IPCC Expert Meeting on Short-lived Climate Forcers
Geneva 28-31 May 2018

Emission metrics for SLCFs

Keith P Shine
Department of Meteorology, University of Reading, UK
k.p.shine@reading.ac.uk

With particular thanks to: Myles Allen, Michelle Cain, Jan Fuglestvedt

University of Reading

- Background and how we got to where we are
- Metrics in the context of long-term temperature goals

Note: In this talk, I often use CO_2 as the example long-lived gas and methane (CH_4) as the example SLCF. But conclusions apply more generally to other SLCFs

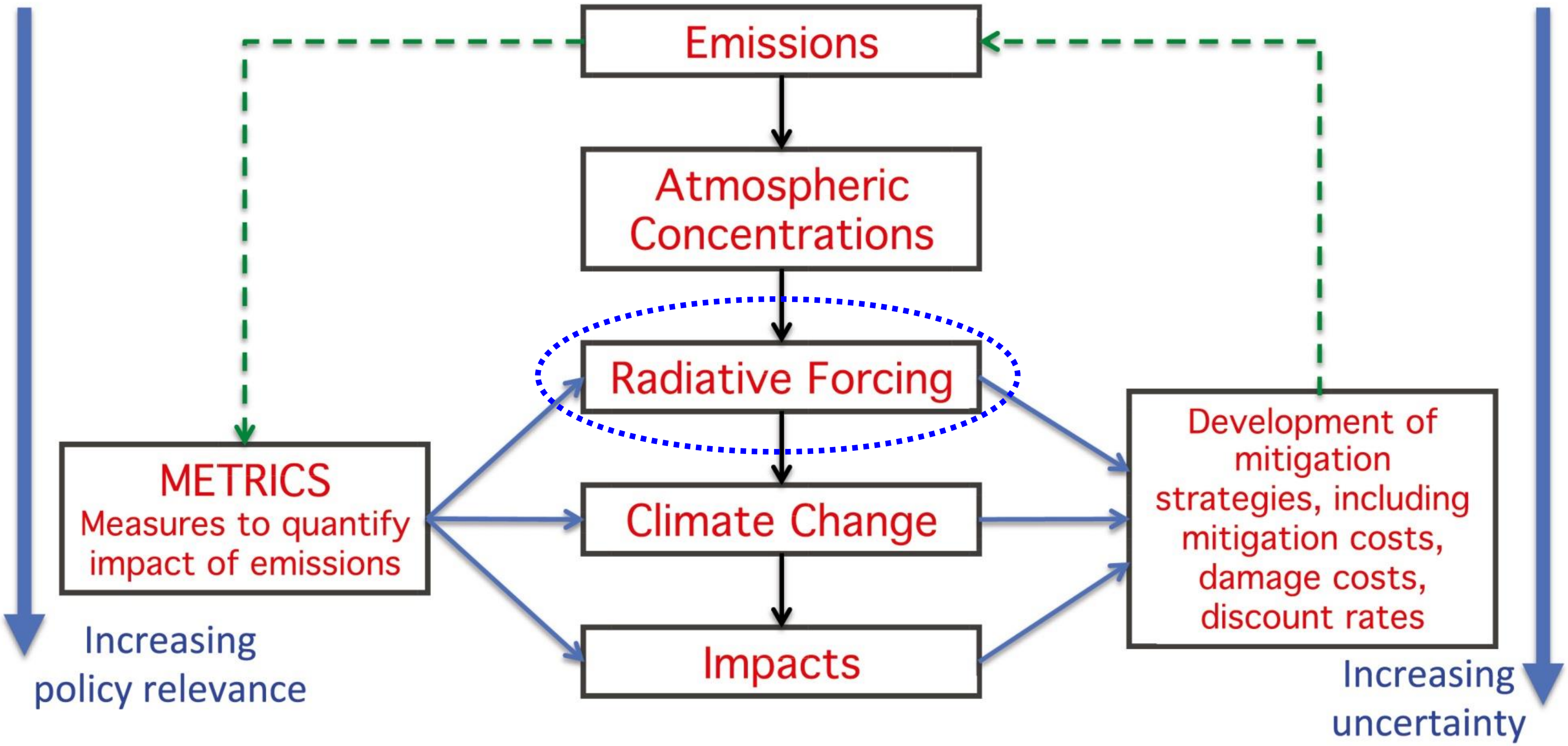
University of Reading

Metric design

- Climate emission metrics provide an "exchange rate". They allow the climate effect of emissions of species to be compared with emissions of CO_2
- Emissions of all species can then be placed on a common scale ("CO_2-equivalent (CO_2-e) emissions")
- If a metric is perfect, the same CO_2–e emissions from a different mix of species would produce the same climate effect; in practice conventional metrics fail to do this
- Many choices have to be made in choosing an appropriate metric
- Ultimately, choices should be guided by the policy that the metric aims to serve

University of Reading

Choice of climate impact

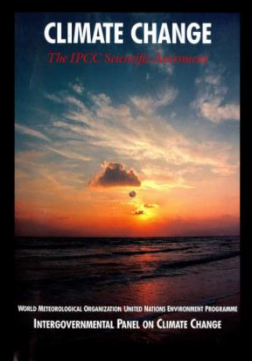


IPCC AR5 WG1 Fig 8.27

IPCC, the Kyoto Protocol and GWP

- Kyoto Protocol uses the *100-year* GWP (GWP_{100}), mostly from IPCC's 2nd Assessment (1995)
- NDC's use values from a variety of assessments
- GWP is *generally* accepted as an appropriate measure by the user community, and has played an important role in enabling Kyoto
- At the time of Kyoto, GWP was the only metric that IPCC had assessed: Kyoto chose GWP_{100}
- AR5 also assessed the Global Temperature-change Potential (GTP) but recommended *neither* the GWP or GTP (AR4 *did* recommend GWP)
- The CO_2-e problem is shared by all these conventional metrics

