INTERACT

International Network for Terrestrial Research and Monitoring in the Arctic

Reducing CO_2 Emissions in Arctic Science

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Reducing CO_2 Emissions in Arctic Science

Content

Photo: Jean-Marie Trudeau

About this guidebook

Our travel, work and personal lives leave a trail of greenhouse gas emissions contributing to global warming. Researchers working in the polar realms study the effect of Climate Change on the polar regions and its inhabitants by seeking to 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 developments, changes in geopolitics and adaptation actions by the people inhabiting the Arctic.

The polar scientific community is engaged in various types of fieldwork, conferences, education, training and collaboration, which all come with a significant carbon footprint. Many are concerned about Climate Change and its impact on the environment. In the Arctic, temperatures are increasing three times faster than in the rest of the world (AMAP, 2021) and 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 handbook attempts both to summarize existing **knowledge** and to offer **solutions** for researchers who want to **reduce CO_2 emissions** related to their **research activities**. One of the most significant areas under individual control is travel, which is the main 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.

Association of Polar Early Career Scientists (APECS) and International Network for Research and Monitoring in the Arctic (INTERACT)

This handbook focuses on researchers engaged in Arctic science. However, much of the content is also applicable to others who are looking to reduce their environmental impact from science related activities elsewhere.

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 the carbon footprint is, calculation methods and various tools, with a short reference to life cycle analysis and individual carbon footprints.

Chapter three gives an overview of fieldwork and related CO_2 emissions. CO_2 emissions associated with travel to meetings and conferences are covered in chapter four.

Chapter five focuses on the role of Arctic research institutions and how they could embrace their responsibilities for contributing to global CO_2 emissions.

Although this handbook is dedicated to CO_2 reduction while travelling, 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 how to conduct sustainable science in the future. Here, recommendations on reducing travel-related emissions for scientists, conference organisers and institutions are presented.

This guidebook, supplements another INTERACT publication on Reducing the Environmental Impacts of Arctic Fieldwork produced in 2021.

All INTERACT books are available on the INTERACT website – www.eu-interact.org.

Preface

Arctic researchers often find themselves in a particularly difficult bind: On one hand, our day-to-day research, again and again, highlights the stark reality of Climate Change and its rapidly increasing impact on the fragile Arctic environment in particular. On the other hand, the fieldwork, research and knowledge exchange that we need to take part in to be able to come to this understanding produces greenhouse gases in itself, thereby making the problem worse. Finding a balance between these factors – wanting to understand the situation, but not wanting to worsen it – can at times feel like a minefield. There has never been a more important time to face this dilemma head-on.

The urgency of addressing the climate crisis is being increasingly acknowledged in public life, especially with rise of climate movements such as *Fridays for Future*. Meanwhile, the recently-published Intergovernmental Panel on Climate Change (IPCC) report has delivered its strongest warning yet, stating that with any further delay in climate action, we will miss a "brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all."

This pocket guide presents a much-needed, clear-eyed analysis that will help researchers navigate this difficult topic in their work lives. Incorporating themes from the carbon footprint of travels in Arctic regions to the benefits and challenges associated with moving conferences online, it contains the information researchers need to be able to weigh up the costs and benefits of different approaches. With this information at hand, researchers will have a better knowledgebase to make their decisions enabling them to carry out excellent research while still reducing the environmental impact to the greatest extent possible.

As well as guiding individual researchers on their journey towards sustainability, this guide book also includes recommendations and advice for research institutions and organisations. This is a particularly valuable aspect. Individual researchers can and should regularly take concrete actions towards reducing their carbon footprints. However, if we want to see long-lasting, built-in climate action, it is really important for institutions, employees and governments to change the culture by making sure that sustainable approaches are not just accepted, but actively encouraged.

While the news around Climate Change is rarely uplifting, it is exciting to see more and more organisations and groups stepping up to improve their approach to sustainability. I very much hope that in the future suggestions like those contained within this guide will be so commonly used that it will simply be a part of our everyday behaviour. For now, however, this guide contains information that every scientist, not just those working in the Arctic, will need to start reducing the impact of their own research on the environment.

Sophie Haslett
Researcher at Stockholm University
Co-chair of the IASC Action Group on Carbon Footprint.

Photo: Morten Rasch

1 Facts about greenhouse gas emissions

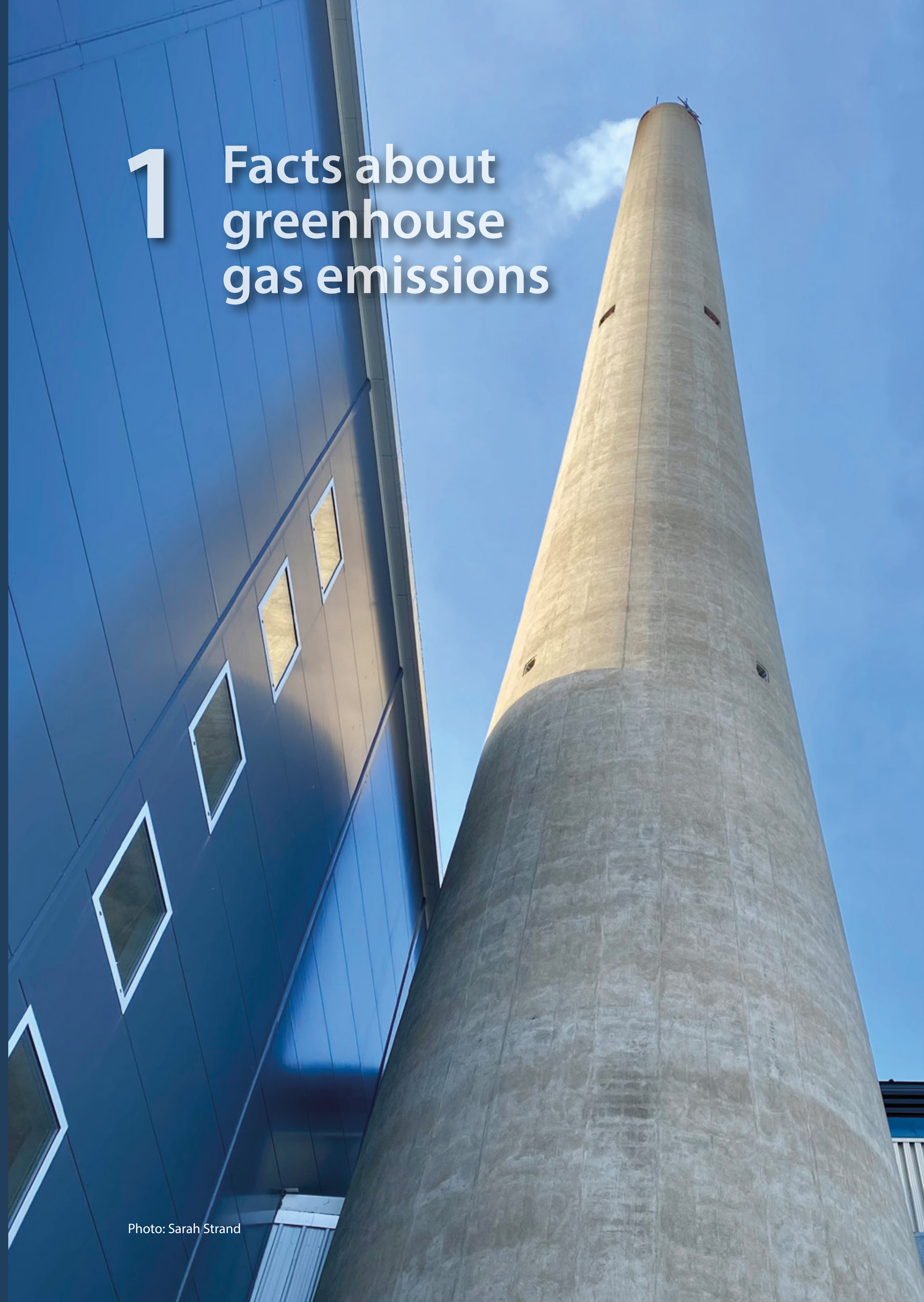
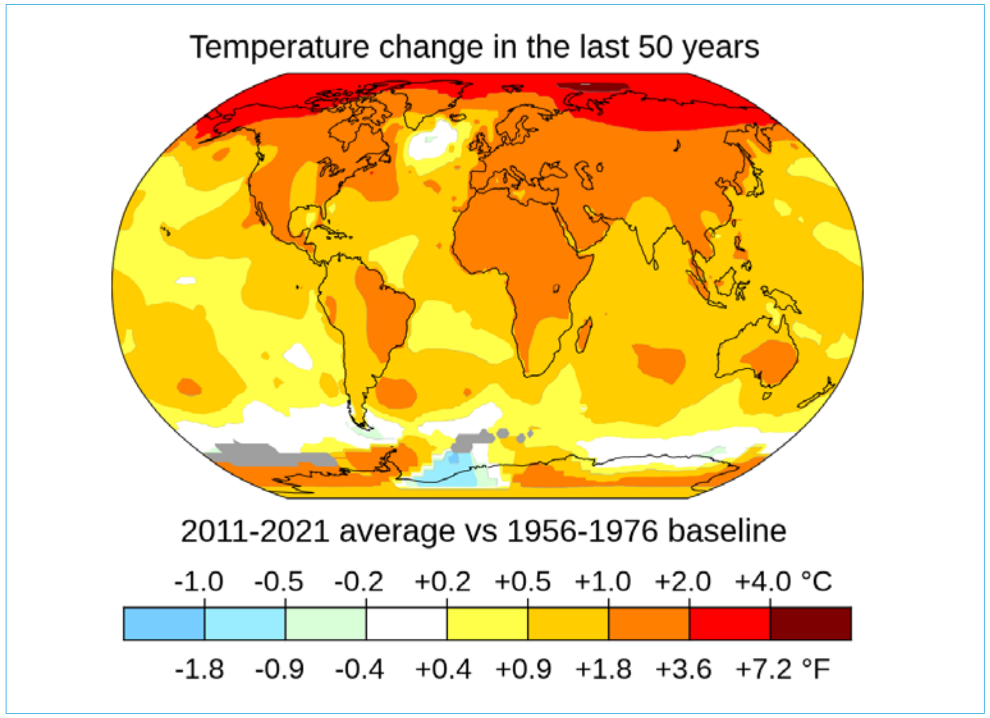


Photo: Sarah Strand

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 is the sea-ice and snow albedo feedback mechanism (Serreze and Barry, 2011). Both the snow, sea-ice and glacial extent have decreased and are likely to continue to do so with increased warming. This changes the energy balance as less solar radiation is reflected back into space and instead absorbed by the Earth. Also of particular concern is the projected loss of permafrost due to rising temperatures, since the decomposition of previously frozen plant material may lead to significant release of greenhouse gases (GHG's) 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 oceans are expected to undergo a long-term change given their long response times (IPCC, 2019) and thus continue to impact ecosystems for many years to come.



Average surface air temperatures from 2011 to 2021 compared to a baseline average from 1956 to 1976, according to NASA, Goddard Institute for Space Studies.

Climate Change, the long-term changes in temperatures and weather patterns, has already started to affect human societies around the globe (e.g. food production, livelihoods, infrastructure stability, education, health, etc.). 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 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 minimise the multi-dimensional damage caused by a changing climate. One of the key responses is Climate Change mitigation, which consists of action to decrease the warming rate through reducing our GHG emissions.

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 GHG's. The conference of the parties (COP) to the UNFCCC has 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).

Permafrost degradation severly affects infrastructure.

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 (NDC's)

Under the Paris Agreement (United Nations, 2015, Article 4, paragraph 2), all parties are required to prepare and report on their NDC's, 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 differences. The first NDC's 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.).

NDC's can be either unconditional or conditional. As the name suggests, unconditional NDCs are those that can be implemented without any further requirement, whereas conditional NDC's 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 NDC's (UNEP, 2020).

GHG emissions

The main GHG's with increasing concentrations 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 higher, 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).

