another according to e.g. topography and climate conditions (Musselman and Korfmacher, 2007). The alpine and the Arctic tundras may be particularly vulnerable to snowmobiles, which can affect their plant communities (Greller et al., 1974) or leave prints in the permafrost (e.g. thermos-cast due to wear on the terrain).

Cars, trucks and other types of motorised vehicles, such as ***tracked vehicles*** and ***all-terrain vehicles,*** allow scientists and logisticians to carry equipment, especially heavy loads, from one point to another. If available, designated driving paths should always be used to reduce the disturbance of the environment. The choice of vehicles safety and reliability plays an important role in the Arctic. The number of individual transports needed to move scientists from a bigger city to a remote research station and back can be reduced by good coordination of these trips (to fill up each car). Hybrid cars might be considered as an alternative to cars running solely on fuel. However, due to a general lack of charging facilities, the use of electrical vehicles in these regions is often impossible.

Box 3.7: Science by foot: the Catlin Arctic Surveys

The Catlin Arctic Surveys consists of a series of field trips that gathered an international team of scientists and polar explorers from 2009 to 2011 to study the effects of climate change on the Arctic sea-ice in the High Canadian Arctic and close to the North Geographic Pole. While the first expedition, a three-person team, travelled by foot over hundreds of kilometres of sea-ice, the next two expeditions combined scientific work at a stationary research base on sea-ice located off the coast of Ellef Ringnes Island, Nunavut (Canada) with a long journey on foot across the sea-ice. Explorers and scientists drilled through the floating ice and collected water samples to measure the amount of carbon dioxide at various depths. This extreme survey investigated how fast the Arctic Ocean is acidifying due to rising CO_2 levels and it explored the effects of this phenomenon on marine species. Samples of phytoplankton and zooplankton are particularly decisive to understand potential effects of ocean acidification on the arctic food web.

3.2.3 Local shipping

Boats of all different sizes and engine types are used for arctic scientific research. Some field sites can only be reached by boat or the objects of study themselves can only be observed, sampled or measured at sea and/or underwater (e.g. glacier front, marine sediments, marine species, salinity, turbidity). The size and type of the engine(s), their age, the fuel type, the average cruising speed, the fuel efficiency and the number of hours of use can contribute to modify the carbon footprint. Individuals can reduce the carbon footprint of a boat trip by:

- reducing the fuel usage (e.g. by performing routine engine maintenance, reducing extra weight, monitoring boat performance to find the most efficient speed for the vessel),
- reducing the speed, and
- minimizing the duration of the utilization.

However, researchers often rely on finding their means of transportation on the private market (either for purchase or renting), and thus cannot solely choose what type of a boat they can use during their field campaign. Cooperation and shared logistics are key to reduce both costs and CO_2 emissions.

Sailing boats were historically used for long distance travel in the arctic region. Nowadays, a combination of both wind, solar and engine energy is used by sailing boats, leading to an increase in their carbon footprint. Some may have the capacity to navigate in icy-water, but most of them do not, and therefore are only seasonally used.

Zodiacs and speed boats are used both to support the activities of bigger ships (i.e. icebreakers, bigger engine driven ships or sailing boats), terrestrial field bases, camps and research stations. Disturbance to marine wildlife and birds might be an issue. For local waters, electric engines could be considered for small boats used for local operations.


Zodiac used to deploy autonomous instruments during the DarkEdge mission in the North Water Polynya, Canada. [Credits: Laure Vilgrain, 2021]

Traditional ***ice-canoe*** or ***kayak*** can for some project types be of relevance in arctic waters. As these boats are moving very quietly do to its human-power driven engine and have a very small carbon footprint.

Traditional Quebec Ice Canoe used for research on sea-ice, transported in the North Water Polynya, Canada. [Credits: Paul Nicot, 2021]

TIP: Field site access

CO_2 footprint can be reduced by using low-carbon means of transport or by optimizing field trips, for instance, by camping or finding accommodation in the immediate vicinity of the field site rather than travelling to and from a distant base on a daily basis.

3.2.4 Remote sensing

Airborne remote sensing can be used to collect data (e.g. hyperspectral images, aerial photographs) from above. Depending on the projects and the number and variety of datasets, this strategy can be either highly carbon-intensive or low carbon intensive. A high carbon-intensive project would be a project in which a single team of scientists rent a helicopter to fly over a particular study area for a specific research purpose. On the other hand, a shared platform equipped with sensors mounted on a small aircraft can allow for data collection for different researchers from different institutions, lowering the individual carbon footprint. Collaboration may also have a major benefit of reducing the costs related to the sampling.

Remote sensing in the form of ***unmanned vehicle systems (UVSs)***, ***satellites*** and ***ground-based technologies*** can provide virtual access to objects of study. Although they give access to objects of study, most remote sensing technologies require access to the field either for calibration with observational data.

Unmanned aerial vehicles (UAVs), e.g. drones, are often operated remotely from the vicinity of a studied area and do not necessarily imply CO_2 reduction from transportation. Besides, these high technology devices encompass manufacturing processes, transportation, distribution and end-of-life treatment, thus emitting CO_2. However, UAV's generally use much less fuel than manned aircrafts and are more flexible for data collection for instance to cover risky as well as inaccessible areas. Before starting your own drone-based data collection, it is advisable to first consider satellite based remote sensing data. It might be that you are well off with data from satellites. Satellites also have a very high environmental imprint, but the CO_2 has already taken place. So, the more we use the data, the less the CO_2 imprint. Researchers can reduce their carbon footprint by coordinating activities with the purpose of optimising the amount of data being collected for every minute the drone is in use.

In general, in addition to remote sensing, what is more likely to reduce the CO_2 reduction in Arctic science is cooperation regarding scientific instruments, field parties and data retrieved from the field.

3.3 CO_2 emission from living/staying in the Arctic

3.3.1 Power supply

In arctic science, a wide range of energy source are used for a variety of services and activities. Energy is used for, but not limited to: transportation to/from/in the field, manufacturing of scientific equipment, run of scientific stations, field camps etc. (i.e. heat, electrical power and connectivity), cooking, transferring data to outside the circumpolar region. It is not always possible to replace a source of energy by renewables as, for instance, in a remote cabin. Besides, most scientists use scientific infrastructures they do not always reflect on. Data centers consumes enormous amounts of energy which, depending on the country in which they are located, may imply burning of fossil fuels.

Box 3.8: The transitioning of Longyearbyen from coal mining to new sources of energy

In Svalbard, the town Longyearbyen is hosting many different arctic research facilities such as the University Centre in Svalbard (UNIS), the Norwegian Polar Institute, the Czech Arctic Research Station and the EISCAT Svalbard Radar. The settlement covers its needs for electricity and heat from Norway's only coal-fired power plant supplied by locally mined coal. Coal-mining represented for decades the only source of income for Svalbard and it still has an important sociocultural and symbolic function in the local community. The mine, still operated by the Store Norske Spitsbergen Kulkompani, provides about 40 GWh of electricity and 70 GWh of heat to the approximately 2,200 residents in Longyearbyen. In addition to the coal-fired power plant, there are five diesel generators to cover peak electricity demand and to serve as reserve generator capacity (Ringkjøb et al., 2020). In total, the energy supply in Longyearbyen emits about 80,000 tonnes CO_2 annually (Rud et al., 2018). This leaves Longyearbyen as the highest CO_2 emitter per capita in the world with ~40 tonnes per capita. For perspective, mainland Norway emits ~7 tonnes per capita and the United Kingdom emits ~5.5 tonnes per capita, based on 2018 data (World Bank, 2021). The Longyearbyen's Community Council announced that coal mining operations will cease in 2023. As the settlement was founded for coal mining, the power plant shutdown marks the end of an era and opens a new post-mining future. However, this decision is highly controversial within the local community.

Coal-fired power station in the harbour zone of Longyearbyen, Svalbard. [Credits: Sophie Duveau, 2020]

A reliable energy supply is particularly important in the Arctic due to the harsh environment, low population density and the long distances between settlements. Arctic communities depend largely on fossil fuels for heating, transportation and electrical power generation. The region uses a lot of fossil fuel for their operation, and most (if not all) of the fossil fuel have to be transported far to reach the Arctic destination – adding further to the carbon footprint of arctic communities. One of the most important concerns for the communities in the polar regions is access to affordable and reliable sources of alternative energy (Arctic Council, 2009).

