ISO/TC 207/SC 7/WG 13
Radiative forcing management

Email of convenor: tod@firstenvironment.com
Convenorship: ANSI (United States)

Working Draft 02

Document type:	Working draft
Date of document:	2019-07-23
Expected action:	COMM
Action due date:	2019-08-16
Background:	Please see below for ISO 14082 WD02, to be discussed at the next meeting in Berkeley, CA. Please submit comments using the official comment form by Friday, August 16, 2019. Let me know if you have any questions, thank you!
Committee URL:	https://isotc.iso.org/livelink/livelink/open/tc207sc7wg13

ISO/WD 14082:####(X)
ISO TC 207/SC 7/WG 13
Secretariat: SAC (China)

ISO/WD 14082
GHG management – Guidance for the quantification and reporting of radiative forcing based climate footprints and mitigation efforts

WD stage

Table of Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 7, *Greenhouse gas management and related activities*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

NOTE TO COMMITTEE:

This guidance standard provides an application of climate science as described and summarized by the Intergovernmental Panel on Climate Change (IPCC). The scientific equations and methods provided in Annex A of this guidance standard are currently under review by the United Nations' Climate and Clean Air Coalition Scientific Advisory Panel. This simultaneous review is being conducted to ensure that IPCC-recognized climate science has been fully and properly incorporated into the scientific methods contained in the guidance standard, and will enable the ISO subcommittee to focus on standardizing the protocols to calculate and report progress toward achieving the goal of stabilizing the climate system at various temperature thresholds in the near-term. The most current science should be used in the application of this standard when quantifying and reporting radiative forcing based climate footprints.

Introduction

0.1 Background

Climate change arising from anthropogenic activity has been identified as one of the greatest challenges facing the world. Climate change is accelerating, with implications for both human and natural systems, including significant impacts on resource availability, economic activity and human wellbeing for decades to come. In response, international, regional, national and local initiatives are needed, involving the public and private sectors, to address the urgent threat of climate change on the basis of the best available scientific knowledge.

ISO produces documents that support the transformation of scientific knowledge into tools that will help address climate change. However, existing ISO climate accounting protocols address only a portion of the emissions and other factors contributing to an energy imbalance (excess energy trapped in the Earth's atmosphere), measured as "radiative forcing" (RF), that in turn is causing climate disruption and leading to temperature rise. The most current science indicates that in order to achieve climate stabilization, all anthropogenic emissions and other factors affecting radiative forcing must be addressed.

This document provides guidance for quantifying, monitoring, reporting, and validating and verifying reductions in climate forcers. It can be used to:

— develop RF management roadmaps;

— track and report progress toward global RF stabilization targets and RF reduction goals over specific time horizons;

— establish the radiative forcing reduction potential of different project categories;

— establish the potential of project categories to reduce RF within high-risk zones;

— assess the climate and other consequences associated with implementation of projects within a project category;

— evaluate RF climate footprints of organizations and government entities; and

— calculate RF in a consistent manner across all of the applications above.

The use of this guidance standard is designed to:

— facilitate the use of RF-based climate accounting protocols;

— enhance the credibility, consistency and transparency of climate forcer and RF climate footprint quantification, monitoring, and reporting; and

— facilitate the development and implementation of RF management strategies and plans, and ensure the credibility, consistency and transparency of project verification and validation in order to reduce global RF sufficiently by 2030 and thereafter to hold global mean temperature (GMT) significantly below +1.5°C and stabilize the climate system.

This document details principles and guidance for designing, developing, managing and reporting organization-level, government entity-level and project-level climate forcer inventories (Table 1).

0.2 IPCC projections and Radiative Forcing (RF)

The Intergovernmental Panel on Climate Change (IPCC) periodically releases consensus assessment reports that summarize the findings of the latest peer-reviewed climate science literature. The Fifth Assessment Report (AR5), "Climate Change 2013: The Physical Science Basis," used a framework for evaluating climate forcers based on their projected contribution to increased radiative forcing (RF). Measured in watts per square meter (W/m²), increased RF is the measure of the excess energy upsetting the earth's energy balance and driving climate change. AR5 modelled four Representative Concentration Pathway (RCP) scenarios to project future trends in global emissions and resulting RF and temperature, which included annual emissions, the emissions accumulated in the atmosphere from the past (i.e., background concentrations) that still continue to contribute to climate change, factors other than emissions (e.g., landscape changes affecting albedo) affecting radiative forcing, and projected increases in atmospheric concentrations of various climate forcers.

The uncertainty in projected increases in total anthropogenic radiative forcing was a principle justification for modelling the four scenarios described in AR5 (Figure 1). The business-as-usual projection, RCP8.5, assumed that industrial activity would proceed without significant reduction of the major contributors to an RF level reaching 8.5 W/m² by the end of this century. The heightened RF would, in turn, result in GMT rising to over +4°C by 2100, the hottest the planet has been in over 34 million years (Hansen, et. al. 2013 https://royalsocietypublishing.org/doi/10.1098/rsta.2012.0294).

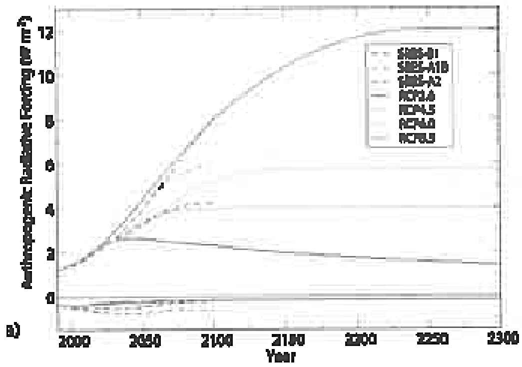

Figure 1 — Representative Concentration Pathway Scenarios
(Source: IPCC AR5, Climate Change 2013: The Physical Science Basis, Figure 12.3)
Time evolution of the total anthropogenic (positive) and anthropogenic aerosol (negative) radiative forcing (RF) relative to pre-industrial (about 1765) between 2000 and 2300 for RCP scenarios and their extensions (continuous lines), and SRES scenarios (dashed lines) as computed by the Integrated Assessment Models (IAMs) used to develop those scenarios. The four RCP scenarios used in CMIP5 are: RCP2.6 (dark blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red). The three SRES scenarios used in CMIP3 are: B1 (blue, dashed), A1B (green, dashed) and A2 (red, dashed). Positive values correspond to the total anthropogenic RF. Negative values correspond to the forcing from all anthropogenic aerosol-radiation interactions (i.e., direct effects only).

The 2018 IPCC Special Report on Global Warming of 1.5°C used the RCP framework of AR5 to more precisely examine scenarios for holding the GMT anomaly below +1.5°C or +2.0°C (the lower and upper temperature maximums identified in the Paris Accord), and to shed light on the differences in impacts at each of these levels.

0.3 Understanding the relationship between radiative forcing and rising temperatures

Lack of understanding of the relationship between rising RF and the gradual rise in GMT has contributed to confusion as to the best strategy for developing a comprehensive roadmap to achieve a sustainable climate system. Thermodynamically, rising atmospheric heat is largely absorbed into the oceans (about 90%), but then a significant amount of that stored heat is re-released back into the atmosphere periodically by oceanic oscillations such as El Niño. This, in turn, eventually pushes GMT higher.

The more that the RF rises steadily over an extended time period, the higher the GMT response. For this reason, increases in RF levels are considered a *leading indicator* of climate change, while observed increases in GMT are considered a *lagging indicator* of climate change. Therefore, basing strategies to control or curb the impacts of climate change solely on GMT maximums (+1.5°C or +2°C) identified in the Paris Accord is problematic because major impacts will have occurred *long before* these increases in temperature are observed.

0.4 The need for this guidance

This guidance standard draws upon the IPCC AR5 and IPCC SR1.5 RF framework as the basis for Radiative Forcing Management (RFM) climate accounting protocols. It complements existing climate standards by providing guidance for developing a roadmap to contribute toward reducing global RF levels sufficiently to stabilize the global mean temperature significantly below +1.5°C by 2030, and for achieving longer-term climate stability, in order to fulfill the UNFCCC objective.

This guidance standard is inclusive of all climate forcers (e.g., gases, aerosols, particulates, landscape-level albedo changes), accounts for the accumulated atmospheric build-up of long-lived greenhouse gases emitted in the past that are still contributing to current RF levels, and addresses the future RF contribution of long-lived greenhouse gas emissions.

This guidance standard provides terms and definitions for use by organizations and government entities in implementing an effective RF reduction roadmap. It also clarifies the difference between mitigation projects aimed at climate forcer emissions reduction, projects aimed at restoring elements of the natural baseline conditions of the climate system, and projects aimed at rebalancing the earth's energy budget that rely on means beyond natural climate systems, such as chemical emissions that may have measurable impact trade-offs. Finally, this document provides a robust technical framework to guard against unintended climate and other trade-offs that could arise from the implementation of any of these RF reduction projects.

0.5 Goals

The goals of this guidance standard are to:

— Provide RF accounting protocols to facilitate greater understanding of the quantitative impacts of RF climate forcers in the near term and longer term.

— Stabilize RF at the reduced levels necessary to prevent GMT from overshooting the UNFCCC goal of +1.5°C and to maintain GMT significantly below this level.

— Reduce RF to sustainable levels in regional high-risk zones.

To achieve these goals, this guidance standard:

— Utilizes updated IPCC climate science and metrics as the basis of a unified method to quantitatively account for all climate forcers;

— Defines RF climate footprints that address long-lived, mid-lived and short-lived climate forcers, including annual emissions, accumulated concentrations of long-lived climate pollutants, non-emissions forcers, and both negligible- and measurable-impact climate coolants;

— Describes steps to develop an RF Management Plan;

— Describes aspects of emissions reduction projects and other categories of projects that can be scaled to contribute toward reduction of regional and global RF levels; and

— Describes methods to determine the scale of co-benefits, such as reduced regional air pollution, associated with specific projects and RF Management strategies, as well as potential adverse climate and other trade-offs.

0.6 Benefits

This guidance standard benefits organizations, project proponents and stakeholders worldwide by providing guidance for voluntary efforts to contribute to achieving sustainable global climate stabilization without overshooting UNFCCC temperature targets. Specific benefits may include:

— understanding the scale of RF reduction required by 2030 and beyond to achieve climate stabilization;

— identifying the types of projects and actions that can contribute appreciably to an effective RF Management Roadmap without unintended adverse trade-offs, and in the most cost-effective manner, thereby supporting the prioritization of projects to stabilize RF and temperature rise by 2030 and support the goal of long-term stability;

— enhancing the credibility, consistency and transparency of RF climate footprints and RF reduction project quantification, monitoring, reporting and verification;

— facilitating the development and implementation of RF reduction projects;

— identifying risks related to RF, and identifying opportunities to manage risks;

— supporting regulatory/government reporting;

— extending the range of mitigation options available to meet an entity's climate targets and obligations; and

— facilitating the establishment of RF reduction markets, including the buying and selling of RF reduction allowances or credits.

0.7 Approach

This document provides a technology-neutral framework and specific guidance for evaluating the impacts of climate forcers, determining RF climate footprints, establishing RF targets and roadmaps in order to avoid overshooting temperature thresholds, evaluating project categories, and assessing RF projects. Presented terms and concepts are designed to be compatible with existing programs and good practice while maintaining conformance with ISO directives for standards development.

The summary information presented in Box 1 is provided to assist users of this document.

Box 1 —
Summary information to assist users of this document

Guidance Standard

ISO defines a standard as a document, established by consensus and approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context (ISO/IEC Guide 2:2004 [39], definition 3.2). This guidance standard contains no requirements; therefore, the word "shall", which indicates a requirement in ISO language, is not used. Recommendations use the word "should". The word "may" is used to indicate that something is permitted. The word "can" is used to indicate that something is possible, for example, that an organization or individual is able to do something.

As a guidance standard, this document may contain recommendations. In ISO/IEC Directives, Part 2, a recommendation is defined as an "expression in the content of a document conveying that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited."

Terms

Terms that are not defined in Clause 3 are used in the common sense of the word, assuming their dictionary meanings.

Bibliography

The Bibliography, which is an integral part of an International Standard, provides information to identify and locate other documents referenced in the text. It consists of references to international instruments that are considered authoritative sources for the recommendations in this guidance standard. These instruments may contain additional useful guidance and information; users of this document are encouraged to consult them to better understand and implement radiative forcing management. References are shown in the text by superscript numbers in square brackets.

NOTE: Reference numbers are not assigned in the order of the documents' appearance in the text. ISO documents are listed first; then the remaining documents are listed in alphabetical order of the issuing organization.

Text boxes

Text boxes provide supplementary guidance or illustrative examples. Text in boxes should not be considered less important than other text.

GHG management – Guidance for the quantification and reporting of radiative forcing based climate footprints and mitigation efforts

1 Scope

This document specifies principles and provides guidance at the project, organization and government entity level for the establishment of radiative forcing (RF) targets and the quantification, monitoring and reporting of RF climate footprints, assessment of RF project categories, and the validation and verification of RF projects. It addresses:

— Key concepts and terms;

— A summary of the RF reduction levels needed by 2030 and in subsequent decades to achieve GMT stabilization below +1.5°C and to cool regional "high-risk" zones;

— Algorithms and methods needed to establish RF targets over specific time horizons, and to calculate RF levels by source (both emissions and non-emission sources);

— Steps for calculating RF climate footprints;

— Steps for determining the potential RF reduction, co-benefits and adverse trade-offs related to human health and the environment associated with specific RF projects and activities;

— Steps for validating and verifying RF reduction; and

— A discussion of uncertainty related to RF and RF climate footprints.

This document is intended to facilitate the enhancement of climate accounting protocols and programs to incorporate the latest climate science regarding RF climate drivers as well as co-benefit and trade-off analysis.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/
— ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1 Terms relating to radiative forcing and climate forcers

3.1.1.1
radiative forcing
RF
change in the net, downward minus upward, radiative flux (expressed in W/m^2) at the tropopause or top of atmosphere due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun

Note 1 to entry: Radiative forcing, unless otherwise noted, refers to a global annual average value.

Note 2 to entry: IPCC Fifth Assessment Report: Climate Change 2014.

3.1.1.2
climate forcer
emission or other process or activity that causes a change in *RF* (3.1.1.1), either positive or negative

Note 1 to entry: Includes *long-lived climate forcers* (3.1.1.7), *mid-lived climate forcers* (3.1.1.8) and *short-lived climate forcers* (3.1.9)

Note 2 to entry: Climate forcers include, but are not limited to, *climate pollutants* (3.1.1.4)

Note 3 to entry: A change in *albedo* (3.1.5.3) (e.g., surface, cloud, clear sky) is an example of a process that causes a change in *RF* (3.1.1.1) but that is not an emission.