University of Reading

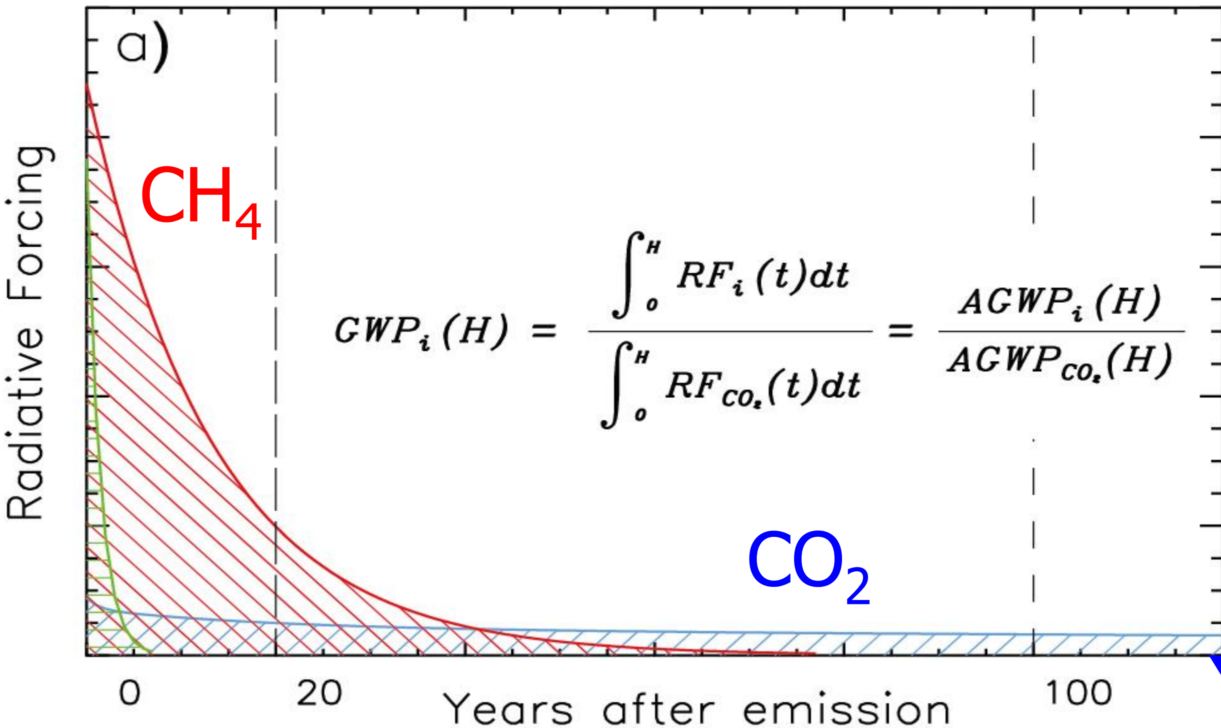


The Global Warming Potential (GWP) - the view from IPCC's First Assessment Report …

Section 2.2.7: "… there is no universally accepted methodology for combining … relevant factors into a single (metric) … A *simple* approach [i.e. the GWP] has been adopted here to illustrate the difficulties inherent in the concept …"

It presented three time-horizons (20, 100 and 500 yr)… `*as candidates for discussion [that] should not be considered as having any special significance*'

What is the GWP?



The time-integrated radiative forcing in response to a pulse emission of a species (relative to the same quantity for a emission of the same mass of CO_2)

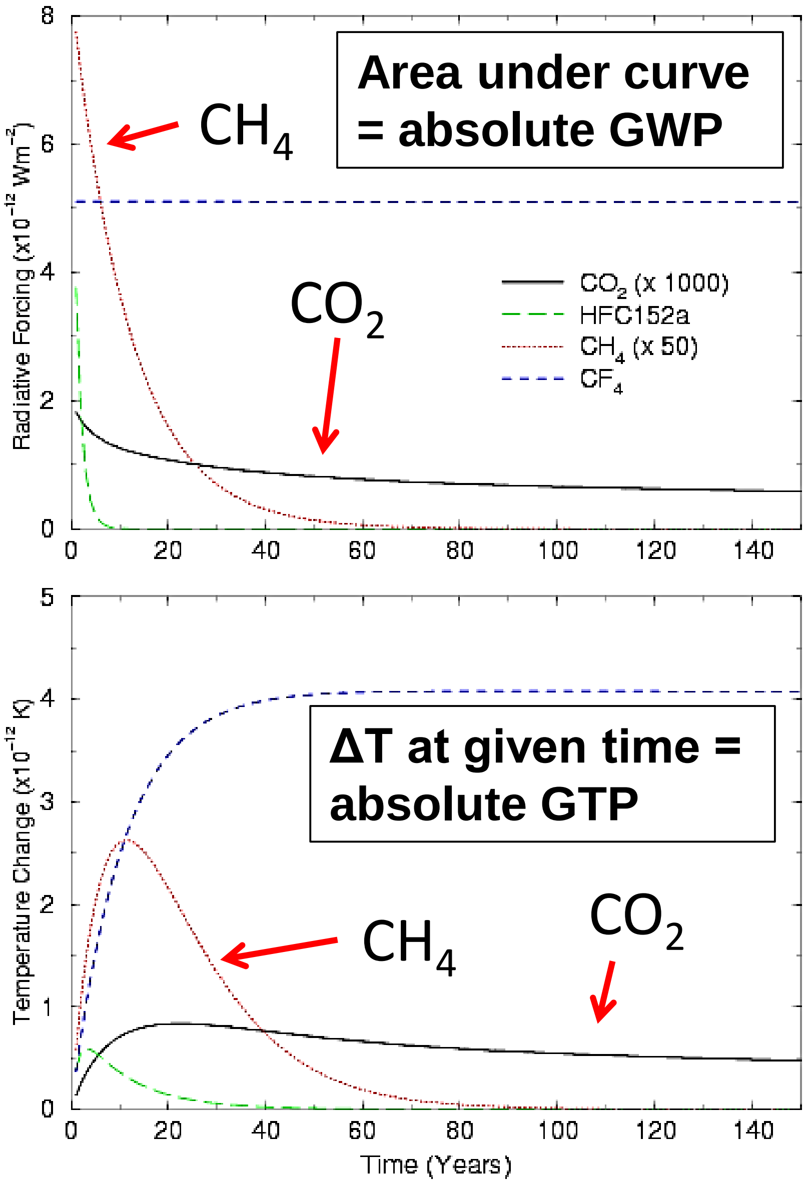
Note! Persistence of CO_2

GWP has a strong memory of short-lived emissions even after they have disappeared from the atmosphere