A greater interest in renewable energy is emerging in the Arctic. In remote communities, supplementing diesel-based electricity with renewables cannot be easily achieved, and technical challenges of operating these in the most extreme cold and remote conditions still have to be overcome (Nefedova et al., 2016). When technological developments allow the use of renewables in these harsh environments, lack of infrastructure can still be a limiting factor to the development of Arctic energy, which requires connecting rural settlements to a regional or national network (Arctic Council, 2010). Moreover, renewable energy resources are heterogeneously distributed across the Arctic, with some regions having more potential than others (Popel et al., 2015). For example, Arctic tidal power will be limited to areas without sea-ice (Arctic Council, 2010).

Box 3.9: Energy consumption in the field

Supported by the Arctic Council Arctic Hydrogen Energy Applications and Demonstration (AHEAD) project, the Snowflake International Arctic Station, which will be inaugurated during the Russian Chairmanship of the Arctic Council in 2021-2023, will consist of a diesel-free research facility powered by renewable energy sources. Thanks to locally produced hydrogen and wind power, this will become a symbol of international cooperation towards a more sustainable Arctic.

Princess Elisabeth Station in Antarctica is another example of how a ZERO-emission station can be in operation, even in very cold polar areas.

Despite these challenges, renewable energy is one of the most promising ways to reduce CO_2 consumption in arctic science. At a small scale, local energy resources such as solar energy and wind are more and more used to run automated scientific instruments and devices are becoming increasingly common. During the polar summer, the sun constitutes an advantageous energy source in remote areas. Although low temperatures represent a technical constraint (Ladvishchenko and Lagunov, 2020), solar panels can be found in the field, for instance to supply automated cameras with power to monitor e.g. population dynamics of certain species, monitoring of changes of glacier front positions or landscape change.

A solar cell mounted on an automated camera in Bjørndalen, Svalbard. [Credits: Sophie Duveau, 2020]

Box 3.10: The Corbel base, an example of shift to clean research facilities in the Arctic

The Corbel base was set up in summer 1963 by French expeditions in the vicinity of the Ny-Aalesund settlement, Svalbard, which, at that time, was far from the international research campus we know today. Bringing all construction material from France, through a long and epic journey on land and at sea, French researchers, technicians and other staff built several wooden houses to accommodate their needs in the field (i.e. accommodation facilities, laboratory, equipment and supplies storage) (Duveau, 2020). Now jointly managed by the French Polar Institute Paul-Emile Victor (IPEV) and the German Alfred Wegener Institute (AWI), this facility constitutes the first attempt of having a scientific base which is self-sufficient in energy in Ny-Aalesund. Solar panels, a wind turbine and a sophisticated recycling bin are significant components of the renovation of the base, which aim to reduce the environmental footprint.

4. Necessity and impacts of conference related travel

Over the last few decades, the use of digital media and communication have significantly transformed the means and pace of scientific publications, leading scientific journals to publish papers in a more accessible way, including attractive formats that appeal to general readership (Milić et al., 2020). On the other hand, the format of scientific conferences has practically remained the same despite the digital turn, even though the number of conferences has increased dramatically.

The scientific community itself has been pointing out the environmental impact of intense professional mobility, especially to attend conferences and present papers (Spinellis and Louridas, 2013; Stroud and Feeley, 2015). The carbon footprint of individuals also reveals disparities in terms of travel practices based on the status within the scientific community. To give an example, chemist Prof. Fraser Stoddart reported that the number of his international travel appointments increased from around 20 to more than 60 per year after receiving the 2016 Nobel Prize in Chemistry (Stoddart, 2020). Further, scientists at professor level emit on average 11 tons of CO_2 per year, while students emit around 4 tons (Arsenault et al., 2019).

Arctic science can be regarded as a collective effort, and traveling to meet cooperation partners is therefore an important part of science. Researchers generally have colleagues affiliated with institutions based in different locations, which they must visit, for instance, for undertaking analyses, using a particular rare and costly technology, discussing results or for other kinds of collaboration. Whether conferences take place at a small or larger scale, they provide an opportunity to present the latest scientific advances to a relevant scientific community. Through conferences, researchers find a place to meet in-person, to exchange views and new ideas in direct conversation and to extend their sociability to peers from around the world. The social gatherings related to conferences (i.e. plenary sessions, workshops, side events, meals and other collective activities) can therefore help strengthen research networks and build new ones, whilst also maintaining research fields and friendship amongst scholars. Oral presentations and posters at conferences also constitute key employment and grant application metrics. Researchers are therefore encouraged to travel to many conferences every year, which all comes with a carbon cost.

Despite the central function of conferences in the science community, some researchers have questioned the practice of flying large distances to attend academic conferences for environmental reasons (Jäckle, 2019; Grémillet, 2008). They criticise the very high GHG emissions of scientists (compared to average citizens) due to their frequent work-induced flights, even though they otherwise might live low-carbon emission lives (Grémillet, 2008). They also find that the high carbon footprint from such travels considerably reduces the perceived credibility of climate researchers among the general public (Attari et al., 2016).

Box 4.1: Carbon footprint at COP26

The preliminary carbon footprint for COP26, held in Glasgow in November 2021, estimates 102,500 tCO_2e, with approximately 60% of emissions coming from international aviation (COP 26, 2021). For an estimation of 40.000 registered participants, this would result in an average emission per participant of ca. 2.6 tCO_2e (Booth and Stevens, 2021).

4.1 In-person conferences

In science, most flights are motivated by conference and workshop attendance rather than fieldwork. Doing research is international and meeting colleagues often requires travelling. The reasons for using air transport instead of other means of transport are multiple: Often, it is cheaper, faster (e.g. less time away from home/work) and more practical (e.g. less efficient work during travel and fewer changes between means of transport). The perceptions of individuals on the positive and negative effects of various modes of transportation as well as the rhetoric used to explain practices (i.e., hours flexibility, irregular working hours, children to be dropped at school, etc.) are important to investigate in order to accompany behavioural change within research institutions. (see chapter five: Institutions)

Many scientists use the opportunity of going to a conference to also experience some of the country they visit. It is important as a scientist to discern this and it should not be the only motivation factor for going to a conference that is being held in a beautiful or other attractive place.

In-person conferences contribute to CO_2 emissions through e.g. transport, lodging, conference facilities and catering. The location and choice of venue and catering service therefore affect the carbon footprint for conference organisers, while means of transport and choice of lodging affect the emission levels of the individual traveller.

The choice of a **conference venue** is crucial in order to reduce carbon emissions. In order to encourage participants to use public transport, the venue location must be easily reachable. Partnering with travel providers allow organisers to encourage conference attendees to travel by train, such as the AGU21 Campaign "TRAINGU21". A smart way of scheduling meetings is the Arctic Science Summit Week, organised by the International Arctic Science Committee (IASC) that has evolved as the major annual gathering of Arctic research administrators and organizations, with a multitude of organisation and project meetings held next to the scientific events.
Further recommendations on how to decarbonise conference travel can be found in chapter seven.

Box 4.2: Finding the optimal meeting location to save CO_2

Stroud and Feeley (2015) measured CO_2e emissions to conferences of the International Biogeography Society and compared it to emissions at optimal locations. While the overall average emissions were 857.1 tonnes CO_2, "if meetings had been held at their optimal locations, there would have been an additional average saving of 162.3 tonnes CO_2 per meeting" (Stroud and Feeley, 2015: 402). Having said this, the authors conclude that "this may reflect the relatively-restricted geographic distribution of meeting attendees, which is heavily biased towards the USA and Europe" (Stroud and Feeley, 2015: 403).

TIP: Conference site selection tool to minimise carbon footprint

A travel footprint calculator has been developed which incorporates the methodologies of seven publicly available calculators. It enables the computation of the travel footprint of a large set of travellers and can help identify a meeting place that minimizes the overall travel footprint for a large set of possible city hosts, e.g. cities with large airports. The calculator also includes the option for a minimum distance above which flying is considered the most suitable transport option and below that chosen distance, train journeys are encouraged (Barret, 2020).