3.1.1.3
climate forcer source
the origin of a *climate forcer* (3.1.1.2)

3.1.1.4
climate pollutant
emission that causes a change in *RF* (3.1.1.1), and might also cause measurable environmental or human health *impacts* (3.1.5.5)

Note 1 to entry: Includes *long-lived climate forcers* (3.1.1.7), *mid-lived climate forcers* (3.1.1.8) and *short-lived climate forcers* (3.1.1.9)

3.1.1.5
accumulated climate pollutant emissions
background concentration

fraction of climate pollutant emissions that were emitted in the past and are still retained in the atmosphere today

Note 1 to entry: Relevant only to *mid-lived climate forcers* (3.1.1.8) and *long-lived climate forcers* (3.1.1.7).

3.1.1.6
greenhouse gas
GHG
gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds

Note 1 to entry: GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).

Note 2 to entry: GHGs are all considered *climate pollutants* (3.1.1.4).

[SOURCE: ISO14064-3:2019, 3.1.1, modified—Note 2 to entry has been replaced.]

3.1.1.7
long-lived climate forcer
LLCF
emission causing a change in *RF* (3.1.1.1), either positive or negative, that has an average atmospheric lifetime of more than twenty-five years

3.1.1.8
mid-lived climate forcer
MLCF
emission causing a change in *RF* (3.1.1.1), either positive or negative, that has an average atmospheric lifetime ranging from one year to twenty-five years

3.1.1.9
short-lived climate forcer
SLCF
emission causing a change in *RF* (3.1.1.1), either positive or negative, that has an average atmospheric lifetime under one year

3.1.1.10
coolant
climate forcer (3.1.1.2) exhibiting negative *RF* (3.1.1.1)

Note 1 to entry: Climate coolants can be further classified into two groups: *Negligible- impact climate coolants*, which have no adverse measurable trade-offs that are observable above established thresholds, and *measurable-impact climate coolants*, which do have measurable, and oftentimes high impact trade-offs that are observable above established thresholds.

3.1.1.11
radiative efficiency
marginal change in *RF* (3.1.1.1) per unit increase in *climate forcer* (3.1.1.2) concentration

Note 1 to entry: Usually expressed as milli-watts per square meter per million tons or Teragrams (i.e., $mW\ m^{-2}\ Tg^{-1}$) or as Watts per square meter per parts-per-billion ($W\ m^{-2}\ ppb^{-1}$).

[SOURCE: Safeguarding the Ozone Layer and the Global Climate System, Glossary (IPCC/TEAP, 2005), modified - "in a gas concentration" changed to "climate forcer concentration"]

3.1.1.12
radiative forcing management
RF management
intentional measurement and control of *climate forcers* (3.1.1.2), including emissions, activities and processes, impacting *RF* (3.1.1.1) aimed at achieving specific RF targets consistent with specified maximum RF and *GMT* (3.1.5.4) goals

3.1.1.13
radiative forcing management roadmap
RF management roadmap
RF management (3.1.1.12) plan for implementing one or a combination of *RF projects* (3.1.2.2) that together can achieve a specific *RF reduction* (3.1.2.4) goal over a specified period of time

Note 1 to entry: The plan to achieve RF reduction sufficient to stabilize *GMT* (3.1.5.4) significantly below +1.5°C is the "2030 Global RF Management Roadmap."

3.1.1.14
PM 2.5
dust fraction containing 50% of the particles with a diameter of 2.5 µm, a higher proportion of smaller particles and a lower proportion of larger particles

3.1.2 Terms relating to the radiative forcing quantification process

3.1.2.1
carbon dioxide force equivalent
CO_2fe
unit for comparing the *RF* (3.1.1.1) caused by one kilogram of a *climate forcer* (3.1.1.2) to the RF caused by one kilogram of carbon dioxide in the atmosphere at a single point in time

[SOURCE: ISO14064-1:2018, 3.1.13, modified—preferred term has been changed, reference to GHG has been replaced/contextualized with climate forcer and Note 1 to entry has been removed.]

3.1.2.2
radiative forcing project
RF project
activity or activities that cause a *RF reduction* (3.1.2.4), *climate pollutant removal* (3.1.2.7) or *climate pollutant destruction* (3.1.2.8)

Note 1 to entry: Activity can include technologies used to alter the conditions of the RF baseline.

[SOURCE: ISO14064-2:2019, 3.2.3, modified—preferred term has been changed and references have been contextualized with radiative forcers and climate pollutants.]

3.1.2.3

radiative forcing project category

RF project category

class of *RF projects* (3.1.2.2) having particular shared characteristics that have the ability to lead to *RF reduction* (3.1.2.4) or result in *climate pollutant removal* (3.1.2.7) or *climate pollutant destruction* (3.2.1.9)

3.1.2.4

radiative forcing reduction

RF reduction

quantified decrease in *RF* (3.1.1.1) between a *baseline scenario* (3.1.2.15) and an *RF project* (3.1.2.2)

[SOURCE: ISO14064-2:2019, 3.1.7, modified—preferred term has been changed and references have been contextualized with radiative forcers.]

3.1.2.5

Radiative forcing reduction potential

RF reduction potential

RFRP

amount of *RF reduction* (3.1.2.4) that could be achieved by an *RF project* (3.1.2.2) or *RF project category* (3.1.2.3) under the *full implementation scenario* (3.1.2.16)

3.1.2.6

radiative forcing climate footprint

RF climate footprint

summation of the *RF* (3.1.1.1) associated with an organization's *climate pollutant* (3.1.1.4) emissions, *accumulated climate pollutant emissions* (3.1.1.5), other *climate forcers* (3.1.1.2), and *climate pollutant removals* (3.1.2.7), both direct and indirect, expressed as CO_2fe (3.1.2.1)

Note 1 to entry: An RF climate footprint can be disaggregated to provide transparency about the specific climate forcers contributing to the total.

Note 2 to entry: Derived from the definition of 'carbon footprint of a product' from ISO 14067:2018.

3.1.2.7

climate pollutant removal

extraction (direct air capture), sequestration, destruction (oxidation) or conversion to lower potency of a *climate pollutant* (3.1.1.4) in the atmosphere

Note 1 to entry: The only known way to eliminate tropospheric ozone is through oxidation. In the tropics, this process occurs naturally through hydroxyl radicals. This phenomenon is well established. In northern latitudes, naturally occurring bromine oxide likewise oxidizes and eliminates tropospheric ozone."

3.1.2.8

climate pollutant destruction

elimination of a climate forcer by destructive oxidation

Note to entry 1: This is perhaps the only known way to eliminate through tropospheric ozone is to oxidize it. In the tropics, it's done naturally through hydroxyl radicals. This phenomenon is well established. In the northern latitudes, naturally occurring bromine oxide likewise oxidizes and eliminates tropospheric ozone.

3.1.2.9
carbon dioxide removal
CDR
set of techniques that aim to remove CO_2 directly from the atmosphere by either (1) increasing natural sinks for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration

[IPCC Fifth Assessment Report Glossary]

3.1.2.10
radiative forcing mitigation
RF mitigation
human intervention to reduce the *RF* (3.1.1.1)

Note 1 to entry: Derived from the definition of 'climate change mitigation' in ISO 14080:2018.

3.1.2.11
radiative forcing assertion
RF assertion
factual and objective declaration that provides the subject matter for the *verification* (3.1.4.2) or *validation* (3.1.4.3)

Note 1 to entry: The RF assertion could represent a point in time or could cover a specified period of time.

Note 2 to entry: The RF assertion provided by the responsible party should be clearly identifiable, capable of consistent evaluation or measurement against suitable criteria by a *verifier* (3.1.4.4) or *validator* (3.1.4.5).

Note 3 to entry: The RF assertion could be provided in an *RF report* (3.1.2.13) or *RF project* (3.1.2.2) plan.

[SOURCE: ISO14064-2:2019, 3.2.1, modified—preferred term has been changed and references have been contextualized with radiative forcers.]

3.1.2.12
radiative forcing information system
RF information system
policies, processes and procedures to establish, manage, maintain and record information on *RF* (3.1.1.1) related to a specific *RF project* (3.1.2.2)

Note 1 to entry: Maintain includes the amendment, removal and addition of information on *climate forcers* (3.1.1.2).

[SOURCE: ISO14064-2:2019, 3.2.2, modified—preferred term has been changed and references have been contextualized with radiative forcers.]

3.1.2.13
radiative forcing report
RF report

stand-alone document intended to communicate to its *intended users* (3.1.3.1) information on *RF* (3.1.1.1) related to an *RF project* (3.1.2.2) or *RF project category* (3.1.2.3)

Note 1 to entry: A RF report can include an *RF assertion* (3.1.2.11).

[SOURCE: ISO14064-1:2018, 3.2.9, modified—preferred term has been changed and references have been contextualized with radiative forcers.]

3.1.2.14
radiative forcing baseline
RF baseline
quantitative level of *RF* (3.1.1.1) that would have occurred in the absence of an *RF project* (3.1.2.2) or *RF project category* (3.1.2.3) for comparison with the project's *RF reduction* (3.1.2.4) and *climate pollutant removals* (3.1.2.7)

[SOURCE: ISO14064-3:2019, 3.4.6, modified—preferred term has been changed and references have contextualized with radiative forcers.]

3.1.2.15
baseline scenario
hypothetical reference case that best represents the conditions most likely to occur in the absence of a proposed *RF project* (3.1.2.2) or *RF project category* (3.1.2.3)

Note 1 to entry: The baseline scenario aligns with the *RF Project* (3.1.2.2) timeline.

[SOURCE: ISO 14064-2:2019, 3.2.6, modified—reference to GHG project has been replaced and reference to RF project category has been added.]

3.1.2.16
full implementation scenario
hypothetical case that best represents the conditions most likely to occur when a proposed *RF project category* (3.1.2.3) is undertaken at full scale

3.1.2.17
project scenario
hypothetical case that best represents the conditions most likely to occur when a proposed *RF project* (3.1.2.2) is fully undertaken

3.1.2.18
monitoring
continuous or periodic assessment of *climate forcers* (3.1.1.2), *RF reduction* (3.1.2.4), and other data related to *RF* (3.1.1.1)

[SOURCE: ISO14064-1:2018, 3.2.2, modified—references have been contextualized with radiative forcers.]

3.1.2.19
uncertainty

parameter associated with the result of quantification that characterizes the dispersion of the values that could be reasonably attributed to the quantified amount

Note 1 to entry: Uncertainty information typically specifies quantitative estimates of the likely dispersion of values and a qualitative description of the likely causes of the dispersion, and should be included in an *RF report* (3.1.2.13).

[SOURCE: ISO14064-1:2018, 3.2.13, modified—Note 1 to entry has been revised to add a reference to radiative forcing report.]

3.1.2.20

avoided emissions

prevented emissions of *climate pollutants* (3.1.1.4) that occur when a process or activity indirectly results in the reduction of emissions (either anthropogenic or natural) or non-emission sources of positive *RF* (3.1.1.1)

Note 1 to entry: An example is the insertion of a highly efficient power plant into a grid that reduces the need for use of inefficient "peaker" plants to accommodate higher demand, resulting in the overall reduction in net GHG emissions.

3.1.2.21

pre-industrial conditions

multi-century period prior to the onset of large-scale industrial activity around 1750

Note 1 to entry: The reference period 1850–1900 to approximate pre-industrial global mean surface temperature (GMST).

[SOURCE: IPCC SR1.5 (2018), Summary for Policy Makers, Box SPM.1.]

Note 2 to entry: Pre-industrial conditions are a reference for the RF and GMT anomalies, but the term is not included here to serve as a project baseline, nor is it included to suggest that the climate system can be returned to this status.

3.1.2.22

regional high-risk zone

high-risk zone

region that is experiencing a sustained *RF* (3.1.1.1) level higher than the global RF, a sustained regional mean temperature significantly higher than the global mean temperature on a consistent basis (over at least 5 years), or that is at extreme risk from sea level rise, climate-change induced wildfires, or other catastrophic climate change related impact endpoints

3.1.3 Terms relating to organizations and interested parties

3.1.3.1

intended user

individual or organization identified by those reporting information related to *RF* (3.1.1.1) as being the one who relies on or refers to that information to make decisions

Note 1 to entry: The intended user can be the organization, the organization's client, the responsible party, the *RF project proponent* (3.1.3.3), the *RF programme* (3.1.3.4) administrators, regulators, the financial community, or other affected *interested parties* (3.1.3.2), such as local communities, government departments or non-governmental organizations.

[adapted from ISO14064-2]

3.1.3.2
interested party
individual or organization that can affect, be affected by, or perceive itself to be affected by a decision or activity

EXAMPLE Person or organization that is affected by or interested in the development or implementation of an *RF project* (3.1.2.2).

[adapted from ISO14064-2]

3.1.3.3
radiative forcing project proponent
RF project proponent
project proponent
individual or organization that has overall control and responsibility for an *RF project* (3.1.2.2)

[adapted from ISO14064-2]

3.1.3.4
radiative forcing programme
RF programme
voluntary or mandatory international, national or subnational system or scheme that registers, accounts or manages *climate forcers* (3.1.1.2), *climate pollutant removals* (3.1.2.7), or *climate pollutant* (3.1.1.4) emission reductions outside the organization or *RF project* (3.1.2.2)

[adapted from ISO 14064-1]

3.1.4 Terms relating to verification and validation

3.1.4.1
level of assurance
degree of confidence in the *RF assertion* (3.1.2.11)

Note 1 to entry: Assurance is provided on historical information.

[adapted from ISO 14064-2]

3.1.4.2
verification
process for evaluating an *RF assertion* (3.1.2.11) of historical data and information to determine if the RF reductions recorded in the assertion are materially correct and conform to criteria

Note 1 to entry: In some cases, independence can be demonstrated by the freedom from responsibility for the development of *RF* (3.1.1.1) data and information.

[adapted from ISO 14064-1]

3.1.4.3
validation
process for evaluating the reasonableness of the assumptions, limitations and methods that support an *RF assertion* (3.1.2.11) about the outcome of future activities

Note 1 to entry: In some cases, independence can be demonstrated by the freedom from responsibility for the development of data and information on *RF* (3.1.1.1).

[adapted from ISO 14064-1]

3.1.4.4
verifier
competent and impartial person or organization with responsibility for performing and reporting on a *verification* (3.1.4.2)

[adapted from ISO 14064-1]

3.1.4.5
validator
competent and impartial person or organization with responsibility for performing and reporting on a *validation* (3.1.4.3)

[adapted from ISO 14064-1]

3.1.5 General Terms

3.1.5.1
climate
statistical description of weather in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years

[ISO 14050 CD2]

3.1.5.2
climate system
complex system consisting of five major components – the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them – which evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and anthropogenic forcings such as the changing composition of the atmosphere and land use change

[SOURCE: Intergovernmental Panel on Climate Change, IPCC Fifth Assessment Report: Climate Change 2014]

3.1.5.3
albedo
fraction of solar radiation reflected by a surface or object, often expressed as a percentage

Note 1 to entry: Snow-covered surfaces have a high albedo (near 1), the albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo (<0.1).