IPCC AR5 WG1 Chapter 8

University of Reading

GWP and temperature

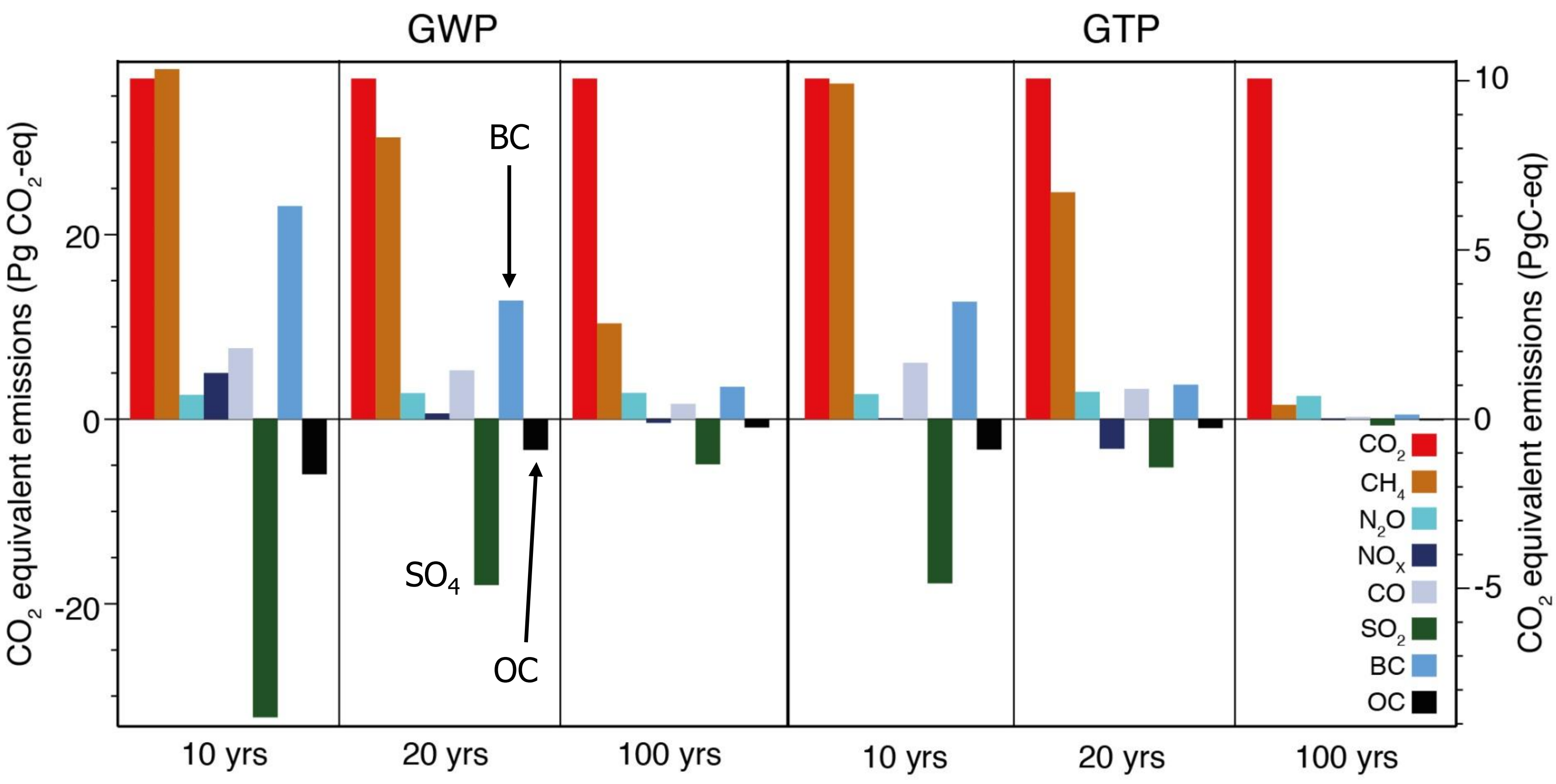


- It does not represent the temperature impact: CO_2's impact persists; CH_4's is small after ≈50 years (neglecting carbon-cycle feedbacks)
- Long-term temperature impact of CO_2 *pulse* emission can only be matched by *sustained* SLCF emissions

Shine et al, Cli Change (2005)

University of Reading

Impact of metric choice on perceived CO_2-e



IPCC AR5 WG1 Chapter 8 – global emissions

Example of uncertainty: evolution of methane GWP_{100}

	GWP (100)
FAR (1990)	21
RF Rep (1994)	24.5
SAR (1995)	**21**
TAR (2001)	23
AR4 (2007)	25
AR5 (2013)	**28**

- IPCC GWP_{100} has changed with time: reflects changing understanding of CH_4 lifetime and indirect effects, CO_2 properties, etc. **Volatility ≥ for other SLCFs** – important in policy usage
- Stated uncertainty in CH_4 GWP_{100} is ±40%. Greater for SLCFs.
- (If post-AR5 science developments are assessed to be robust by AR6, GWP_{100} could increase to ≈ 35)