It is accessible for the science community at: https://travel-footprint-calculator.irap.omp.eu/

Depending on the duration and location of in-person conferences, an overnight stay may be unavoidable and thus requires **lodging**. Most accommodation facilities rely on heating and air conditioning to keep rooms at a pleasant temperature for the guests against hot or cold weather. These energy-intensive systems also result in CO_2 emissions (from e.g. water heaters used to warm showers, pools and spas, electricity used for light, televisions, refrigerators, laundry machines and other equipment, and particularly in the areas with inefficient systems (Sustainable Travel International, 2020)). In addition, emissions released from lodging tend to be the highest in resorts and hotels that offer modern services as compared to smaller lodgings, like homestays and guest houses. Choosing small home stays and hotels with environmental accreditation therefore likely reduces the traveller's carbon footprint.

In general, pursuing diets that are rich in vegetables have lower carbon footprints than meat-rich ones (González-García, 2018). Most conferences offer **catering** to their attendees. The selection of the type of food and the company, which will provide this service are therefore crucial to reduce CO_2 emissions. As conference attendees often organize one or several dinners during the conference, the conveners can also inform the attendees towards locally produced commodities and services in town, by promoting certain companies. In general, choosing eco-friendly and locally grown food and cutting down on meat products in order to reduce the carbon and water footprints are important steps for organising a sustainable conference.

4.2 Online conferences

As discussed in the previous sections, in-person meetings and conferences affect considerably the amount of an individual's carbon footprint. The COVID-19 pandemic has accelerated the use of digital conferencing options to replace or complement in-person meetings, and the conferencing technology will continue to develop. The climate crisis demands that we identify sustainable alternatives to in-person conferences. Defining new environmental standards is an essential step toward reducing carbon footprint and control of GHG emissions (e.g. at workplaces, institutes and scientific-event gatherings).

Digital platforms are widely recognised as a way to reduce emissions from meetings and conferences. During the COVID-19 pandemic, visio and audio conferences were practiced to a certain extent for meetings of different sizes, seminar presentations, conferences and even defence/jury. An added benefit is that online conferences are accessible to a wider set of researchers, including people with severe disabilities and those with limited resources or having caring and family commitments. However, it is not possible to simply shift an in-person meeting to an online format. In particular, the creation of a network experience for participants in a virtual conference appears to be very challenging. Below tables (table 4.1 and 4.2) list some of the advantages and disadvantages of online conferences and meetings.

Hybrid meetings/events facilitate frequent scientific interactions while reducing travel and at the same time improving conference accessibility. Thus, one option in order to reduce the carbon footprint of international participants would be modern communication solutions such as remote conferencing services that make it possible for panellists to attend a conference from home. However, for conference organiser, this requires good technical support and comes along with more organisational time and effort.

Online events also come with a carbon footprint. Digital technologies alone are responsible for 4 % of global GHGs, and energy consumption related to such devices is increasing by 9 % per year (Efoui-Hess, 2019). There are over 4.66 billion active internet users worldwide (ESCP, 2021) and the internet emits 1.6 billion tonnes annually of GHG (Griffiths, 2020). While the live stream and the publication of videos retrieved from conferences may open access to scientific results and discussions, these digital practices are thought to be the most CO_2 intensive emissions released by the internet. Moreover, the organization of conferences as well as the management of speakers, participants and partners usually rely on e-mailing which has a concrete impact on the environment as has any action performed online (e.g. a standard e-mail emits around 4 g CO_2e (Richards, 2018)).

Box 4.3: Data, computing and CO_2

Considering the pollution generated in a computer lifecycle, actions must be taken at all stages by various stakeholders (e.g. raw material producers, manufacturers, retailers, users, waste handlers). One way to reduce CO_2 emissions associated with the computer supply chain is to buy low emission hardware and consider opportunities for re-use. The more institutions prolong the life of their computers and electronics, the less energy consumption is involved in manufacturing of sufficient equipment. A re-use policy reduces the footprint of manufacturing, of transport and distribution and of end-of-life treatment at the same time (Hart, 2016).

This strategy can be deployed for all electronic devices brought into as well as back from the field. Shared computers offer an alternative to individual computers and other incentives can be developed to prevent the purchase of unnecessary equipment. In some academic institutions, it has been shown that there was a practice of using the remaining of an annual budget to buy electronic devices, which were not always needed (Labos 1point5, 2020).

Computation must be regarded as an integral part of arctic fieldwork, since one major dimension of fieldwork is to collect and transfer data through electronic devices. Nonetheless, little research has centered on determining how much computing contributes to GHGs. The ignorance of this issue led to the innovative Green Algorithms project, which aims at providing a freely available online tool to estimate the carbon footprint of computational processes, including data center servers (http://www.green-algorithms.org) (Lannelongue et al., 2021).

Table 4.1: Advantages of online events

Increased participation	Online formats of events or conferences increase the total number of participants. Gathering many geographically distant people becomes easier. This is especially useful for arctic regions with vast distances between people. Increase of each individual's participation in events within a year. Individuals are usually able to attend a limited number of events for e.g., economic and time constraints, but digitised meeting allow them to participate in many more and with participants from across the world.
Better accessibility	Online events allow better accessibility for participants with disabilities, lack of access to childcare or being subject to visa requirements and travel restrictions. Lower conference fees present opportunities for involving researchers with very different socio-economic level, e.g. Early Career Researchers, researchers from relatively poor countries, institutions with limited funding
Time saving	Allows better for a combination of family constraints and professional activity. Allows more flexibility.
Career building	Borders and travel costs generally limit the internationalisation of cooperation and e.g. choice of opponents for PhD defences. Increase the quality of all different kinds of science related reviews by gathering international experts more easily.
Digitalization	Increase and diversification of the participatory approach: Attendees can share their screens, share files, interact with each other through a chat and are asked to participate thanks to digital options. If recordings of the sessions are made available, researchers can watch recordings of sessions that were originally scheduled at the same time.
Health effects	Participants will not experience jet-lag, travel related

	anxiety and other stress related to travelling.

Table 4.2: Disadvantages of online events and possible solutions

Disadvantage	**Possible solutions**
Technical issues	Schedule technical training sessions well in advance. Plan with more time for the transition between sessions. Collect presentations well in advance.
Access (e.g. weak or unstable internet connection and technological skills)	Make the use of online tools understandable for every participant by providing support and information before and during the event. Record the meeting to make the contents available at another time. Use and share meeting minutes.
Time zone difference	Make sure the conference time is understood by participants, using GMT. Schedule contributors' sessions at various times within the day, so that they can attend at the most convenient times. Record videos and making them available through conference platforms (including subtitles).
Health and body effects (e.g. eyes damage and fatigue)	Minimize potential for eye damage by adjusting luminosity or contrast and by using applications to minimize blue light. Spend more time on discussions and less time on presentations. Spend a bit of time on doing some exercises – this might also be funny and lose up a more formal atmosphere.

"Conference" feeling	Use online posters, multimedia content and icebreakers if possible (depending on the platform used for the conference). Making participants get to know each other and organising online coffee-breaks. Actively use the chat function so as to allow attendees to interact without speaking. Respect conference time as conference time although it is an online conference. Stay away from your office-related-work during the time of the conference to be sure you are present at the meeting.
Career building: (e.g. potential reduction of opportunities for ECRs)	Promote the participation of ECRs by offering them the opportunity to give a talk or take part in the organization of the event, or act as session chair/moderators. Encourage ECRs to interact during the event. Establish mentorship schemes.
Social value	Attribute the same value to a PhD thesis that is defended online as a PhD thesis that is defended in-person.

Box 4.4: Group-specific issues

All the above proposed ideas should be carefully assessed in terms of group-specific issues, as these recommendations will more likely impact researchers to various degrees. Pressure to attend conferences or book cheap flights, challenge low-carbon travel. It is important to not detract groups like ECRs or Indigenous Researchers from their ability to get involved in the research community.

Organisations, programmes and projects should strategically plan how their researcher can continue efficient collaboration while reducing meeting related emissions.