[SOURCE: Intergovernmental Panel on Climate Change, IPCC Fifth Assessment Report: Climate Change 2014]

3.1.5.4
global mean temperature
GMT
global mean surface temperature
over one year, the area-weighted global average of (i) the sea surface temperature over the oceans (i.e., the sub-surface bulk temperature in the first few meters of the ocean), and (ii) the surface air temperature over land at 1.5 m above the ground

Note 1 to entry: For changes over time, only anomalies, as departures from a climatology, are used, most commonly based on the area-weighted global average of the sea surface temperature and land surface air temperature anomaly.

[adapted from Intergovernmental Panel on Climate Change, Climate Change Synthesis Report, Annex B, 2001]

3.1.5.5
impact
change, adverse or beneficial, caused by the process being assessed

[ISO 13065:2015]

3.1.5.6
impact category
class representing environmental issues of concern to which life cycle inventory analysis results may be assigned

[ISO 14040, 14044]

3.1.5.7
government entity
official executive branch or agency representing a national or sub-national entity, such as a country state, or province

3.1.5.8
organization
person or group of people that has its own functions with responsibilities, authorities, and relationships to achieve its objectives

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, charity or institution, or part or combination thereof, whether incorporated or not, public or private.
[ISO 14001]

3.1.5.9

global mean temperature anomaly
change in the global mean temperature in a given year compared to *pre-industrial conditions* (3.1.2.21)

:

3.1.5.10
regional mean temperature (RMT)
distinct region's average above-ground and sea-surface temperature, derived by averaging over observations at 2 meters above sea level and 1.2-2.0 meters above the land surface

Note 1 to entry: Only RMTs that are officically established with sufficient data points are recognized (e.g., NOAA state-by-state database; European country databases).

3.1.5.11
regional mean temperature anomaly
change in the regional mean temperature in a given year compared to *pre-industrial conditions* (3.1.2.21)

Note 1 to entry: For many regions historic data may be limited to more near term temperatures than 1750 and is allowed to determine such temperature anomalies. However, it should be noted that more recent baselines represent a better case than 1750 and the actual temperature anomaly, therefore, may be worse than reported.

Note 2 to entry: Baseline years may vary based on data limitations, as long as these limitations are clearly stated.

3.2 Abbreviated Terms

CFC	chlorofluorocarbon
CO_2	carbon dioxide
CO_2fe	carbon dioxide forcing equivalents
ERM	earth radiation management
g	grams
GHG	greenhouse gas
GMT	global mean temperature
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
J	joules
kg	kilograms
km	kilometer
m	meter
ppm	parts per million
ppb	parts per billion
RCP	representative concentration pathway
RF	radiative forcing
RFRP	radiative forcing reduction potential
RMT	regional mean temperature
SLCF	short-lived climate forcer
SR1.5	IPCC Special Report: Global Warming of 1.5°C

SRM	solar radiation management
T	metric ton (1,000 kg)
TH	time horizon
TO	tropospheric ozone
VOC	volatile organic compound
W/m^2	watts per meter squared
WMO	World Meteorological Organization
UNEP	United Nations Environment Programme

4 Principles

4.1 General

The application of principles is fundamental to ensure that RF-related information is a true and fair account. The principles are the basis for, and will guide the application of, this guidance document.

4.2 Relevance

Select the RF-related information, data and methodologies appropriate to the needs of the intended user and relevant to the scope of the assessment being conducted.

4.3 Completeness

Include known relevant climate forcers, climate pollutant removals, and additional contributing factors. Include known relevant information to support criteria and procedures.

4.4 Consistency

Enable meaningful comparisons in RF-related information.

4.5 Accuracy

Reduce bias and uncertainties as far as is practical.

4.6 Transparency

Disclose sufficient and appropriate RF-related information to allow intended users to make decisions with reasonable confidence.

4.7 Conservativeness

Use conservative assumptions, values and procedures to ensure that RF reductions are not over-estimated.

4.8 Scale

All RF reductions should be considered in the context of the amount of global RF reduction needed to meet stated RF stabilization targets, globally and regionally.

4.9 Use of Best Science

Ensure that the latest available climate science is used in all quantification.

4.10 Life Cycle Perspective

Ensure that all co-benefits and adverse trade-offs to the climate, environment, and human health, including all related processes involved, are evaluated, monitored and mitigated to the degree possible based on the life cycle perspective.

5 Analysis of RF climate footprints, RF project categories, and RF projects

5.1 Types of analyses

Users of this document may undertake one or more of the following three types of analysis based on the RF protocols in this document, as appropriate for the specific task at hand:

a) Organization or government entity-level RF climate footprint, in which the RF contribution of an organization or government jurisdiction is evaluated (see Clause 5.2).

b) Project category RF analysis, in which the ability of projects within a project category to reduce RF is calculated in a full implementation scenario (see Clause 5.3).

c) Project RF analysis, in which the level of RF reduction achieved by individual projects is analyzed, validated and verified. Project-level RF analysis can serve as the basis of any RF credits or claims made for individual project installations (see Clause 5.4).

5.1.1 Quantification of radiative forcing levels

RF levels associated with an RF climate footprint, RF project category, or specific RF project should be calculated for a given year using Equation 1.

RF results should be reported in mW/m^2, carbon dioxide forcing equivalents, or both. RF results should also be disaggregated by climate forcer for transparency purposes.

Calculations should factor in the radiative efficiency and atmospheric lifetimes of different climate pollutant emissions, as well as RF from other non-emissions processes or activities leading to a change in RF (e.g., the deposition of black carbon on ice and snow). These and other details of the calculation methods are provided in Annex A.

Equation 1. The equation for calculating RF for a given year.

Radiative Forcing in year t = RF(t) = $\sum_i (RF_{emissions}(t) + RF_{other}(t))$

Where:

- j is a summation over all unit processes
- year t is the number of years after the initiation of the analysis timeframe
- $RF_{emissions}(t)$ is the radiative forcing in year t from climate pollutant emissions, calculated according to Equation A.2 in Annex A.
- $RF_{other}(t)$ is the radiative forcing in year t from non-emissions types of climate forcers.

5.1.2 Establishing an RF management plan

An organization or government entity interested in establishing an RF management roadmap should undertake the following procedure. Additional details are provided in Annex B.

— Establish its RF climate footprint

— Evaluate the RF reduction potential of RF projects that have already been implemented, or are already planned to be implemented.

— Assess co-benefits and adverse trade-offs.

— Calculate the costs of implementation of current and planned RF projects.

— Determine RF stabilization targets and RF reduction goals – i.e., the amount of RF reduction needed to achieve global and, if applicable, regional high-risk zone targets

— Identify project categories of interest that could be implemented directly or contributed to indirectly, then assess the co-benefits, adverse trade-offs, and implementation costs.

— Establish an RF Management Roadmap (i.e., plan of action and timeline) to achieve the stated RF reduction goals.

— Create RF information systems and mechanisms for implementing individual projects, including a financial funding mechanism to implement the RF Management Roadmap in the most cost-effective manner possible.

Personnel with adequate expertise in climate science, economic analysis, and project implementation should be in charge of administering the steps above.

5.2 Organization and government entity-level RF climate footprints

5.2.1 Scope of assessment

RF climate footprints should include all climate forcers and their effect on the current RF compared to pre-industrial conditions, including current emissions, accumulated climate pollutant emissions, other processes and activities leading to excess RF when compared to the pre-industrial baseline, and climate pollutant removals.

If data are not available to assess historic climate forcers, reasonable estimates can be made. (EXAMPLE OF A REASONABLE ESTIMATE TO BE INSERTED)

5.2.2 Emissions data collection for RF climate footprints

5.2.2.1 Emissions data collection time period

Emissions data should be collected for the most recent 12-month period for which data are available. Generally, for RF climate footprint analyses, data should also be collected for as long a historic period as is necessary to capture at least 95% of a pollutant's total current forcing levels.

EXAMPLE Only 5% of a given emission of methane remains in the atmosphere after 40 years. For methane, historic data therefore should be tracked to 40 years in the past, or from the date of the organization's origin, whichever is more recent. Conversely, black carbon, which only persists for a few weeks, need only be tracked in the current year.

EXAMPLE Black carbon emissions remain in the atmosphere for only a few weeks. Accordingly, there is no need to collect any historic data for black carbon emissions.

When compiling historic data, multiple sources of data should be identified and compared. For countries, if the historic dataset overlaps in time with nationally published GHG inventory reports, the historic data should be consistent with the nationally reporting GHG inventory for the overlapping time period.

5.2.2.2 Black carbon and other carbonaceous aerosol emissions

For black carbon and other carbonaceous aerosols:

— The approach used to calculate these emissions should be specific to the region and economic sector of the emission.

  NOTE The source types, seasonality, and number of emission sources varies dramatically country-to-country for black carbon emissions. As a result, black carbon emissions reporting for a country such as the US (where black carbon emissions are dominated by diesel fuel combustion) is largely irrelevant for India. India, in turn, has different reporting needs than the US or China (while residential burning of solid fuels is a major source in both China and India, the solid fuels used are different in each case). Sectors within these countries will have different data collection and calculation needs.

5.2.2.3 Nitrogen oxide emissions

Historic emissions of NOx should be tracked for 40 years to account for the effective timeline of NOx's effect on methane lifetime, a key part of NOx's radiative effect.

5.2.2.4 Measurable-impact climate coolants

The RF climate footprint should include accounting for emissions contributing to negative RF (i.e., climate coolants) but which also have measurable, and in some cases, high impacts on the environment or human health. The primary coolant in this category is tropospheric sulfate aerosol formed by emissions of sulfur dioxide. Any reduction of such coolants should be added to the overall RF footprint from the target historic year for RF reduction.

The historic year from which the loss of such coolants should be assessed depends upon the RFM goal established.

EXAMPLE. If the goal of the RF management plan is to reduce global RF levels back to 1.9 W/m², then the loss of such coolants since 2002 (the year that this level of global RF was exceeded) should be added to the RF footprint.

5.2.2.5 *Negligible-impact climate coolants*

The RF climate footprint should include accounting for substances that contribute to negative RF (i.e., climate coolants) that have no observable or negligible adverse impacts. The only substances recognized as negligible-impact climate coolants are sea salt, dimethyl sulfide (DMS) and water. Any reduction of such coolants should be added to the overall RF climate footprint from the target historic year for RF reduction.

Box 2 –
Collecting Emissions Data for Country-level RF Climate Footprints

For country-level RF climate footprints (i.e., national entities), the following guidance applies:

- For CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3, SF_5CF_3, halogenated ethers, and other IPCC-identified halocarbons, the data collection and reporting for national jurisdictions should be consistent with the *2006 IPCC Guidelines for National GHG Inventories*. Data from existing national GHG inventories should be used.

- For government entities, the RF resulting from black carbon should be evaluated first using emissions datasets based on inventory. This should be evaluated, and, if available, adjusted to be consistent with top-down emissions estimates based upon satellite data (based upon method used in Bond *et al* 2013). When they are used, bottom-up inventory emissions estimates should be based upon publicly reported emissions factors based on local conditions for combustion type, seasonality, and other considerations, affecting the amount of black carbon emissions. To the extent possible, black carbon emission estimates should be based upon multiple methods and data sources.

- Emissions for NOx (the tropospheric ozone precursor) should be based on satellite data to the extent possible, considering column concentrations of NO_2, O_3, HNO_3, and CO (will attempt to add links for such data in the future). Gaps in satellite data should be filled using emissions estimates based on emissions factors. Historic emissions of NOx should be based upon top-down satellite data to the extent possible, with gaps filled using bottom-up inventory estimates. The approach for calculating the top-down emissions estimate should be described. All satellite-based emissions estimates should be compared with existing bottom-up emissions inventories for NOx, calculated as part of existing country criteria air pollutant programs (e.g., in the U.S., the Environmental Protection Agency tracks NOx emissions in the National Emissions Inventory).

- SO_2 emissions should be tracked in the key sectors of coal-fired power generation, fuel combustion used to operate vehicles and equipment (especially diesel vehicles), refineries, and metallurgical facilities using coking coal. SO_2 emissions in these sectors should be calculated based on emissions inventories. The total national emissions should be compared to satellite data regarding SO_2 concentrations over the country. Adjustments to the emission inventory for SO_2 should be made if a major discrepancy between the satellite data and emissions inventory exists. (links to data will be added in the future, if feasible)

— For carbon monoxide and VOCs, emissions should be based upon existing government entity-level inventories. Historic emissions should be tracked to the extent that the radiative influence has a measurable effect on the RF climate footprint.

5.2.3 Calculating RF climate footprints

RF climate footprints should be measured in milli-Watts per square meter (mW/m^2), then normalized to carbon dioxide force equivalents (CO_2fe) using the inherent radiative efficiency of CO_2 from the latest published IPCC report –i.e., mW/m^2 per million tons present in the atmosphere. The RF climate footprint calculation should include the impact from all climate forcers that contribute to positive RF, as well as those that contribute to negative RF (i.e., climate coolants) as follows:

— Negligible impact coolants (e.g., sea salt, water) should be subtracted from the net overall footprint.

— Measurable impact coolants should not be subtracted from the net overall footprint.

— Any reduction in measurable coolants should be added to the overall RF climate footprint from the year that RF first exceeded the target RF stabilization level (for 2030, that would be the year 2002, when RF reached 1.9 W/m^2).

5.2.4 Reporting

The RF climate footprint should be published, together with a transparent statement of assumptions, boundary conditions, uncertainties, and statement of limitations, consistent with principles in this part of the guidance standard.

5.3 RF Project category analysis

5.3.1 Calculating the RF reduction potential of a project category

The RF reduction potential (RFRP) of a project – the difference between the projected level of mean RF of a full implementation scenario compared to the baseline scenario over a specified period of time – should be determined.

— The baseline scenario should be structured in such a way that the calculated RFRP of the full implementation scenario is conservatively low.

— RFRP baseline calculations should factor in the variability of RF in the baseline scenario, which may require multi-year estimates.

— RFRP calculations can be based on: 1) the inherent RF reduction associated with reduction in specific emission rates of various climate pollutants; 2) direct RF measurements based on satellite observations; 3) direct measurements of increased solar reflectivity (e.g., "cool" roofs); or 4) direct measurement of the reduction in trapped energy (e.g., in cirrus clouds).

The RFRP for a project category should be calculated using Equation 2.

