Emissions metrics for multi-component climate policies: Structural and scientific uncertainties

Jan Fuglestvedt

Bonn 3 April, 2012

Thanks to
Keith Shine, Dirk Olivié, Glen Peters, Borgar Aamaas, Terje Berntsen

CICERO Senter for klimaforskning www.cicero.uio.no
Center for International Climate and Environmental Research - Oslo

UNFCCC:

….policies and measures should …., be comprehensive, cover all relevant sources, sinks and reservoirs….

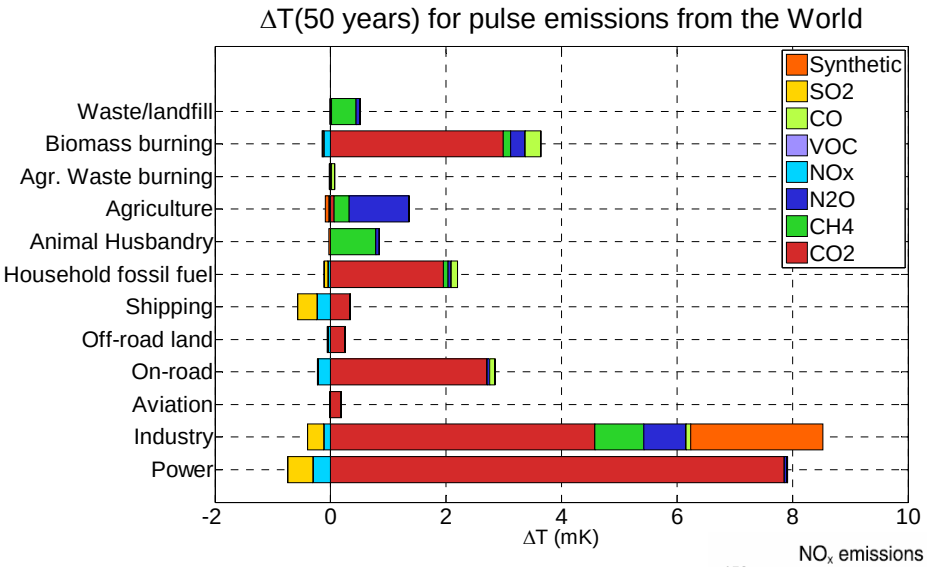
Kyoto Protocol: a *multi-gas approach (or "basket approach")*
CO_2, CH_4, N_2O, HFCs, PFCs, SF_6

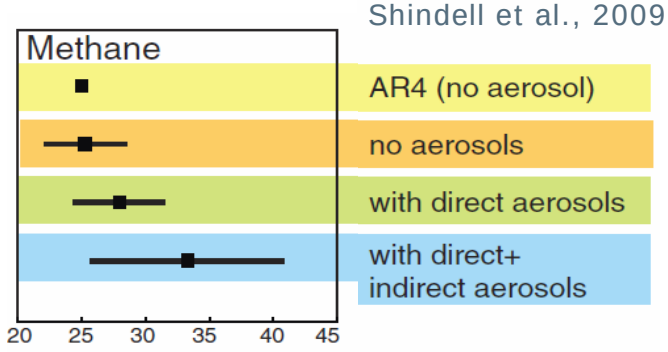
For this we need a metric:

- provides an "**exchange rate**"
- puts emissions on a **common scale**
- **E**mission x **M**etric = CO_2-equivalents
- Ideally, the **same climate effect** regardless of composition of equivalent CO_2 emissions

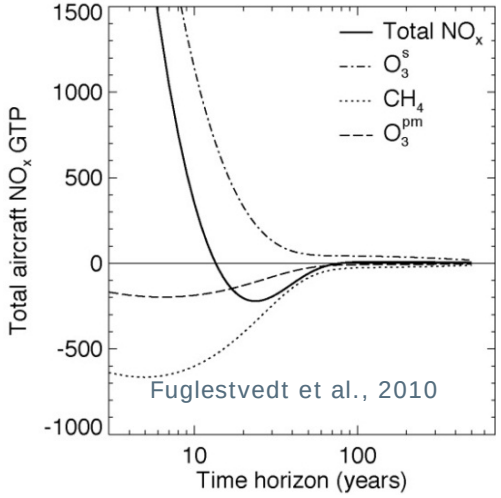
Applications of metrics:

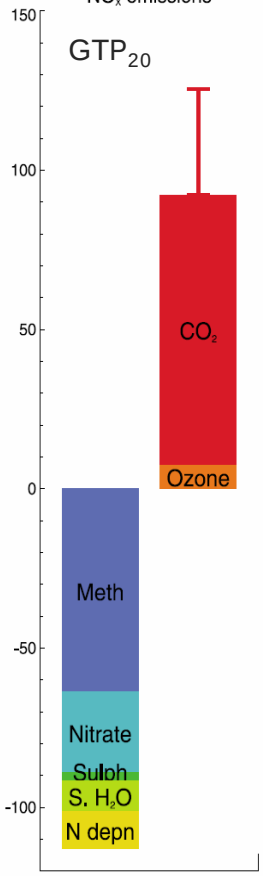
- **Climate agreements**
- **Emission trading**
- **climate policy assessments**
- **trade-offs in policy making**
- design and operation (e.g. aircraft)
- information about **properties** of components and **uncertainties**
- scientific analyses