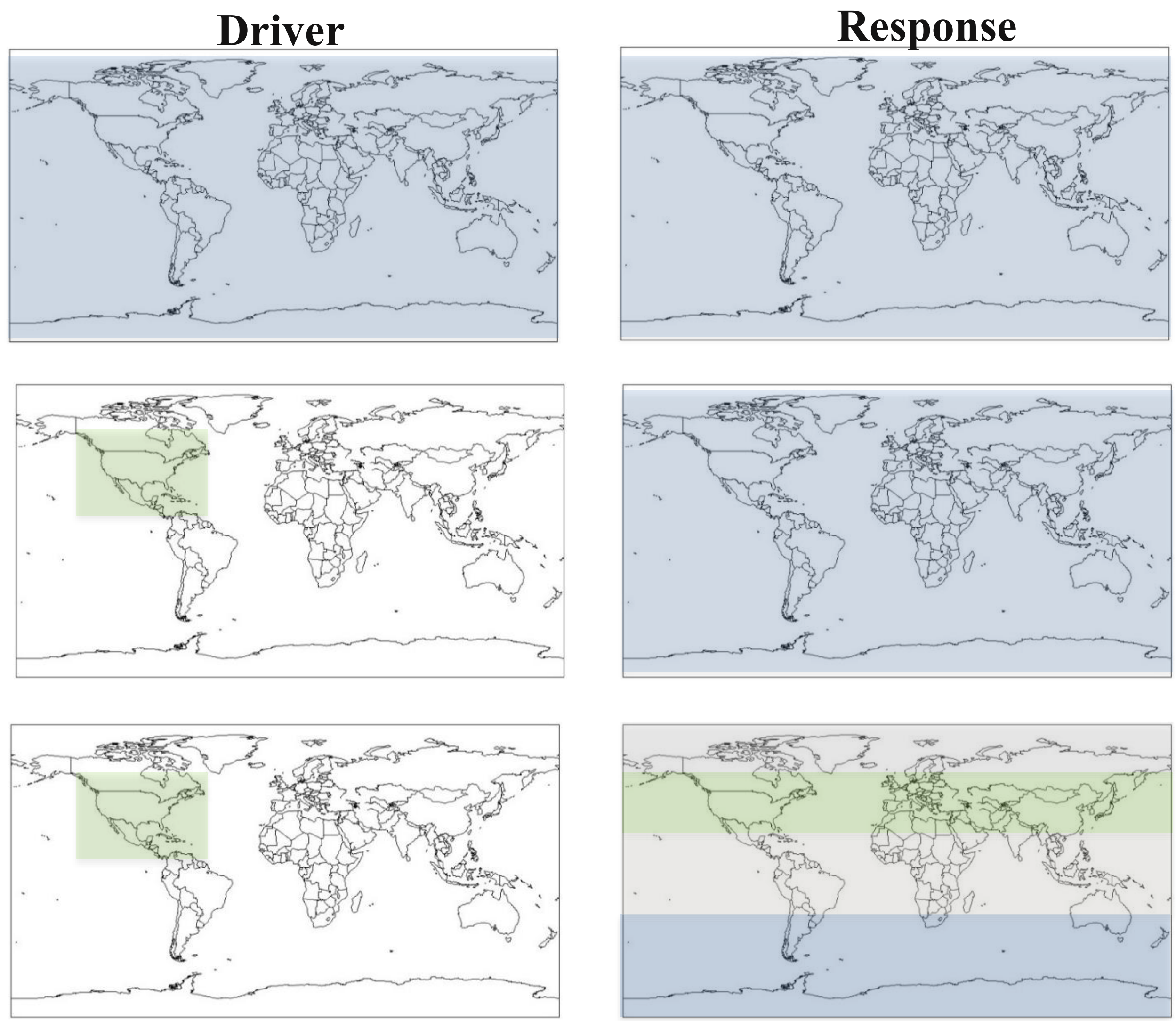
University of Reading

For SLCFs, the <u>global</u> impact depends on where (and when) emissions occurs

Global to global

Regional to global

Regional to regional



Figures from Jan Fuglestvedt

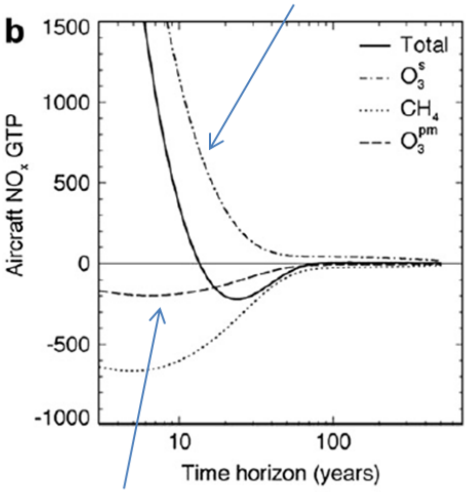
Example of dependence on location of emissions

Table 8.A.3 | GWP and GTP for NO_x from surface sources for time horizons of 20 and 100 years from the literature. All values are on a per kilogram of nitrogen basis. Uncertainty for numbers from Fry et al. (2012) and Collins et al. (2013) refer to 1-σ. For the reference gas CO_2, RE and IRF from AR4 are used in the calculations. The GWP_{100} and GTP_{100} values can be scaled by 0.94 and 0.92, respectively, to account for updated values for the reference gas CO_2. For 20 years the changes are negligible.

	GWP		GTP	
	H = 20	H = 100	H = 20	H = 100
NO_x East Asia[a]	6.4 (±38.1)	–5.3 (±11.5)	–55.6 (±23.8)	–1.3 (±2.1)
NO_x EU + North Africa[a]	–39.4 (±17.5)	–15.6 (±5.8)	–48.0 (±14.9)	–2.5 (±1.3)
NO_x North America[a]	–2.4 (±30.3)	–8.2 (±10.3)	–61.9 (±27.8)	–1.7 (±2.1)
NO_x South Asia[a]	–40.7 (±88.3)	–25.3 (±29.0)	–124.6 (±67.4)	–4.6 (±5.1)
NO_x four above regions[a]	–15.9 (±32.7)	–11.6 (±10.7)	–62.1 (±26.2)	–2.2 (±2.1)
Mid-latitude NOx[c]	–43 to +23	–18 to +1.6	–55 to –37	–2.9 to –0.02
Tropical NO_x[c]	43 to 130	–28 to –10	–260 to –220	–6.6 to –5.4
NO_x global[b]	19	–11	–87	–2.9
NO_x global[d]	–108 ± 35 –335 ± 110 –560 ± 279	–31 ± 10 –95 ± 31 –159 ± 79		

IPCC AR5 WG1 Chapter 8

Short-lived ozone (warming)



methane-induced ozone (cooling)

methane reduction due to NOx (cooling)

NOx as a example. AR5 included additional SLCFs. How would/could this regionality be handled?