Equation 2. Approach for calculating the Radiative Forcing Reduction Potential of a given project category.

$$\Delta RFRP(t) = RF_{Imp}(t) - RF_{Baseline}(t)$$

Where:

- t is the year.
- $\Delta RFRP(t)$ is the potential reduction in global mean RF in year t.
- $RF_{Imp}(t)$ is the global RF in the full implementation scenario in year t.
- $RF_{Baseline}(t)$ is the global RF in the baseline scenario in year t.

— The time horizon for RFRP evaluation should be defined based on a reasonable planning time horizon for the full implementation and baseline scenarios, taking into consideration the time required to reach full implementation of the RF reduction project category in the full implementation scenario.

— All relevant climate forcers should be included. This includes climate pollutant emissions as well as other processes or activities affecting RF that could be increased or decreased with respect to the baseline scenario by full implementation of the project category. At a minimum, all climate forcers listed in Table 1 should be included.

Table 1. Examples of Key Climate Forcers

Climate Forcers Contributing to Net Positive Forcing	***Climate Forcers Contributing to Net Negative Forcing***
Long-lived climate forcers	**Long-lived climate forcers**
Carbon dioxide (CO_2)	None
Nitrous oxide (N_2O)	
Chlorofluorocarbons (CFCs)	
Some Hydrofluorocarbons (HFCs)	
Mid-lived climate forcers	**Mid-lived climate forcers**
Methane	None
Some Hydrofluorocarbons (HFCs)	
Hydrochlorofluorocarbons (HCFCs)	
Short-lived climate forcers	**Short-lived climate forcers**
Tropospheric ozone (non-methane precursors inclu Nitrogen oxides, Carbon Monoxide, and Volatile Orga Compounds)	Mineral dust aerosol **
Black carbon	Nitrate aerosols
Brown carbon	Organic carbon aerosols

Mineral dust aerosol **	Sulfate aerosols
	Sea salt aerosols
	Volcanic aerosols
	DMS (phytoplankton)

** For comprehensive list of climate forcers, see IPCC Fifth Assessment Report, Table 8.A.1.*
*** While for the most part, mineral dust is a coolant, it can also cause warming, depending on the iron and aluminum content and the particle size. See Jacobson, M.Z., Global direct radiative forcing due to multicomponent anthropogenic and natural aerosols, J. Geophys. Res., 106, 1551-1568, 2001.*

5.3.2 Accounting for avoided emissions

Active RF management can indirectly prevent climate pollutant emissions that would have otherwise occurred.

EXAMPLE An RF project that reduces RF could indirectly result in reduced air conditioning usage in an urban area, thus avoiding the associated CO_2 and other power grid related emissions.

— In the baseline scenario, the RF from all climate forcers should be calculated in all systems that may be affected by baseline temperature increase

— In the full implementation scenario, the RF from climate forcers should be calculated for the same systems.

5.3.3 Assessing climate, environmental and human health co-benefits and trade-offs

The project category should be screened to determine if there are any potential adverse impacts or positive co-benefits associated with the full implementation scenario.

5.3.3.1. Identifying relevant impacts

To identify relevant impacts, the following should be considered (see ISO 14090 for additional guidance on impact identification):

— *Impacts relevant to anthropogenic systems* – for example, those related to energy resource depletion, ocean acidification, regional acidification, ground level ozone, and PM 2.5.

— *Impacts found in a literature survey should be included as relevant, unless otherwise justified.* A literature survey should be conducted to determine if project activities or processes have been associated with specific impacts in the past.

— *Observed impacts in similar conditions should be included if relevant.* Determine if project activities or processes similar to those considered for implementation have been associated with specific impacts.

— *Location of project activities or processes should be a factor in determining if an impact is relevant.* Activities or processes in highly polluted regions or regions not subject to environmental regulation may be linked to multiple regional impacts, which could be positive or negative.

— *The fate and transport of climate forcers should be included.* Upon release into the atmosphere, the dispersion, mixing, and ultimate deposition or chemical transformation of each climate forcer should be considered.

— Additional data sources and approaches can also be used to identify other relevant impacts.

5.3.3.2. Determining whether impacts are beneficial or adverse

Once the impacts relevant to a project are identified, their nature as beneficial (i.e., positive co-benefit) or adverse (i.e., negative trade-offs or externalities) should be determined.

Adverse impacts alter conditions away from natural conditions, in the full implementation scenario when compared to the baseline scenario, while beneficial impacts restore conditions more closely to natural conditions. Any alterations must be measured or projected in terms of at least one or more of the following: severity of conditions; spatial extent of alteration; temporal duration of alteration; or effects on exceedance of relevant thresholds.

5.3.4 Stating the RF reduction potential of a RF project category

For each RF project category evaluated, an RFRP statement should be prepared that includes:

— A technical description and technical justification of the full implementation scenario conditions and baseline scenario conditions;

— The main climate forcers directly and indirectly altered under full implementation conditions, and the associated reduction in RF;

— The level of RF reduction that would be achieved between the year of initiation of the project and by 2030, noting when RF reduction begins and the time horizon over which the full potential reduction would be realized; and

— A description of any co-benefits or adverse trade-offs to the climate, environment or human health associated with the implementation of the project category. This description addresses a complete set of relevant impacts.

5.3.5 Reporting of projected threshold exceedances

Thresholds may be crossed in the past, present or future. The types of thresholds may include government legal limits, international consensus thresholds, and biophysical thresholds. Projections of future threshold exceedance should be accompanied by probabilistic uncertainty analysis and reporting of confidence intervals. The assumptions and uncertainty should be disclosed.

5.4 Project RF analysis

RF projects involve actual validation, implementation, verification and ongoing monitoring. Credits for RF reduction are awarded to RF project proponents, based upon the demonstrated ability to reduce RF each year over the RF project's operating timeframe. In this way, project-level accounting and crediting follows the conceptual structure of other carbon markets.

5.4.1 Parties involved

Multiple parties should be involved in the implementation of an RF reduction project, including at least:

— The project proponent, who is responsible for implementation;

— The project funder, who provides the funding;

— The verifier, who validates the project plan, and then verifies the level of forcing reduction achieved and any unintended consequences associated with the project.

NOTE: The validator may be different from the verifier.

Additional stakeholders might include regulators, suppliers, communities, NGOs, technology providers, clients, and those impacted by RF activities.

5.4.2 Assessment and reporting of RF reduction projects

In order to ensure relevance, completeness, consistency, accuracy, and full transparency:

— The climate forcers, data, and methodologies used to calculate and report RF reduction and other aspects should be relevant and appropriate to the needs of the intended user.

— Relevant climate forcers should be included, with resulting RF changes calculated according to the guidance provided in this document.

— Data sources and methodologies used should be consistent, allowing for meaningful comparisons in climate forcer-related information.

— The RF reductions calculated should be as accurate and precise as possible to reduce bias and uncertainties.

— The RF report should include a sufficient amount of appropriate RF driver-related information for intended users to make decisions with confidence (e.g., data on monitoring methane concentrations over a natural gas production site).

— In estimating the RF reduction of a project, assumptions, values, and procedures should be used to ensure that RF reduction calculations are accurate and verifiable.

5.4.3 Developing an RF project plan

The project proponent should develop a written RF project plan, including:

— Project title, purpose(s) and objective(s);

- RF project category, if applicable;

- Project location, including geographic and physical information allowing the unique identification and delineation of the specific extent of the project;

- Conditions prior to project initiation;

- A description of how the project will achieve RF reductions;

- Chronological plan for the date of initiating RF project activities, intended date of RF project termination, frequency of monitoring and reporting, and the RF project period, including relevant activities in each step of the RF project cycle;

- A description of the time-varying effect on RF reduction that will occur as a result of implementation, considering not only the time required to scale up the RF project, but also the RF reduction response from associated climate forcers (e.g., considering factors such as the atmospheric lifetime of affected climate forcers);

- RF project technologies, products, services, and the expected level of activity;

- Aggregate RF reductions, reported in mW/m^2, in each year, anticipated to occur as a result of the RF project over its operating timeframe, and how this relates to the maximum force reduction achievement level possible in the RF project category;

- Identification of risks that may substantially affect the RF reductions achieved;

- Roles and responsibilities, including contact information of the RF project proponent, other participants, relevant regulator(s) and/or other interested stakeholders as relevant;

- A description of the other consequences on the environment and human health, the approach used to estimate these consequences, and how this relates to consequences associated with other projects in the RF reduction project category;

- Relevant outcomes from stakeholder consultations and mechanisms for on-going communication.

5.4.4 Determining the RF project and baseline scenarios

Project-level RF climate accounting should include development of "Project" and "Baseline" scenarios, each of which should include projections of RF changes. Changes in RF should be assessed comprehensively.

The RF project proponent should select or establish criteria and procedures for identifying and assessing potential baseline scenarios, considering the following:

- The RF project description, including identified climate forcers;

- Data availability, reliability, and limitations; and

- Other relevant information concerning present or future conditions, such as legislative, technical, economic, sociocultural, environmental, geographic, site-specific, and temporal assumptions or projections.

The project proponent should demonstrate equivalence in the type and level of activity of products or services provided between the project and baseline scenarios, and should explain, as appropriate, any significant differences between the project and baseline scenarios.

The project proponent should select or establish, explain and apply criteria and procedures for identifying and justifying the baseline scenario. In developing the baseline scenario, the RF project proponent should select the assumptions, values, and procedures that help ensure that RF reductions are not over-estimated.

The project proponent should select or establish, justify, and apply criteria and procedures for demonstrating that the RF project results in RF reductions that are additional to what would occur in the baseline scenario.

5.4.5 Identifying and monitoring climate forcers

5.4.5.1 Determining climate forcers relevant to the project

The project proponent should identify climate forcers relevant to the RF project, and that present potential opportunities for reducing RF within the RF project. Climate forcers should be identified as being:

- Controlled by the project proponent –i.e., the operation is under the direction and influence of the project proponent through financial, policy, management or other instruments;

- Related to the RF project – i.e., the climate forcer source has material or energy flows into, out of, or within the project; or

- Affected by the RF project – i.e., the climate forcer source is influenced by a project activity, through changes in market demand or supply for associated products or services, or through physical displacement.

Related climate forcers are physically linked to a RF project. They are generally both upstream or downstream from the project, and can be either on or off the project site. Related climate forcers also may include activities related to design, construction and decommissioning of a project. Affected climate forcers are only linked to a RF project by changes due to market demand and supply, and are generally off the project site.

This could include relevant climate forcers that could lead to reduced RF, as well as increased RF that could negate the RF reductions.

5.4.5.2 Determining climate forcers relevant to the baseline scenario

In identifying climate forcers relevant to the baseline scenario, the project proponent should:

— Consider criteria and procedures used for identifying climate forcers relevant to the RF project;

— If necessary, explain and apply additional criteria for identifying the climate forcers;

— Compare the RF project's identified climate forcers with those identified in the baseline scenario; and

— Consider the climate forcers relevant to the RF project that are affected by the project implementation.

5.4.5.3 Monitoring or estimating relevant climate forcers

The project proponent should select or establish criteria and procedures for regular monitoring or estimation of relevant climate forcers.

NOTE: The approach used in monitoring or estimation will vary by climate forcer.

If the project proponent does not select a relevant climate forcer for regular monitoring, a justification should be provided.

5.4.6 Quantifying the RF reduction of an RF project

The project proponent should select or establish criteria, procedures, or methodologies used for quantifying the projected changes in RF levels over time for selected climate forcers. These criteria, procedures, and/or methodologies should follow the provisions of this guidance standard.

Based on selected or established criteria and procedures, the project proponent should quantify RF reductions achieved separately for each relevant climate forcer for the project and baseline scenario, projected each year in the RF project category-defined time horizon.

When relying upon highly uncertain data and information, the project proponent should select assumptions and values that ensure that the quantification does not lead to over-estimation of achieved RF reductions, provided the estimate is still reasonable.

EXAMPLE For a project reducing black carbon and organic carbon, the project proponent could estimate RF reduction using the lowest positive RF estimate for black carbon and the most negative RF for organic carbon, such that the net benefits of reductions are at the lowest possible value (in order to avoid an overestimate). This can have very large impacts on the valuation in cases where both positive and negative climate forcers affect an RF project implementation, and should be carefully considered.

The project proponent should establish and apply criteria, procedures and methodologies to assess the risk of reversal of an RF reduction, and the effect on the RF reduction achieved.

5.4.7 Managing data quality

While well-mixed GHG emissions have well-characterized RF levels, the RF levels of SLCFs can be highly variable on a regional and global level, as well as in time. For each SLCF, spatial and temporal characterizations, which may include dispersion and atmospheric lifetime data, should be factored into the data quality analyses that are used.

5.4.8 Monitoring the RF reduction project

The project proponent should establish and maintain criteria and procedures for obtaining, recording, compiling, and analyzing data and information important for quantifying and reporting RF reductions relevant for the project and baseline scenario.

Monitoring procedures should include the following:

- Purpose of monitoring;
- Types of data and information to be reported, including units of measurement;
- Origin of the data
- Monitoring methodologies, including estimation, modeling, measurement or calculation approaches;
- Monitoring roles and responsibilities; and
- RF information system, including the location and retention of stored data.

Where measurement and monitoring equipment is used, the project proponent should ensure that the equipment is calibrated according to good practice.

The project proponent should apply monitoring criteria and procedures on a regular basis during the project implementation.

5.4.9 Documenting the RF project

The project proponent should have documentation that demonstrates conformance of the project with this guidance standard. Documentation should be consistent with validation and verification needs.

5.4.10 Validation and verification of the RF project

The project proponent should have the RF project plan validated, and the RF reduction achievements from implementation should be verified. The project proponent should present an RF reduction assertion for the project to the validator or verifier.

5.4.11 Basis of awarding RF reduction credits

Projects that reduce RF should be eligible for RF reduction credits. RF reduction credits should be awarded only over the duration of the operating timeframe.

Only RF reductions that have been independently validated should be eligible for public RF reduction credits. Ongoing verification is required to determine that the projected RF reductions are actually realized.

Irrespective of RF reductions achieved, no RF project that increases the level of measurable-impact climate cooling above a recognized threshold should be eligible for RF reduction credit.

RF reduction credits should be awarded on an annual basis and assigned a "vintage" tying them to RF in a specific year.

EXAMPLE A company wants to use funding derived from RF reduction credits to construct a new 300-MW thorium power plant instead of a coal plant. It could not do so otherwise, as the thorium power plant costs more, both upfront, and in ongoing fuel costs. The "Project" scenario is the thorium plant construction, while the "Baseline" scenario is the coal plant construction. The RF of Project vs. Baseline is estimated over the power plant's lifetime (30 years). The RF reduction of the Project (i.e., thorium plant) is calculated prior to the plant construction; this RF reduction is then compared to the RF of the baseline scenario (Figure 2). (Measurable-impact climate coolants, since they would be increased, are excluded from the scope of the credit). Subsequently, assuming that the projected RF reduction is actually achieved and verified, the company becomes eligible for more RF reduction credits in each year, reflecting the accumulating benefit of the CO_2 reduction over time compared to the baseline scenario. The company can use the ever-increasing projected funding stream from RF reduction credits to help secure the extra loan amounts needed to fund capital expenditures in advance, and also offset the increased fuel costs associated with this project's installation.