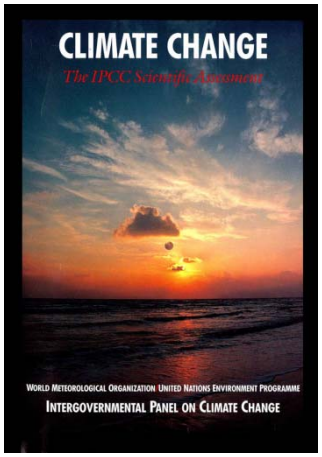
Shindell et al., 2009

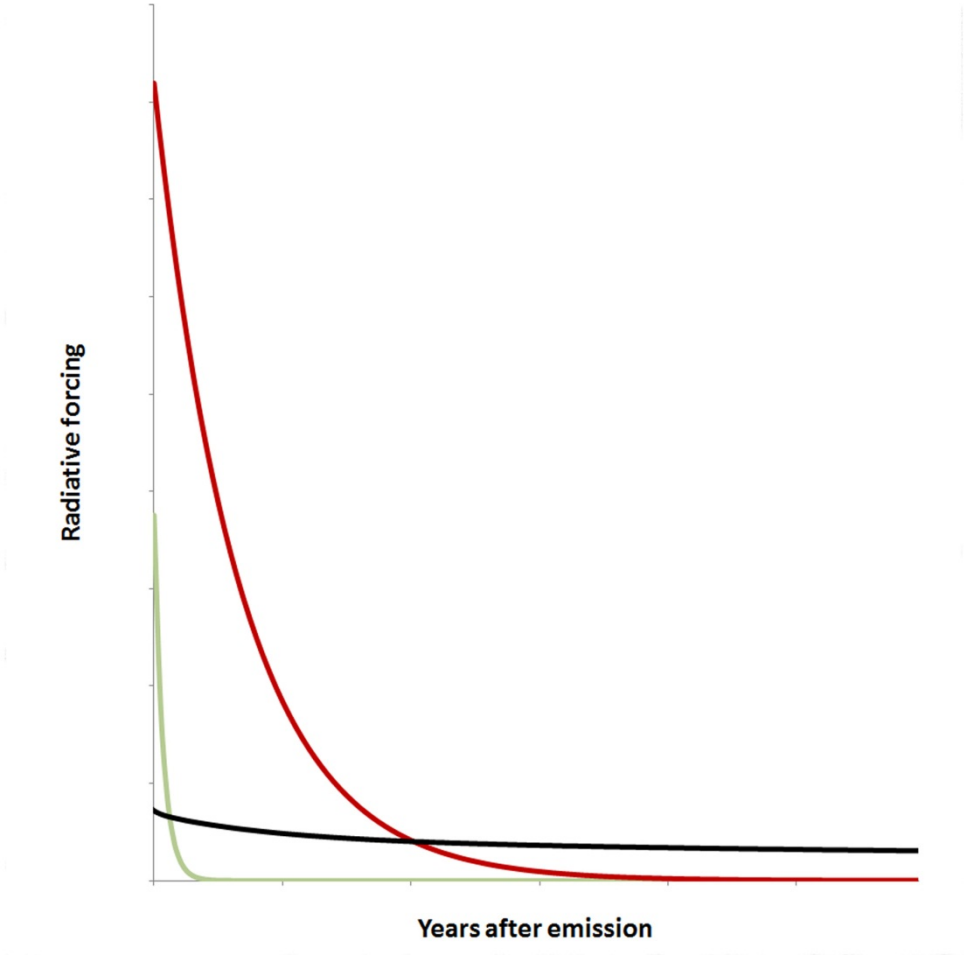




Collins et al., 2010

GWP: Based on pulses of different gases

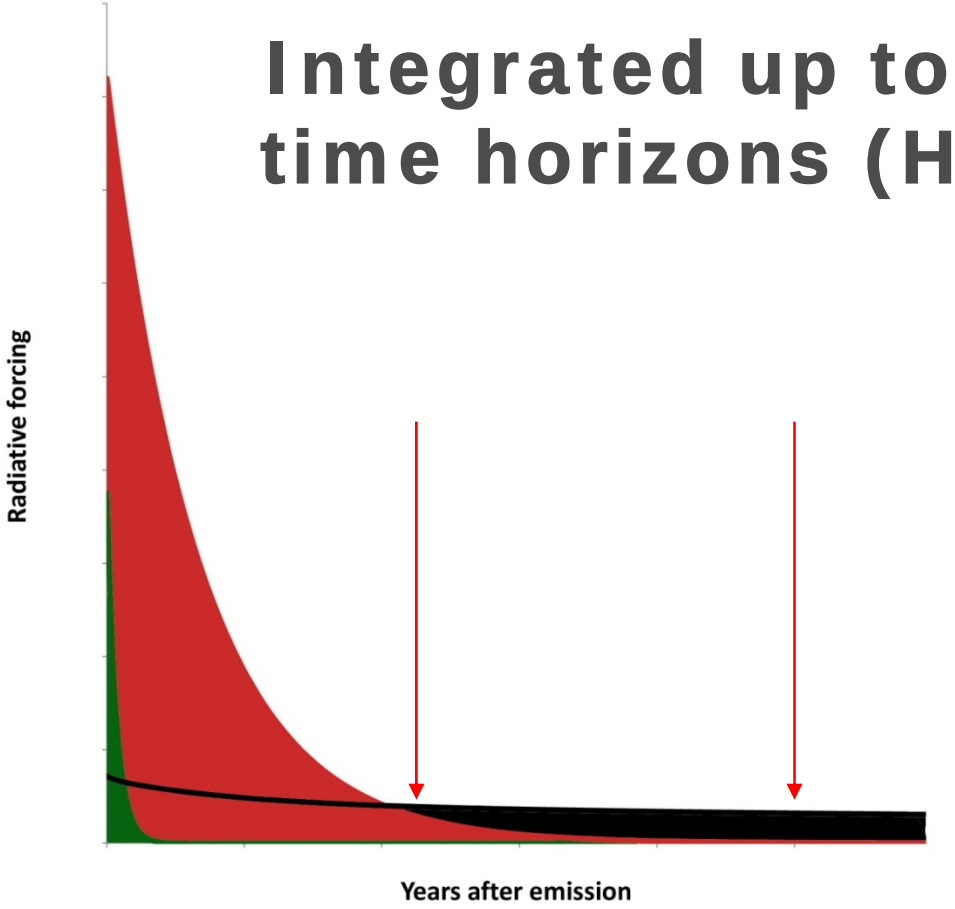


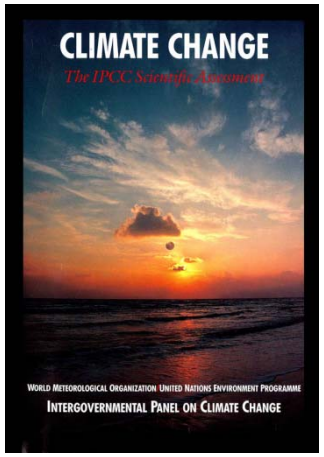


Adapted from Shine et al., 2005

GWP: Based on pulses of different gases

Integrated up to chosen time horizons (H)





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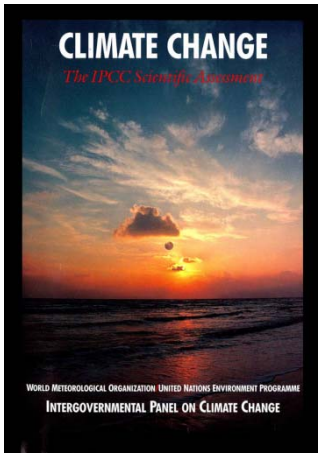
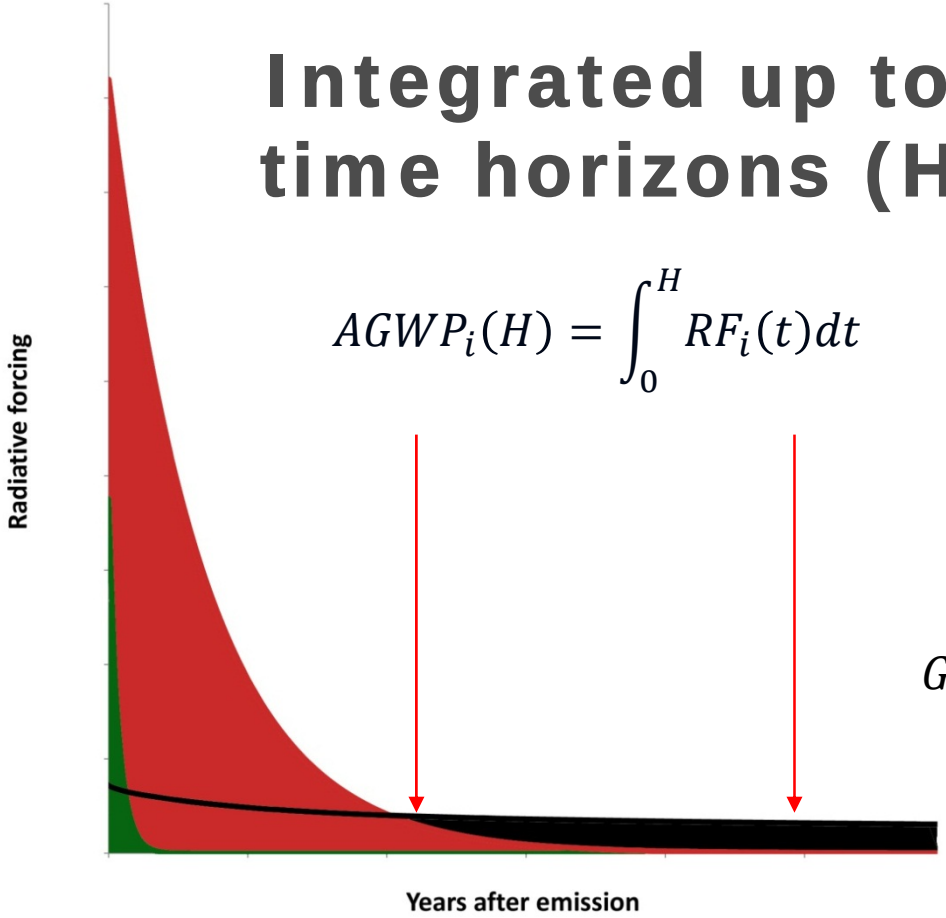
GWP: Based on pulses of different gases



Integrated up to chosen time horizons (H)

$$AGWP_i(H) = \int_0^H RF_i(t)dt$$



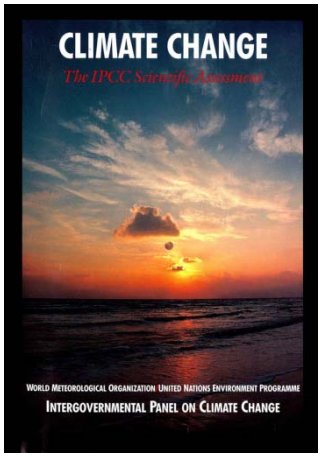
Then normalized to AGWP for CO_2:

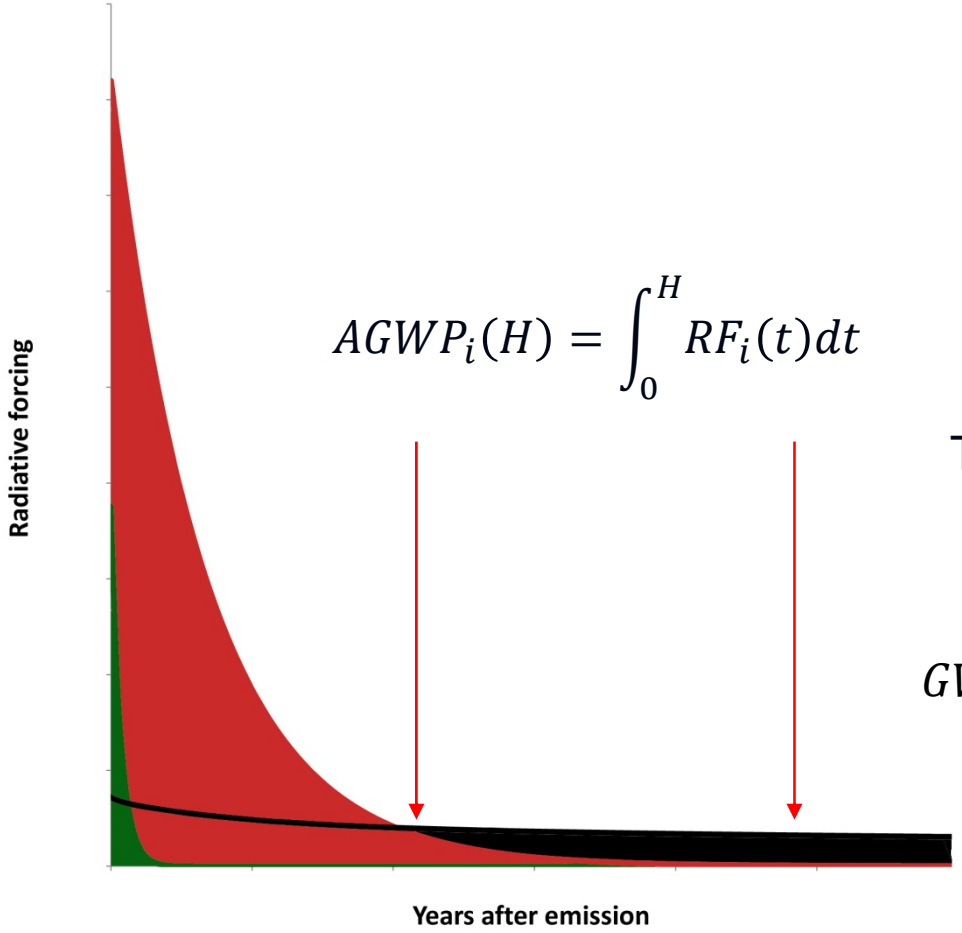
$$GWPi(H) = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)} = \frac{\int_0^H RF_i(t)dt}{\int_0^H RF_{CO_2}(t)dt}$$

Adapted from Shine et al., 2005

GWP has a strong and «artifical» memory.

Often misunderstood; no climate response included.





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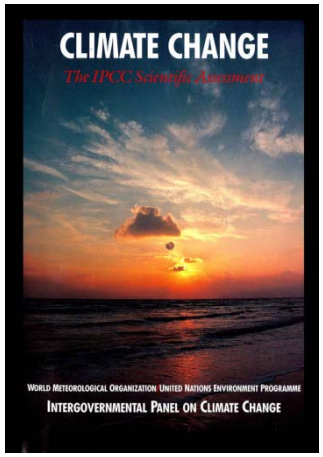
Adapted from Shine et al., 2005

The view from IPCC's First Assessment Report



"It must be stressed that there is no universally accepted methodology for combining all the 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 …" (Section 2.2.7)

GWP made the multi-gas approach in the Kyoto Protocol possible.

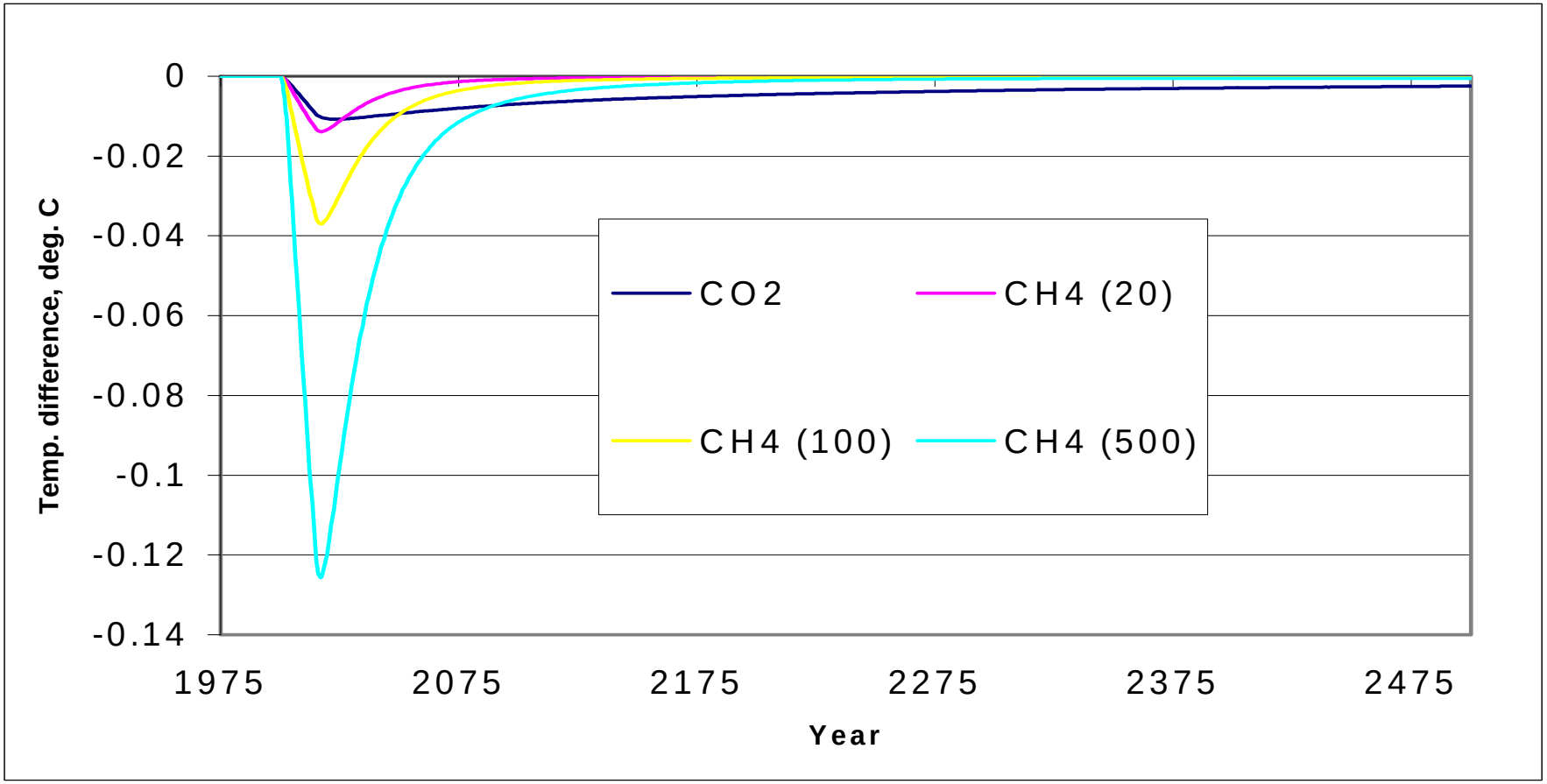
Interpretation?
What is the GWP an indicator of?

- Temperature effect at t=H ?
- Integrated Temperature change ?
- Proxy for damage ?
- ….?
- Ambiguous?
- Just the accumulated radiative forcing imposed on the system.

”The common scale”: CO_2 equivalents

$$CO_2\text{-eq}(H) = GWP_i(H) \times E_i$$

Equivalence?



No equivalence in Temperature, only a ”protocol equivalence”

Fuglestvedt et al. 2003 *Climatic Change*

UNFCCC ARTICLE 2:

….., stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a ***level*** *should be achieved* ***within a time-frame sufficient to allow ecosystems to adapt*** *naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

Explicit: ***Level*** of change Implicit: ***Rate*** of change

How to define a metric that fits with the goal of UNFCCC?

And/or the 2 deg C target

Climate impact:

RF, ΔTs, ΔSL, Damage (e.g. damage = $\alpha\Delta T^n$)

Adopted by the Kyoto Protocol as GWP

Temporal frame:

Rate or *level* of change at a chosen time

Integrated change over a finite time horizon

Discounted: changes in near future are more important than changes in far future ($\propto e^{-rt}$)

Pulses or sustained emissions?