In general, radiative forcing describes the change in energy flux in the atmosphere caused by natural or anthropogenic factors of Climate Change.

The integrated radiative forcing of a greenhouse gas over a certain period of time depends on its lifetime and its ability to influence energy fluxes. 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 GHG's lifetime, i.e. 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 GHG's 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 $GtCO_2e$ (UNEP, 2020). The main component of these GHG emissions was fossil CO_2 emission (38 $GtCO_2e$), followed by CH4 (9.8 $GtCO_2e$), N_2O (2.8 $GtCO_2e$) and fluorinated gases (1.7 $GtCO_2e$). The more uncertain and variable emissions from LUC are split in LUC CO_2 (6.3 $GtCO_2e$) and LUC CH_4-N_2O (0.5 $GtCO_2e$) (UNEP, 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, high-income countries emit 10.3 tCO_2/capita, while low-income countries emit 0.2 tCO_2/capital according to the World Bank

(2018). In the EU (incl. UK) it is 6.47 tCO_2/capita (Crippa *et al.*, 2020). 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 Organisation and the United Nations Environment Programme. 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 2021-22. In its 1st Assessment Report, the IPCC established four 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. The first part of the 6th Assessment Report was published in August 2021 and the whole report will be released in 2022. The report states that global warming is accelerating and strengthens the links between human impacts and increasingly severe extreme weather.

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 NDC's. Of those NDC's, 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 NDC's for 2030 (UNEP, 2021).

The *emission gap* is the difference between the projected global GHG emissions assuming that the NDC's are implemented and the emission level needed to limit global warming to well below 2 °C above pre-industrial levels (least-cost pathway) (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 NDC's (Figure 1.1). If current conditional and unconditional NDC's are implemented, global warming is estimated to reach 2.6 °C at the end of this century (UNEP, 2021).

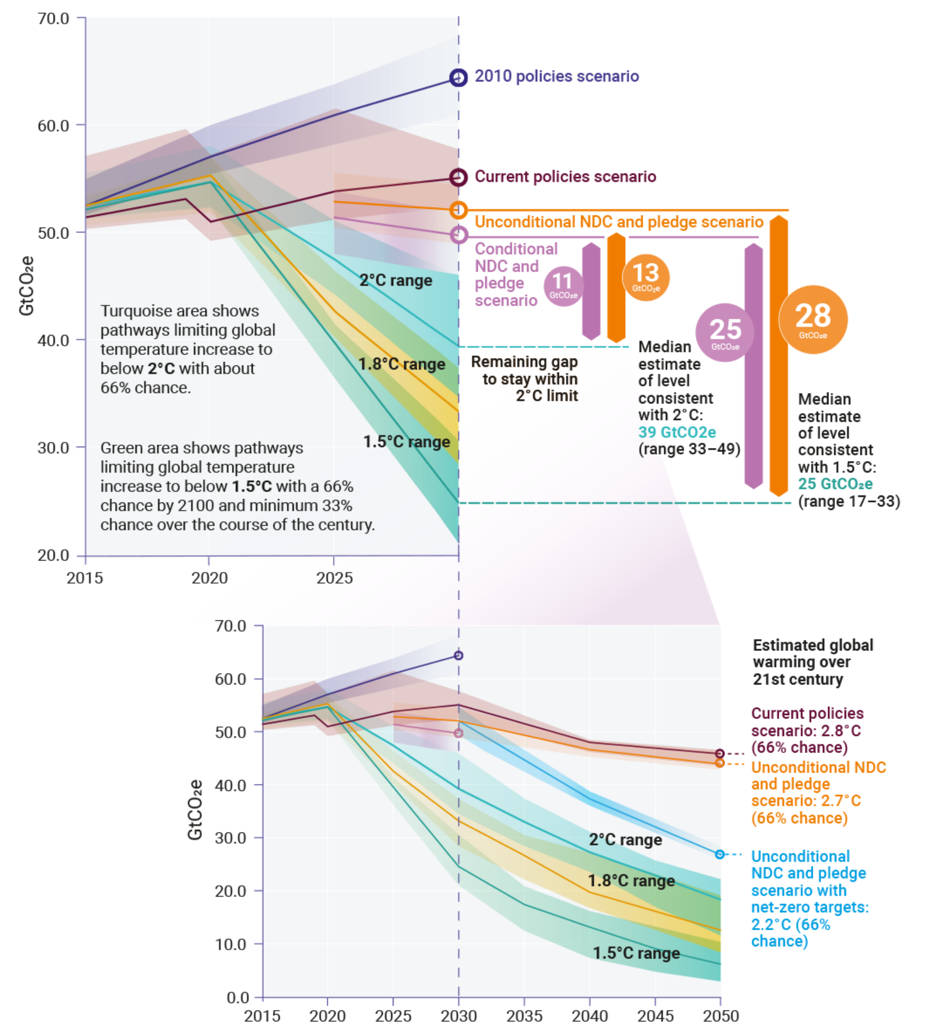


Figure 1.1: Global greenhouse gas emissions under different scenarios and the emission gap in 2030 (median estimate and 10th to 19th percentile range) (UNEP Emission Gap Report 2021: 35).

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 NDC's 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 °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 political decisions at the national and international levels but also in their own scientific institutions.

2 The carbon footprint

Photo: Morten Rasch

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 GHG's (CO_2, CH_4, N_2O, O_3, etc.). In carbon footprint analysis, the unit of unit typically used is tons of mass of CO_2 equivalent (tCO_2e; see Box 1.2) emitted per year for a given activity, process or product (Franchetti and Apul, 2013).

Carbon footprint and travel emissions

The calculation 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 calculated 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

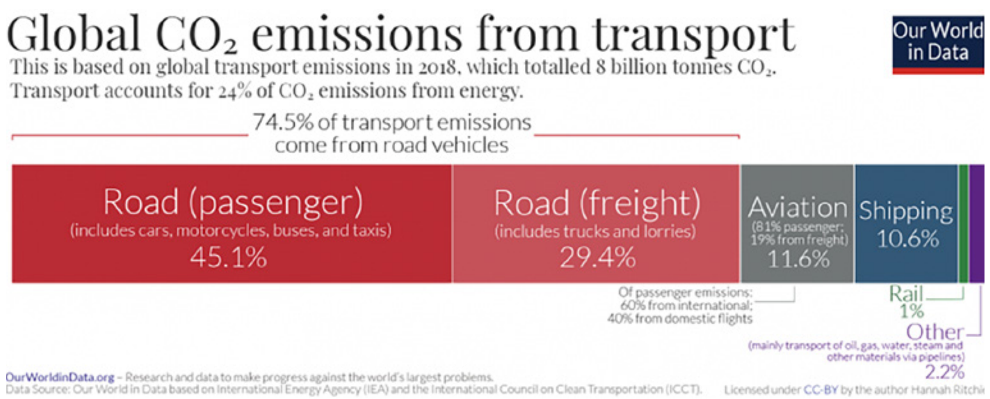


Figure 2.1: Global CO_2 emissions from transport (Ritchie, 2020a. Our World in Data based on data from International Energy Agency (IEA) and the International Council on Clean Transportation (ICCT)).

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 potential actions would be to live free of cars, 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 transport by private car). 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.

Carbon footprint calculation

Life-cycle assessments

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. As this method requires detailed information on the entire life-cycle of the product, it is very expensive in terms of time and computation. Another issue is that the detailed data required is often not available causing reductions in accuracy.

In the case of transport, the different life cycle stages can be grouped into three components (Figure 2.2).

The vehicle component describes everything in the manufacturing process: the extraction and processing of materials, the fabrication of vehicle components, e.g. battery production or production and use of fluids, the assembly, the delivery and end-of-life treatment.

The fuel component refers to the production and distribution of the fuel/energy vector. This includes the so-called well-to-tank phase (production, processing and delivery) and the tank-to-wheel phase (actual use).

Finally, the infrastructure component is related to construction (including materials extraction), operation, maintenance and end-of-life management of roads, rails, airports, ports, etc. (ITF, 2020).

Individual carbon footprint of travel

The term individual carbon footprint, which relates to the amount of CO_2 emitted from the daily activities of individuals, has been used increasingly over the past decade. Carbon footprint calculations require detailed and activity specific emission data for all life cycle stages of products, processes and activities. Today tools have been developed to facilitate the complex calculations, using emission data from a variety of repositories. However, information may not be available for all types of products and services and you may need to feed the calculation tool yourself with the amount of energy consumed for a particular product or service.

In general, online calculators are available for e.g. transport/travel, household/workplace, products, food consumption, electronic devices and lifestyle. A significant number of datasets may be open access, but not all of them focus on transport services and only a 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.

Often, when booking a particular journey, the carbon footprint is provided by the airline or booking company 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

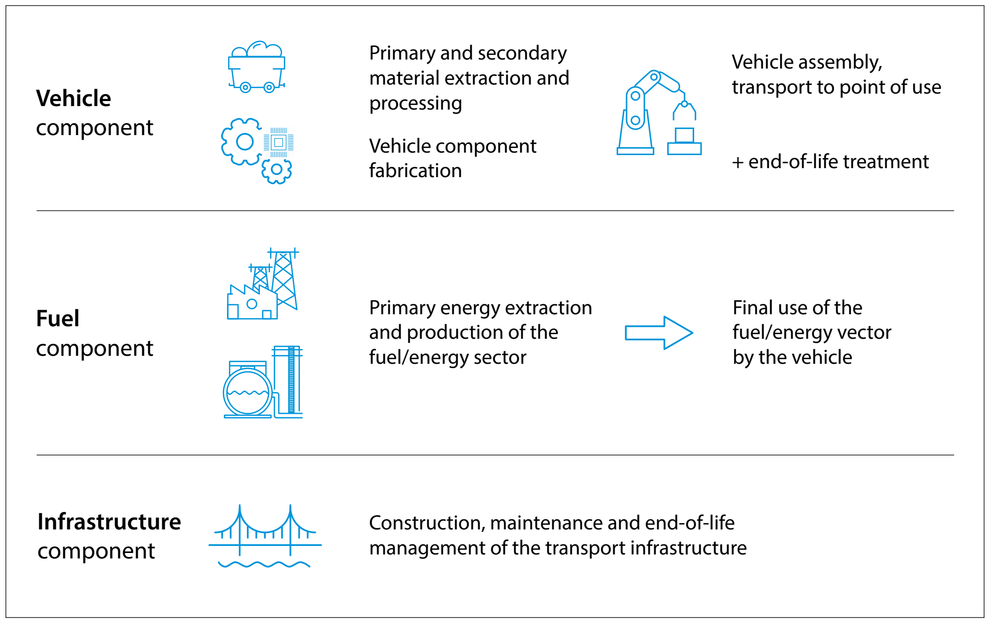


Figure 2.2: Key components of life-cycle assessments used in transport (ITF, 2020: 16).

economy seating) differ by up to a factor of five (Barret, 2020). Figure 2.3 illustrates these differences between widely-used tools by offsetting providers, national governmental agencies and the aviation industry. The difference between calculators 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, i.e. type of aircraft.
- 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 and disposal).
- Airport infrastructure.

So far, no standardised 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/standardisation (Barret, 2020).