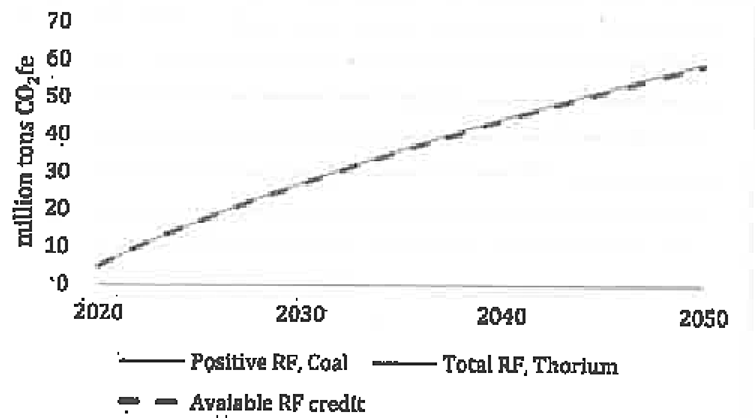

Figure 2. RF reduction project example, for a project installing a thorium power plant versus a coal power plant. Estimates of the emission factors for coal are from *Hu, et al., 2015* (link). For thorium, the emission factors consider the full life cycle, using uranium power as representative (see link).

5.4.12 Assessing climate and other co-benefits and trade-offs

RF projects should be screened to determine if there are any co-benefits or adverse tradeoffs associated with the project scenario based upon a full evaluation using environmentally relevant LCA metrics and methods (see Annex C).

5.4.13 Preparing the RF reduction project report

The project proponent should prepare and make available to intended users an RF report. This report should:

— Identify the intended use and intended user of the RF reduction report.

— Use a format and include content consistent with the needs of the intended user.

If the project proponent makes a public RF reduction assertion claiming conformance with this guidance standard, the project proponent should make the following available to the public:

— An independent third-party validation or verification statement; or

— An RF report that includes at least:
  - The name of the project proponent;
  - The RF assertion, including a statement of RF reductions achieved to date, and projected future reductions relative to a specific time horizon, e.g., 2030;
  - The RF assertion validation or verification, including type of validation or verification and level of assurance achieved;
  - A brief description of the RF reduction project, including size, location, duration, and types of activities;
  - A break-down of the RF reduction achieved by climate forcer for all climate forcers controlled by the project proponent;
  - A description of the baseline scenario and demonstration that the RF reductions are additional to what would have happened in the absence of the project;
  - A description of any co-benefits documented for the project;
  - A description of any adverse impacts identified for the RF project;
  - A general description of the criteria, procedures, or good practice guidance used as a basis for the calculation of the RF reduction achieved conforming to this guidance standard; and
  - The date of the report and time period covered.

Annex A
(informative)

Quantification of Global Radiative Forcing

ISO 14082 provides a summary of the procedure for calculating RF climate footprints, quantifying the RF reduction associated with RF project categories and specific RF projects (Clauses 5.2 – 5.4). This Annex further expands on the concepts referenced in that text. Specifically, it *describes the rationale for using radiative forcing as the basis for calculations, and the methods and equations used to calculate global RF attributable to project categories, projects, and organizations and government entities.*

Throughout this Annex, default factors are presented for use in equations. These default factors are based on conservative assumptions that will result in upper-bound estimates in calculated results, which will be improved by performing site-specific modelling with higher temporal and geographical representativeness. Specific data should be used to assess results, rather than default data, for better temporal and geographical representativeness.

0. Glossary of Terms

In addition to terms defined in the guidance standard document, these additional terms and definitions are relevant to the contents of Annex A.

0.1
absolute global warming potential
absolute GWP
time-integrated RF up to a given time horizon due to a pulse emission of 1 kg of the gas under present-day background conditions; it has units of W m−2 kg−1 year

0.2
albedo restoration
returning albedo (surface, cloud, or clear sky) to its preindustrial baseline conditions

0.3
climate restoration
returning the global or regional climate system to its preindustrial baseline conditions

0.4
category endpoint
attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern

[ISO 14040 and 14044]

Note 1 to entry: In this guidance standard, refers to observable alterations in conditions of a component of an Earth system that can be measured or modeled.

0.5
Earth radiation management (ERM)
The intentional reduction of the trapped Earth's longwave radiation with the aim to reduce net global radiative forcing by enhancing the outgoing earth radiative energy fluxes back into outer space (typically 4-100 μm).

0.6
environmental mechanism
System of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis results to category indicators and to category endpoints
[ISO 14040, 44, 46 and 50]

0.7
global warming potential
GWP
time-integrated RF due to a pulse emission of a given component, relative to a pulse emission of an equal mass of CO_2

0.8
impact category indicator
Quantifiable representation of an impact category

Note 1 to entry: The shorter expression "category indicator" is used in this International Standard for improved readability.
[ISO 14040 and 14044]

0.9
impact group
impact categories (3.5.11) with similar types of endpoints and environmental mechanisms
[ISO 14040, 14044]

0.10
midpoint
node in a cause-effect chain representing an observed chemical, physical, radiological or biological impact that is linked to the final category endpoint(s)

Note 1 to entry: In this guidance standard, midpoint refers to observable alterations in conditions of a component of an Earth system that can be measured or modeled.
[ISO 14040, 14044]

0.11
projected residual RF
The continued, measurable warming influence of the retained atmospheric fraction of current or historic accumulated long-lived greenhouse gas emissions over specified future time horizons

0.12
solar radiation management (SRM)
The intentional reduction of incoming solar shortwave infrared energy with the aim to reduce net regional or global RF levels

0.13
threshold
recognized environmental condition that, when exceeded, is linked to measurable or observed impact levels to climate, environment or human health

0.14
unit process
smallest element considered in the life cycle inventory analysis for which input and output data are quantified

[ISO 14040 and 14044]

0.15
vertical energy budget
(placeholder for definition)

A.1 Analyzing the cause-effect chain of global and regional climate change

The well-established method for analyzing any environmental mechanism and its impacts is to establish the biophysical pathway from its origin to its final endpoint(s), modeled as a cause-effect chain. The cause-effect chain for global climate change is modeled in Table A.1. Accounting for climate change impacts requires choosing a category indicator from among all possible options in the cause-effect chain, considering which choice will best reflect the scale, duration, severity and potential reversibility of climate change endpoints. This process ensures that the accounting metric selected is at the "critical control point" that will provide information to enable prioritization of RF reduction actions with the best chance of mitigating, or even reversing, endpoints.

Table A.1. Cause-effect chain for global climate change

Node	Nodal Description Characterization	Pros or Cons of Category Indicator Selected at this Node
1. Initial Releases (Stressors)	• Current emissions of long-lived climate forcers, mid-lived climate forcers, short-lived climate forcers (particulates, aerosols), and climate coolants (e.g. sulfate aerosols). • Conversion of climate precursor emissions into climate pollutants (e.g., NOx into Tropospheric Ozone).	• No reflection of the scale of emission reductions required to mitigate climate change endpoints • Cannot be used to analyze when climate change benefits may arise from an emission reduction • Does not include accumulated emissions and the climate impacts they continue to cause • Leads to confusion in prioritizing the hundreds of radiatively active pollutants • Leaves out 60% of RF influence of climate forcers • No ability to track which activities lead to relevant radiative effects • Cannot account for sequestration of carbon with partial release (e.g., soil carbon stocks) • No link to adverse changes in climate change endpoints
2. Increasing Concentrations	• Increase in atmospheric concentration of long-lived and mid-lived climate forcers	• No option available.

(Midpoint)	from current and past emissions • Steady-state concentrations of short-lived climate forcers from continuous and episodic emissions (e.g., from wildfires and from daily cooking and heating fires using wood and dung by hundreds of millions of people) • Increase in indirect non-emissions related sources, such as albedo changes from land use alterations, increased exposure of dark land and sea surfaces as snow/ice cover retreat, reduced albedo of snow/ice from black carbon deposition, re-releases of stored heat from oceanic oscillations (e.g., El Niño, Pacific Decadal Oscillation)	
3. Changes in Radiative Forcing (Midpoint)	• Increase in net global RF from the combination of various climate forcers • Global RF levels are on a trajectory to reach +3 W/m² by 2030, +5 W/m² by 2055 and +8.5 W/m² by 2100.	• As a direct measure of the increase since pre-industrial times of the excess RF in the Earth climate system, RF is a leading indicator of climate change endpoints • Current RF data identifies the four climate pollutants responsible for over 90% of adverse climate change impacts: CO_2, methane, black carbon, and tropospheric ozone • Relatively high accuracy and precision in linking emissions to RF is possible (SOURCES WILL BE ADDED) • Necessary for understanding the climate impacts from non-emissions related activities that lead to climate changes (e.g., albedo changes from land use alterations; reduced snow cover from black carbon deposition; enhanced sunlight absorption in seawater from ship icebreakers in the springtime Arctic) • RF increases can be projected with high confidence
4. Changes in climate and circulation patterns (Midpoint)	• Intensification of Pacific Ocean heat oscillations (e.g., El Niño, PDO) and Siberian methane hydrate pulse (5,000 billion tons CO_2fe) (SOURCES WILL BE ADDED) • Conversion of the Arctic Oscillation permanently into the negative phase • Closing of Antarctic Ozone Hole (reduced intensification of Antarctic vortex) • Local temperature changes, rainfall pattern changes, extreme heat instances, increased ocean temperatures, ocean deoxygenation	No option available.
5. Impacts (Endpoints)	• Exponential increases in ecosystem and human health impacts (e.g., coral bleaching, super typhoons and hurricanes, wildfires, droughts, sea level rises, climate refugees, diseases, species extinctions, ocean acidification) (SOURCES WILL BE ADDED)	No option available.
6. Changes in GMT and RMT Equilibrium (Endpoint)	• After decades of increased and excessive levels of RF, GMT gradually equilibrates to higher levels. • Changes in regional mean temperatures (RMT) and regional amplification effects	• GMT is a lagging indicator of adverse climate change. By the time certain temperature levels are reached, significant endpoints will already have occurred and may be "locked in", while further alterations will be unavoidable.

		• Linking of any one emission source or activity to GMT or RMT changes has a higher level of uncertainty than earlier nodes. • Projections of GMT and RMT increases (averaged over decades) and temperature spikes (e.g., from El Niño and Pacific Decadal Oscillation changes) are highly uncertain due to natural variability, ocean and atmosphere circulation patterns, and other considerations

As Table A.1 makes clear, the critical control point for climate stabilization is Node 3 – i.e., Changes in RF. This node has the right elements to support climate stabilization decision-making, and was the basis of the IPCC Representative Concentration Pathway (RCP) scenario modeling in AR5 and SR 1.5. It is therefore the basis of the RF climate accounting protocols in this guidance standard.

A.2 Calculating global radiative forcing levels

A.2.1 General parameters

RF calculations encompass the contributions of all climate forcers, including emissions and other activities that affect RF. RF calculations should:

— Be based upon the global-mean annual average RF measurement;

— Be reported on yearly basis, or alternatively as an average across multiple years;

— Consider all emissions and radiative effects that are increased or decreased as a result of the project, organization or government entity; and

— Be calculated following clearly documented procedures and a transparent approach.

A.2.2 Climate system impact group

Global RF calculations should be reported using the following indicators:

— Long-lived climate forcers– Annual

— Long-lived climate forcers – Accumulated

— Long-lived climate forcers – Projected Residual

— Mid-lived climate forcers (e.g., Methane) - Annual and Accumulated

— Mid-lived climate forcers (e.g., Methane) - Projected Residual

— Short-lived climate forcers - particulates (e.g., Black Carbon)

— Short-lived climate forcers - gases (e.g., Tropospheric Ozone, CO, Organic Carbon)

— Measurable-impact climate coolants

— Negligible-impact climate coolants

All RF analysis should report a total Net RF result, as well as results for each of the above categories of climate forcer (see also Table 1).

(Additional guidance on the kind of data that is relevant will be added.)

A.2.3 Defining the RF analysis and reporting timeframe

There are two types of calculated RF climate footprints:

— Annual RF climate footprints are the calculation of RF in an individual year (e.g., mW/m^2 in 2020).

— Integrated RF climate footprints are mathematically integrated across a time horizon (e.g., mW yrs / m^2 from 2020 to 2050).

NOTE The Absolute Global Warming Potential for a pollutant is a type of integrated RF climate footprint.

The analysis timeframe is the period of time (i.e., time horizon) for which RF is calculated. There are two time horizons are relevant within the analysis timeframes:

— Current RF climate footprints include all category indicators in the climate system impact group (see discussion above).

— Projected RF climate footprints are calculated based upon IPCC RCP methods (IPCC AR5), which involve estimating future concentration pathways of contributions, and include all indicators in the climate system impact group. Projections for any time horizon may be selected but should include projections for 2030, 2050, 2070 and 2090.

Table A.2 summarizes the analysis timeframe, reporting, and calculation parameters (reporting of annual or integrated RF) for each analysis scope.

Table A.2. RF climate footprint analysis timeframe and reporting. Whether RF is calculated as an annual (year-by-year) value (in mW/m^2), or in integrated values (i.e., mW yrs. /m^2) is also described.

Scope	Analysis Timeframe and Reporting Guidance	Annual RF Calculation	Integrated RF Calculation
Global radiative forcing reduction goals	The analysis timeframe should include the calculation of the RF reduction required by 2030 and afterwards.	Applicable	
Project category	The analysis timeframe should begin in the present year or year in which implementation begins and extends until after 2030. RF is evaluated and reported for every year across the analysis timeframe.	Applicable	
Project-level	The analysis timeframe should extend from the year of first project implementation through the end of the project monitoring period, defined according to project-category protocols developed in accordance with this guidance standard. RF is evaluated and reported for every year across the analysis timeframe.	Applicable	

Government entity (i.e., national; sub-national)	The analysis timeframe should begin with 1750. It should also include forward-looking projected analyses of different RF levels resulting from different policies that a country may undertake.	Applicable	Optional

A.2.4 Equation for calculating RF

The RF for each indicator should be calculated in each year using Equation A.1 (identical to Equation 1 in the body of the guidance standard).

