updates since that report. Section 7.6.1 updates the physical assessment. Section 7.6.2 assesses developments in the comparison of emissions of short- and long-lived gases. Box 7.3 assesses physical aspects of emissions metric use within climate policy.

7.6.1 Physical Description of Metrics

This section discusses metrics that relate emissions to physical changes in the climate system. Other metrics, for instance relating to economic costs or 'damage' are discussed in WGIII, Chapter 2. The same Chapter also assesses literature examining the extent to which different physical metrics are linked to cost–benefit and cost-effectiveness metrics. One metric, the 100-year global warming potentials (GWP-100), has extensively been employed in climate policy to report emissions of different GHGs on the same scale. Other physical metrics exist, and these are discussed in this section.

Emissions metrics can be quantified as the magnitude of the effect a unit mass of emission of a species has on a key measure of climate change. This section focuses on physical measures such as the radiative forcing, GSAT change, global average precipitation change, and global mean sea level rise (Myhre et al., 2013b; Sterner et al., 2014; Shine et al., 2015). When used to represent a climate effect, the metrics are referred to as absolute metrics and expressed in units of 'effect per kg' (e.g., absolute global warming potentials, AGWP or absolute global temperature-change potentials, AGTP). More commonly, these are compared with a reference species (almost always CO_2 in kg (CO_2)), to give a dimensionless factor (written as e.g., global warming potentials (GWP) or global temperature-change potential (GTP)). The unit mass is usually taken as a 1 kg instantaneous 'pulse' (Myhre et al., 2013b), but can also refer to a 'step' in emissions rate of 1 kg yr^{-1}.

There is a cause–effect chain that links human activity to emissions, then from emissions to radiative forcing, climate response and climate impacts (Fuglestvedt et al., 2003). Each step in the causal chain requires an inference or modelling framework that maps causes to effects. Emissions metrics map from emissions of some compound to somewhere further down the cause-and-effect chain, radiative forcing (e.g., GWP) or temperature (e.g., GTP) or other effects (such as sea level rise or socio-economic impacts). While variables later in the chain have greater policy or societal relevance, they are also subject to greater uncertainty because each step in the chain includes more modelling systems, each of which brings its own uncertainty (Figure 1.15; Balcombe et al., 2018).

Since AR5, understanding of the radiative effects of emitted compounds has continued to evolve and these changes are assessed in Section 7.6.1.1. Metrics relating to precipitation and sea level have also been quantified (Section 7.6.1.2). Understanding of how emissions metrics are affected by the carbon cycle response to temperature has improved. This allows the carbon cycle response to temperature to be more fully included in the emissions metrics presented here (Section 7.6.1.3). There have also been developments in approaches for comparing short-lived GHGs to CO_2 in the context of mitigation and global surface temperature change (Section 7.6.1.4). Emissions metrics for selected key compounds are presented in Section 7.6.1.5.

7.6.1.1 Radiative Properties and Lifetimes

The radiative properties and lifetimes of compounds are the fundamental component of all emissions metrics. Since AR5, there have been advances in the understanding of the radiative properties of various compounds (see Sections 7.3.1, 7.3.2 and 7.3.3), and hence their effective radiative efficiencies (ERFs per unit change in concentration). For CO_2, CH_4 and N_2O, better accounting of the spectral properties of these gases has led to re-evaluation of their stratospheric-temperature-adjusted radiative forcing (SARF) radiative efficiencies and their dependence on the background gas concentrations (Section 7.3.2). For CO_2, CH_4, N_2O, CFC-11 and CFC-12 the tropospheric adjustments (Sections 7.3.1 and 7.3.2) are assessed to make a non-zero contribution to ERF. There is insufficient evidence to include tropospheric adjustments for other halogenated compounds. The re-evaluated effective radiative efficiency for CO_2 will affect all emissions metrics relative to CO_2.

The effective radiative efficiencies (including adjustments from Section 7.3.2) for 2019 background concentrations for CO_2, CH_4 and N_2O are assessed to be 1.33×10^{-5}, 3.89×10^{-4} and 3.19×10^{-3} W m^{-2} ppb^{-1} respectively (see Table 7.15 for uncertainties), compared to AR5 assessments of 1.37×10^{-5}, 3.63×10^{-4} and 3.00×10^{-3} W m^{-2} ppb^{-1}. For CO_2, increases due to the adjustments do not quite balance the decreases due to the increasing background concentration. For CH_4, increases due to the re-evaluated radiative properties more than offset the decreases due to the increasing background concentration. For N_2O the addition of tropospheric adjustments increases the effective radiative efficiency. Radiative efficiencies of halogenated species have been revised slightly (Section 7.3.2.4) and for CFCs include tropospheric adjustments.

The perturbation lifetimes of CH_4 (Section 6.3.1). and N_2O (Section 5.2.3.1) have been slightly revised since AR5 to be 11.8 ± 1.8 years and 109 ± 10 years, respectively (Table 7.15). The lifetimes of halogenated compounds have also been slightly revised (Hodnebrog et al., 2020a).

Although there has been greater understanding since AR5 of the carbon cycle responses to CO_2 emissions (Sections 5.4 and 5.5), there has been no new quantification of the response of the carbon cycle to an instantaneous pulse of CO_2 emission since Joos et al. (2013).

7.6.1.2 Physical Indicators

The basis of all the emissions metrics is the time profile of effective radiative forcing (ERF) following the emission of a particular compound. The emissions metrics are then built up by relating the forcing to the desired physical indicators. These forcing–response relationships can either be generated from emulators (Cross-Chapter Box 7.1; Tanaka et al., 2013; Gasser et al., 2017b), or from analytical expressions based on parametric equations (response functions) derived from more complex models (Myhre et al., 2013b).

To illustrate the analytical approach, the ERF time evolution following a pulse of emission can be considered an absolute global forcing potential (AGFP; similar to the 'Instantaneous Climate Impact' of Edwards and Trancik, 2014). This can be transformed into an absolute