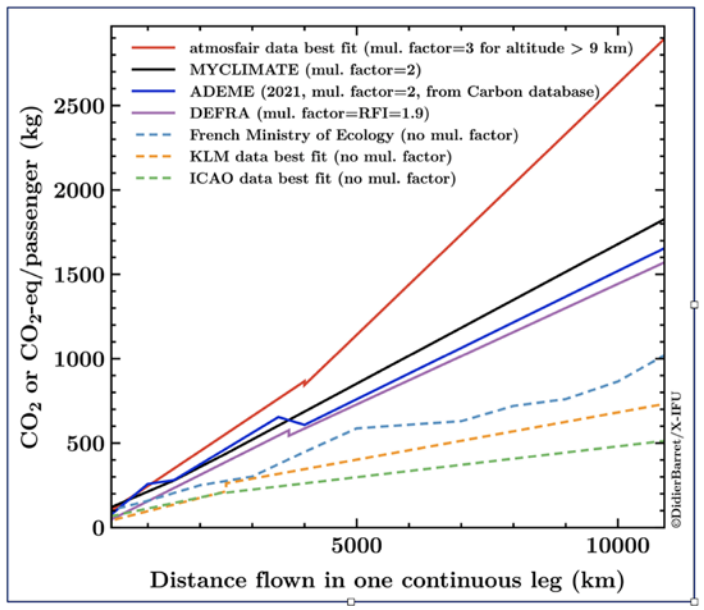


Figure 2.3 Emission factors (CO_2 in dashed lines, or CO_2e in continuous lines, per passenger in kg) as a function of the distance flown in one continuous leg (km) as derived from the seven data sources used by X-IFU calculator. The emission is computed assuming economy seating. Jumps in the functions are related to boundaries of interval distances over which the fit is applied or the mean emission factors defined (Barret, 2020: 189).

Box 2.1 Examples of carbon footprint calculators that includes transport components

	Plane	Car	Train	Ship/Ferry	Bus/Taxi/Tram
Atmosfair	X				
MyClimate		X	X		X
Labos 1point5	X	X	X	X	X
Ecopassenger			X	X	X
The Engineer Toolbox	X	X	X		

Based on the town of departure, the town of destination and the mode of transportation at each step of the travel, these calculators compute the total distance and the carbon footprint (in CO_2e) of the travel. In most cases, emissions from lifecycle are not considered in the calculation.

As an example, using Labos 1point5, from Paris, France, to Tromsø, Norway (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 with its remote locations, limited access to public transport, challenging logistics and harsh climate conditions (general emission figures may not apply under Arctic conditions).

Atmosfair : https://www.atmosfair.de/en/offset/flight/
MyClimate: https://www.myclimate.org/
Labos 1point5: https://labos1point5.org/travels-simulator
Ecopassenger: http://www.ecopassenger.org/bin/query.exe/en?L=vs_uic
The Engineer Toolbox: https://www.engineeringtoolbox.com/CO2-emissions-transport-car-plane-train-bus-d_2000.html

3 Necessity and impacts of fieldwork related travel

Photo: Elmer Topp-Jørgensen

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 and from archaeology to glaciology, access to the field is the foundation for knowledge production and development of scientific skills in most disciplines within Arctic science.

With the rise of Climate Change, we need to reduce contributions from Arctic science and hence need to seek alternative ways of acquiring knowledge and developing skills without compromising scientific results and safety.

For a long time, these trips have been an integrated part of Arctic science and education programmes 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 and 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.

By sending students and researchers on field trips, 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 3.2 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).

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, e.g. selection of transport means (see Figure 3.1), choice of route, use of capacity, source of energy (renewables, nuclear plant, fossil fuel power plant) and infrastructure.

When travelling to remote locations allow for some flexibility in the planning of the logistics. Delays and cancellations are common in the Arctic, so make sure that you are able to achieve what you set out to do, otherwise you will only contribute to emissions and not to science.

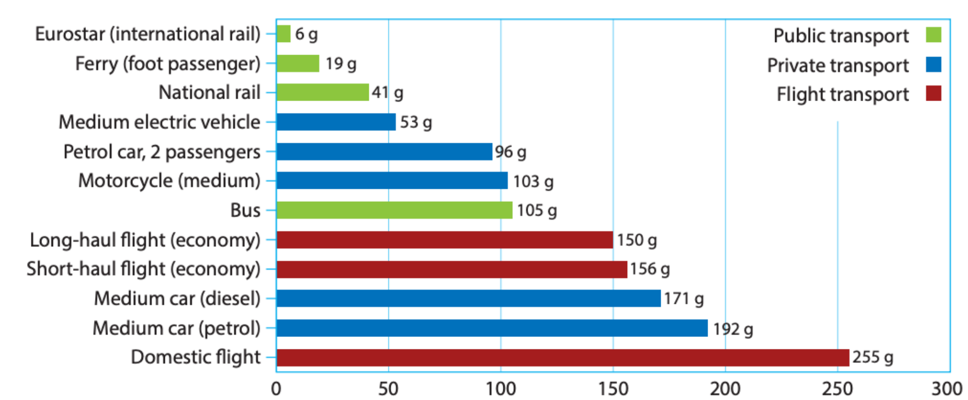


Figure 3.1 Carbon footprint (g carbon emitted per km transport) for different types of transportation. Note that increasing the number of passengers per vehicle in private transport can reduce the emission levels per person. Source: UK Department for Business, Energy and Industrial Strategy. Greenhouse gas reporting: Conversion factors 2019.

Some research stations have bicycles for visiting scientists to provide emission free transport to station surroundings and field sites. Photo: Morten Rasch.

In general, researchers can reduce their CO_2 footprint of fieldwork related travel by:

- Using low-carbon means of transport.
- Optimising their field trip, e.g. by camping or finding accommodation in the immediate vicinity of their field site rather than travelling to and from a distant base on a daily basis.
- Sharing of logistics in order to use maximum capacity.
- Allow for flexibility when visiting remote locations. Logistics are challenging and delays/cancellations not uncommon.

Air transport

Global contributions to greenhouse gas emissions

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 average persons 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 and effective radiative forcing*. Although uncertainties in determining influence of non-CO_2 factors are acknowledged, studies indicate that aviation non-CO_2 forcings might double or even triple the impact flying has on global warming (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). The decarbonization of aviation is challenged by, e.g. robust demand growth, industry structure and the physics of flight (IEA, 2020b).

Box 3.3 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% biofuel together with fossil fuel. When booking a trip with SAS, one can purchase 20-minute blocks of biofuel (10 Euro's 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 implications and impacts on local societies and environment. Certified biofuels may ensure that such impacts are minimised.

Fixed winged aircraft bringing scientists to East Greenland. Photo: Gwenaëlle Gremion.

Box 3.4 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 emissions, NOx 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, NOx and noise emissions by 20 to 30% compared to state-of-the-art aircrafts entering into service as of 2014" (Clean Sky 2, 2020: 13).

While long-haul flights often represent the primary and major cause of CO_2 emissions from institutions (e.g. Langsdale, 2019), the carbon intensity is higher for short flight distances of less than 1,000 km (see Figure 3.2). This demonstrates the importance for scientific institutions and scientists to develop strategies for minimising the impacts of both long-haul and short-haul flights.

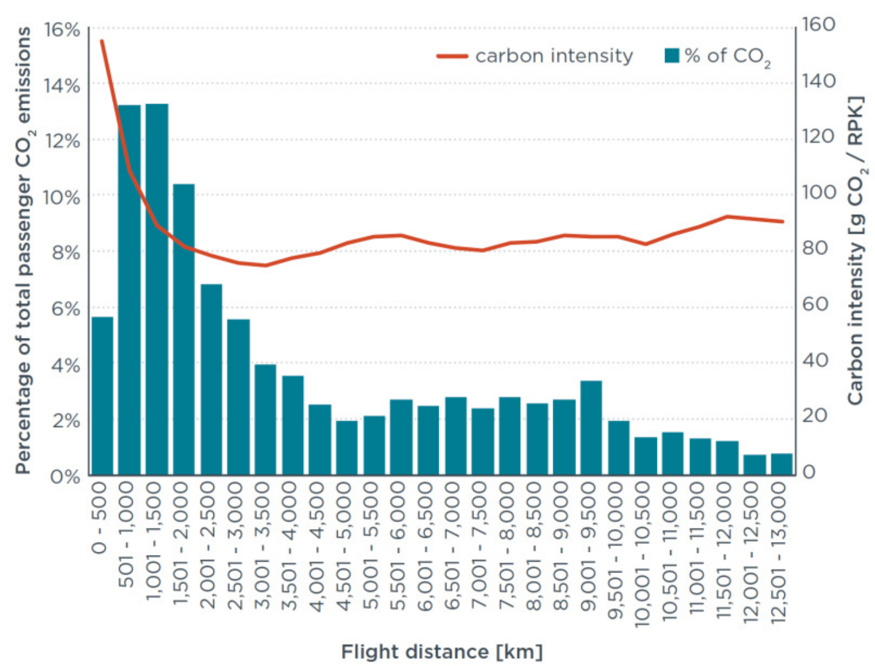


Figure 3.2: Share of passenger CO_2 emissions and carbon intensity in 2018, by flight distance (Graver et al., 2019: 8). RPK (Revenue Passenger Kilometre) is the number of kilometres travelled by paying passengers (i.e. number of revenue passengers multiplied with total travel distance). The carbon intensity describes the emission rate of a given pollutant relative to the intensity of a specific activity (e.g. the number of grams of CO_2 that it takes to make a kilowatt per hour).

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 choices that can help reduce the carbon footprint:

- Choose direct flights - most fuel is spent on take-off and landing.
- Choose airlines with newer and more fuel-efficient planes.
- Choose airlines with alternative non-fossil fuels with relatively low environmental impacts.
- Fly economy instead of business or first class to transport more people per emission.
- Choose scheduled flights instead of charter flights, where possible.
- Pack light - the heavier the plane, the more fuel is needed.
- Choose daytime flights when it is possible.

Types of aircrafts used in Arctic science

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, fixed winged aircrafts and drones), there is a potential for reducing fuel emission (and costs) significantly by sharing logistics. 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. 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 often reduce the duty hours of aircrafts and their fuel consumption (and the resulting costs) with at least 50 %.

Such a reduction of fuel is of even bigger importance in the Arctic than elsewhere, because it takes a lot of fuel just to bring in the fuel to be used for actual flights. For bigger campaigns, it is therefore advisable to include professional logisticians to take care of flight coordination.

Box 3.5 The payload-endurance relation for aircrafts

The maximum total load of an aircraft (the maximum load it can take off with) consists of (i) the weight of passengers, (ii) the weight of cargo (passenger and cargo is jointly called the payload) and (iii) the weight of the fuel to drive the engine(s). As a result, an aircraft can carry a higher payload if it only has a short distance to fly than if the distance is far. The maximum payload indicated in Table 3.1 is therefore only for very short flights. A specific payload-endurance relation for the aircraft of relevance is necessary to estimate how much you can carry with a specific aircraft on the distance of relevance, and how much fuel you will use for doing so. Such calculations requires either a pilot or an experienced logistician – at least for verification – as there are many other factors controlling how much cargo, you can carry on a given distance, e.g. whether the aircraft flies after VFR (Visual Flight Rules) or IFR (Instrument Flight Rules), the weather and the distance to nearest alternate landing site.

Table 3.1 gives the fuel economy and the payload economy for different aircrafts (both fixed winged aircrafts and helicopters) normally being used for field operations in the Arctic. The fuel economy is the number of liters of fuel needed to move the specific aircraft one kilometer. The lower the number, the better the economy. The payload economy is the liters of fuel it takes to move 1 kilogram of cargo one kilometer. The lower the number, the better. The maximum payload, the cruising speed and the fuel consumption of any aircraft relies on a huge number of parameters and among them the volume and character of payload, weather, distance of transport, distance to nearest alternate landing site, etc. The numbers in the table are therefore only for comparing different aircraft types – not for calculating your actual spending of fuel per kilogram when you move personnel or cargo.

Helicopters used for field operations in the Arctic can be either 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 into the area of use, either by sea or by air.

Although helicopters allow researchers to reach very remote and otherwise inaccessible areas, it comes with a relatively high environmental footprint. However, the technological development goes towards less and less fuel consuming helicopters.

Fuel provision is particularly challenging in some remote regions and needs careful planning way ahead to ensure good and sufficient fuel positioning. Depending on the engine type (i.e. piston, turbine) and age of the aircraft type, helicopters are generally using more fuel per kilogram being carried than fixed winged aircrafts. Besides spending a lot of fuel, helicopters are also known to disturb wildlife, especially if they fly low (Hoang, 2013).

The burn rate of small 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 the cabin), etc.

Table 3.1: Fuel and payload economy for different aircrafts.