Equation A.1. The equation for calculating RF for a given year.

$$\text{Radiative Forcing in year t} = RF(t) = \sum_j (RF_{emissions}(t) + RF_{other}(t))$$

Where:

- j is a summation over all unit processes
- year t is the number of years after the initiation of the analysis timeframe
- $RF_{emissions}(t)$ is the radiative forcing in year t from emissions, calculated according to Equation A.2.
- $RF_{other}(t)$ is the radiative forcing in year t from other effects.

A.2.5 Climate forcers included in RF reduction analysis

Table 1 in the guidance standard lists the key climate forcers addressed in RF analysis.

A.2.6 Radiative effects included

All emissions and activities that can be linked to positive and negative RF (i.e., both warming and cooling) should be included across the entire analysis timeframe. This should include all emissions that cause direct RF, as well as those that lead to radiative forcing indirectly, through effects such as chemical reactions in the atmosphere and effects on cloud cover.

For projects that remove atmospheric CO_2, the effect of subsequent leakage of the CO_2 must be factored in to evaluate the net CO_2 removal resulting from the activity.

Provided an RF project's net CO_2 removal is too small to measurably perturb the trend in CO_2 emissions, Equation A.3 can be used to calculate the resulting RF, calculated by treating the net removal as a negative emission of CO_2. However, if the net CO_2 removal is large enough to effect the trend of CO_2 emissions and concentrations, a modified Equation A.3 may need to be used to account for different oceanic and terrestrial CO_2 absorption and ocean mixing.

For certain unit processes, there may be activities linked to RF (considering top of the atmosphere changes) that are not associated directly with emissions. The following activities are known to induce RF changes, and should be included, provided that the scale of the induced RF change related to the considered activity is significant:

— Deposition of black carbon and other darkening materials on ice surfaces (which should be accounted for when calculating the RF related to black carbon emissions);

— Infrastructure-related land use changes that lead to an unintended decrease of surface reflectivity;

— Albedo restoration through eliminating destruction of Arctic sea ice due to ship ice breaking, especially in spring and summer months (which removes high-albedo ice and replaces it with low-albedo seawater);

— Brightening of urban areas (i.e., "cool roofs" or "cool roads"), which can cause a negative RF change at sufficient scale;

— Other land use changes, leading to either positive or negative RF changes (depending on the albedo modification);

— Restoring ocean albedo when considering reflectivity from the top of the atmosphere (e.g., cloud restoration);

— Destruction of stratospheric ozone by Ozone Depleting Substances, especially by CFCs (which should be accounted for when calculating the RF related to CFC emissions).

If the effect on RF is material given the analysis scope, such activities should be included, and a trade-off analysis should also be included to determine any negative unintended consequences.

A.2.7 Calculating RF from emissions

The RF related to emissions is calculated using Equation A.2.

Equation A.2. The equation to calculate $RF_{emissions}$ in Equation A.1. for year t_F, for a defined analysis timeframe that begins in year t_0.

$$RF_{emissions}(t_F) = RF_{GHG}(t_F) + RF_{SLCP}(t_F) + RF_{TOPr}(t_F) =$$

$$\sum_{i=GHGs} \int_{t=t_0}^{t_F} E_i(t) \times uRF_i(t_F - t_0)\,dt + \sum_{j=SLCPs} E_j(t_F) \times RE_j$$

$$+ \sum_{k=TOPr} \int_{t_0}^{t_F} E_k(t) \times uRF_k(t_F - t_0)\,dt$$

Where:

- t_F is the year in which RF is being calculated.
- t_0 is the first year in the analysis timeframe.
- $RF_{emissions}(t_F)$ is the total RF resulting from all unit processes in year t_F
- $RF_{GHG}(t_F)$, $RF_{SLCP}(t_F)$, and $RF_{TOPr}(t_F)$ are respectively the total radiative forcing from GHGs, SLCPs, and non-methane tropospheric ozone precursors, in year t_F
- i is a summation across all of the GHGs in the analysis scope
- $E_i(t)$ accounts for emissions of the "ith" GHGs in the scope (the emissions value may vary each year)
- $uRF_i(t)$ is the unit RF for "ith" GHG, calculated using Equation A.3 for CO_2 and Equation A.4 for other GHGs.
- j is a summation across all of the SLCFs in the analysis scope (only includes SLCFs with an atmospheric lifetime of less than one year)
- $E_j(t)$ accounts for emissions of the "jth" SLCP in the scope (the emissions value may vary each year)

- RE_j is the radiative efficiency of the "jth" SLCP
- k is a summation across all of the tropospheric ozone precursors (TOPr) in the analysis scope
- $E_k(t)$ accounts for the emission of the "kth" non-methane tropospheric ozone precursor in the scope (the emissions value may vary each year)
- $uRF_k(t)$ is the unit radiative forcing from the "kth" non-methane tropospheric ozone precursor, calculated using Equation A.6

For each pollutant, uRF (the RF resulting from the pulse emission of one million tons of a pollutant) in Equation A.2 is calculated using Equation A.3 through Equation A.6. Calculation details are also included in the equations.

Equation A.3. The RF resulting from the pulse emission of one million tons of CO_2 (i.e., the unit RF equation), from the IPCC Fifth Assessment Report.

$$uRF_{CO2}(t) = RE_{CO2} \times R_{CO2}(t) = RE_{CO2} \times \left(a_0 + \left(a_1 \times e^{\frac{-t}{\tau_1}}\right) + \left(a_2 \times e^{\frac{-t}{\tau_2}}\right) + \left(a_3 \times e^{\frac{-t}{\tau_3}}\right)\right)$$

Where:

- t is the number of years after the pulse emission occurred.
- $uRF_i(t)$ is the RF of one million tons of CO_2 for a pulse emission, 't' years after the pulse emission
- RE_{CO2} is the radiative efficiency of CO_2, in mW/(m² Tg)
- $R_{CO2}(t)$ is the fraction of CO_2 remaining in the atmosphere (t) years after the pulse emission.

Requirements for calculating uRF for CO_2:

- The radiative efficiency (RE_{CO2}) from the latest IPCC report should be used as a default. A default RE_{CO2} value of 0.0017517 mW/(m² · Tg)should be used unless more up-to-date values are available [IPCC AR5, §8.SM.11.3.1]
- The atmospheric concentration equation from the latest IPCC report should be used as a default.
- The default values for the atmospheric concentration equation parameters (i.e., a_0, a_1, τ_1, τ_2, etc.) in Table A.7 should be used unless more up-to-date values are available.

Equation A.4. The RF resulting from the pulse emission of one million tons of a non-CO_2 GHG (i.e., the unit radiative forcing equation).

$$uRF_{GHG}(t) = RE_{GHG} \times R_{GHG}(t) = RE_{GHG} \times e^{-t/\tau}$$

Where:

- t is the number of years after the pulse emission occurred.
- $uRF_{GHG}(t)$ is the RF of one million tons of the non-CO_2 GHG', 't' years after the pulse emission
- $R_{GHG}(t)$ is the fraction of the non-CO_2 GHG remaining in the atmosphere after t years.
- RE_{GHG} is the radiative efficiency of the GHG, in mW/(m² Tg).
- τ is the atmospheric lifetime of the non-CO_2 GHG, in years.

Requirements for calculating uRF for non-CO_2 GHGs:

- The radiative efficiency (RE_{GHG}) should be reported in units of mW/(m² Tg) (i.e., milli-Watts per square meter per million tons / Tg pulse emission).
- Any radiative efficiency values that are converted into units of mW/(m² Tg) from W m⁻² ppbv⁻¹ should follow the requirements of IPCC Fifth Assessment Report Chapter 8 Supplemental Material: "To convert RE values given per ppbv values to per kg, they must be multiplied by (MA/Mi)(10⁹/TM) where MA is the mean molecular weight of air (28.97 kg kmol⁻¹), Mi is the molecular weight of species I and TM is the total mass of the atmosphere, 5.1352 x 10¹⁸ kg."
- For non-CO_2 GHGs besides methane, the pollutant average atmospheric lifetime (τ) and RE_{GHG} from the latest IPCC reported should be used as a default.
- For methane, RE_{CH4} should include the following indirect effects that influence the radiative efficiency:

formation of tropospheric ozone; effect on sulfate aerosols concentrations; effect on stratospheric water vapor; effect on nitrate aerosol concentrations; and from CO_2 formation. [Shindell et al 2009]

- Default values for τ and RE_{CH4} from Table A.3 should be used.

Equation A.5. The RF resulting from the pulse emission of one million tons of a SLCP with an atmospheric lifetime of less than one year (i.e.. the unit radiative forcing equation).

$$uRF_{SLCP}(t) = \begin{cases} RE_{SLCP} \text{ when } t < ARTMP \\ 0 \text{ when } t > ARTMP \end{cases}$$

Where:

- t is the number of years after the pulse emission occurred.
- ARTMP is the Atmospheric Residence Time Modeling Parameter, in units of time, which is equal or less than one year, and as a default one year.
- $uRF_{SLCP}(t)$ is the radiative forcing of one million tons of the SLCP at time t
- RE_{SLCP} is the radiative efficiency of the SLCF, in mW/(m² Tg) evaluated as the annual average radiative forcing resulting from the pulse emission of one million tons of the SLCF (see Table A.6 default values for sulfur dioxide, and Table A.7 for default values for black and organic carbon). If ARTMP is less than one year, RE_{SLCP} is then the average RF from the same size pulse emission over the duration of ARTMP (e.g., if ARTMP is one month, then the RE_{SLCP} is the average RF over one month).

Requirements for calculating uRF for SLCFs with atmospheric lifetime of less than one year

- The radiative efficiency should be reported in units of mW/(m² Tg) and should be evaluated as the annual average radiative forcing resulting from the pulse emission.
- RE_{SLCP} should take into account the fact that these SLCFs are not evenly distributed in the global atmosphere and their impact varies regionally, and by source type.
- The following factors that affect the induced RF of these SLCFs should be considered:
  - Rate of emission, weather conditions, location, timing (season, hour of day), and altitude of emission source. Data used to characterize RF from SLCFs should be based on multiple years to minimize the effects of natural climate variability. This can be achieved by basing results upon average seasonal or average annual atmospheric concentrations of the SLCFs.
  - For all aerosols, indirect effects should be characterized to the extent possible. This can involve use of conservative estimates. Examples include the enhancement of cloud albedo by sulfate aerosols, and deposition of black carbon on ice, snow and other reflective surfaces.
  - Other factors that can affect the induced RF should be considered if they have a material effect.
  - Estimates of RF by source should be obtained from peer-reviewed published research.
- When assessing the contribution to RF from black carbon, organic carbon, and brown carbon:
  - Direct observations of RF should serve as the basis of the forcing of these pollutants, where it is available. Model-based calculations based solely on bottom-up emissions estimates should be compared to direct observations before being used to calculate the result. [NOTE: RF derived from climate models based on bottom-up emissions estimates have in some studies been found to underestimate black carbon concentrations by 3- to 10-fold. [*Bond, T., 2013; Menon, S. 2010]*
  - The induced RF per ton of black carbon differs significantly based on the region of emission, due to latitudinal differences in solar radiation, regional differences in baseline clouds, vertical transport of black carbon, underlying albedo, and vegetation cover. Differences based on the region in which black carbon is emitted should be taken into account.
  - Special care must be taken when including brown carbon, the composition of which can be highly variable; as such, an analysis should be done for each specific situation. In most cases, the positive forcing from brown carbon is similar in magnitude to the negative forcing from organic carbon. [*Feng, Y. et al, 2013; Chung, C.E. et al, 2012]* Accordingly, in the result, it can be assumed as a default that RF from co-emitted brown and organic carbon aerosols offset each other. This assumption should be recorded and justified.
  - The enhanced RF resulting from deposition on ice and snow should be included.
  - Indirect effects on clouds, to the extent they are relevant and can be estimated, should be included.
  - For all carbonaceous aerosol emissions, the type of combustion should be factored into the overall calculations. Note that black carbon emissions from fossil fuels are known to have different characteristics than black carbon emissions from open burning sources.
- When assessing the contribution to RF from sulfate coolants, the following should be included in the RF

calculation:

- The conversion rate of SO_2 emitted to sulfate (SO_3, SO_4).
- Regional wash out rates and other meteorological factors affecting aerosol lifetime.
- Estimates of indirect radiative effects (i.e. cloud brightening effects).

Equation A.6. Unit RF equation for a pulse emission of 1 million tons of a non-methane tropospheric ozone precursor.

$uRF_{TOPr}(t)$ =

Tropospheric Ozone Effect(t) + Sulfate Effect(t) + Nitrate Effect(t) + Methane Effect (t) + Plant indirect Effect(t)=

$$[TOPr_{O3} + TOPr_{SO4^{-2}} + TOPr_{Nl}] + k \times uRF_{CH4}(t) + RE_{CO2} \times \Delta CO2(t)$$

Where:

- t is the number of years after the pulse emission occurred.
- $uRF_{TOPr}(t)$ is the RF of one million tons of the non-methane tropospheric ozone precursor, 't' years after the pulse emission
- Tropospheric ozone, sulfate, nitrate, methane, and plant indirect effects are the respective radiative effects from the non-methane tropospheric ozone precursor.
- $TOPr_{O3}$, $TOPr_{SO4}$, $TOPr_{Nl}$, are the respective magnitude of the non-methane tropospheric ozone precursor's indirect effects on tropospheric ozone, sulfates, and nitrates. (see Table A.8 for default values for NOx, the primary non-methane tropospheric ozone precursor).
- RE_{CO2} is the radiative efficiency of CO_2, while ΔCO_2 is the amount of excess CO_2 resulting from the NOx plant indirect effect (see Table A.9 for default values).
- k is a unitless value equal to the tons of methane oxidized per ton of TOPr emitted. (see Table A.8 for default values for NOx).

Requirements for calculating uRF for the non-methane tropospheric ozone precursor:

- The following radiative effects of the emissions should be taken into account in calculating the RF using Equation A.6.
  - Direct RF increase from the formation of tropospheric ozone.
  - Perturbation of sulfate formation (resulting from NOx reactions to break down these aerosols – not relevant to precursors other than NOx).
  - Generation of ammonium nitrate aerosols (in regions of high ammonia abundance).
  - Enhanced atmospheric decay of methane resulting from ozone oxidation. *[Collins, W.J. et al, 2013]*
  - In calculating these radiative effects, climate models considering chemistry and dispersion should be used. Default values for $TOPr_{O3}$, $TOPr_{SO4}$, $TOPr_{Nl}$, k, for NOx emissions from Table A.8 should be used if necessary.
- The indirect effect of the precursor emissions on the disruption of plant respiration from exposure to increased surface ozone should be included, if the emissions occurs in a region where ground-level ozone formed from the emissions could transport to regions where the ambient ozone concentration exceeds 40ppb for at least once per year. *[Ashmore, M.R. 2005; Myre, G. et al, 2013]*
  - Dispersion modeling should be used in this determination and the calculation of the radiative effect.
  - If included, the change in land carbon should be converted to the change in atmospheric CO_2 using a molar mass ratio of 44/12.
  - For NOx emissions, the Equation 9 default values for ΔCO_2 for 20 years in Table A.9 should be used if necessary.