5. Get the institutions involved

The international research community is heterogenous, vast and growing. UNESCO's recent science report *The Race against Time for Smarter Development* (Schneegans et al., 2021) highlights that spending on research activities has increased 19% and the number of scientists has increased by nearly 14%, totalling 9 million scientists globally (*Number of Scientists Worldwide Reaches 8.8M, as Global Research Spending Grows Faster than the Economy*, n.d.). Further, there is a significant increase in the quantity of papers published about sustainability, not only in the natural sciences but also in social sciences, humanities, engineering, medicine and other areas. While the concept of sustainability has gained prominence across disciplines, the size and scale of the scientific research community – not to mention its accelerating growth and influence – brings attention to the potential environmental and social impacts this group can have in pursuit of its research activities. For these reasons, it is important that scientists not only reflect upon their own practices, but also try to influence those of their institutions.

5.1 The role of institutions

If action is taken at the **individual level** (e.g. trying to reduce travel-related emissions), success can be rather limited. This is especially the case, when institutional structures hinder or even disadvantage such decisions. It is therefore up to the **system level** and decision-makers to establish a foundation/culture for low-carbon research activities. Scientists have a role to play in this and can lead change in their own institutions, following a bottom-up approach. A transition towards more sustainable organizations may occur at interconnected scales - from the individual to the institution and vice-versa.

However, only few initiatives on carbon reduction so far exist in polar research institutions and Arctic Science in general. As part of an organisation enhancing international collaboration within polar research and promoting better access to the Arctic, the 2020 established International Arctic Science Committee (IASC) Action Group on Carbon Footprint develops recommendations to minimise the carbon footprint of IASC-related activities.

Over the years, researchers working in different fields in the Arctic have observed and described drastic climate warming implications in the Arctic. Many of them are involved in the decision-making processes leading to climate and environmental policies at both national and international levels as they engage in consultancy services, share recommendations and reports (see Box 1.3). More strikingly, others participate actively in the public debate on climate change and tell their personal values and convictions aloud.

Scientific institutions can reduce social pressure on researchers to undertake international travels while at the same time deploy incentives for modes of transportation which emit less CO_2. Reducing the carbon footprint does not necessarily compromise cooperation nor decrease opportunities (i.e., socialization, training, networking) for the personnel.

Acknowledging the above, institutions, especially universities, have started developing detailed internal action plans, sustainability guidelines as well as travel policies to trigger structural change. As more and more governments adjust their national policies to achieve their climate goals (see box

1.1), environmental regulations have already started to affect all parts of society. These policies will sooner or later affect how scientific organizations conduct their research. By being proactive in this regard, "science organizations can either prevent legal regulations or at least contribute shaping them" (Fardet et al., 2020: 2).

5.2 First steps

In recent years, a number of research institutes have published scientific articles in which authors quantified the institute's carbon footprint (carbon emissions reporting, e.g. Jahnke et al., 2020; Ciers et al., 2019). An accurate estimation of the institute's emissions related to travel forms a basis for further action towards a reduction of carbon footprint within the organization and in all its activities. Travel agencies can support and contribute in collecting relevant datasets over time (Ciers et al., 2019).

Clearly communicated priorities by decision-makers may be decisive, but objectives may be reachable only if they are defined collectively. The involvement of personnel appears to be critical from the definition of problems and the elaboration of solutions to the implementation of new policies in the daily work. This means an inclusive approach and the gathering, on an equal level, of both researchers and administrative personnel. It is important to create an institution-wide atmosphere that allows for critical conversations about CO_2 emissions, without fearing personal disadvantages or missing opportunities. An engaged scientific community that is promoting climate action forms the basis for change. The involvement of critical voices and concerns, acknowledgement of group-specific issues and a respectful open dialogue count as the key success factors.

5.3 Incentives

One option is for institutions to encourage a low carbon lifestyle (at least while at work) amongst its employees and members through direct incentives. There are many forms of incentives, e.g. make bookings of less emitting transport easier (or assisted), require compensation actions for flights, regular sharing institution emissions (to show that it matters), recognition of an individual's commitment, implementing an organization's sustainability award for sections/individuals that has made a difference (award may come with a monetary benefit), etc.

When travel options are sorted by time, costs and CO_2 emissions, it helps employees make more environmentally friendly decisions. Easy to implement is a **"street light system"** that classifies popular travel destinations according to distance from home institution into three different categories:
Green cities means that a plane is no longer offered as means of transportation
Orange cities train or bus are the preferred options (but flights permitted in some cases)
Red cities are best to reach via air travel.

In the form of a monetary benefit, organizations can also provide direct incentives for employees who do not fly for work, or perhaps, do so only to one **red city** a year. These can either be in the form of a financial payment or through offering an extra day of **annual holiday**.

Some companies also monitor the carbon equivalent used by its staff, either in the form of a carbon budget or a carbon tax. The idea behind a **carbon budget** is that each member, or the institution at large, has a certain amount of carbon or carbon equivalents that may be emitted per year. Any travel, whether by train to work or by plane for research, eats away at this number, thereby ultimately capping actions. This idea, however, does not offer incentives to limit emissions that could still fit within the budget, and thus, relies on having an appropriately-sized budget to still limit pollution. A **carbon tax** is a fee levied on emissions. Long used at the national and sub-national levels, a tax can be used very locally as well. For instance, an institution may collect an additional fee for each plane trip accrued by its members, which can support the institution's net zero efforts, such as discount railcards, office bikes, infrastructure for electric cars, solar investments, financial awards or carbon compensation action.

5.4 Restrictions

As with everything else, voluntary measures and incentives only have a limited impact on individual action. Only institution-wide decisions and binding commitments on low-emission travel policy ensure equal treatment and non-discrimination of the personnel.

One step here could be a prioritization of collective terrestrial modes of transport (train, boat, bus, car) over air travel. However, many times it is more challenging to travel with trains (e.g. additional visa requirements, higher expenses and more booking effort), therefore working with travel agencies is advisable. Especially, if it is a travel agency that has been working for the institute for a long time, it might be useful to reconcile goals and to insist on the prioritization of land-based travel. For Europe-wide travel, train journeys are feasible. The University of Ghent in Belgium, for example, has a commitment to travel by train if reachable within eight hours by train and offers an interactive map of travel distances and community stories to support this policy. For staff at University College London, domestic flights are not offered as a travel option, while the travel policy encourages the most carbon-efficient way to reach a destination, even if more expensive. If air travel is still needed, all business and first-class trips should be replaced by economy class trips.

Box 5.1: Scientist's voluntary self-commitments

More than 4,100 scientists have signed the self-commitment for not flying short-haul flights (e.g. air travel of less than 1,000km distance), a campaign by **Scientists4Future** (https://unter1000.scientists4future.org/signatures).

Another initiative is **No Fly Climate Sci** by earth scientists, academics, members of the public who either do not fly or who fly less (https://noflyclimatesci.org/).

The **FlyLess** blog (https://sites.tufts.edu/flyingless/) and **ExPlane** (https://www.timetoexplane.com/), an international network of students and university staff against the impacts of flying, developed a thoughtful travel pledge with over 1,000 supporters so far.

5.5 Other policies

5.5.1 Open data

Data sharing is usually an institutional commitment and relies on cooperation. Many grants, scholarships and awards have conditions that require research and data generated through their funding to be published as open access. Open access refers to the practice of releasing research outputs in a form free of barriers. This is contrasted by conventional, closed access journals, which rely on pay-per-view or membership fees to cover publication costs.

Open access data relies on a set of principles known as FAIR, *findability*, *accessibility*, *interoperability* and *reusability* (Wilkinson et al. 2016). *Findability* refers to data being easy to find, possibly through machine-readable metadata. *Accessibility* means that the data and metadata are retrievable once located, and procedures for authentication and authorization are provided. *Interoperability* is that data needs to be formatted as to be stored, analysed and integrated with other data. Lastly, *Reusability* indicates data stored in formats that readily enable them to be replicable, meaning usage licences need to be available as do any descriptions of use.

From a strictly scientific standpoint, there are numerous benefits to open access data ranging from an open and rigorous peer-review process to increasing the transparency and reproducibility of results. Moreover, the amalgamation of data through open access may allow for problems too complex for any one individual, team or institution to be solved. Although there are disadvantages, notably the potential for misuse and low-quality interpretations of datasets, some of these can be mitigated through the use of the FAIR principles.