Normalized or absolute metrics

CO_2 as reference

Not obvious that this matches the overall goal of UNFCCC

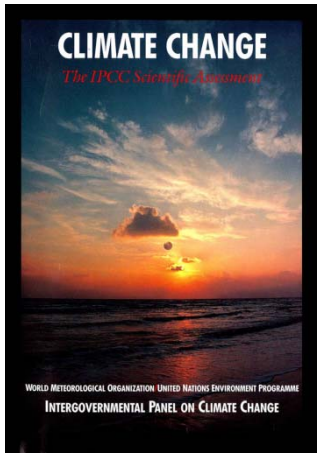
Space

Global mean vs *regional resolution (*applies both to emissions and response*)*

Economic approach:

Minimise abatement costs + climate damage costs

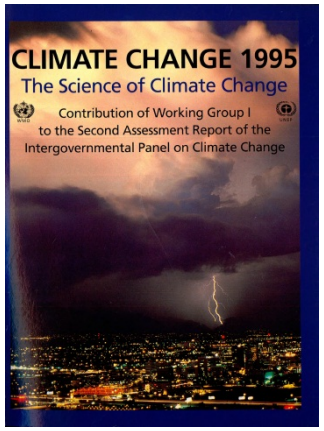
Abatement costs minimised with a climate impact as a given ceiling



Time horizon

IPCC 1990 presented three time-horizons (20, 100 and 500 yr)…

….'*as candidates for discussion [that] should not be considered as having any special significance*'

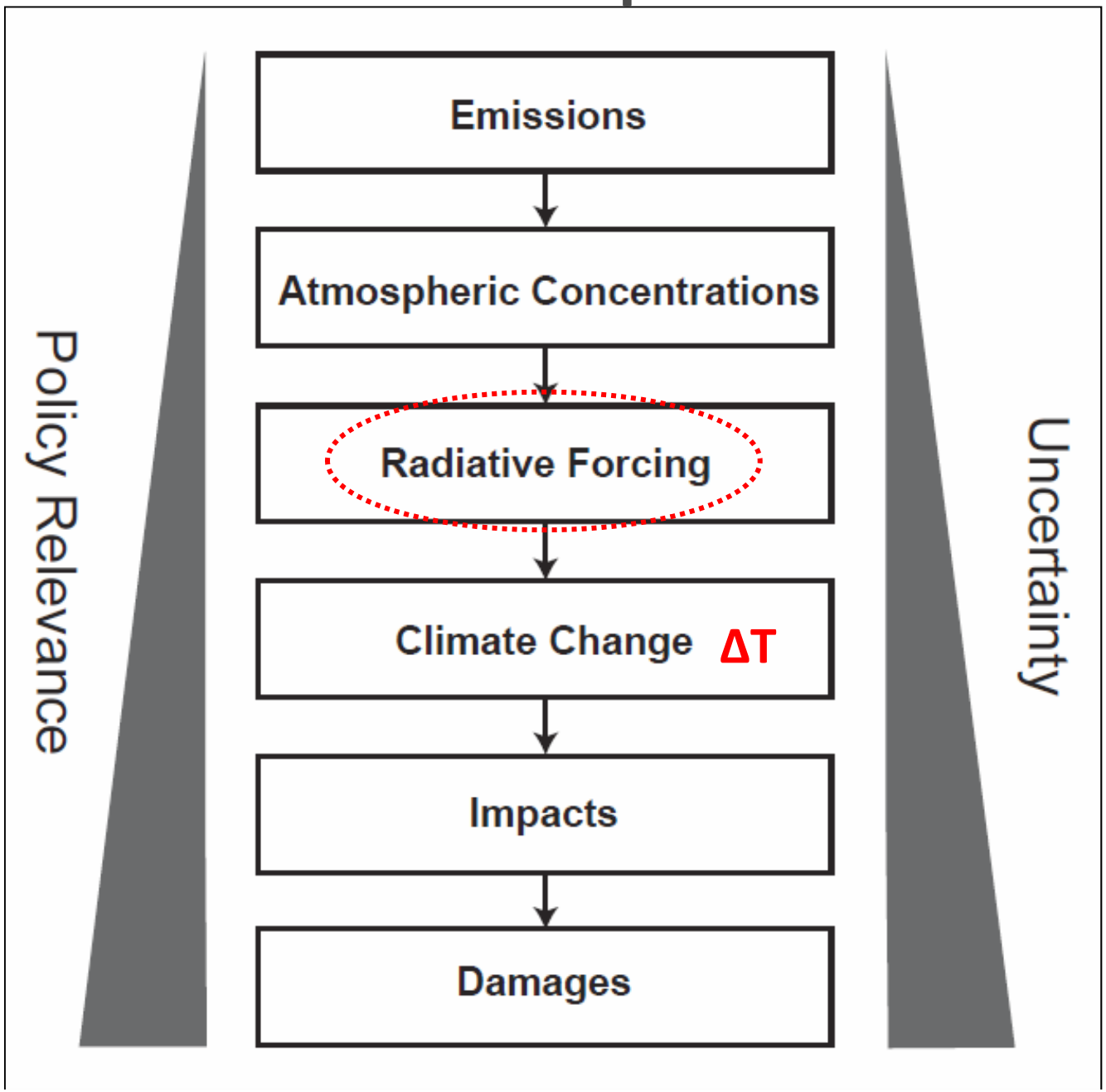


Kyoto Protocol: 100 years was chosen

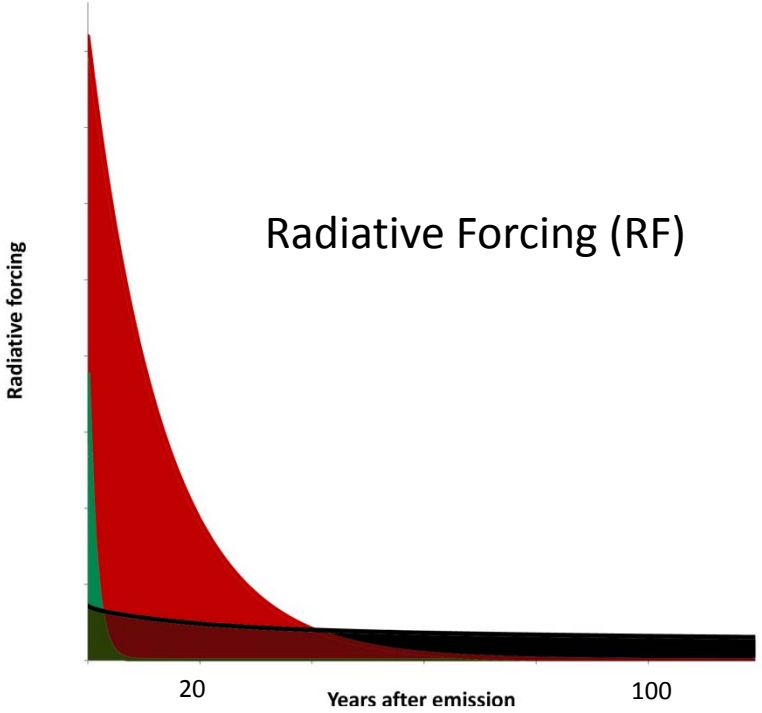
SAR	GWP_{20}	**GWP_{100}**	GWP_{500}
CH_4	56	**21**	6.5

Shine, 2009: *"It seems to be widely believed that the Kyoto Protocol chose a 100 year time horizon, because it was the middle one of the three (20, 100 and 500 years) that happened to be presented in IPCC reports."*

Choice of climate impact



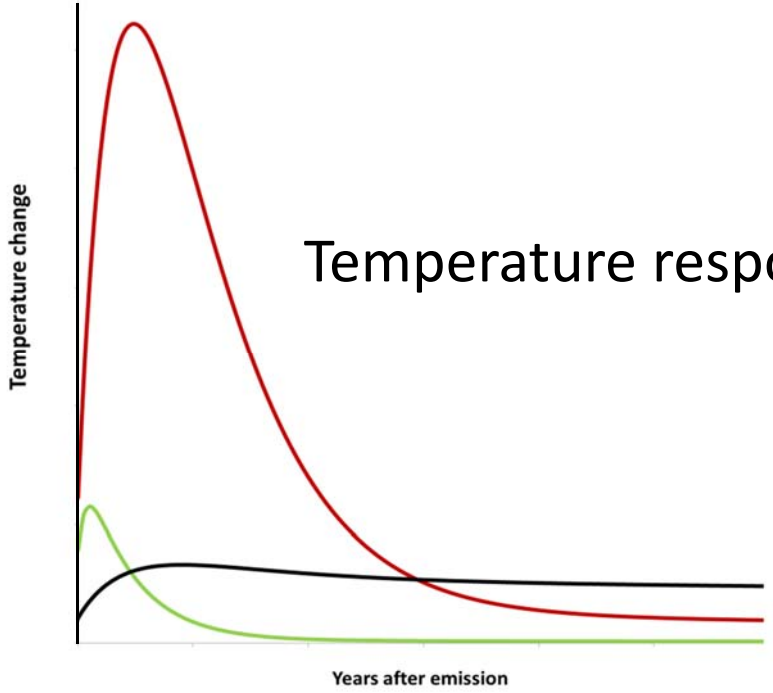
Fuglestvedt et al., 2003;
Plattner et al., 2009