Type	Structural payload (kg)	Fuel consumption (l/h)	Cruising speed (km/h)	Fuel economy (l/km)	Payload economy (kg/km/l)
Fixed winged aircrafts mainly for cargo transport					
Ilushin 76	46.000	11.250	750	15,0	3.067
Antonov 12	20.000	3.000	575	5,2	3.833
C-130 Hercules	20.400	2.875	550	5,2	3.903
Antonov 74	7.500	2.000	550	3,6	2.063
Fixed winged aircrafts for both passenger and cargo transport					
Dash 8 Q100 & Q200	4.600	625	500	1,3	3.680
Fokker 50	6.000	1.000	520	1,9	3.120
ATR-72	7.500	938	520	1,8	4.160
Dash 7	5.100	938	425	2,2	2.312
DC-3	5.000	475	330	1,4	3.474
Bassler 67	4.500	475	380	1,3	3.600
DHC-6 Twin Otter (400)	2.000	275	280	1,0	2.036
Dornier 228	1.700	250	315	0,8	2.142
Helicopters					
Eurocopter EC-225	5.700	838	260	3,2	1.770
Sikorsky S-61	3.900	650	220	3,0	1.320
Eurocopter EC-155	2.300	431	280	1,5	1.493
Bell 412	2.200	425	230	1,8	1.191
Bell 212	1.800	500	190	2,6	950
Bell 206	600	120	200	0,6	907
AS-350 B2	850	188	220	0,9	1.100
AS-350 B3	1.000	200	220	0,9	1.100
1 kg of fuel equals 1.25 l					
Payload for helicopters is for comparison indicated as cabin load					

While efforts are made to replace fuel driven aircrafts with electrically powered aircrafts in the future, the difficulty of battery autonomy in cold regions makes it improbable that electrically powered aircrafts (except from drones) will be very normal in the Arctic in the near future.

Unmanned aerial vehicles (UAV's), such as drones, are often operated remotely from the vicinity of a studied area and do not necessarily imply CO_2 reduction. However, UAVs generally use much less fuel than manned aircrafts and are more flexible for data collection for instance to cover risky as well as more inaccessible areas. During recent years, drones have taken over many of the research related duties, formerly being carried out by manned fixed winged aircrafts or helicopters, and in some cases also time consuming ground surveys. Drones are used in relation to remote sensing (e.g. taking pictures of light with different wavelengths), surveying, monitoring of wildlife, gathering data from remote data loggers, carrying smaller instruments to inaccessible places, etc. These high technology devices often include a complex and energy consuming development and manufacturing process, transportation to the place of use and end-of-life treatment, all emitting CO_2.

If you in any way can accomplish any of your tasks with a drone instead of a manned aircraft or extensive field activities, it is always an advantage both in relation to costs and in relation to the CO_2 emission. In addition, researchers can reduce their carbon footprint by sharing drones and carefully coordinating their activities with the specific purpose of optimising the amount of data being collected while the drone is in use. Before starting your own drone-based data collection, it is advisable to first consider whether e.g. existing satellite based remote sensing data could be sufficient for your research purpose.


Photo: Ole Zeising

Box 3.6 Remote sensing

Airborne remote sensing is used to collect data (e.g. hyperspectral images, aerial photographs) from above. Depending on the project and the data to be collected, use of remote sensing can either have a high or a low carbon footprint. A shared platform equipped with many different sensors mounted on a small aircraft can allow for data collection for different researchers from different institutions, lowering the carbon footprint for each of the participants in the joint operation. Collaboration may also have a major benefit of reducing the costs related to the sampling.

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

Balloons and non-motorised airborne instruments 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) and remote sensing. 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 balloons emit CO_2 and as such have an environmental impact in itself.

Land transport

Global contributions to greenhouse gas emissions

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

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).

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), Northwest Territories (Canada), 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.

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 close settlements and streets inside towns. Here, most transport between settlements is with fixed winged aircraft, helicopter, snow mobile or boat.

Transport infrastructure (road, rail) and natural ice roads are affected by Climate Change due to melting permafrost and reduced ice formation, making remote Arctic settlements increasingly inaccessible in some areas (see Figure 3.3).

Types of vehicles used in Arctic science

Cars, trucks and other types of motorised vehicles, such as tracked vehicles, snowmobiles 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 to the environment.

The choice of vehicle with due consideration to safety and reliability plays an important role in the Arctic. Though safety and reliability should always be your first priority in relation to the choice of a car for passenger transport, paying due consideration to fuel consumption per kilometer driven is also advisable both in relation to CO_2 emissions and costs. This is especially the case in the Arctic, where distances in terrain between cities, field sites, etc. can be far.

The number of trips needed to get scientists to a research station or into the field can be reduced by good coordination of the trips (to fill up each car). Often there is a more intense traffic of people to a research station early in the season, while the transport of

Motorised land transport is often needed to get to a research station. Photo: Elmer Topp-Jørgensen.

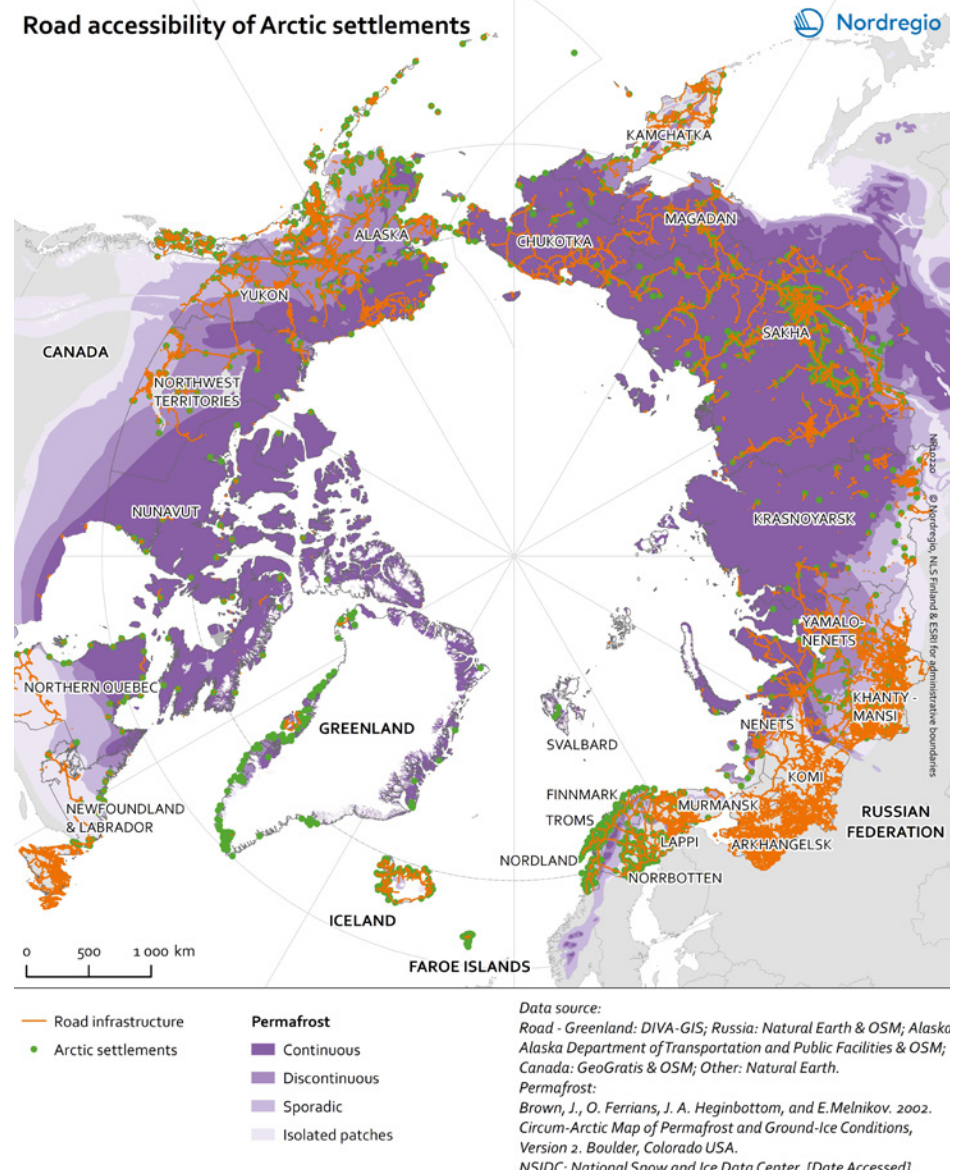


Figure 3.3: Road accessibility of Arctic settlements. Designer/Cartographer: Eeva Turunen, January 2019 (Nordregio, 2019). Note: It is the authors' impression that the information gathered for the map paints a general picture of road infrastructure, but might be insufficient – roads that do not exist appear in some areas of the map.

people away from the station is more intense late in the season – the same applies for field campaigns. With some planning, the resulting free capacity can be used to bring equipment and garbage out of the station/field site early in the season and bring equipment (for use the next year) into the station/field site late in the season.

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 the Arctic is at present not possible unless provided by the research facility or local community.

Snowmobiles are commonly used for recreational activities, for hunting and fishing, for rescue operations and by scientists to access their field sites. While snowmobiles may facilitate scientific activities during the winter season, they still emit substantially more CO_2 than cars.

The type and condition of a snowmobile determines the extent of environmental impact. Having a well-running engine, changing filters, performing regular 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 higher quantities of carbon monoxide and particulate matter than four-stroke engines.

Consequently, snowmobiles can have a significant impact on the environment, yet the extent of this can be partly mitigated by using newer and higher quality machinery. However, buying new snowmobiles, while the old ones are still working, is pushing over-consumption and increasing industrial waste.

Snowmobile used for transport of researchers to a field site and as an anchor for rapelling scientists. Photo: Simon Escalles.

Attention should also be paid to other kinds of pollution resulting from snowmobiles. In a recently published study, the highest polycyclic aromatic compounds concentrations observed in spring in Longyearbyen, Svalbard, is attributed to local emissions from snowmobiles (Drotikova *et al*., 2021).

Further, snowmobile traffic can affect the local fauna. For instance, on the same Svalbard archipelago, a comparative analysis of Arctic Fox behaviour in two areas, i.e. one control area with low snowmobile traffic intensity and one experimental area with high snowmobile traffic intensity, revealed 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 more strict management measures in sensitive nature and close to 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).

Alpine and Arctic heath and fen areas are particularly vulnerable to snowmobiles, which can affect their plant communities and leave prints in the permafrost (e.g. thermo-cast due to wear on the terrain), especially if driving is permitted when the snow depth is low.

Box 3.7 Science by foot: The Catlin Arctic Surveys

The Catlin Arctic Surveys consisted 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 Geographic North 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.

Transport on water

Global contributions to greenhouse gas emissions

As a result of Climate Change, sea ice thickness and its 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 in the Arctic Ocean that connects the Atlantic and Pacific Oceans. 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 (PAME) Working Group of the Arctic Council states that the number of ships in the Polar Code Area has increased by 25 % from 2013 to 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 3.8 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 Organisation. The objective is not only to make shipping in polar waters safer, but also to mitigate its impacts on the Arctic environment (Polar Code, 2017).

Icebreaker Kronprins Håkon, Dronning Maud Land, Antarctica. Photo: Samuel Martinez Llobet.