Open access to data can significantly reduce CO_2 emissions: Researchers usually rely on several datasets, thus using data which were gathered by others, retrieved from automated instruments and remote sensing technologies in combination with their own field data. While open access data enables more prolific sharing and dissemination of material, field research trips can be reduced by data sharing and related guidelines for protecting intellectual property. In this regard, fewer individuals are traveling to collect the same, or similar, raw information. For instance, fieldwork campaigns can sometimes be replaced by access to datasets, for instance, permafrost monitoring (Bouffard et al., 2021). In this case, the individual carbon footprint resulting from fieldwork is shared with those who travel to the Arctic and perform fieldwork, or install or maintain instruments, thus lowering CO_2 emissions at the individual level. In this regard, opening access to data and promoting collaboration among scientists and between institutions constitute an interesting strategy to reduce the environmental impact of Arctic science.

Box 5.2: INTERACT Remote and Virtual Access

While INTERACT offers researchers physical access to infrastructures in the Arctic and adjacent cold regions, the call for *Remote Access (RA)* allows them to conduct research remotely. Through this service, researchers benefit from the presence of personnel on-site who collect samples, make measurements and contribute to monitoring projects following instructions and protocols. With

Virtual Access (VA), a free and open access to data gathered at INTERACT stations is provided.

INTERACT Access programs: https://eu-interact.org/accessing-the-arctic/
INTERACT Data Portal: https://dataportal.eu-interact.org/

However, it should be noted that the opening of data does not comply with the ethical concerns and practices of all disciplines, especially in the social sciences that have to deal with the legal framework of personal data. Furthermore, data sharing also has an environmental impact since data centres contribute to carbon emissions through the powering of computers as well as the long-term storage of data. As phrased in a recent paper: "data centres use an estimated 200 terawatt hours (TWh) each year. That is more than the national energy consumption of some countries, including Iran, but half of the electricity used for transport worldwide ..." (Jones, 2018: 163).

The importance of data sharing, both to remove extraneous research travels and to remove barriers to access (Figure 5.1), has received increasing attention following the success of the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) Expedition, which necessitated a global effort to collect its body of data. The Office of Polar Programs (National Science Foundation, USA) is an example of a federal-level research institution that has encouraged the use of open data, in part to circumvent research issues related to travel, in particular, those associated with the COVID-19 pandemic.

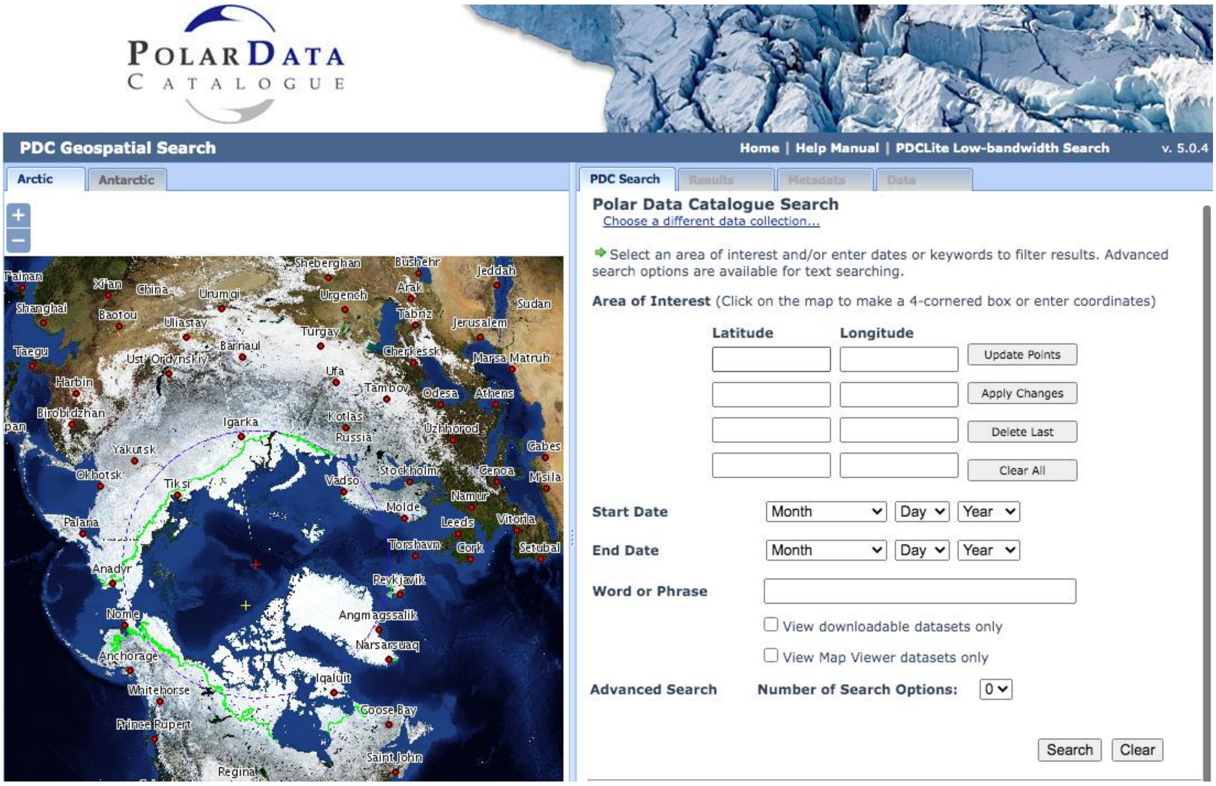


Figure 5.1. Example of open access repository with polar data: User interface of Polar Data Catalogue, information management infrastructure provided by Canadian Cryospheric information network. Screen copy retrieved in 2021 from: https://www.polardata.ca/.

5.5.2 Flexibility

Reducing emissions cannot just be a matter of the individual cycling to campus or prioritising long distance trains over planes. It requires a shift in the entire workplace ethos. Looking at this ethos shift is the focus of this entire chapter, however, there are critical areas that will be reiterated in this subsection.

One of the biggest contribution employers can make toward a low-carbon culture is to encourage remote or mobile working. Daily, allowing remote work can save on the emissions related to commuting to and from work, as well as those associated with maintaining office space. However, by supporting mobile working, employers can make it easier for its employees and associated members to travel by slower methods. Many trains have tables, power outlets and wifi, meaning that individuals can use their travel time just as they might at an office. Using time in this way ensures that employees are not using their holiday leave to compensate for slower, but more environmentally-efficient, travel. Further, such a system can also benefit the employer. Although point-to-point travel is faster by air, there are substantial blocks of time during which an employee cannot work - flight check-in, security, boarding, taxiing, landing, disembarkment, waiting for baggage. Cumulatively, this time can amount to several hours of unproductive time. Moreover, power outlets and wifi are not yet universally available on all flights, and when they are, they are typically an added cost. Thus, although the ratio of productive and non-productive work time corresponds to the length of the journey, employers can expect to have more productive employees when travelling by train (or bus).

6. CO_2 Compensation

6.1 The concepts of carbon offsetting

Mitigation and reduction of CO_2 emissions count as the most important climate protection measures but it is not always possible to avoid emitting CO_2, nor to reduce emissions. A **carbon offset** is the act of increasing the carbon storage, to compensate for emissions at an individual or institutional level (Broekhoff et al., 2019). According to this approach, emissions produced at one location can be compensated by capturing a similar amount of carbon (often at a distant location).

The key principle of offsetting is the prevention of emissions in selected human activities, and thus in particular locations, when this may be economically advantageous. This can be applied to any activity, for instance, travel, energy consumption and industrial production. In the specific context of arctic science, this could be applied to all fieldwork and conference travel-related emissions, as well as accommodation, computing, etc. When individuals or organisations make use of an offsetting mechanism, carbon certificates come into play. These certificates define the number of emissions the purchaser wants to be compensated for (or "offset") in climate protection projects elsewhere. Every purchased offset is related to a defined number of emissions.