NOTE. The effect of ozone on the suppression of CO_2 uptake in land plants could account for 0.2 to 0.4 W/m^2, or 10-20% of the total RF resulting from excess atmospheric CO_2. This could be a major RF driver and very important to account for in the ozone precursors. [Sitch, S. et al, 2007]

Table A.3. Default parameters for calculating uRF for CO_2 in Equation A.3. See Equation 8.SM.10 and Table 8.SM.10 in IPCC Fifth Assessment Report Working Group 1, Chapter 8 Supplemental Material for reference

	1st term	2nd term	3rd term	4th term

Unitless exponential coefficient (a_i)	a_0 = 0.2173	A_1 = 0.2240	A_2 = 0.2824	a_3 = 0.2763
Time scale (τ_i) in years	Not applicable	τ_1 = 394.4	τ_2 = 36.54	τ_3 = 4.304

Table A.4. Default Radiative Efficiencies (REi) and Average Atmospheric lifetimes for GHG pollutants

Pollutant	REi, mW/(m² Tg)	Average Atmospheric Lifetime	Data Source
Methane (CH_4)	0.267	12.4 years	Shindell et. al 2009
Nitrous Oxide (N_2O)	0.385	121 years	IPCC AR5 Table 8.A.1. and calculation
Sulfur Hexafluoride (SF_6)	22.0	3200 years	IPCC AR5 Table 8.A.1. and calculation
HFC-134a	8.85	13.4 years	IPCC AR5 Table 8.A.1. and calculation
Nitrogen Trifluoride (NF_3)	15.9	500 years	IPCC AR5 Table 8.A.1. and calculation

Table A.5. Default Radiative Efficiencies (REi) for sulfur dioxide emitted in four different regions

Pollutant	REi, mW/(m² Tg)	Data Source
Sulfur Dioxide (SO_2) from East Asia	-5.1	Collins 2013 and Shindell 2009
SO_2 from Europe	-6.8	Collins 2013 and Shindell 2009
SO_2 from North America	-6.8	Collins 2013 and Shindell 2009
SO_2 from South Asia	-6.8	Collins 2013 and Shindell 2009

(Note about difference in East Asia to be added)

Table A.6. Black carbon and organic carbon radiative default efficiency values, for different regions and source types. Incudes both the direct and indirect effect from deposition on ice and snow. Calculated using Table 1 of Bond 2011.

	Black carbon REi, mW/(m² Tg)	Organic Carbon REi, mW/(m² Tg)
Global average	71.6	-3.98
<u>Energy-related sources</u>		
Average energy	69.1	-2.61
Canada	74.1	-1.31
USA	62.9	-1.93
Central America	74.1	-3.30.
South America	75.9	-3.05
Northern Africa	82.8	-3.61
Western Africa	77.2	-3.86
Eastern Africa	72.8	-4.23
Southern Africa	78.4	-4.86
OECD Europe	60.4	-1.99
Eastern Europe	65.4	-2.30
Former USSER	84.0	-1.87
Middle East	84.7	-3.61
South Asia	88.4	-5.04
East Asia	63.5	-1.62
Southeast Asia	61.0	-2.80
Oceania	64.1	-3.49
Japan	49.2	-0.87

Open burning-related emissions		
Average open burning	76.6	-4.61
Europe	89.0	-4.48
Northern Asia	128.2	-3.55
Southern Asia	90.3	-5.98
North America	117.7	-3.55
S/C America	85.9	-5.73
Africa	56.0	-3.80

NOTE: Specific forcing pulse values were converted to GWP-20 values by dividing by 4×10^{-4} and then to AGWP-20 by multiplying with AGWP-20 of CO_2. As the AGWP-20 is identical to AGWP-1 for black carbon, this value was taken as the annual average radiative efficiency. *[Bond, T., et al. 2011.]* Value is based on the highest SFP value for black carbon.

Table A.7. Radiative efficiency and k values for different effects of NOx that can used as a default. These values result in a conservatively high RF estimate for NOx.
[Columns TOP_{r,O_3} and K from Fry, M. M. et al, 2012; Column $TOP_{r,N}$ from Collins, W.J. et al, 2013]

	$TOP_{r,SO_4^{2-}}$	TOP_{r,O_3} [1]	$TOP_{r,N}$ [2]	K [3]	RE_{CO_2}
East Asia	0.16	2.47	-2.0	-0.87	0.0017517
European Union	-0.37	0.93	-2.0	-0.56	0.0017517
North America	0.14	2.42	-2.0	-0.93	0.0017517
South Asia	-0.48	4.28	-2.0	-1.71	0.0017517
Averaged 4 regions	-0.08	2.14	-2.0	-0.87	0.0017517

NOTE 1 GWPs for 20-year time horizons were converted to AGWP values using the AGWP-20 of CO_2. These AGWP-20 values, which are largely invariant over time for short-lived ozone and SO_4, are assumed to be identical to AGWP-1 values, which are taken as average over one year for the radiative efficiency of methane's effect on these pollutants. *[Fry, M.M. et al, 2012.]*

NOTE 2 "We can use the results of Bauer et al (2007) who calculated a normalized direct RF from global anthropogenic NOx emissions of -2.0×10^{-12} W m^{-2} kg^{-1}." *[Collins, W.J. et al, 2013]*

NOTE 3 Calculated from Table S2 of Fry, et al, 2012, by dividing the calculated AGWP-20 of the NOx methane effect with the AGWP-20 of methane. *[Fry, M.M. et al, 2012.]*

	AGWP-20, methane, calculated using Equation A.4.	AGWP-20, methane effect, Table S2	K, unitless
East Asia	2.55	-2.21	-0.87
European Union	2.55	-1.42	-0.56
North America	2.55	-2.36	-0.93
South Asia	2.55	-4.35	-1.71
4 regions	2.55	-2.22	-0.87

Table A.8. ΔCO_2 values for calculating longer-term RF effects from reduced uptake of CO_2 related to Nitrogen oxide emissions, derived from the literature. *[Collins, W.J. et al, 2010]*

Years After Pulse Emission *I*	ΔCO_2 (kg CO_2 / kg NOx)	Years After Pulse Emission *I*	ΔCO_2 (kg CO_2 / kg NOx)
1	843.525	11	308.07
2	770.175	12	286.065
3	696.825	13	264.06

Years After Pulse Emission t	ΔCO_2 (kg CO_2 / kg NOx)	Years After Pulse Emission t	ΔCO_2 (kg CO_2 / kg NOx)
4	623.475	14	242.055
5	550.125	15	220.05
6	506.115	16	207.825
7	462.105	17	195.6
8	418.095	18	183.375
9	374.085	19	171.15
10	330.075	20	158.925

A.2.8 Global radiative forcing changes from other activities

RF changes from non-emission related activities are calculated directly, as follows:

— RF is evaluated in terms of mW/m^2, considering annually and globally averaged Top-of-the-atmosphere RF changes consistent with the definitions of this guidance standard. All such analyses should be based upon publicly available information that has undergone peer review.

— RF evaluated from such activities should be combined with any radiatively active emissions associated with these activities using Equation A.1 at the immediate and long-term timeframes.

— All such activities, if considered, should undergo a trade-off analysis.

— The effect of such activities on regional high-risk zones should be considered.

— Direct effects on surface reflectivity should be considered (i.e., changes in the albedo resulting from land use changes, reflectivity of clouds, etc.).

— Indirect effects on surface reflectivity should be calculated or estimated, provided they are expected to have a material effect on net RF results.

— If indirect effects would lead to an increase in RF, they should be calculated, in order to understand the total net RF change induced by the activity.

— As well as reflectivity changes resulting in RF, direct and indirect changes to RF resulting from increased emittance of lower frequency radiation (i.e., Earth radiation) should also be considered if they are material.

— The effect on known feedback loops should be considered, and their effect on the induced RF, should be considered if they have a material effect.

A.3 Methods of reporting of excess RF

The excess RF compared to the historic baseline can be described and reported in three ways (Table A.9). The RF, reported in watts per square meter, can also be reported as "Total Heat Level Increase" based on the excess heat absorbed across the total surface area of the Earth (510 million square kilometers), or by an ordinal scale akin to the Saffir-Simpson Hurricane Wind Scale for hurricanes (i.e., Category 1, 2, 3, 4, and 5).

Table A.9. Three Approaches to Measuring and Reporting the Excess RF

Radiative Forcing measured in W/m^2	Total Heat Rate Level Increase
1 W/m^2	510 trillion Watts
2 W/m^2	1,020 trillion Watts
3 W/m^2	1,530 trillion Watts
4 W/m^2	2,040 trillion Watts
5 W/m^2	2,550 trillion Watts
6 W/m^2	3,060 trillion Watts
7 W/m^2	3,570 trillion Watts
8 W/m^2	4,080 trillion Watts

A.4 Regional high-risk zone impact evaluation

Regional high-risk zones are regions where local climatic conditions are significantly altered from pre-industrial condition. Regions are designated as regional high-risk zones if distinct regional climate disruptions reflected in specific midpoints and endpoints are significant.

Examples of altered conditions that would define regional high-risk zones include regions of the earth's surface experiencing:

— Significant localized changes in the vertical energy budget, either positive or negative;

— Significant localized changes in the hydrological cycle;

— Changes in regional atmospheric circulation patterns;

— Changes in local temperature or temperature gradients;

— Changes in seasonality of temperature and/or RF changes;

— High rates of sea level rise;

— Significant increases in wildfires induced from climate change;

— Surface dimming; and

— Effects on local snowpack, ice cover, or other albedo changes.

EXAMPLE Brown cloud pollution in South Asia is implicated as reducing the hydrological cycle and leading to significant local changes, as a result of the reduction of solar insolation to the surface. *[UNEP 2008]*

A.4.1 Identification and characterization of regional high-risk zones

The characteristics (e.g., spatial, temporal, severity) of regional high-risk zones should be described in the summary report. If identified, the following information should be described and reported regarding the high-risk zone, at a minimum:

— The cause-effect chain that has led to the regional high-risk zone. This should include a specific description of the observations and measurements related to the midpoints that characterize the regional high-risk zone. The main contributors to these midpoints should be ascertained.

— The size, duration, seasonality, and periodicity of the key midpoint(s) for the regional high-risk zone.

For a project, government entity, or organization, the effect of emissions and/or activities should be evaluated to determine if there are any linkages, intended or unintended, and positive or negative, to regional high-risk zones. Linkages involve any climate pollutant emissions that transport into known regional high-risk zones and affect their magnitude, size, or severity, or activities that have an influence on the severity of the local regional high-risk zone, directly or indirectly.

As a default, any project, government entity or organization that contributes positive RF emissions (e.g., aerosols, precursor pollutants). in the following regional high-risk zones should be considered to be linked to these regional high-risk zones, identified by UNEP as the major brown cloud hot spots: East Asia, South Asia, Southeast Asia, Indonesia/Malaysia, South America, and Central Africa. *[Ramanathan, V., et al., 2008]* In addition, any activities occurring in the Arctic that could influence the local Arctic climate in any fashion should include the effect on the Arctic regional high-risk zone.

Additional identification of linkage to regional high-risk zones should be determined on a case-by-case basis.

A.4.2 Calculating effects on regional high-risk zones (general parameters)

For any project, government entity, or organization that is directly contributing to climate disruptions within a regional high-risk zone:

— the specific factors that are most relevant to the severity of the regional high-risk zone conditions should be identified. Careful consideration of the cause-effect chain is required to identify the underlying causes of the regional high-risk zone, which may be linked to regional-level activities, or to larger climatological patterns or feedback loops.

— the contribution of the project, government entity, or organization activities to the key conditions that characterize the regional high-risk zone's severity should be calculated.

— the altered regional RF level within the regional high-risk zone (i.e., the increased top-of-the-atmosphere RF averaged across the spatial extent of the regional high-risk zone), should be calculated.

A.4.3 Calculating effects on regional high-risk zones tied to black carbon pollution

Effects of black carbon pollution in several regional high-risk zones are well known and understood (UNEP 2008 Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia, Published by the United Nations Environment Programme, Nairobi, Kenya) to be relevant for many government entities, organizations, and projects. These impacts are relevant if unit processes are located in regions in or near these regional high-risk zones, and emit black carbon, nitrogen oxides, sulfur dioxide, carbon monoxide, volatile organic compounds (VOCs), or other pollutants contributing to these local regional high-risk zones.

Separate category indicator results are included for each regional high-risk zone relevant in the scope. The category indicator addresses the local emissions of SLCPs contributed to local regional high-risk zone conditions.

The results for the regional high-risk zone impact category are calculated in terms of tons of black carbon equivalent using Equation A.7.

Equation A.7. Equation for calculating regional high-risk zone impacts tied to brown cloud pollution

$$\text{Regional high-risk zone Impacts (tons black carbon equivalent)} = \sum_j \sum_i \text{Short-Lived Climate Pollutant Emissions}_{i,j} \times CF_i$$

Where:

- SLCP emissions are tons of emissions, including: black carbon, NOx, SO_2, and organic carbon contributing to the local regional high-risk zone.
- j is the total number of unit processes in the scope
- i represents the total number of aerosols and aerosol precursors emitted
- CF is the characterization factor

The characterization factor used to calculate results in Equation A.7 characterizes the potential release of aerosol and aerosol precursors and the equivalent mass of black carbon formed in the atmosphere that results. CFs should be calculated using regional dispersion and atmospheric chemistry modeling.

Annex B
(informative)

Implementing Radiative Forcing Management

ISO 14082 provides a summary of the procedure for determining RF reduction goals and establishing an RF management roadmap (Clause 5.1.2). This Annex further expands on the some of the concepts referenced in that text.

0. Glossary of Terms

In addition to terms defined in the guidance standard document, these additional terms and definitions relevant to the contents of this Annex.

0.1

global RF stabilization target

numerical target for global RF levels over a specified time period (e.g., 1.5 W/m^2, 1.9 W/m^2, 2.6 W/m^2 by 2030)

Note 1 to entry: The global RF stabilization target can additionally be defined in relation to the linkage of certain RF levels to other specifically defined endpoints, or to projections of future threshold exceedances. The use of such thresholds should be accompanied by probabilistic uncertainty analysis and reporting of confidence intervals.

0.2

regional RF stabilization target

numerical target for RF levels in regional high risk zones (e.g., 1.5 W/m^2 by 2030)

0.3

representative concentration pathway (RCP)

modeled scenario that includes time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover

Note 1 to entry: RCPs refer to the portion of the concentration pathway extending up to 2100. RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding emission scenarios.