Radiative Forcing (RF)

$$GWP_i(H) = \frac{\int_0^H RF_i(t)dt}{\int_0^H RF_{CO_2}(t)dt} = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)}$$

➔ strong memory
(often misunderstood; no climate response included)



Temperature response

$$GTP_i(t) = \frac{AGTP(t)_i}{AGTP(t)_{CO_2}} = \frac{\Delta T(t)_i}{\Delta T(t)_{CO_2}}$$

Large differences between GTP and GWP for short-lived components

	Lifetime (yrs)	GWP(20)	GWP(100)	GWP(500)	GTP(20)	GTP(50)	GTP(100)
CH_4	12	72	25	7.6	57	12	4
N_2O	114	289	298	153	303	322	265
CF_4	50 000	5210	7390	11200	5620	7560	9180
HFC-134a	14	3830	1430	435	3140	795	225
HFC-152a	1.4	437	124	38	149	22	18

Fuglestvedt and Shine et al. (ATTICA) 2010

UNITED NATIONS

Framework Convention on Climate Change

Distr.
GENERAL

FCCC/CP/1997/7/Add.1
25 March 1998

Original: ENGLISH

CONFERENCE OF THE PARTIES

REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997

Addendum

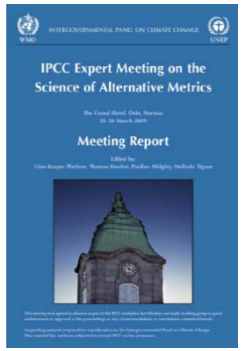
PART TWO: ACTION TAKEN BY THE CONFERENCE OF THE PARTIES AT ITS THIRD SESSION

…global warming potentials used by Parties should be those provided by the Intergovernmental Panel on Climate Change in its Second Assessment Report ("1995 IPCC GWP values") based on the effects of the greenhouse gases over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in global warming potential estimates.

What does this mean? Any implications?

Uncertainties in the values of metrics can be classified as **structural** or **scientific**

(Shine et al. 2005 (PNAS); Plattner et al. 2009 (IPCC Meeting report), Fuglestvedt et al. 2010, (ATTICA))



Structural uncertainties refer to the consequences of using different *types of metrics* for a given application, or to choices about key aspects such as *impact parameter*, *time* horizon and *discounting*.

Scientific uncertainties refer to the range of values that can be calculated for a given metric due to incomplete knowledge of the important aspects of the climate or economic system that relate some anthropogenic emission to climate impacts, damages, and/or mitigation costs

For example: GWP for CH_4:

TAR to AR4: 23 → 25

But choice between GWP and GTP: 25 vs 4

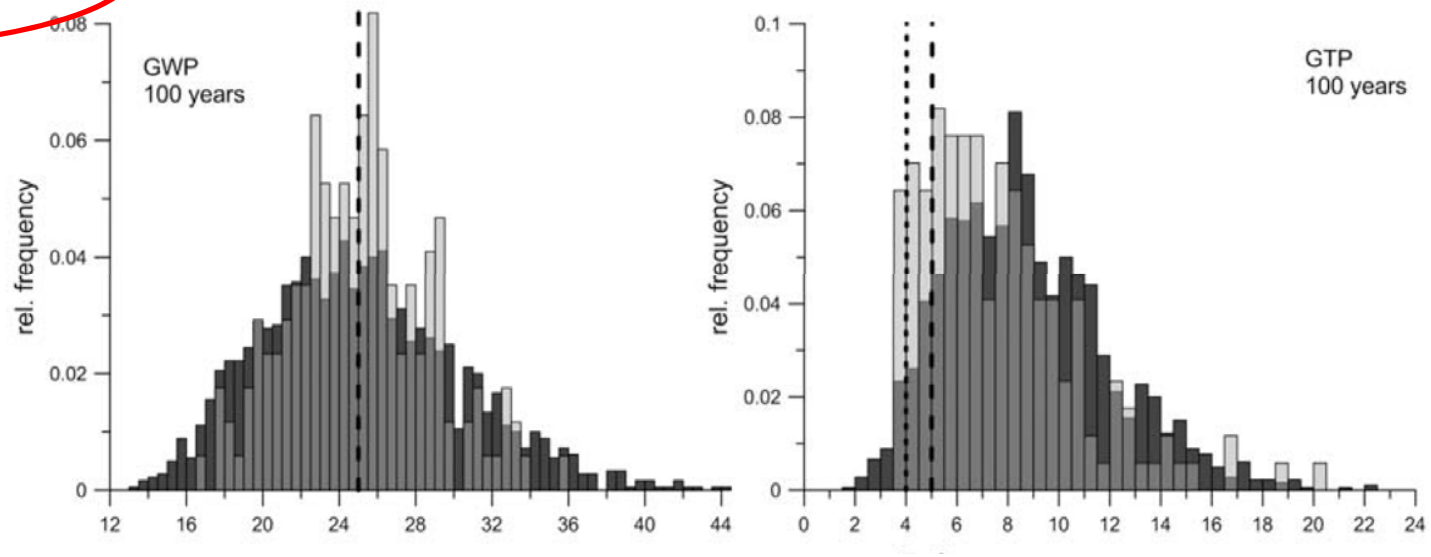
Structural

- Impact (RF, ΔT, …)
- Time horizon
- Discount rate
- Global vs regional
- Inclusion of indirect effects/feedbacks?
- Background conditions
- Pulse vs sustained
- Absolute vs relative metrics

Scientific

- Radiative efficency (Wm^{-2}/kg)
- Lifetime of non-CO_2 components
- Impulse response function for CO_2
- Efficacies
- Climate sensitivity and impulse response function for ΔT
- Response functions for other impacts

Reisinger et al., 2010



Absolute vs **relative** metrics

- When CO_2 increases: i) ocean uptake reduced and ii) marginal radiative forcing reduced