The ownership of an offset certificate stands for a certain amount - usually tonnes of CO_2 - saved by a climate protection project. Anyone who gives money to these projects purchases certificates. The operator of a specific project can sell the carbon certificate either to traders or to offset service providers. After an individual or an organization buys a carbon credit, the credit is permanently retired so it cannot be reused.

Box 6.1: Carbon neutrality and the Arctic

Carbon neutrality can be defined as the balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks (e.g. soil, forests, oceans). Even if stored in those natural sinks, carbon can be released into the atmosphere through natural processes, fires, logging or land-use changes. Climate change is a threat to some carbon sinks, e.g. causing the permafrost to thaw and emit methane and CO_2 from decomposition processes in stored organic matter. In addition, by burning fossil fuels, humans are emitting carbon dioxide at a much higher rate into the atmosphere than natural sinks can remove it. In order to limit global warming to 1.5 °C, there is a consensus on the necessity to achieve carbon neutrality or "net-zero" by 2050. Thus, carbon offsets represent a popular mean for companies to achieve certain carbon reduction goals but it should not replace reduction efforts.

6.2 What makes a good offset?

Carbon credits are measurable, verifiable emission reductions from certified climate action projects. These climate projects reduce, remove or avoid GHG emissions. In addition, they can entail a variety of other positive benefits/side-effects such as empowerment of local communities, protection of ecosystems, restoration of forests or reduction of the reliance on fossil fuels. But how to ensure the effectiveness of climate protection projects?

The starting point should always be a realistic calculation of emissions. The more detailed and differentiated the calculation is, the more accurately the GHG emissions actually caused are recorded.

Box 6.2: The carbon markets

Emission trading systems are a type of market-oriented environmental policy instruments. Here, economic incentives can lead to a reduction and control of major pollutants. Putting a price on emissions results in climate-friendly behaviour becoming cheaper than emission-intensive activities. (Edenhofer and Jakob, 2017).

Trading CO_2 certificates are regulated at two levels, i.e. (i) at nation state level through compliance mechanisms and (ii) at voluntary markets:

- **Compliance markets** are formed and regulated by regimes at regional, national or international level.
- **Voluntary markets** have been established for individuals and companies who want to compensate for their emissions.

Both compliance and voluntary markets are open for voluntary offsetting. However, it is not possible to compensate for emissions at voluntary markets in order to fulfil legal obligations as contracted in the Kyoto Protocol/Paris Agreement.

Fair and meaningful carbon offsetting only works when one's own emissions are compensated with efficient climate protection projects. The *Carbon Offset Guide* (Broekhoff et al., 2019) provides a list of criteria that should be taken into account:

- **Additionality:** Additionality means that the reduction in emissions achieved by the project must go beyond the usual scope. The emission savings from the climate compensation project must be calculated carefully (and conservatively!) in advance and compared to the emissions coming from the project itself. Financially, the project should not have been viable without the revenue from carbon credits. In a regulatory sense, the project should not already be compulsory by national legislation.

- **Exclusivity**: An offset credit should be exclusive, meaning that it is not used multiple times nor claimed by another entity.

- **Avoiding Overestimation and Absence of Leakage:** Baseline emissions and actual emissions of a project must be correctly calculated and reported. Leakage refers to the shifting of emissions, when the implementation of a project increases GHG emissions elsewhere, and thus the emissions that were basically to be avoided (partially), occur after all.

- **Permanence:** Carbon saving must be permanent, meaning that the mitigation measure continues for the project time guaranteed. This criterion is difficult to check, because it comes along with a lot of uncertainty. A classic example would be a forest with a forecasted number of removed carbon from the atmosphere over a certain number of years - a wildfire would lead to a reversal. Risk analysis and buffering in calculations are necessary to meet this challenge.

- **Avoiding Social and Environmental Harms**

In addition to that, all project activities and data should be made transparent in a public registry. Furthermore, projects should be verified by internationally recognised standards.

CO_2 certificates that are certified by recognised institutions help to ensure the effectiveness of climate projects. Projects must adhere to a rigorous set of criteria to pass verification by third-party agencies and a review by a panel of experts at leading carbon offset standards, e.g. Clean Development Mechanism (CDM), Gold Standard or Verified Carbon Standard (VCS).

Box 6.3: International regulations resulting from the COPs to the UNFCCC

The Kyoto Protocol (adopted in 1997, entered in force 2005) established three mechanisms to encourage industrialized countries and economies in transition to mitigate GHG emissions: Emission Trading (ET), Joint Implementation (JI) and Clean Development Mechanism (CDM). The European Union's Emission Trading Scheme (EU ETS) also functions as part of the 'carbon market' that allows countries to meet their national emission reduction target through additional means. Since 2012, CO_2 emissions from aviation have been included in the EU ETS.

The *Paris Agreement* (2015) supports voluntary cooperation and the "use of internationally transferred mitigation outcomes to achieve nationally determined contributions" (Art. 6, paragraph 2).

6.3 Offsetting in question

Offsetting has been criticised (e.g. by Greenpeace) as a tool that enables 'greenwashing' of emission-intensive activities, because the option to pay for emitting reduces incentives to change to climate-friendly behaviour (Al Ghussain, 2020). This 'indulgence trading' often absolves personal, organizational or industrial responsibility and can disrupt the public debate on low-emission technologies and behavioural change. Offsetting can be surprisingly cheap (Spiekermann, 2014). In fact, numbers of offsets have increased to an enormous number among airline passengers, also as a result of growing environmental awareness and concepts like 'flight shame' (from Swedish 'Flygskam') that describes guilty feelings among people who fly (Bösehans et al., 2020). Anderson (2012) argues that it is impossible to ensure the offset and related project leads to zero emission in the end over the long-time span. According to Anderson, the "high probability that the offsetting projects contributing to prosperity will increase emissions over and above those solely arising from the activity being offset" (Anderson, 2012: 7).

Box 6.4: The Carbon Offset and Reduction Scheme for International Aviation (CORSIA)

International aviation is not included under the UNFCCC, because it falls outside the scope of national climate action targets. CORSIA is a global offsetting mechanism to help reach the goal of a *carbon-neutral growth* for international aviation from 2020 onwards. Between 2021 and 2035, CORSIA should help to mitigate around 2.5 billion tonnes of CO_2.
However, a report for the European Commission evaluates the potential climate impacts of CORSIA as not compatible with climate neutrality goals by 2050. In addition, CORSIA has been criticised by environmental NGOs, because it does not address the non-CO_2 climate impacts of aviation. Even though “reduction” is part of the name, concrete “reduction” targets for airlines are lacking.

CORSIA website: https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

By taking a climate justice perspective, offsetting schematically divides our globe in two worlds: The one (usually called the Global North) that can afford emitting CO_2 while continuing a carbon-intensive lifestyle and the other one (usually called the Global South), which already emits less or rely on sources of energy, which emit significant quantities of CO_2. While the second can be involved in intensive industrial activities to satisfy the needs of the rest of the world or because ‘Global North’ countries have partly or totally delocated their industrial process to get a cheaper labor force and other benefits, they also depend on selling their certificates. Mostly, offset providers operate in international projects in the Global South.

In relation to the **Arctic** that means that money from offset certificates will probably not be used for restoration of arctic ecosystems or other climate protection projects in the region.

7. Futures of the scientific world

A scientific world which offers climate-friendly working conditions appears suitable, even though solutions might not be easy. A mind shift is needed in the scientific community. Discussions on travel related CO_2 reduction in science come along with complex normative arguments. But recent studies show that the assumption that researchers need to fly around the world in order to establish their careers have been put in question (Nusey-Bray et al., 2019; Kreil, A., 2021). Flying to a conference to give a brief presentation to build *curriculum vitae* leads to questions on the necessity of individual actions of this type. However, the pressing question for the research community is what are the desirable conditions to conduct science in the near future? As more and more researchers and institutions are engaged in these discussions, there will be some difficult and wide-ranging decisions to be taken in the years to come. The COVID-19 pandemic has opened up a variety of opportunities and alternatives in conducting research with many solutions continuing.