Note 2 to entry: Each RCP represents only one of many possible scenarios that would lead to the specific radiative forcing characteristics. *[IPCC Fifth Assessment Report Glossary]*

[SOURCE: Intergovernmental Panel on Climate Change, IPCC Fifth Assessment Report: Climate Change 2014]

0.4

RF reduction goal

the amount of RF reduction desired within a specified period of time

B.1 Determining the RF stabilization target

Establishment of RF reduction goals and an RF management roadmap (i.e., plan of action) is contingent upon the RF stabilization target adopted. The RF stabilization target should include a specific target RF value (i.e., defined in W/m^2) for specific target years, including but not limited to 2030.

Equation B.1 describes how to calculate a global RF stabilization target associated with a specific maximum global mean temperature (GMT) anomaly target.

Equation B.1. Calculating a global RF reduction target associated with a maximum GMT anomaly target.

$$RF_{target} = \frac{Temperature_{target}}{Climate\ Sensitivity}$$

Where:

- RF_{target} is the ~~global~~ RF stabilization target, in Watts per square meter.
- $Temperature_{target}$ is the maximum temperature anomaly target, in °C.
- Climate sensitivity is the equilibrium climate sensitivity, in °C per W/m^2

[Source: IPCC Fifth Assessment Report]

The equilibrium climate sensitivity value used in Equation 1 should be that which is published by the IPCC in the latest Assessment Report edition. In the 2018 IPCC SR1.5 report, 1.9 W/m^2 is identified as the RF anomaly limit to maintain the global mean temperature below 1.5ºC. The equilibrium climate sensitivity which should be used is 0.79ºC per W/m^2.

Organizations and government entities should have a process to choose which time horizons of RF reduction are of the highest priority, and therefore which RF reduction goals should be set. Any prioritization should be stated and the justification provided.

B.2 Calculating RF reduction objectives

The amount of RF reduction needed in a given year should be calculated by subtracting the RF_{target} in Equation B.1 from the reasonable business-as-usual RF level in each year using Equation B.2.

Equation B.2. Calculating a global RF reduction objective associated with an RF stabilization target linked to maximum GMT anomaly goals.

$$\Delta RF(t) = RF_{bau}(t) - RF_{target}$$

Where:

- t is the year.
- $\Delta RF(t)$ is the reduction in RF required in year t.
- RF_{target} is the RF stabilization target calculated according to Equation B.1.
- $RF_{bau}(t)$ is the reasonable business-as-usual ("BAU") RF level in year t.

The reasonable business-as-usual RF level is based upon peer-reviewed projections from major climate models (e.g., as noted in AR5).

NOTE Four RCPs were modeled in the IPCC Fifth Assessment Report: RCP2.6, RCP4.5, RCP6,0 and RCP8.5. Under RCP2.6, RF peaks at approximately 3 W/m^2 before 2100 and then declines to stabilize at about 2.6 W/m^2. RCP4.5 and RCP6.0 were two intermediate stabilization pathways in which RF is stabilized at approximately 4.5 W/m^2 and 6.0 W/m^2 until 2100. Under RCP8.5, RF was projected to exceed 8.5 W/m^2 by 2100 and continue to rise for some amount of time.

Table B.1. RF reductions required using the global RF reduction objectives associated with maximum temperature anomaly goals of 0.0°C, 1.5°C, and 2.0°C. RF reductions, compared to RCP8.5. All RF reductions are calculated using Equation B1. ***Source: To be inserted***

Temperature Maximum	**0°C**	**1.5°C**	**1.5°C**
RF Stabilization Target	**0.0 W/m^2**	**1.5 W/m^2 (conservatively low equilibrium climate sensitivity of 1.0°C per W/m^2)**	**1.9 W/m^2 (equilibrium climate sensitivity of 0.79°C per W/m^2)**
Year	**RF reduction required**	**RF reduction required**	**RF reduction required**
2025	**2.9**	**1.4**	**1.0**
2030	**3.3**	**1.8**	**1.4**
2035	**3.6**	**2.1**	**1.7**
2040	**3.9**	**2.4**	**2.0**
2045	**4.3**	**2.8**	**2.4**
2050	**4.7**	**3.2**	**2.8**
2055	**5.1**	**3.6**	**3.2**
2060	**5.4**	**3.9**	**3.5**
2065	**5.8**	**4.3**	**3.9**
2070	**6.2**	**4.7**	**4.3**
2075	**6.5**	**5.0**	**4.6**
2080	**6.9**	**5.4**	**5.0**
2085	**7.3**	**5.8**	**5.4**
2090	**7.6**	**6.1**	**5.7**
2095	**7.9**	**6.4**	**6.0**
2100	**8.3**	**6.8**	**6.4**

Figure 1 illustrates the level of global RF reduction needed by 2030 (and subsequent decades) to achieve two different GMT stabilization goals relative to the IPCC AR5 RCP8.5 scenario: 1) to prevent GMT from crossing +1.5°C; and 2) to achieve an even more aggressive goal of lowering GMT back to the 2012 level of +0.8°C (e.g., that would be required for high-risk zones).

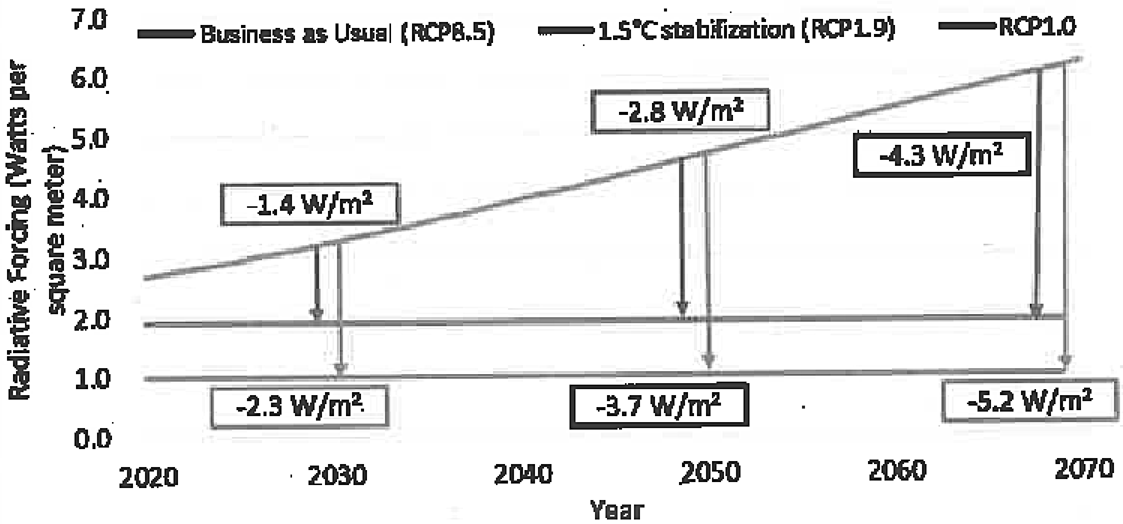

Figure 1. RF reduction required to maintain the global mean temperature at +1.5°C (i.e., 1.9 W/m²) or below +0.8°C (i.e., 1.0 W/m²). or below +0.8°C (i.e., 1.0 W/m²), when compared to RCP 8.5. While there is uncertainty regarding future RF levels included in this figure, the most widely accepted estimates by the IPCC in its Representative Concentration Pathways (RCPs) scenarios project a rise to about +3.0 W/m² by 2030 –a rate that, if sustained, would eventually lead to an increase in average global temperature to over +2.0°C. The framework provides guidance on how to estimate the level of RF reduction required each year in the future compared to what is expected, in order to maintain RF at specific levels. As described in the IPCC SR1.5, maintaining RF at 1.9 W/m² will provide a 50% likelihood of stabilization at about 1.5°C. [**Sources: IPCC Fifth Assessment Report and IPCC Special Report on Global Warming of 1.5°C**]

B.3 Establishing an RF management roadmap

B.3.1. Global RF management roadmap

Government entities should, and organizations can, establish RF management roadmaps that are:

— Global in scope, focusing on the reduction of global RF levels

— Include a stated RF stabilization target and global RF reduction goals for specific years, including 2030.

— Include a set of RF reduction projects sufficient in scale to achieve the stated RF reduction goal by 2030;

These roadmaps should:

— Include a timeline for implementation and completion of each RF reduction project;

— Be based on RF projects demonstrated to have no significant climate or other adverse trade-offs that cannot be mitigated, as determined based on procedures provided in this guidance standard;

— Provide transparent milestones for all RF projects;

— Include the available budget for implementation of all RF projects;

— Include the estimated cost of implementation of each RF project;

— Be fully documented, including a listing of data, climate models, and assumptions used to generate the list of RF projects and justification for the RF reductions projected.

— Be peer reviewed by a panel of independent experts and stakeholders.

These roadmaps can be developed by a body that is independent from the existing entities within the organization or government entity (e.g., an independent commission). Personnel with adequate expertise in climate science, economic analysis, and project implementation should participate in this development.

The review process should involve individuals who have no conflict of interest. The peer review panel expertise should cover all relevant aspects of the proposed RF projects (e.g., climate science, engineering, economics, environment, and human health).

B.3.2. Regional high-risk zone management roadmap

Government entities and organizations should establish specific roadmaps for regions facing extreme risks from climate change by or before 2030.

NOTE Examples of high-risk zones include: regions at extreme risk of flooding from rising sea levels, such as small island nations and many coastal cities; regions at risk of temperature spikes and mean temperatures far in excess of GMT, such as parts of the western US; regions at risk of major food or water insecurity due to drought or other food source imperilment, such as parts of India and sub-Saharan Africa; and regions subject to major ecosystem alterations, such as the Arctic.

Regional high-risk zone management roadmaps should:

— Be regional in scope, identifying the nature of the particular risk and the means by which this risk is monitored;

— Include quantified goal(s) in each high risk-area (e.g., restoration of regional mean temperature to 1950 levels, or reduction in extreme heat wave incidence by 50%);

— Include RF projects sufficient in scale and timeliness to prevent regional climate-induced impacts by or before 2030;

— Include timelines for implementation and completion of each RF project;

— Be based on projects demonstrated to have no significant climate or other trade-offs that cannot be mitigated, as determined based on procedures provided in this guidance standard;

— Provide transparent milestones for all RF projects;

— Be documented, including a listing of data, climate models, and assumptions used to generate the list of RF projects and roadmap; and

— Be peer reviewed by a panel of independent experts and stakeholders.

Bibliography

Ashmore, M.R. "Levels of ozone exceeding this concentration may cause leaf injury and plant damage, and suppress the absorption of CO_2 by plants." *Assessing the future global impacts of ozone on vegetation.* Plant Cell Environ., 28, 949-965 (2005).

Bond, T., et al. "Quantifying immediate RF by black carbon and organic matter with the specific forcing pulse. *Atmos. Chem. Phys.*, 11, 1505-1525, 2011.

Bond, T.C., S.J. Doherty, D.W. Fahey, P.M. Forster, T. Berntsen, O. Boucher, B.J. DeAngelo, M.G. Flanner, S. Ghan, B. Karcher, D. Koch, S. Kinne, Y. Kondo, P.K. Quinn, M.C. Sarofim, M.G. Schultz, M. Schulz, C. Venkataraman, H. Zhang, S. Zhang, N. Bellouin, S.K. Guttikunda, P.K. Hopke, M.Z. Jacobson, J.W. Kaiser, Z. Klimont, U. Lohmann, J.P. Schwarz, D. Shindell, T. Storelvmo, S.G. Warren and C.S. Zender. "Bounding the role of black carbon in the climate system: A scientific assessment." *J. Geophys. Res.*, in press, DOI: 10.1002/jgrd.50171, 2013.

Chung, C.E., V. Ramanathan, D. Decremer. "Observationally constrained estimates of carbonaceous aerosol radiative forcing." Proceedings of the National Academy of Sciences, 2012.

Collins, W. J., M. M. Fry, H. Yu, J. S. Fuglestvedt, D. T. Shindell, and J. J. West. "Global and Regional Temperature-change Potentials for Near-term Climate Forcers." *Atmos. Chem. Phys.* 13.5 (2013): 2471-485.

Collins, W. J., S. Sitch, and O. Boucher (2010), "How vegetation impacts affect climate metrics for ozone precursors," *J. Geophys. Res.*, 115, D23308, doi:10.1029/2010JD014187, 2010.

Feng, Y., Ramanathan, V., and Kotamarthi, V. R. "Brown carbon: a significant atmospheric absorber of solar radiation?" *Atmos. Chem. Phys.*, 13, 8607-8621, doi:10.5194/acp-13-8607-2013, 2013.

Fry, Meridith M., Vaishali Naik, J. Jason West, M. Daniel Schwarzkopf, Arlene M. Fiore, William J. Collins, Frank J. Dentener, Drew T. Shindell, Cyndi Atherton, Daniel Bergmann, Bryan N. Duncan, Peter Hess, Ian A. Mackenzie, Elina Marmer, Martin G. Schultz, Sophie Szopa, Oliver Wild, and Guang Zeng. "The Influence of Ozone Precursor Emissions from Four World Regions on Tropospheric Composition and Radiative Climate Forcing." *Journal of Geophysical Research: Atmospheres J. Geophys. Res.* 117.D7 (2012). Table S2, Supplemental Material.

Intergovernmental Panel on Climate Change (2013-14) *Fifth Assessment Report (AR5)* – Climate Change 2013: The Physical Science Basis

Intergovernmental Panel on Climate Change (2013-14) *Fifth Assessment Report (AR5)* – Climate Change 2013: The Physical Science Basis, Chapter 8 Supplemental Material. 2013.

Intergovernmental Panel on Climate Change (2018) Special Report: *Global Warming of 1.5°C* (SR1.5)

International Organization for Standardization. ISO 14090:2019.

MacCracken, M., The Climate Institute, "Expert Input to the Talanoa Dialogue," *2018 Talanoa Dialogue Platform*, April 2018.

Menon, S., D. Koch, G. Beig, S. Sahu, J. Fasullo, and D. Orlikowski, 2010. "Black carbon aerosols and the third polar ice cap." *Atmos. Chem. Phys.*, 10, 4559-4571, doi:10.5194/acp-10-4559-2010.

Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Chapter 8, Anthropogenic and Natural Radiative Forcing. Section 8.3.3.1: Tropospheric Ozone. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ramanathan, V., et al., *Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia.* 2008. Published by the United Nations Environment Programme, Nairobi, Kenya.

Shindell, D.T. et al, "Improved Attribution of Climate Forcing to Emissions," *Science*, Vol. 326, 716-720. October 2009.

Sitch, S. et al. *Indirect radiative forcing of climate change through ozone effects on the land-carbon sink.* Nature, 448, 791-794. 2007.

UNEP, 2008. *Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia, Summary.* (link)

UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone, 2011