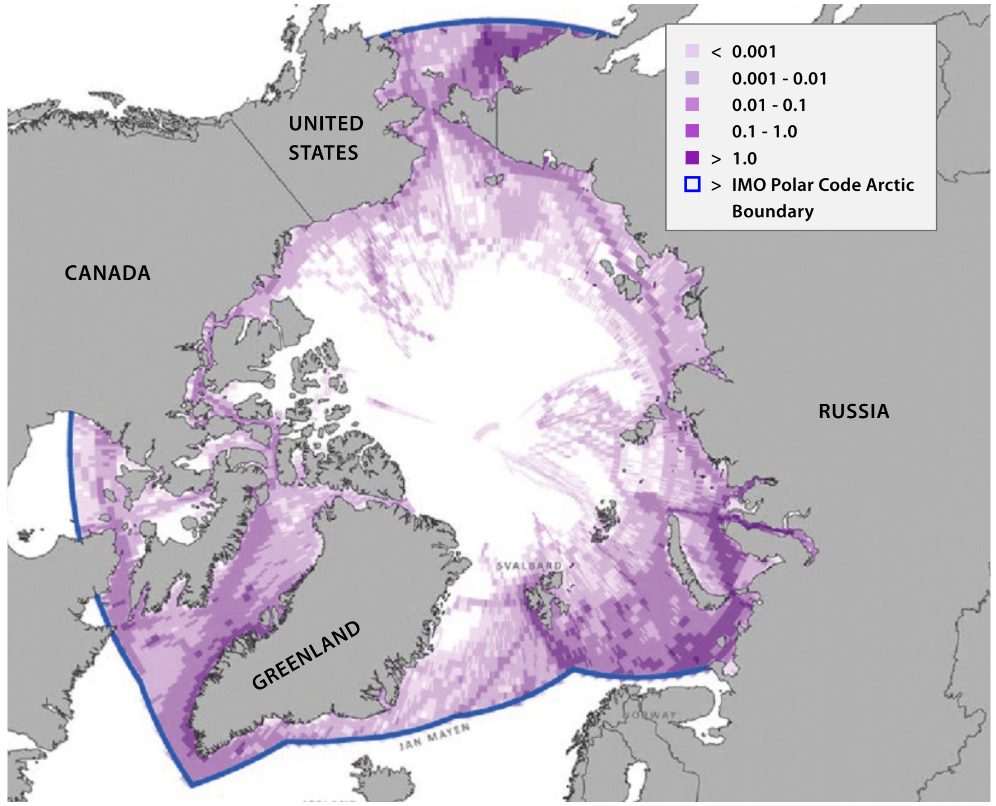


Figure 3.3. Black carbon emissions from Arctic shipping (all fuels) in 2019 (Comer et al., 2020: 8).

Ships do not only emit CO_2, but also black carbon (BC), when burning fossil fuels such as heavy fuel oil (HFO). 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).

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). In the near future, international regulations are expected to change the use of marine fuels in the Arctic, with major benefits for health and the 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 3.9 A drifting ice station: The 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 (1893-1896), the icebreaker *RV Polarstern* drifted with the ice across the central Arctic Ocean 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 relating to atmosphere, ocean, sea ice, biogeochemistry and ecosystem conditions. 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 estimated to be 15 tons per day, mainly used for 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 back (33 days in total) through ice and water have been calculated with an average of 54 tons diesel per day. As one ton of diesel produces around 3.1 tons of CO_2 emissions, it has been estimated that in total ca. 22,100 tons of CO_2 were produced by the expedition (AWI, 2019).

Types of vessels and boats used in Arctic science

Larger vessels (ships) of all different sizes and engine types are used for a diversity of purposes in Arctic scientific research. Some field sites can only be reached by boat and some samples/observations can only be gathered from a vessel (e.g. glacier fronts, marine sediments, bird observations at sea, marine species, the oceanography, etc.).

Cargo vessels transport goods, like engines, fuel, food, samples or equipment to and from 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.

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

The size and type of a ship and its engine(s), the age of the ship and its engine(s), the displacement (weight) of the ship, the fuel type used, the average cruising speed, the fuel efficiency and the number of hours of use all contribute to determine the carbon footprint of a transport by ship.

In addition, emissions vary depending on e.g. the area of operation, sea ice conditions and weather.

Sailing boats were historically used for long distance travel in the Arctic region. Nowadays, a combination of both wind and fuel energy (sometimes supplied with solar energy) is used for the run of most sailing boats, leading to an increase in their carbon footprint.

Some sailing boats may have the ability to navigate in icy-water. However, most of them do not and can therefore only be used seasonally.

Wind conditions can be challenging for sailing across the Arctic. The wind is often too weak or too strong. For instance, many sailing boats navigate Greenland waters, but it is very rare to see them carrying sails.

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 such relatively noisy and fast moving vessels. For local waters, electric engines could be considered for small boats used for local operations only.

Traditional ice-canoes or kayaks can for some project types be of relevance in Arctic waters. These boats have a very limited carbon footprint and move very quietly due to their human-power driven propulsion.

Individuals can reduce the carbon footprint of a boat trip by:

- Reducing the fuel burn (e.g. by performing routine engine maintenance, reducing extra weight, monitoring boat performance).
- Find the most efficient speed for the vessel.
- Minimizing the duration of utilization.

However, researchers often rely on finding their means of transportation on the private market (e.g. chartering a ship, buying ship time on a research vessel), and thus they normally cannot exclusively choose what type of a vessel they have available for their field campaign.

International scientific cooperation and shared logistics are key to reduce both costs and CO_2 emissions. The more science that is conducted during a cruise and/or the more cargo or passengers being transported by a ship on a specific travel, the better is both the economic and CO_2 balances.

Sometimes scientists need to ship a large amount of cargo to/from their field sites. This is often done by commercial cargo ships. Often there is only one shipping company (and ship) navigating small communities in the Arctic. But if there is more than one company, it might be a good idea to consider which of them have the least CO_2 imprint relating to their transports.

Traditional Quebec Ice Canoe used for research on sea-ice in the North Water Polynya, Canada. Photo: Paul Nicot.

CO_2 emission from living/staying in the Arctic

In the Arctic, and therefore also in Arctic science, a wide range of energy sources are used for a variety of services and activities. Energy is for example used for transportation to/from/in the field, operating research stations, operating field camps, etc. (i.e., heat, electrical power and connectivity), cooking, transferring data to outside the circumpolar region. Renewable energy sources can play a role in many of these activities, though it is not always possible.

Many scientists most probably also use scientific infrastructures that they do not always reflect on. For example, data centres may require substantial amounts of energy, which, depending on the country in which they are located, might rely on fossil fuel only. In addition, manufacturing of scientific equipment, camp equipment clothing, etc. comes with carbon costs that is difficult to estimate and often not avoidable.

Box 3.10 The transition of Longyearbyen from coal-based energy to new sources of energy

In Svalbard, the town of Longyearbyen hosts 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 own need 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 is an important socio-cultural part of 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 spare generator capacity (Ringkjøb *et al*., 2020). In total, the energy supply in Longyearbyen emits about 80,000 tons CO_2 annually (Rud *et al*., 2018). This leaves Longyearbyen as the highest CO_2 emitter per capita in the world with ~40 tons per capita. For perspective, mainland Norway emits ~7 tons per capita and the United Kingdom emits ~5.5 tons per capita, based on 2018 data (World Bank, 2021). The Community Council of Longyearbyen has announced that coal mining operations will stop 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.

Coal-fired power station in the harbour zone of Longyearbyen, Svalbard. Photo: Sophie Duveau.

Renewable energy

A reliable energy supply is particularly important when living in the Arctic due to the harsh environment and in some places limited back-up opportunities and access to spare parts. Arctic communities have traditionally depended largely on fossil fuel for heating, transportation and electrical power generation.

Communities in the Arctic (including research stations) normally use more fossil fuel per capita than more southerly communities. This is due to e.g. the cold climate, living standards and transport distances for commodities, fuel, food, etc.

An important concern in many Arctic communities is access to affordable and reliable sources of alternative energy. Solar panels are normally very efficient during the Arctic summer (while they barely produce any energy during the winter). Wind energy as well as hydro-power are also used widely in the Arctic. For hydro-power, many Arctic areas have the advantages of local glaciers being able to act as a buffer of water during the dry and warmer autumn. However, for most alternative energy solutions in Arctic communities, a back-up system, normally operating on fossil fuel, is necessary to maintain a reasonable delivery safety. Many Arctic communities are very vulnerable towards power failure during the winter. If the power fails at an outdoor temperature of well-below -20 ºC, it will only take a few hours for a large amount of infrastructure (e.g. radiators in all private homes) to be destroyed by frost blasting.

Box 3.11 Snowflake International Arctic Station

The Snowflake International Arctic Station was planned to be inaugurated during the Russian Chairmanship of the Arctic Council in 2021-2023. The station, which was supported by the Arctic Council Arctic Hydrogen Energy Applications and Demonstration (AHEAD) project, was planned to consist of a diesel-free research facility powered by renewable energy sources. Thanks to locally produced hydrogen and wind power, the station was planned to become a symbol of international cooperation towards a more sustainable Arctic and to inspire others to follow the example. All cooperation with Russia in Arctic Council has been put on hold due to the war in Ukraine, and accordingly the status of the station is unknown. Princess Elisabeth Station in Antarctica is another example of a ZERO-emission station operating in harsh polar climates.

Snowflake Internaitonal Arctic Station. Photo: arctic-mipt.com.

A greater interest in renewable energy is emerging in the Arctic, however, there are also significant challenges relating to implementing new practices. The challenges of transitioning to renewable energy sources include cost of purchase and operation, system reliability and local skills/expertise to operate new systems.

The potential for using renewable energy resources is also heterogeneously distributed across the Arctic, with some regions having more potential than others. For example, Arctic tidal power will be limited to coastal areas without sea-ice (Arctic Council, 2010), while hydro-power is limited to areas with rivers and with a geomorphology allowing for relatively easily to construct infrastructure to be able to extract and distribute the energy.

Despite the 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 standard off-the-shelf 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 are used 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 changes.

Box 3.12 AWIPEV - Corbel base

The Corbel base was set up in the summer of 1963 by a French expedition in the vicinity of the Ny-Aalesund settlement, Svalbard, which, at that time, was far from the international research campus we know today. 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-sustained with energy in Ny-Aalesund. Solar panels, a wind turbine and recycling facilities are significant components of the base, which aims at lessening the environmental footprint of the research activities.

A solar cell mounted on an automated camera in Bjørndalen, Svalbard. Photo: Sophie Duveau.

4 Necessity and impacts of conference related travel

Photo: Elmer Topp-Jørgensen

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 and an increase in the number of conferences.

The scientific community has documented the environmental impact of research related travel, 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, Professor in chemistry 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 of CO_2 per year (Arsenault *et al*., 2019).

Arctic science can be regarded as a collective effort, and travelling to meet cooperation partners is therefore an important part of science. Researchers generally have colleagues affiliated with institutions based in different locations, which they 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 the 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).

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. 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).

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 it is being held in a beautiful or otherwise 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. To encourage participants to use public transport, the venue location must be easily reachable. Collaborating 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 organisations, 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 of conferences of the International Biogeography Society and compared it to emissions at optimal locations. While the overall average emissions were 857.1 tons CO_2, the calculation showed a saving of 162.3 tons CO_2 per meeting could have been reached, if the meetings had been held at their optimal locations (Stroud and Feeley, 2015: 402). The authors further 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. 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 or non-renewable energy 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 carbon footprint of travellers.

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 organise 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 com-

panies. 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.

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 towards reducing carbon footprint and control of GHG emissions (e.g. at workplaces, institutes and scientific gatherings).

Digital platforms are widely recognised as a way to reduce emissions from meetings and conferences. During the COVID-19 pandemic, online 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 scientific interactions while reducing travel and at the same time improving conference accessibility. The conference offers in-person as well as virtual participation. In order to reduce the carbon footprint of international participants, modern communication solutions such as remote conferencing services 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 options for participating in meetings, workshops and conferences have significantly increased in recent years.