Fuglestvedt et al. Atmos Env 2010

Returning to the global perspective …

Reconciling short-lived versus long-lived emission in the context of 1.5/2º target

nature climate change
LETTERS
PUBLISHED ONLINE: 2 MAY 2016 | DOI: 10.1038/NCLIMATE2998

New use of global warming potentials to compare cumulative and short-lived climate pollutants

Myles R. Allen[1,2]*, Jan S. Fuglestvedt[3], Keith P. Shine[4], Andy Reisinger[5], Raymond T. Pierrehumbert[2] and Piers M. Forster[6]

And: Allen et al. (2018) to appear in npj Climate and Atmospheric Science on 5 June
10.1038/s41612-018-0026-8 (not yet active)

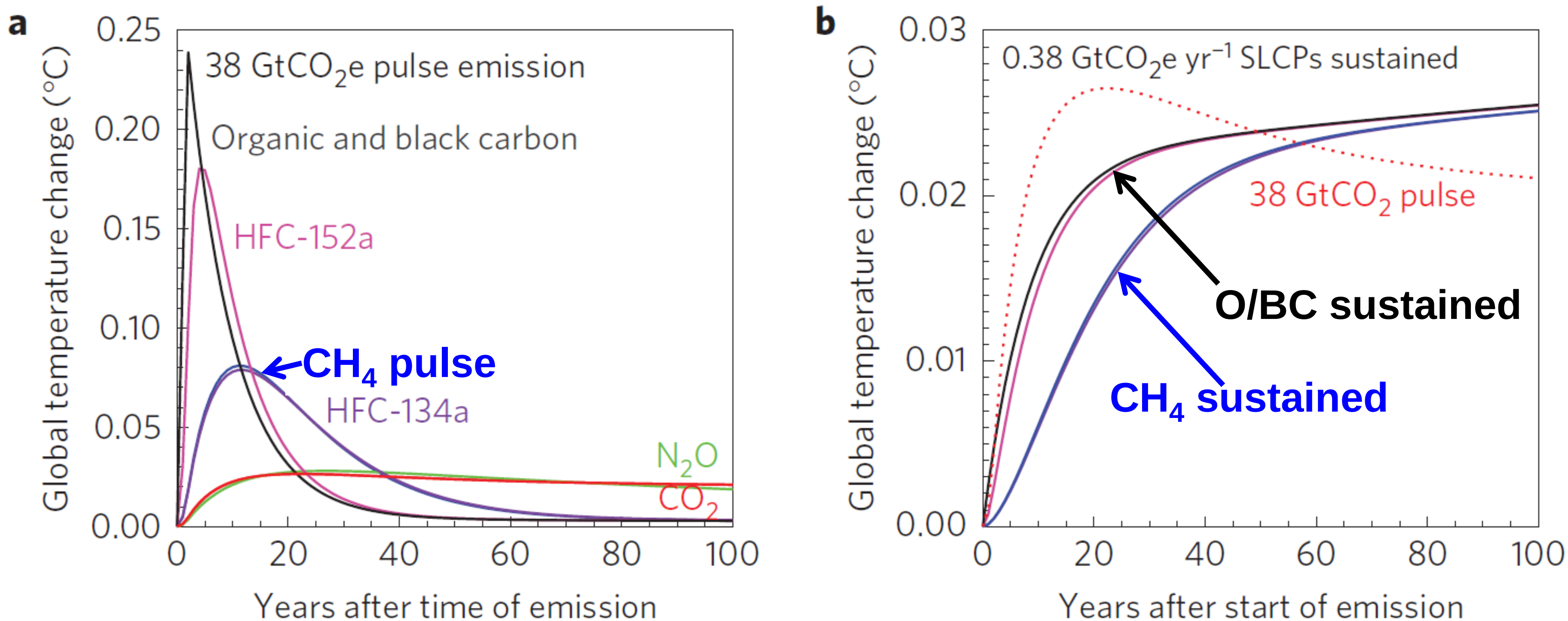
Environ. Res. Lett. 13 (2018) 054003 https://doi.org/10.1088/1748-9326/aab89c

Increased importance of methane reduction for a 1.5 degree target

William J Collins[1,6], Christopher P Webber[1], Peter M Cox[2], Chris Huntingford[3], Jason Lowe[4,5], Stephen Sitch[2], Sarah E Chadburn[2,5], Edward Comyn-Platt[3], Anna B Harper[2], Garry Hayman[3] and Tom Powell[2]

University of Reading

Equivalence between a *pulse* CO_2 emission and *sustained* change in SLCF emission rate



(38 $GtCO_2$ is the 2011 anthropogenic emissions of CO_2; total CH_4 emissions are the same in both frames)

Allen et al. Nature CC (2016),

University of Reading

An improved metric? GWP*

- The conventional usage of GWP_{100} says that the CO_2 equivalence of CH_4 emission is given by

$$CO_2\text{-e[tonnes]} = GWP_{100} \times CH_4 \text{ Emission[tonnes]}$$

- The "equivalence" is such that the integrated radiative forcing over 100 years is the same for the CH_4 pulse and the equivalent pulse of CO_2
- Under GWP*, the CO_2 equivalence comes from the *change* in CH_4 emission *rate*

$$CO_2\text{-e*[tonnes]} = H \times GWP_H \times \text{change in } CH_4 \text{ emission rate [tonnes per year]}$$

- The "equivalence" is temperature change rather than integrated forcing: arguably more aligned with Paris goals