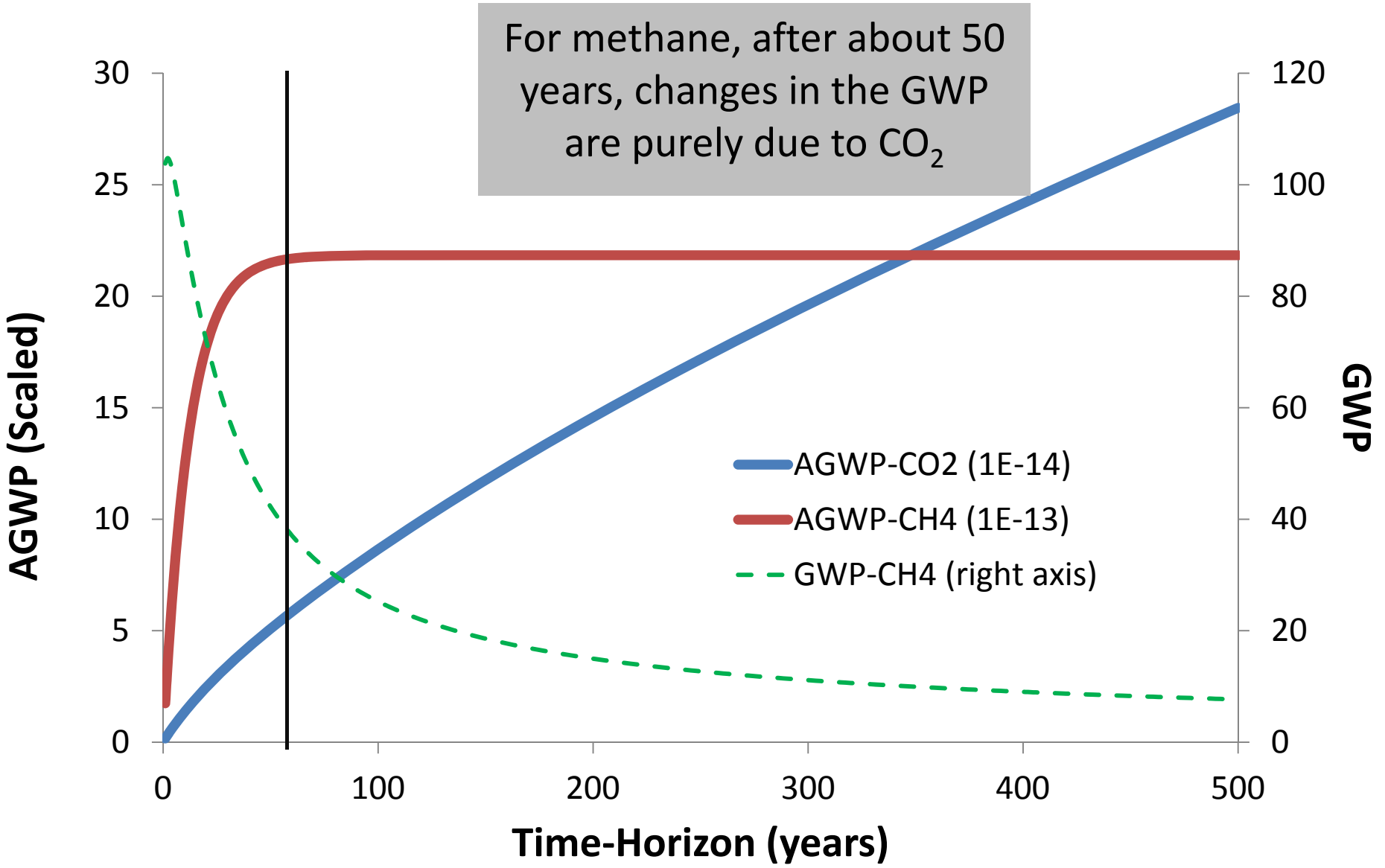
  ➔ AGWP-CO_2 is updated by IPCC

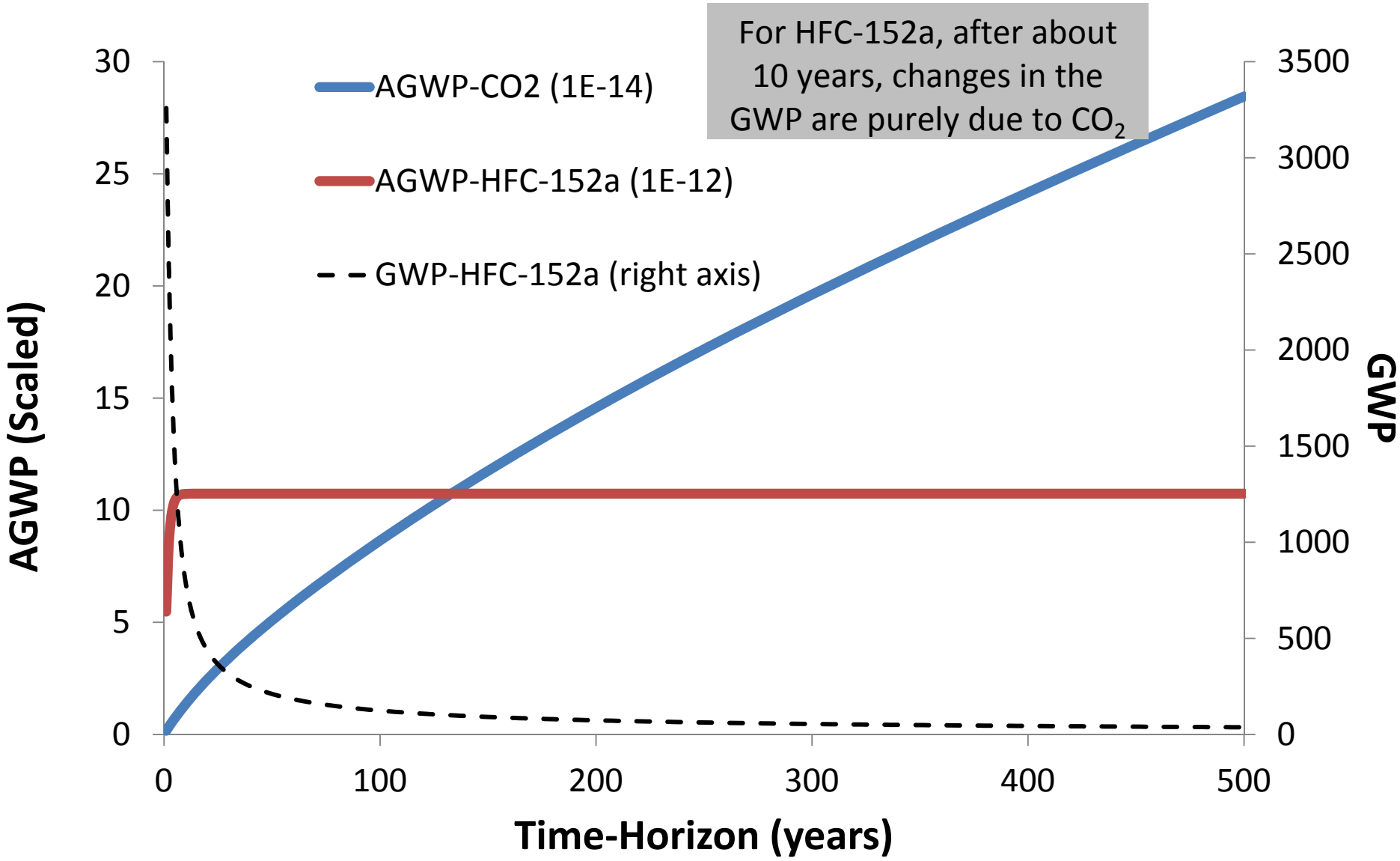
$$GWPi(H) = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)}$$

  ➔ All GWPs change

- Is AGWP a solution? i.e. $AGWP_{CH4}$, $AGWP_{N2O}$
- Could be easier for users to understand the changes

- **In addition: Understand dependence on Horizon**


For methane, after about 50 years, changes in the GWP are purely due to CO_2
AGWP (Scaled)
GWP
Time-Horizon (years)
AGWP-CO2 (1E-14)
AGWP-CH4 (1E-13)
GWP-CH4 (right axis)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
0
100
200
300
400
500


For HFC-152a, after about 10 years, changes in the GWP are purely due to CO_2
AGWP-CO2 (1E-14)
AGWP-HFC-152a (1E-12)
GWP-HFC-152a (right axis)
AGWP (Scaled)
GWP
Time-Horizon (years)
0
5
10
15
20
25
30
0
500
1000
1500
2000
2500
3000
3500
0
100
200
300
400
500

Calculations of metrics

- Models (e.g. MAGICC)

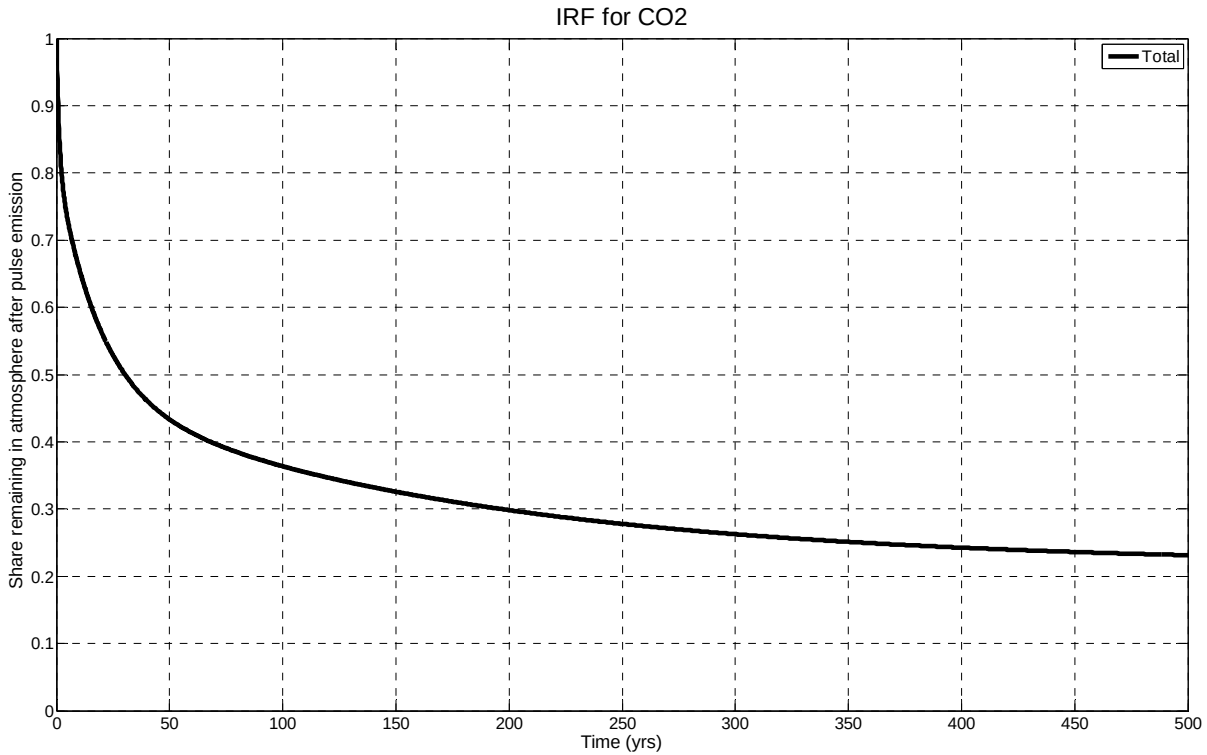
- Simple analytical equations
  - e.g. GWP calculations by IPCC
  - Transparent
  - Use radiative efficiency, lifetimes and **I**mpulse **R**esponse **F**unction for CO_2 (IRF_CO_2)