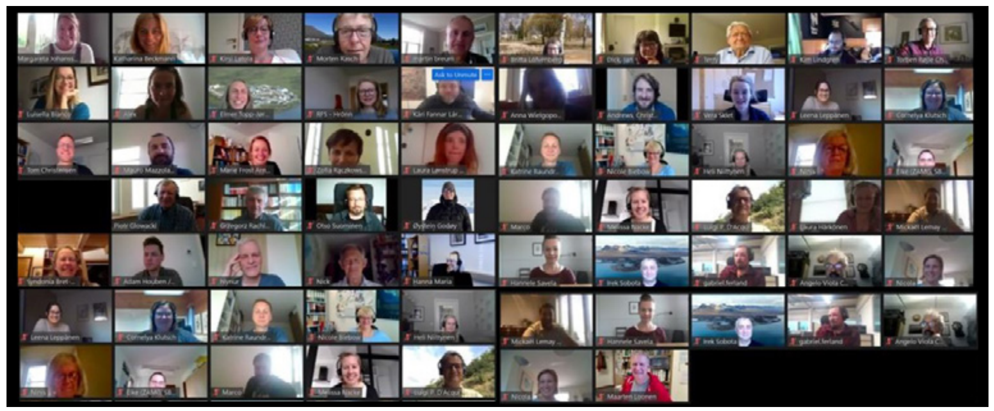


Table 4.1: Advantages of online events.

Advantage	Examples
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 meetings 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. researchers from relatively poor countries, Early Career Researchers and researchers from 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. Increases the quality of 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. Involve a technician to help participants with technical problems during the meeting, for example by guidance through the chat.
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 an other time. Use and share meeting minutes.
Time zone difference	Make sure the conference time is understood by participants, e.g. by using GMT. By using calendar invitations, it is secured that all participants are synchronised despite being in different time zones. Schedule contributors' sessions at various times within the day, so that they can attend at the most convenient times. Record videos and make them available through conference platforms (including subtitles). Be careful in the planning of an international meeting by choosing a meeting time that allows for most of the attendees to participate within the normal work day. Alternatively, arrange regional meetings (but be aware of potential implications for truly circum-Arctic cooperation).
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.

Table 4.2: Disadvantages of online events and possible solutions.

Disadvantage	Possible solutions
Conference feeling	Use online posters, multimedia content and icebreakers if possible (depending on the platform used for the conference). Make participants get to know each other and organise online coffee-breaks. Actively use the chat function to allow attendees to interact without speaking. Respect conference time: stay alert and active although it is an online conference. Stay away from your office-related-work during the time of the conference to be sure that you are present at the meeting. This is a good advice for many also at physical meetings.
Career building: (e.g. potential reduction of opportunities)	Promote the participation of Early Career Researchers by offering them the opportunity to give a talk or take part in the organisation of the event, or act as session chair/ moderators. Encourage Early Career Researchers to interact during the event. Establish mentorship schemes introducing Early Career Researchers to online conference networking and session planning, run and reporting.
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 Diversity, Equity and Inclusion: Group-specific issues

Recommendations to minimise carbon footprint of research activities will most likely impact researchers to various degrees. It is important not to detract groups like Indigenous researchers or Early Career Researchers from their ability to get involved in the research community and to find ways of meaningful participation.

It is important that organisations are aware of these challenges and carefully think about how their projects and programmes could meet the needs of specific groups. They should also strategically plan how their researchers can continue efficient collaboration, while still reducing meeting related emissions.

Online events also come with a carbon footprint. Digital technologies alone are responsible for 4% of global GHG's, 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 tons 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. As an example, one hour of video conferencing emits between 150 and 1,000 grams CO_2. Turning off the camera can reduce these emissions by 96% (Purdue University, 2021). Moreover, the organisation 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

While the carbon footprint of transportation and power supply may be obvious, there are other sources of CO_2 emissions which appear more hidden and harder to quantify. Considering the pollution generated in a computer lifecycle, actions must be taken to include emissions from all levels in the supply chain (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, also them going into as well as back from the field. Computers, smartphones, GPS'es, sensors and other electrical devices affect the environment in several ways. Shared computers offer an alternative to individual computers and other incentives can be developed to prevent the purchase of unnecessary equipment.

Sometimes in academic institutions, there is a practice of using the remaining of an annual budget to buy electronic devices, which are not always needed. It is worth a consideration on carbon footprint before doing so.

The Green Algorithms project provides a freely available online tool to estimate the carbon footprint of computational processes, including data centre servers (http://www.green-algorithms.org) (Lannelongue *et al*., 2021).

5 Get the institutions involved

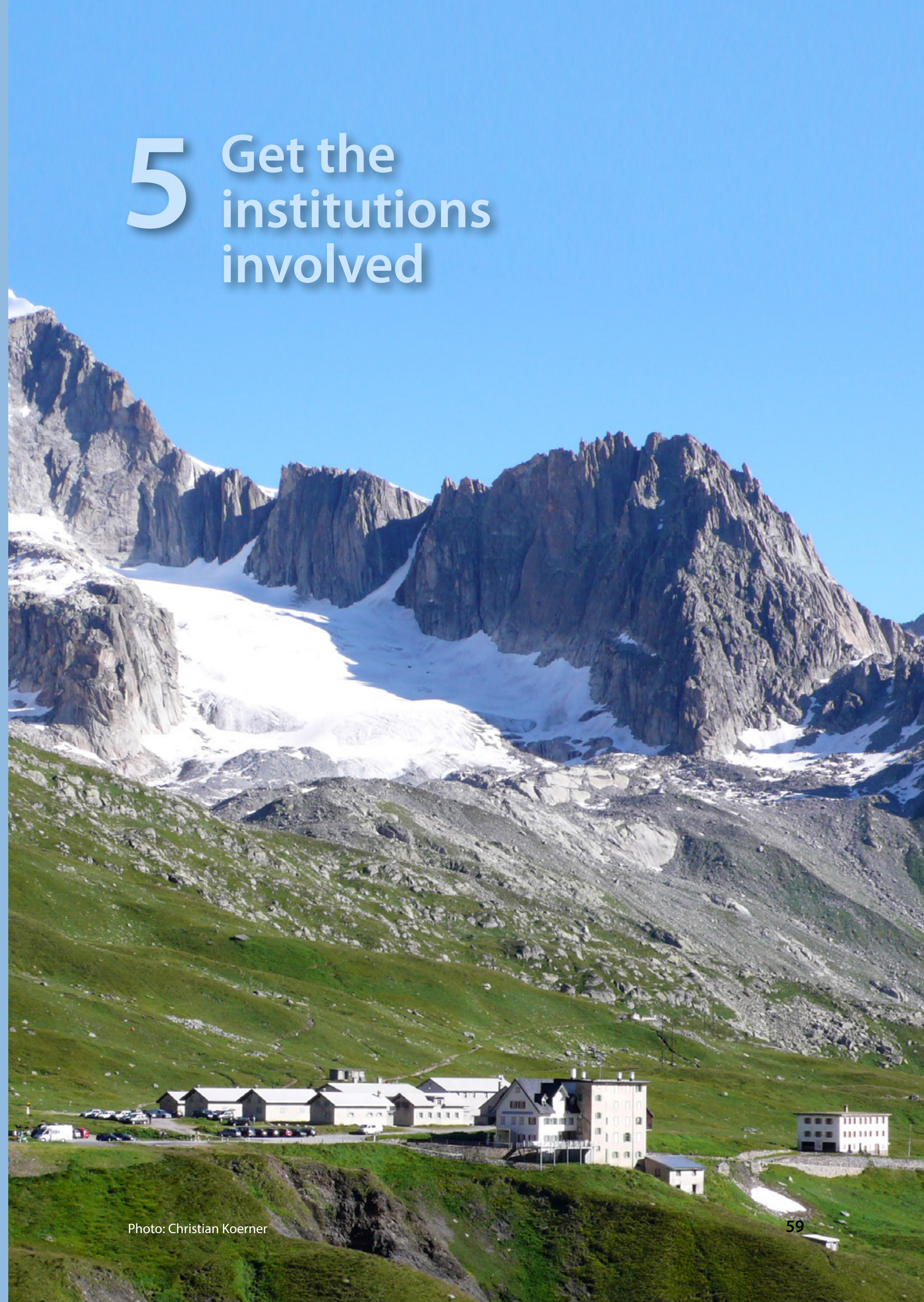


Photo: Christian Koerner

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% between 2014 and 2018, totalling 9 million scientists globally. 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.

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 *institutional level* (system and decision-makers) to establish a foundation/culture for low-carbon research activities. Scientists have a role to play in this and can lead changes in their own institutions, following a bottom-up approach. A transition towards more sustainable organisations 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.

Scientists raising awareness on Climate Change by demanding policy-makers to translate their facts into action. Photo: AWIs4Future.

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 and share recommendations and reports (see Box 1.3 on IPCC). 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 (and 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 organisations conduct their research. By being proactive in this regard, "*science organisations can either prevent legal regulations or at least contribute shaping them*" (Fardet *et al*., 2020: 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 organisation 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 gathering, on an equal level, of both researchers and administrative personnel. It is important to create an institution-wide atmosphere that allows for critical conversation 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.

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, regularly sharing institution emissions (to show that it matters), recognition of an individual's commitment, implementing an organisation sustainability award for sections/individuals that have 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 to 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	plane is not an option
Orange cities	train or bus are the preferred options (but flights may be permitted in some cases)
Red cities	are best to reach by air.

In the form of a monetary benefit, organisations 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.

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, it is often 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.

Box 5.1 Best practice examples from universities

The University of Ghent in Belgium has a commitment to travel by train if the destination is reachable within eight hours by train and the university 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.

In 2017, ETH Zurich launched the air travel project "Stay Grounded, Keep Connected" to motivate staff members to reduce their GHG emissions generated by business trips. Sustainability has been defined a strategic goal and the aim is to reach net zero emissions by 2030.

Box 5.2 Scientists' 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 1,000 km distance), a campaign by Scientists 4Future (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 the ExPlane international network of students and university staff against the impacts of flying (https://www.timetoexplane.com/), developed a thoughtful travel pledge with over 1,000 supporters so far.'

Other policies

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 and peer-review process.

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 or 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. In this regard, fewer individuals are travelling to collect the same, or similar, raw data. For instance, fieldwork campaigns can sometimes be replaced by access to datasets or other scientists/local communities already present in the field can collect data on behalf of others (known as remote access). 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 5.3 INTERACT Remote and Virtual Access

While INTERACT offers researchers physical access to infrastructures in the Arctic and adjacent cold regions through its Transnational Access programme, INTERACT calls for Remote Access (RA) allow scientists to conduct research (or at least collect data) remotely. Through this service, researchers benefit from the presence of personnel on-site at research stations to 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 (typically monitoring data) is provided.

INTERACT Access programmes: https://eu-interact.org/accessing-the-Arctic/
INTERACT Data Portal: https://dataportal.eu-interact.org/

However, it should be noted that the open access to data does not comply with the ethical concerns and practices of all disciplines, especially in the social sciences dealing 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. Data centres consume around 200 terawatt hours (TWh) each year, which is half of the electricity used for worldwide transport (Jones, 2018: 163).

The importance of data sharing, both to remove extraneous research travels and to remove barriers to access, 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 (See Box 3.9 on page 41). 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.