Carbon footprint has to become a metric, there are tools to assess these, alternative solutions are often at hand and there are ways to compensate if emissions can't be avoided. Thus, it has to become part of the everyday mindset of scientists and could be included in the evaluation of scientific activities (e.g. cost calculation). There is a need to identify what kind of strategic research towards negative emissions and solutions are needed in future. Scientists could be challenged with requirement to add a section about '*Environmental impacts of research'* in the acknowledgement section of each published paper. To understand and identify efficient reduction efforts inter-disciplinarity is a keyword, because exchange and cooperation provide not only cost-effective solutions and specific recommendations for how to reduce carbon emissions across sectors.

Box 7.1: Climate Sentinels Expedition

A "carbon neutral" expedition took place in April 2021. Six female researchers travelled 450 km by skis across Svalbard to sample and study black carbon. Science outreach and education was an important part of this project, and partnerships with schools in France, Sweden, Norway and USA have been made, so children could follow the expedition and learn about novel ways of working climate friendly in the Arctic.

Website: https://www.climatesentinels.com/

Automation and sophisticated technologies can appear as appropriate alternatives to scientific travels, when related to fieldwork. While pushing for automation, unmanned sampling and remote sensing represent some mechanisms for doing research without travelling to the field (even though remote sensing also requires calibration and be supplemented by on-site activities), these technologies may generate problems on their own and have a carbon footprint. Finally, urging academic departments to incentivise carbon-neutral learning initiatives would facilitate offsetting individual carbon-footprint.

Besides researcher's individual travel decisions and developments towards more sustainability on institutional level, there are a few more actions that can be taken. Science communication is becoming more and more important in order to create awareness of pressing scientific findings, especially in relation to climate change. Communication of one's own results helps to keep these important topics on the agenda and social media appears to be a powerful tool for reaching the younger generations. Sophisticated media strategies are an essential part of today's research projects and scientific expeditions, helping to get their results and messages out to the public and furthermore supporting and strengthening the role of civil society.

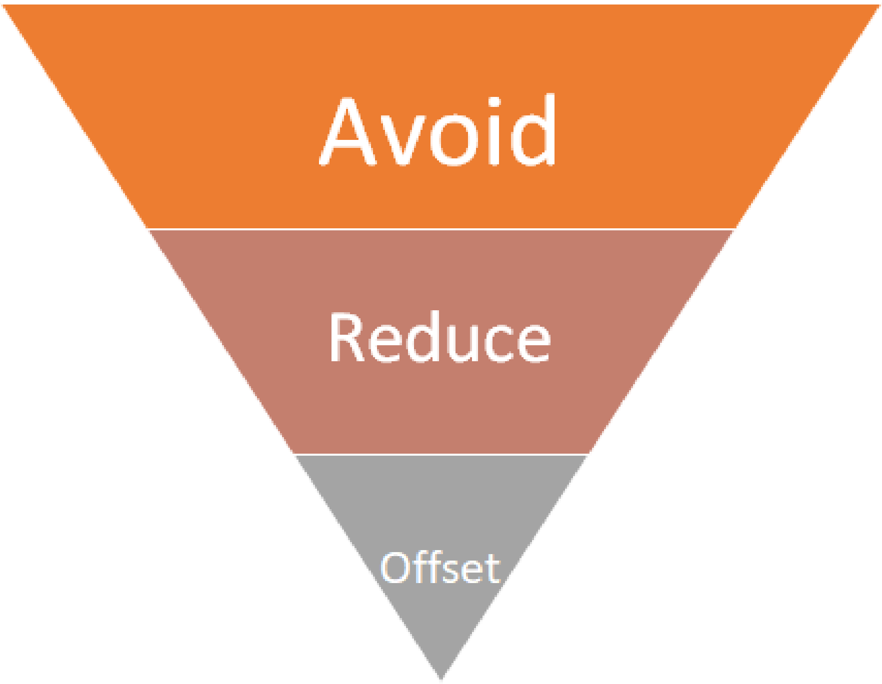
Box 7.2: Community and Citizen Science in the Arctic

The COVID-19 pandemic can be regarded as an opportunity to reflect on Arctic Science. While arctic communities have been severely impacted in terms of health issues, food security and economic losses, research capabilities especially for researchers from southern-based institutions have been justifiably limited by travel bans. For the scientific community, this resulted in data gaps. In their article, Petrov et al. assess how to in future respect the needs and security concerns of local communities while at the same time ensuring fieldwork and data generating. In fact, they argue for "building resilient Arctic Science" as a response to the COVID-19 pandemic, stating a "local turn" (Petrov et al., 2020) is needed. Once invested in good infrastructure, local community observation systems could be strengthened, thus reducing the need for travelling to the Arctic. In addition, it strengthens the co-production of knowledge, ensures meaningful participation of local and Indigenous communities, helping also in the process of decolonizing science.

Citizen Science projects allow non-scientists to participate in scientific processes such as data collection in their regions. While such projects strengthen curiosity, knowledge and motivation of citizens for research projects, it also enhances exchange and networking between scientific and local communities. Moreover, the involvement of young students creates promising learning capacities for the future.

7.1 Recommendations: How to reduce travel-related carbon footprint?

CO_2 reduction in science is not a question of “if”, but “how”? There is not the one and only solution, but rather millions of little steps towards conducting research and travelling in sustainable ways. It clearly is work in progress and we present recommendations and tips for scientists, conference organisers, research institutions and funding agencies in the following pages.



- ➔ **Avoid** emissions, when it is possible to avoid them.
- ➔ **Reduce** emissions, when it is possible to reduce them.
- ➔ **Offset** as a supplement to other attempts to reduce CO_2 emissions, not as an objective itself.

7.1.1 Tips for scientists

A significant number of field locations are remote or difficult to reach using low emission forms of transport. However, there are a few things scientists can do to reduce their travel-related carbon footprint.

➔ Plan a low-carbon field trip.

If planning a field trip, ask yourself:

Is it necessary to go?

- Can I find already existing data to use instead?
- Can I get others to collect the data/samples I need?
- Can I take advantage of remote or virtual access or community and citizen science projects?
- Can data be acquired through existing remote sensing options?

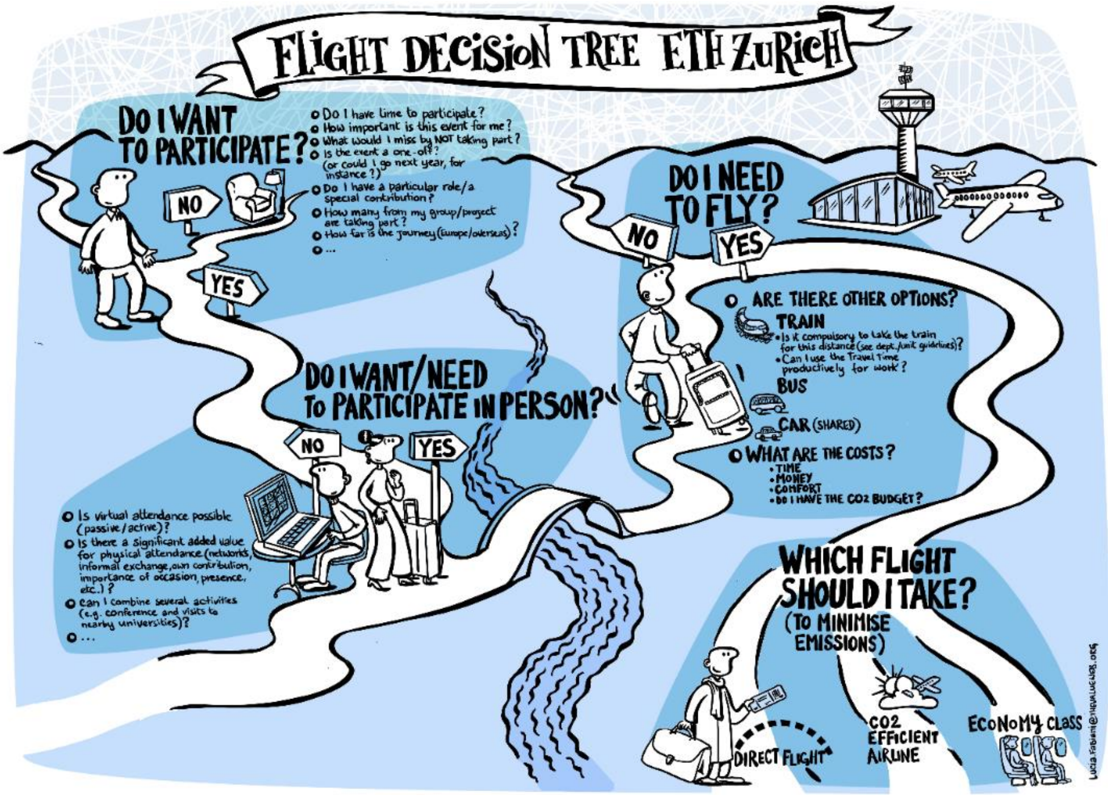
If necessary to go, think about:

Transport/Travel to the Arctic

- Use online tool to calculate your expected carbon footprint getting to the Arctic.
- Choose least emitting transport option (where you have a choice).
    - Use public transport where possible.
    - Prefer land-based travel over air travel.
    - Share transport and logistics to fill up capacity.
- Offset unavoidable emissions by using trusted organisations.