University of Reading

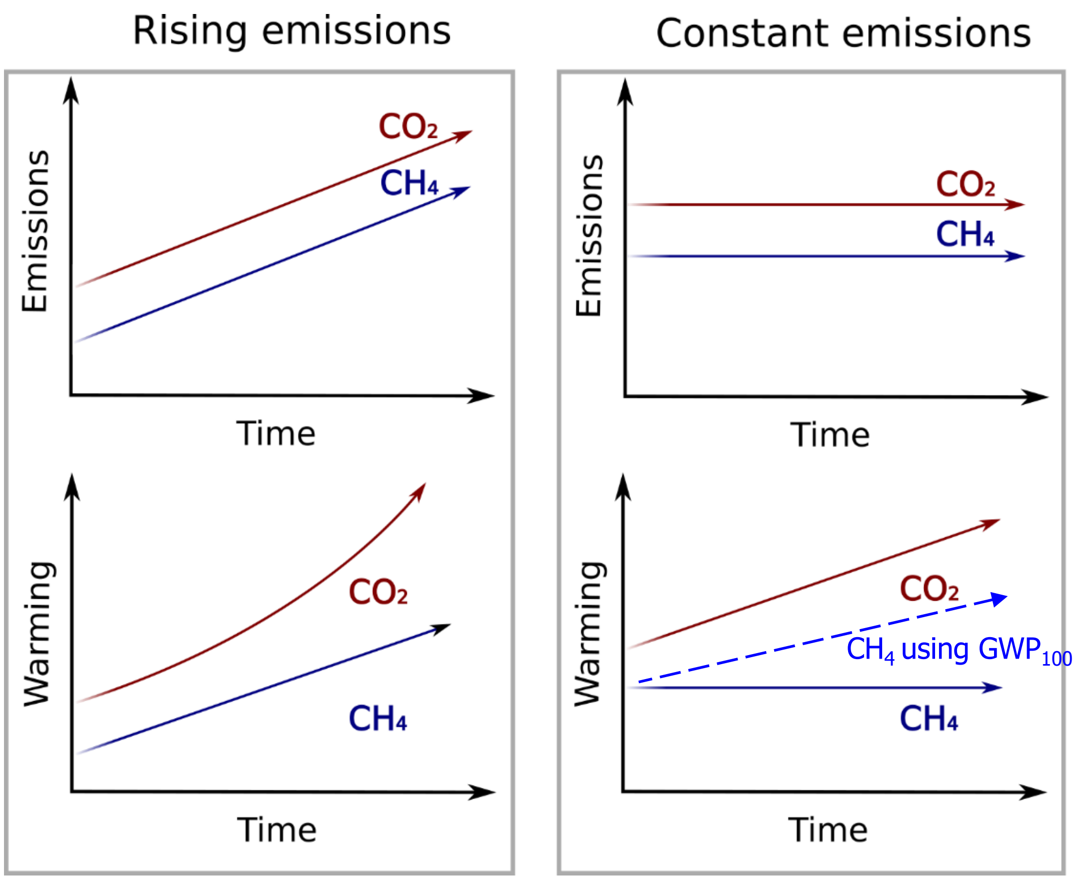
Examples

- Under GWP, a 1 tonne CH_4 pulse is "equivalent" to a 28 tonne CO_2 pulse (IPCC AR5 GWP_{100} for CH_4=28)
- Under GWP* = H x GWP(H), a 1 tonne per year *increase* in CH_4 emission rate is equivalent to a 100x28 = 2800 tonne (one-off) CO_2 pulse. (Dependence on H is quite modest)
- And similarly, a 1 tonne per year *decrease* in CH_4 emission rate is equivalent to a 2800 tonne (one-off) *removal* of CO_2
- Equivalence only holds if CH_4 decrease is sustained indefinitely. If emissions go back up, equivalence is lost. A policy challenge.

University of Reading

Point 1: constant SCLF emissions equivalent to zero CO_2 emissions

- Constant CH_4 emissions cause no *further* ΔT
- CO_2-e using GWP_{100} would say they continue to warm
- (Constant CH_4 emissions continue to elevate temperature and so retain mitigation potential)

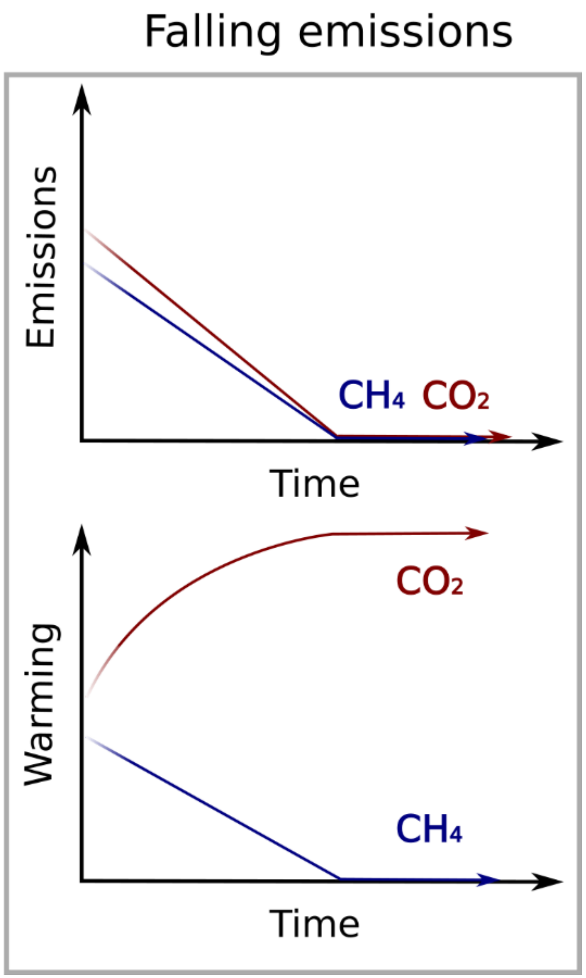


Cain et al. Martin School Brief

University of Reading

Point 2: falling SLCF* emissions equivalent to CO_2 removal

- *Falling* CH_4 emissions are equivalent to CO_2 removal; they cause a cooling
- Conventional (GWP_{100}) CO_2-e says that they cause additional warming until emissions reach zero



* Assuming the SLCF causes a warming!