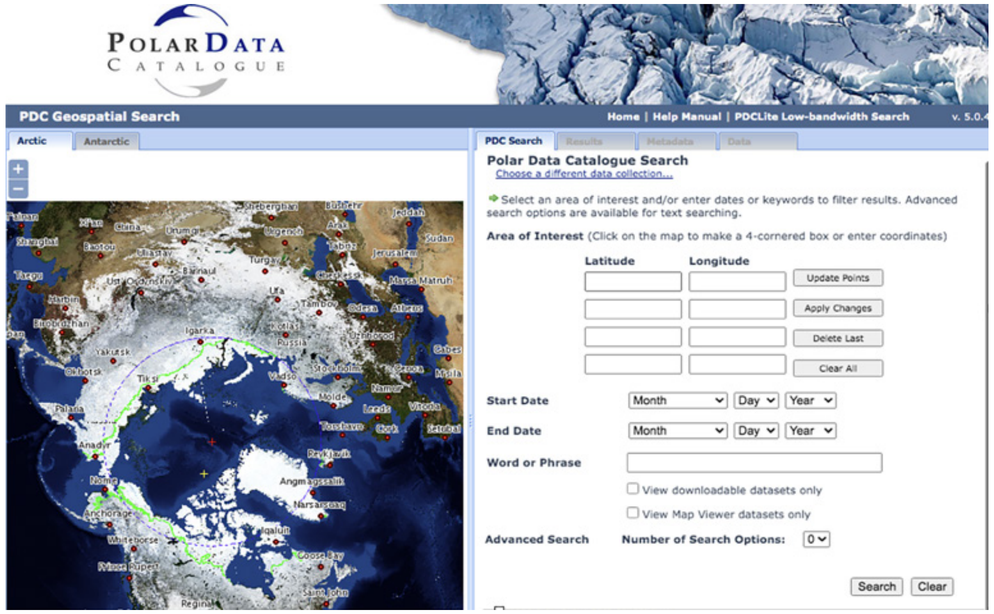


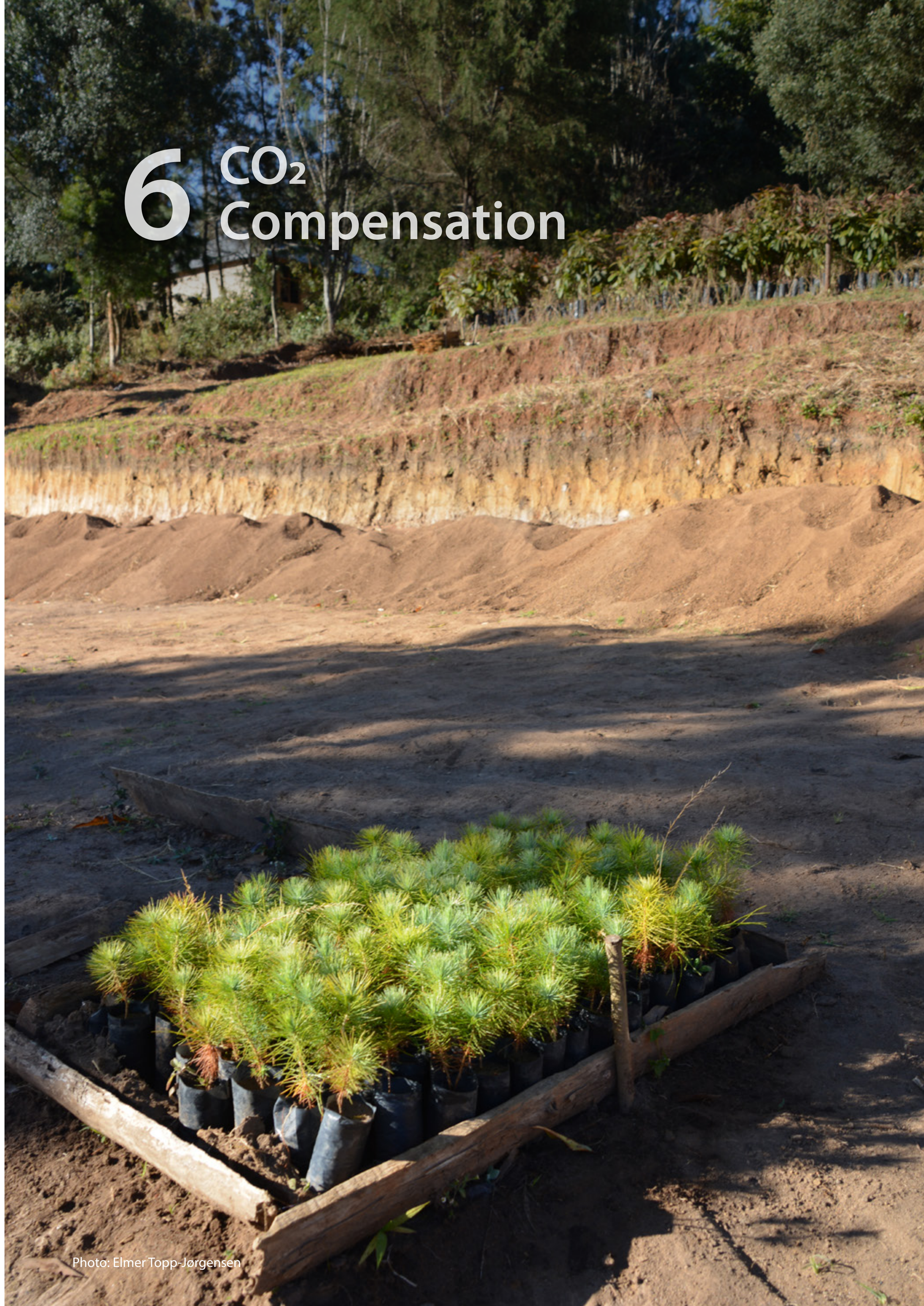
Figure 5.1: The user interface of the Polar Data Catalogue provided by the Canadian Cryospheric information network. This is an example of an open access repository with polar data. Screen copy retrieved in 2021 from: https://www.polardata.ca/

Flexible worklife

Reducing emissions is not just a matter of each individual cycling to campus or prioritising long distance trains over planes. It requires a shift in the entire workplace ethos.

One of the biggest contributions employers can make toward a low-carbon culture is to encourage remote or mobile working. Allowing remote work can save on the emissions related to commuting to and from work, as well as those associated with maintaining office space.

By supporting mobile working, employers can make it easier for their employees and associated members to travel by slower methods. Many trains have tables, power outlets and Wi-Fi, 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, e.i. 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 Wi-Fi 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) than if they travel by air.



6 CO_2 Compensation

Photo: Elmer Topp-Jørgensen

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, often in locations where 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 a fixed level of emissions that the purchaser wants to compensate for (or offset) through investments in climate protection projects elsewhere. Examples of these climate protection projects are reforestation, use of renewable energy or introduction of energy-efficient technologies. Every purchased offset is related to a defined number of emissions.

The ownership of an offset certificate stands for a certain amount - usually tons 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 organisation 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. soils, 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 manage to 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.

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 is the effectiveness of climate protection projects ensured?

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.

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 and certified climate protection projects. The *Carbon Offset Guide* (Broekhoff *et al*., 2019) provides a list of criteria that should be taken into account:

Additionality: Reduction in emissions is only additional, if they would not have occurred in the absence of an offset credit market, i.e. they would not have happened anyway. The emission savings from the chosen climate protection project must be reliable.

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 if a forest with a forecasted amount of removed carbon from the atmosphere over a certain number of years experienced a wildfire that would lead to a reversal of what was intended. 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).

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, organisational 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 that describes guilty feelings among people who fly (Bösehans *et al*., 2020). Anderson (2012) argues that it is impossible to ensure that 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 6.3 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 and onwards. Between 2021 and 2035, CORSIA should help to mitigate around 2.5 billion tons of CO_2.

However, critical voices evaluate the potential climate impacts of CORSIA as not compatible with climate neutrality goals by 2050. In addition, CORSIA has been criticised by environmental NGO's, 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: One, usually called the Global North, can afford emitting CO_2 while continuing a carbon-intensive lifestyle. The other one, usually called the Global South, already emits less or relies on sources of energy, which emit significant quantities of CO_2. Often, Global North countries have partly, or totally, relocated their industrial process to the Global South, to get a cheaper labour force and other benefits. While the Global South can be involved in intensive industrial activities to satisfy the needs of the rest of the world, they also depend on selling their certificates. Therefore, most offset providers operate in international climate protection projects in the Global South.

This means that with carbon compensation used by scientists travelling and working in the Arctic, money from offset certificates will probably not be used for restoration of Arctic ecosystems or other climate protection projects in the Arctic regions, but elsewhere in the world. One regional example, however, is the Iceland Carbon Fund (ICF) that offers carbon offsets through tree planting in designated areas in Iceland.

7 Towards a more sustainable future of the scientific world

Photo: Andrea Schneider

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. However, 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 a 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 for conducting 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 to come.

Carbon footprint has to become a metric. There are tools to assess emissions, alternative solutions are often at hand and there are ways to compensate if emissions cannot be avoided. There is a need to identify strategic research priorities and solutions that can move Arctic science towards the zero or negative emissions needed in the future. To understand and identify efficient reduction efforts inter-disciplinarity is a keyword, because exchange and cooperation provide cost-effective solutions and specific recommendations for how to reduce carbon emissions across sectors.

Thus, reduction of carbon footprint has to become part of the everyday mindset of scientists and could be included in the evaluation of scientific activities (e.g. cost calculation). Scientists could be challenged with requirement to add a section about Environmental Impacts of Research Activities in applications or the acknowledgement section of each published paper (Grogan, 2021).

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 were 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. Unmanned sampling and remote sensing represent some mechanisms for doing research without travelling to the field (even though remote sensing also requires calibration and to be supplemented by on-site activities). While pushing for automation, these technologies may generate problems on their own and have a carbon footprint. Using local staff at research stations or members of a local community to conduct field investigations based on detailed protocols could be another way. Finally, urging academic departments to incentivise carbon-neutral learning initiatives would facilitate offsetting of individual carbon-footprints.

Besides researchers' individual travel decisions and developments towards more sustainability at 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*. (2020) assess how to respect the needs and security concerns of local communities in the future while at the same time ensuring fieldwork and data generation. In fact, they argue for building resilient Arctic science as a response to the COVID-19 pandemic, stating that a local turn is needed (Petrov *et al*., 2020). Once institutions have invested in good research infrastructure, local community observation systems could be strengthened, thus reducing the need for travelling to the Arctic. In addition, that would strengthen the co-production of knowledge, ensure meaningful participation of local and indigenous communities and help 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.

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 many little steps towards conducting research and travelling in sustainable ways. Calculating your carbon footprint often helps as a first step to estimate the impact of research activities. However, this is definitely not an easy task, as for instance life-cycle of products and activities play a role as well and seldom are incorporated into calculation tools. International cooperation, shared logistics and open data sharing are key to reduce both costs and CO_2 emissions. Developing and implementing challenging recommendations on how to reduce travel-related emissions in Arctic science is and will always be a work in progress. In this sense, the next pages with tips for scientists, conference organisers and institutions should be taken as a starting point towards science that is more ready for the future.

Figure 7.1. Principal priorities when moving towards zero emission science.

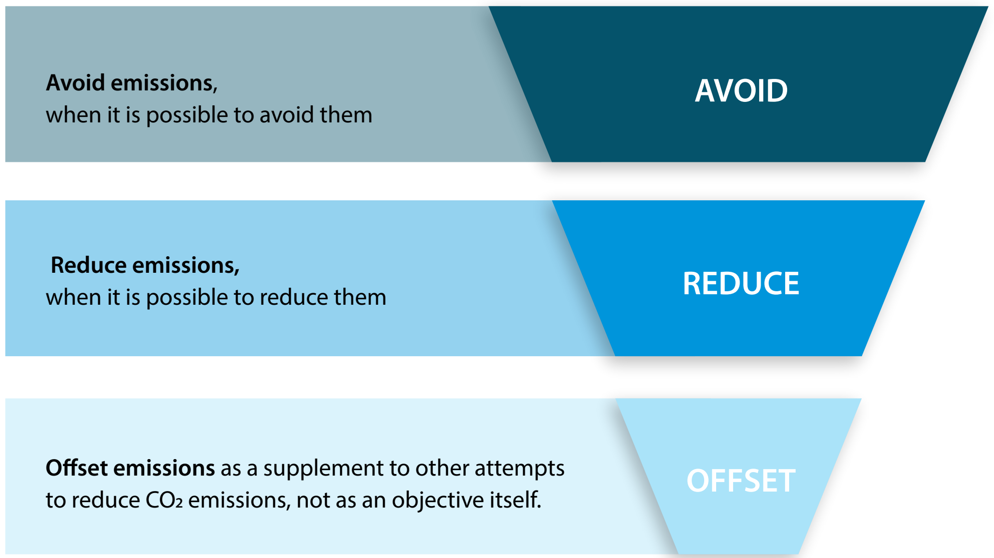


Photo: Morten Rasch

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 tools to calculate your expected carbon footprint for getting to the Arctic and back.
- Choose the least CO_2 emitting transport option (where you have a choice).
- Use public transport where possible.
- Prefer land-based travel over air travel.
- Choose a CO_2 efficient airline where possible.
- Share transport and logistics to fill up capacity.
- Compensate for unavoidable emissions by using carbon offsetting schemes that comply with internationally recognised standards.