Impulse **R**esponse **F**unction: IRF_CO_2

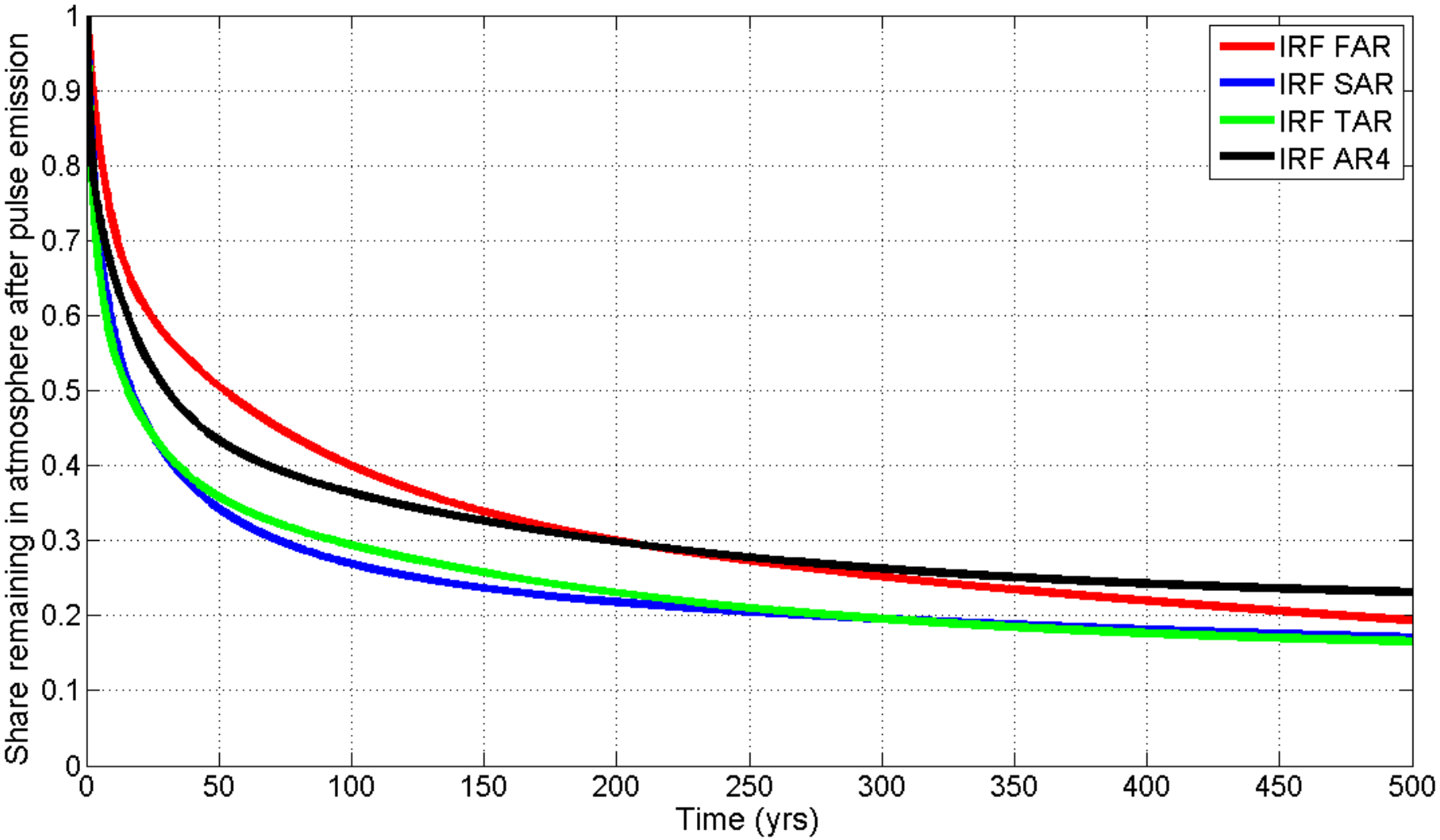
$$IRF_{CO_2}(t) = a_0 + \sum_{i=1}^{k} a_i exp\left(-\frac{t}{\tau_i}\right)$$

Not much attention in FAR, SAR, TAR, AR4

But updated in every IPCC report



IRF_CO_2: FAR, SAR, TAR, AR4

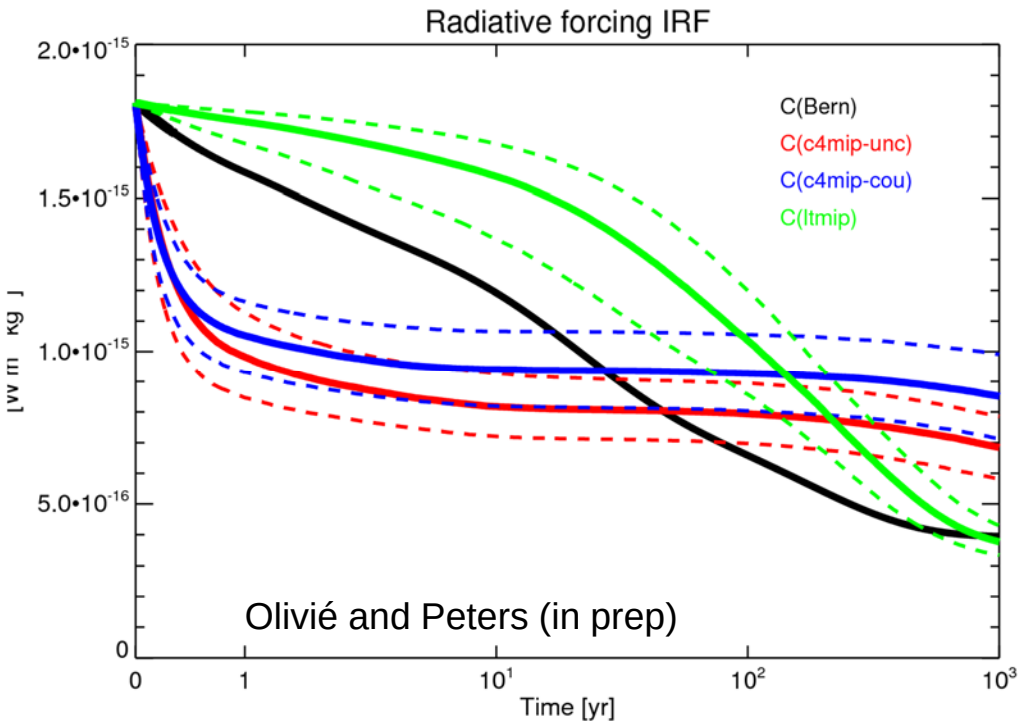


Exploring the sensitivity of GWP to IRF_CO_2

- Bern07 is the reference as used in IPCC [2007]
- Figure shows RF evolution normalized to 1kg of CO_2 emission

Relative uncertainty:

- independent of species
- not very dependent on H



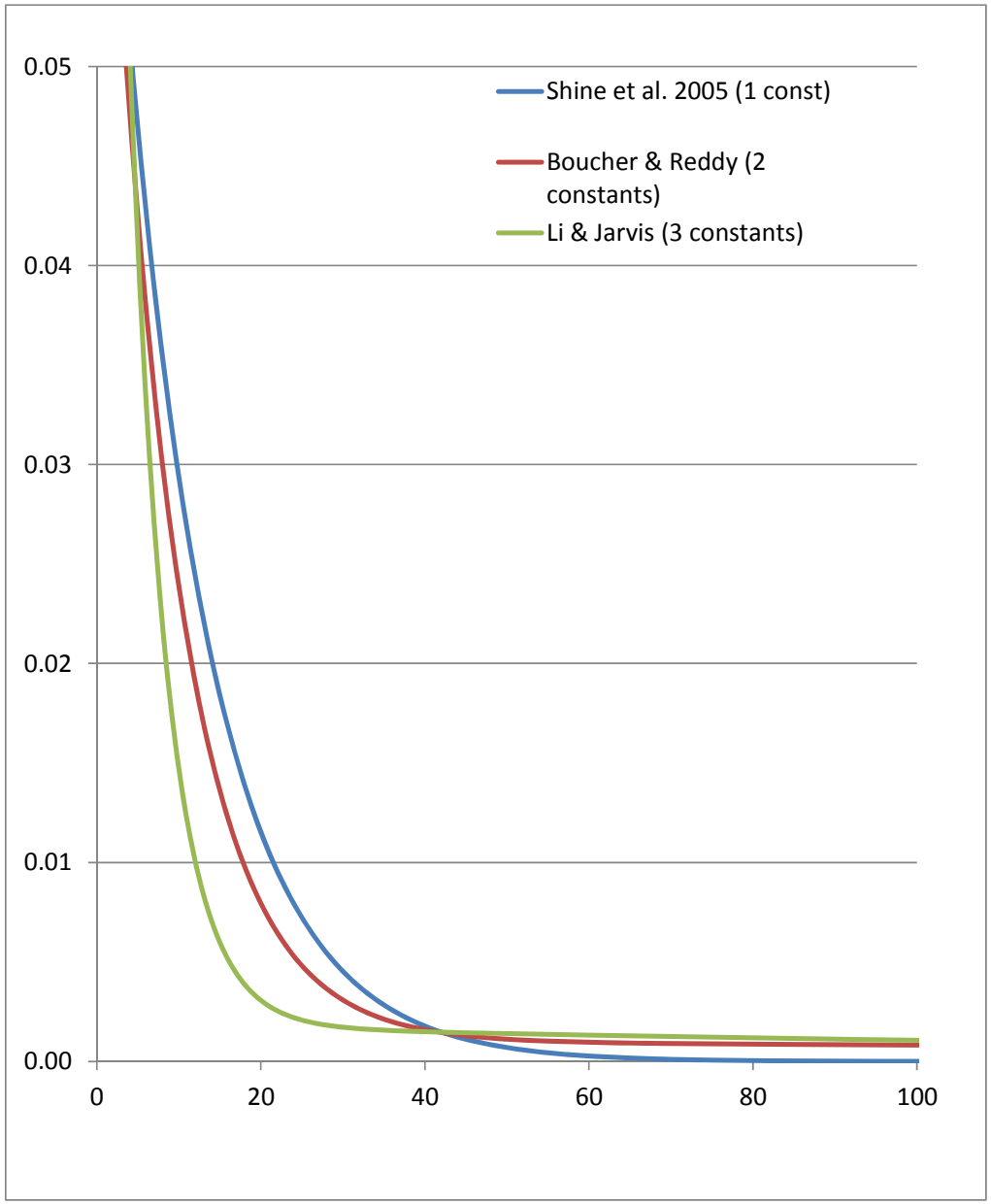
Olivié and Peters (in prep)

For case based on LTMIP (1 SD):

[%]	BC	CH_4	N2O	SF_6
20	-6% / +14%	(id.)	(id.)	(id.)
100	-10% / +21%	(id.)	(id.)	(id.)
500	-13% / +18%	(id.)	(id.)	(id.)

Temperature response function

$$R(t) = \sum_{j=1}^{2} \frac{c_j}{d_j} \exp\left(-\frac{t}{d_j} \right)$$



GTP: relative uncertainty

Reference: IRF_dT by Boucher and Reddy (2008)

Uncertainty (1SD) contribution from IRF_dT:

	BC	CH_4	N_2O	SF_6
20	-34% / 43%	-6% / 6%	-1.0% / 0.9%	-1.7% / 1.6%
100	-34% / 42%	-33% / 39%	-1.6% / 1.7%	-1.8 % / 1.7%
500	-71% / 77%	-70% / 74%	-36% / 35%	-2.4% / 2.3%

Uncertainties:

- increase with time horizon
- decrease with lifetime

Olivié and Peters (in prep)

- Multi-gas approach increases flexibility and may reduce costs
- Probably useful in the process leading to the Kyoto Protocol

Man-made emissions / mechanisms go beyond the Kyoto basket

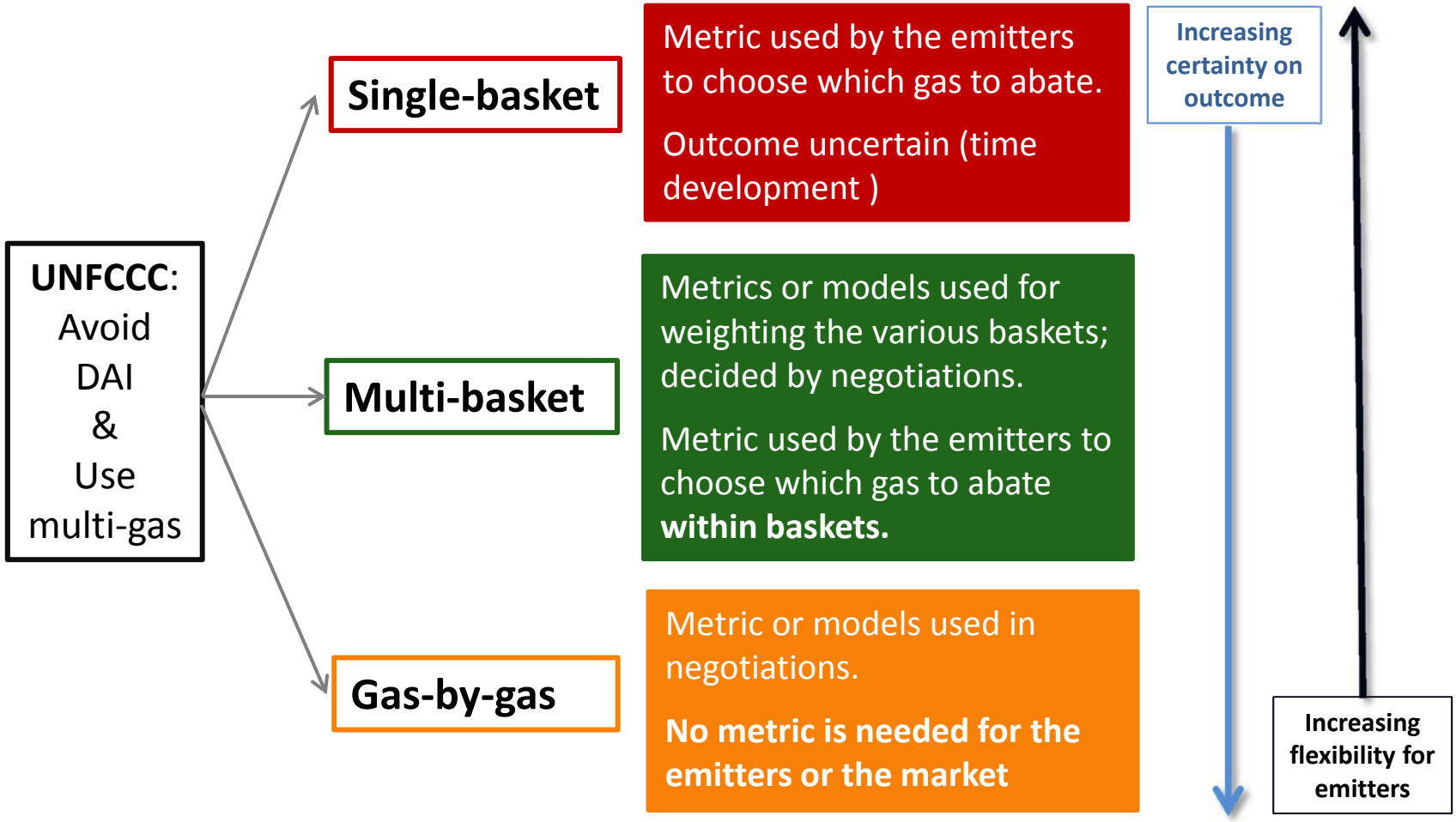
+ NOx, SO_2, CO, VOC, BC, OC, H_2O, contrails, cirrus, albedo changes.....

Difficult to force all these on to the same scale

A ***separate basket*** for short-lived components has been suggested

(Fuglestvedt et al., 2000; Rypdal et al., 2005; Jackson 2009; Daniel et al., 2011)

Alternative multi-component policies



SUMMARY

- GTP and GWP fundamentally different → effects on calculated contributions
- Our perception of importance of short-lived vs long-lived gases depends on *i*) choice of metric and *ii*) choices within that metric
- Two different kinds of uncertainties: ***structural*** *and* ***scientific***
- ***Structural:*** *Value based and policy dependent choices*
- **Scientific:** Need to explore uncertainties in metrics due to lifetimes, radiative efficiency , IRF_CO_2 and IRF_dT
- **Fortunate Joos leading the excercise: CO_2 pulse response function for the calculation of GWPs: a multi-model analysis**
  www.climate.unibe.ch/~joos/IRF_Intercomparison/index.html

- Force all components – long- and short-lived – on to the same scale?

- Possible alternatives: a **multi-basket** or a **gas-by-gas** approach
- Assessment of metrics in the context of different multi-gas policies ?