Cain et al. Martin School Brief

University of Reading

The story so far

- CO_2-e using GWP might be reasonable when emissions increase; it **fails** when they are constant or falling
- Arguably the greatest challenge to the "integrity" of GWPs since IPCC's First Assessment (1990)

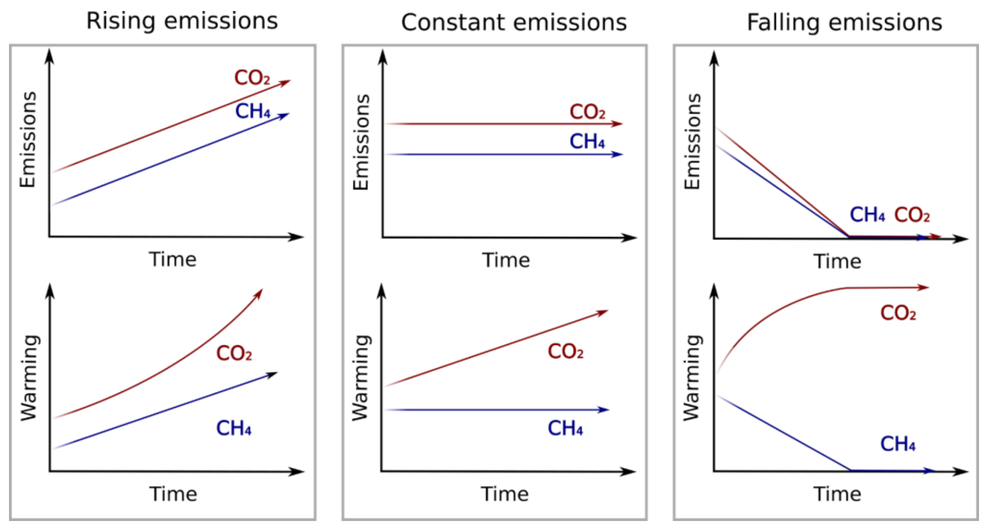
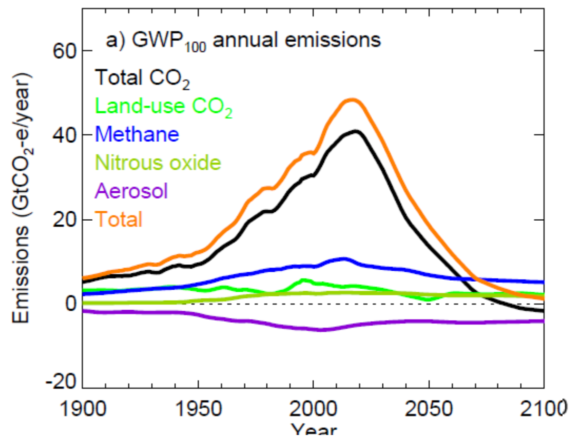
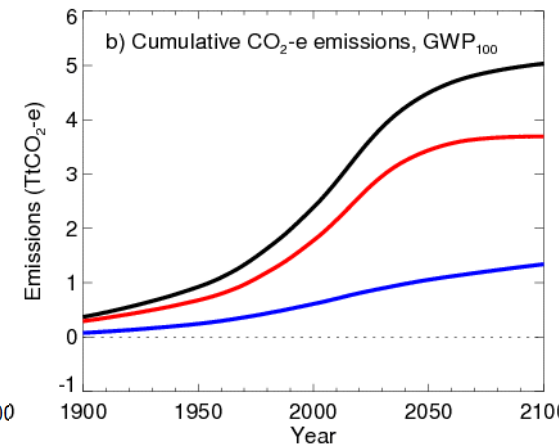


Illustration using RCP2.6†: with GWP_{100}

Annual emissions in CO_2-e using GWP_{100}





Cumulative CO_2–e emissions using GWP_{100}

- The CO_2-e is calculated using GWP_{100}
- CO_2 and CH_4 emissions rise and then fall; but using CO_2–e, CH_4 seems to accumulate in the atmosphere

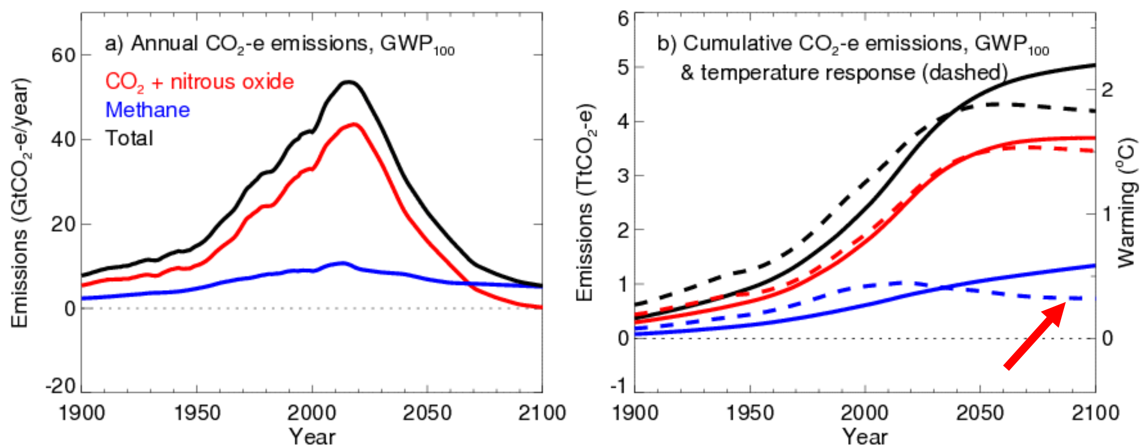
† RCP2.6: IPCC's Representative Concentration Pathway aiming for 2 deg C

Allen et al. 2018 to appear in npj Climate and Atmospheric Science

University of Reading

Illustration using RCP2.6: with GWP_{100}

Annual emissions in CO_2-e using GWP_{100}



Cumulative CO_2–e and temperature changes (dashed)