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

→ **Reflect on your conference/meeting participation.**
Rather than conference consumerism or routine, researchers and other personnel could be encouraged to take a more reflective approach in relation to their work-related travels.

What is your motivation to go?

- What is the desired outcome of participating in the event?
- Why is it important for me to attend the event, are there others that could represent me?
- What will be my role and is it important to attend physically or can I achieve my aims through online participation?
- How many of my colleagues are going?
- Are there expected spin-offs from meeting colleagues?
- Can I combine it with other work-related visits?
- Where does the conference take place (distance to venue)?
- Are there low-carbon transport options?

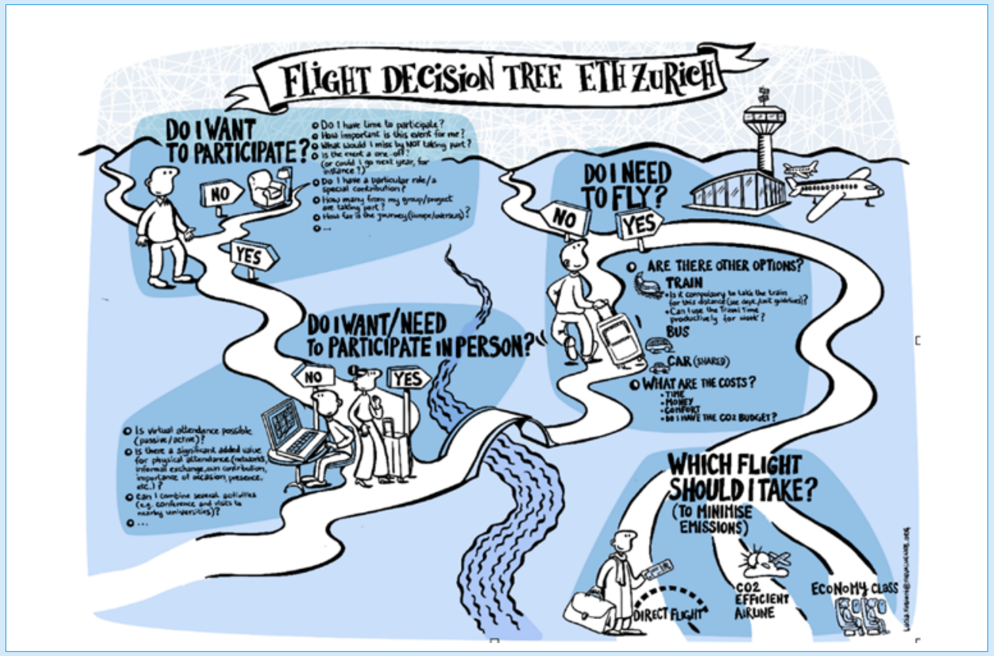
If going to the conference, prioritise low-carbon transport options.

→ **Influence your institution.**

Promote a low-carbon travel policy at your institute that makes it easier for you to implement more sustainable travel choices in your life as researcher. Depending on your situation (time, family duties, finances) this might be more or less easy.

Engage in and support critical and open discussions. You could even organise events or activities to raise awareness. Inspire each other with good and fresh ideas about how to live in a more sustainable way. But, keep in mind that reasons for individual behaviour (travel choices) might be complex and different, so do not blame others if they do not follow your example.

ETH Zurich's Flight Decision Tree. Illustrator: Lucia Fabiani.



Tips for conference organisers

It is advisable to develop a strategy for organising sustainable events, including a check-list of means for carbon footprint reduction. In general, several aspects have to be taken into account, e.g. travel, venue, lodging, local logistics (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 of advantages and disadvantages on pages 53-54)?
- Consider hybrid formats and work towards conditions that improve online participation.

→ **Decarbonise conference travel.**

- **Promote low carbon travels.** Organisers can encourage participants to use trains and public transport, when it is possible, and design incentives such as a discount on conference fees for those who favour a low-carbon mode of transportation. Free conference trains/busses that collect participants on their way to the conference locations are good examples of how to save carbon emissions, while engaging in short workshops and discussions during a relaxed trip to the venue.

- **Choose a central location**, which can be easily reached by public transport. This in combination with the promotion of low-emission land-bound travel options result in a significant reduction of the carbon footprint.

- A smart way to reduce the carbon footprint related to conference travels is also 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 emission 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 Early Career Researchers 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 maximise the advantages of both in-person and digital conferencing.

- To 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.

Plenary session at major Arctic conference. Photo: Elmer Topp-Jørgensen.

Tips for institutions

Research institutions play a key role in efforts to reduce CO_2 in Arctic science. Of course, a complete picture towards leading a low-carbon pathway at your institutes includes many more considerations than only looking at how to reduce travel emissions. The energy consumption in all life cycle stages of buildings, instrumentation, food provisioning, etc. needs also to be taken into account, and introduction of renewable energy within the institution (e.g. laboratories, digital infrastructure, buildings) and research facilities (research stations, research vessels) must be pursued. When making new investments, attention should be paid to carbon emissions, environmental impacts and social aspects.

Here are key aspects to take into consideration when developing a sustainable travel policy at your institute.

→ Develop a sustainable travel policy.

- Develop an institution-wide commitment to CO_2 reduction as a collective objective within the institution.
- Improve monitoring and internal reporting systems 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).
- Reflect on the relevance of travels and mode of transport collectively.
- Promote low-emission transport especially for short distance and day-to-day travels.
- Improve infrastructure for more sustainable day-to-day travel.
- Prioritize online meetings, where possible.
- Encourage more flexible work life within the institution.
- Raise employee and/or student 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.

→ Be open for discussions and change.

Ensure a good environment for open exchange, new ideas and meaningful communication at your institute. Most likely there will be bureaucratic, financial or administrative barriers to implement the demanded actions. Do not get discouraged, but try to develop solutions. Exchange and learn from other institutions and best practice examples.

Engagement of staff in developing institutional guidelines help create awareness and understanding of institutional guidelines to reduce CO_2 emissions. Photo: Morten Rasch.

Box 7.3 The role of funding agencies

While funding agencies should ensure and support excellent research, opportunities should be developed to also encourage low-carbon research activities. Thus, it might be considered to include CO_2 reduction in the evaluation scheme, e.g. by making the use of low-emission transport and attempts to reduce the carbon footprint of research part of the funding criteria. Funding agencies have shown that they can bring about institutional change when acting collectively. Today many require that data from funded projects are made available as open access data.

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
CF_4	Carbon tetrafluoride
CFC-11	Trichlorofluoromethane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CH4	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
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)
G20 (countries)	The Group of Twenty (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States and the European Union)
GWP	Global Warming Potential
GHG	Greenhouse Gas
IASC	International Arctic science Committee
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
ICF	Iceland Carbon Fund
IEA	International Energy Agency
IPCC	International Panel on Climate Change
IPEV	Institut Paul-Emile Victor – the French polar research institute
LUC	Land Use Change
MOSAiC (expedition)	Multidisciplinary drifting Observatory for the Study of Arctic Climate
NDC	Nationally determined contributions
NGO	Non-governmental organisation
N2O	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	Verified Carbon Standard


Photo: Morten Rasch

Carbon acknowledgement

While producing this guidebook, we were aware that our project has its own CO_2 imprint. We therefore wanted to calculate this carbon footprint, but realised that this is a very complex task and not currently possible to the full extent. The calculations would include zoom meetings, emails, research on the internet, use of computers and other devices, data storage, printing and shipping.

Emissions from video calls are an increasingly important factor, when considering the carbon footprint of projects. As we did not travel, we took advantage of the pleasant possibility to interact face-to-face via ZOOM. While this might be considered a rather small contributor to the overall carbon footprint of the publication, we still decided to make a rough estimate of the CO_2 emission resulting from our ZOOM meetings. In doing so, we followed David Mytton's (2021) methodology:

(https://davidmytton.blog/zoom-video-conferencing-energy-and-emissions/).

A simple calculation of all our calls with different numbers of participants resulted in a total of 0.92 kg CO_2 produced by our ZOOM meetings.

With this carbon acknowledgement we want to reflect that we are making our own CO_2 contribution and that we, too, could not avoid but only reduce the CO_2 imprint of our everyday communication.

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Editor's short biographies

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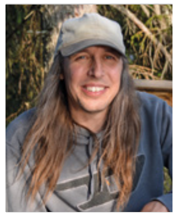

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Elmer is a biologist working for INTERACT Station Managers' Forum. Elmer has worked with biodiversity, wildlife management and community-based monitoring in the Arctic and beyond. Today he also works with circumArctic logistics organisations with strong ties to international science organisations and Arctic Council working groups.

About INTERACT

INTERACT is a circum-Arctic network with over 85 terrestrial field stations in the Arctic and adjacent boreal and alpine areas. INTERACT specifically seeks to build capacity for research and monitoring in the Arctic and beyond. INTERACT offers access to numerous research stations through its Transnational Access Programme.

One of the main objectives of INTERACT, being funded by the European Union through the Horizon 2020 Programme, is to build capacity for identifying, understanding, predicting and responding to diverse environmental changes throughout the Arctic. This is fundamental, since the Arctic is so vast and sparsely populated that the environmental observing capacity is limited compared to most other regions.

INTERACT offers a multi-disciplinary research platform, and together the INTERACT stations host thousands of scientists from around the world, working on projects within the fields of e.g. glaciology, permafrost, climate, ecology, biodiversity and biogeochemical cycling. The INTERACT stations also facilitate many international single-discipline networks and support educational activities by hosting courses and training schools.

It is a priority for INTERACT to support the education of future polar scientists, and INTERACT therefore cooperates closely with the Association of Polar Early Career Scientists (APECS). One of the results of this cooperation is this guidebook developed to provide information and guidance on how to reduce CO_2 emissions in Arctic science.

The guidebook is one in a series of publications by INTERACT to improve the services offered by research stations to the scientific community and to facilitate efficient and safe fieldwork by the scientists themselves.

About APECS

The Association of Polar Early Career Scientists (APECS) is an international and inter-disciplinary organisation for undergraduate and graduate students, postdoctoral researchers, early faculty members, early career professionals, educators and others with interests in the polar and alpine regions and the wider cryosphere. APECS strives to create opportunities for early career researchers to enhance innovative and inter-disciplinary collaborations across the globe, helping to retain and promote the next generation of polar enthusiasts. APECS serves as an institutional partner supporting the involvement of early career researchers in a wide range of activities and organisations, including international research and infrastructure projects such as INTERACT.

Working together with the INTERACT Station Managers' Forum, a group of APECS members has helped put together this guidebook, with the aim of providing a resource for anyone performing fieldwork at Arctic research stations and elsewhere in the polar and alpine regions of the world.

The INTERACT Reducing CO_2 Emissions in Arctic Science guidebook raises awareness about the carbon footprint of scientific activities. It is published to help you make decisions that balance the need to reduce carbon emissions while still conducting excellent research.

The guidebook contains information about fieldwork and conference related travels, discusses benefits and challenges of online conference attendance and stresses the important role of institutions to get involved in this endeavour.

The book has been made by members of APECS, INTERACT and the managers of arctic and northern boreal and alpine research stations with funding provided by the European Union through the Horizon 2020 Research and Innovation Programme.

With a similar purpose, the INTERACT Reducing Environmental Impacts of Arctic Fieldwork guidebook was published to help you reduce all the environmental impacts that are related to fieldwork. If you are planning fieldwork, we also strongly encourage you to take a look at the comprehensive INTERACT Fieldwork Planning Handbook, which is meant as a planning tool for studies in the Cold North, and the shorter INTERACT Practical Field Guide, which is meant as a handy tool to be brought with you into the field.

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