Local transport

- Choose an appropriate field site that minimises your need for local transport.
- Choose least emitting transport option.
    - Use non-motorised transport (foot, ski, kayak).
    - Use public transport where possible.
    - Share transport and logistics to fill up capacity.



A flight decision tree as developed by ETH Zurich is a simple tool visualizing different reflections you might have before your next research-related travel. Reference: https://ethz.ch/content/dam/ethz/associates/services/organisation/Schulleitung/mobilitaetsplattform/images/Decision%20Tree_eng%20copy.png [Credits: Lucia Fabiani]

➔ Reflect on conference/meeting participation.

Rather than conference consumerism or routine, researchers and other personnel could also be encouraged to take a more reflective approach in relation to their work-related travels.

Ask yourself: **Why is it important to attend the event and what outcome can I expect and can online participation achieve the same?**

If going to the conference consider the travel decision tree to find a low-carbon transport option.

➔ Influence your institution.

Scientists have a role to play in shifting responsibility and action from their individual level to the system level.

- Initiate an open discussion and exchange about possible ways to reduce CO_2 with your colleagues and at your institution in general.
- Promote a low-carbon travel policy at your institute (including incentives and restrictions).

7.1.2 Tips for conference organisers

It is advisable to develop a strategy for organising “sustainable events”, including a checklist of carbon footprint reduction. In general, several aspects have to taken into account, e.g. travel/transport, venue, lodging, local logistics and conference facilities (energy use, local transport, catering).

➔ Choose the suitable meeting format.

- Is an in-person conference necessary or would an online format work as well? (see tables 4.1. and 4.2. presenting advantages and disadvantages)
- Consider hybrid formats and enable online participation.
- Work towards conditions that improve online participation.

➔ Decarbonize conference travel.

- **Promote low carbon travels.** Organizers can encourage using trains and collective transports, when it is possible, and design incentives such as a discount on conference fees for those who favour a low-carbon mode of transportation. One example is free conference trains that collect participants on their way to the conference locations, providing short workshops and discussions during a relaxed trip to the venue.
- **Choose a central location**, which can be easily reached by public transport can in combination with the promotion of low-emission land-bound travel options result in a significant reduction in the carbon footprint.
- A smart way to reduce the carbon footprint related to conference travels is to **pool conferences and meetings at major events** in the same town. Accordingly, it becomes possible to attend more meetings for a reduced CO_2 emissions and cost.
- **Limit the number of attendees per institution.** Convenors of conferences or institutions can define a quota to limit the number of attendees sent by each institution. Such quotas could be included in strategies at institution level to make the organisation greener. A part of such quota system could be criteria for staff to attend physical meetings or events. Priorities could, for instance, be given to ECRs or certain categories of personnel according to its relevance for the individual and the institution.
- **Enable hybrid attendance.** Large conferences could also take the form of hybrid conferences that maximize the advantages of both in-person and digital conferencing. As with online conferences, time zone differences can appear as an issue.
- Organise **regional hubs** follows the idea of hybrid conferences. Participants can travel to well-connected locations within their own continent using land transport. Because all hubs are virtually connected with each other, global exchange is ensured. However, time zone differences and disparities in the number of participants can be an issue.
- **Change in-person conference rhythm to every second/third year.** Several conferences have become a routine and some researchers may feel that it does not make sense to attend

an event just because their institution encourages them to do so. Reducing the frequency of events significantly reduces carbon emissions.

7.1.3 Tips for institutions

Institutions play a key role in efforts to reduce CO_2 in arctic science. Here are key aspects to take into consideration when developing a sustainable travel policy at your institute.

- Develop an Institution-wide **commitment to** CO_2 **reduction as a collective objective within the institute.**
- Improve **monitoring and internal reporting system** for travel activities to quantify CO_2 emissions. Travel agencies might offer support.
- Develop a **strict travel policy** and take concrete actions (e.g. establish a **travel decision tool** and improve the online booking system).
- **Promote low-emission transport** especially for short distance and day-to-day travels.
- **Improve infrastructure** for day-to-day travel.
- Prioritize **online meetings,** where possible.
- **Encourage more flexibility within the institution.**
- Raise employees and/or students' **awareness** and contribute to education and information at a wider level.
- Develop additional **incentive schemes** for employees.
- Adopt a policy which offers a **free and open access to data** and knowledge.
- **Reflect on the relevance** of travels and mode of transport collectively.

Box 7.1.: Best practice examples from institutions

- Sustainable Travel Policy University Ghent: https://www.ugent.be/en/ghentuniv/principles/sustainability/guidelines/travel/overview.htm
- Low Impact Travel University College London: https://www.ucl.ac.uk/sustainable/positive-climate/low-impact-travel
- LUCSUS Travel Policy: https://www.lucsus.lu.se/sites/lucsus.lu.se/files/lucsus_travel_policy.pdf
- Travel Decision Tool by ETH Zurich: https://ethz.ch/services/en/organisation/executive-board/vice-president-infrastructure/mobilitaetsplattform/air-travel/routerank.html
- Reducing Academic Flying Symposium at University of Sheffield (2019): https://www.carbonneutraluniversity.org/reducing-academic-flying.html

8. Glossary

- AHEAD - Arctic Hydrogen Energy Applications and Demonstration
- AMAP - Arctic Monitoring and Assessment Programme
- APECS - Association of Polar Early Career Scientists
- ASSW - Arctic Science Summit Week
- ATSD - Arctic Ship Traffic Data
- AWI - Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
- BC - Black carbon
- CDM - Clean Development Mechanism
- CO_2 - Carbon dioxide
- CO_2e - Carbon dioxide equivalent
- CH_4 - Methane
- COP - Conference of the Parties
- COP21 - 21st Conference of the Parties (2015)
- COP26 - 26th Conference of the Parties (2021)
- CORSIA - Carbon Offset and Reduction Scheme for International Aviation
- ECR - Early-career researcher
- ET - Emission Trading
- ETS - Emission Trading Scheme
- EU - European Union
- FAIR (charter) - Findable, Accessible, Interoperable, Reusable
- G7 (countries) - the Group of Seven (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States)
- G10 (countries) - the Group of Ten (Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom and the United States)
- GWP - Global Warming Potential
- GHG - Greenhouse gas
- IASC - International Arctic Science Committee
- ICAO - International Civil Aviation Organization
- ICCT - International Council on Clean Transportation
- IEA - International Energy Agency
- IPCC - International Panel on Climate Change
- IPEV - Institut Paul-Emile Victor
- JI - Joint Implementation
- LUC - Land Use Change
- MOSAiC (expedition) - Multidisciplinary drifting Observatory for the Study of Arctic Climate
- NDC - Nationally determined contributions
- NGO - Non-governmental organisation
- N_2O – Nitrous oxide

- NOx - Nitrogen oxide
- PAME - Protection of the Arctic Marine Environment
- RV - Research vessel
- UAV - Unmanned aerial vehicle
- UVS - Unmanned vehicle system
- UNEP - United Nations Environment Programme
- UNFCCC - United Nations Framework Convention on Climate Change
- UNIS - The University Centre in Svalbard
- VCS - Gold Standard or Verified Carbon Standard

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