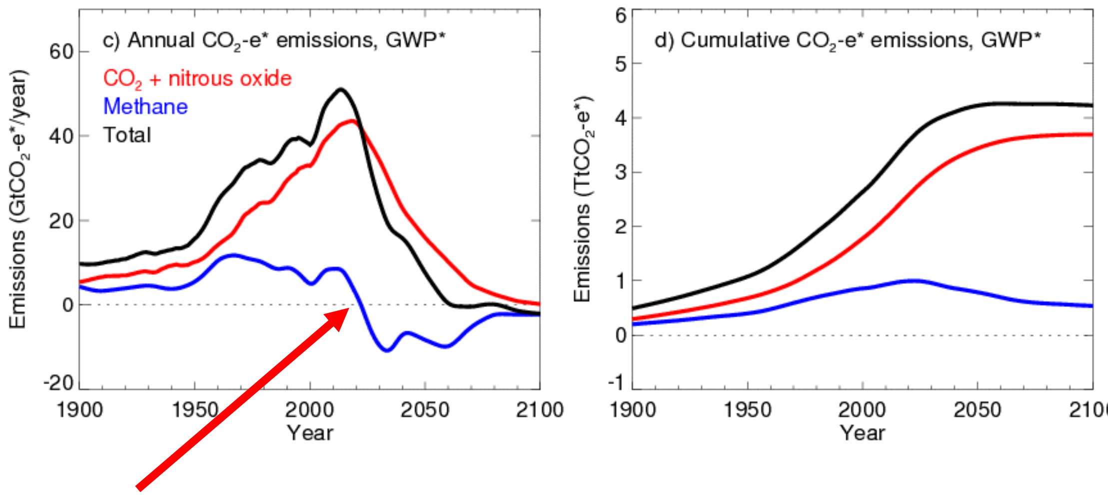
- Cumulative CO_2-e works well for CO_2 (!)
- For CH_4, even though emissions fall and cause temperature to decrease, CO_2-e using GWP_{100} cannot capture this

Allen et al. 2018 to appear in npj Climate and Atmospheric Science

University of Reading

Illustration using RCP2.6: with GWP*

Annual emissions in CO_2-e* using GWP*



Cumulative CO_2–e* emissions using GWP*

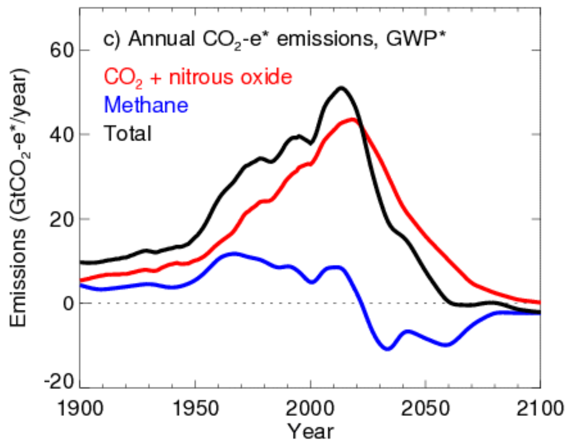
- Under GWP*, the <u>change</u> in CH_4 emissions holds the CO_2 equivalence
- Once CH_4 emissions begin to fall, they become equivalent to removal of CO_2

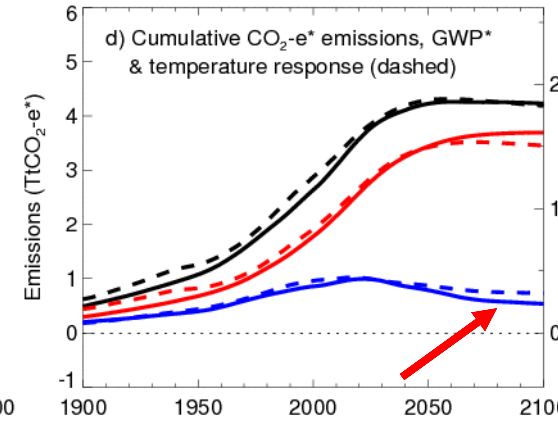
Allen et al. 2018 to appear in npj Climate and Atmospheric Science

University of Reading

Illustration using RCP2.6: with GWP*

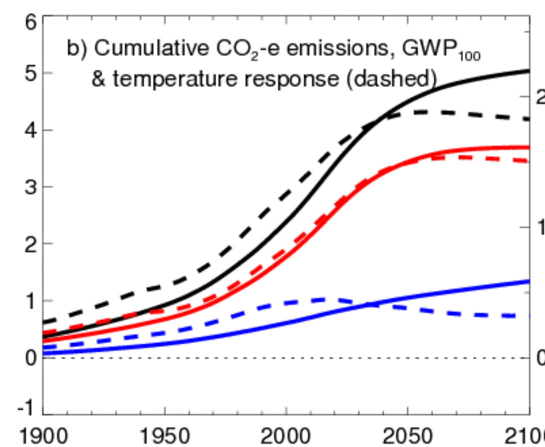
Annual emissions in CO_2-e* using GWP*





Cumulative CO_2–e* and temperature changes (dashed)

- Temperature response to CO_2-e* now works well for CH_4 (and hence for the total)



Using GWP_{100}

Allen et al. 2018 to appear in npj Climate and Atmospheric Science

University of Reading

Concluding thoughts

- GWP_{100} seems poorly suited for characterising CO_2-equivalence for constant/falling SLCF emissions in the temperature context
- The problem could be resolved via a new GWP usage that we call GWP*. This equates a sustained step decrease in SLCF emission rate with a one-off removal of CO_2 from the atmosphere
- GWP* seems better than GWP for monitoring progress to a long-term temperature goal, but the comparison of pulse (long-lived) and sustained (SLCF) emissions requires a change of thinking
- Any change in the metric used in international agreements would be disruptive and likely to be resisted by some/many
- Dependence of global impact on time and location of SLCF emissions is also a challenge

University of Reading