Vulnerability in the global carbon cycle

What is the risk from parts of the system not yet fully integrated?

Chris Field
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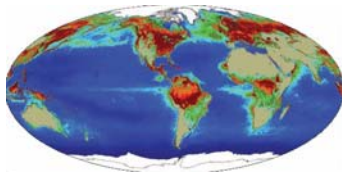
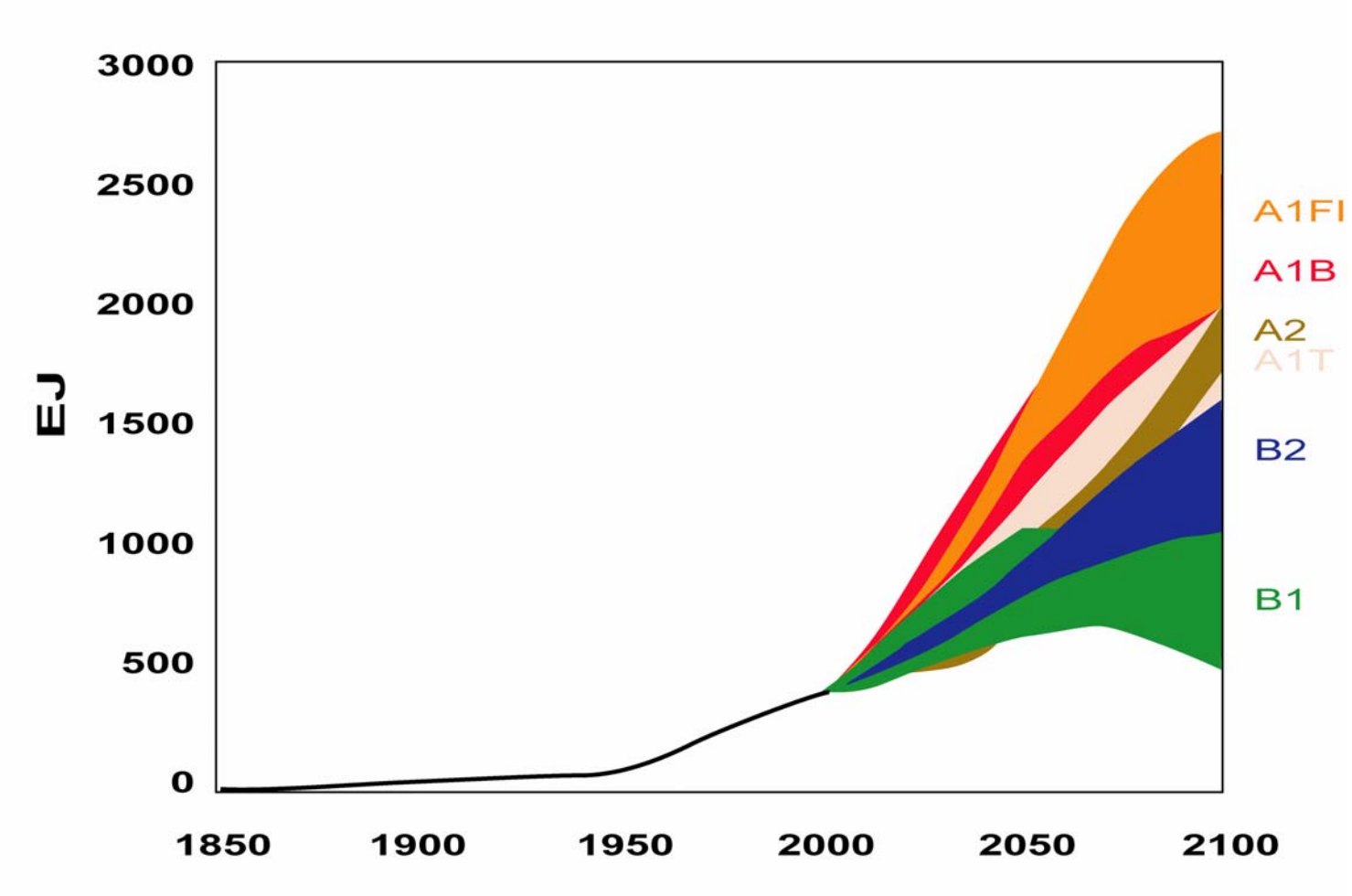
Carnegie Institution
www.global-ecology.org



Implications for policy

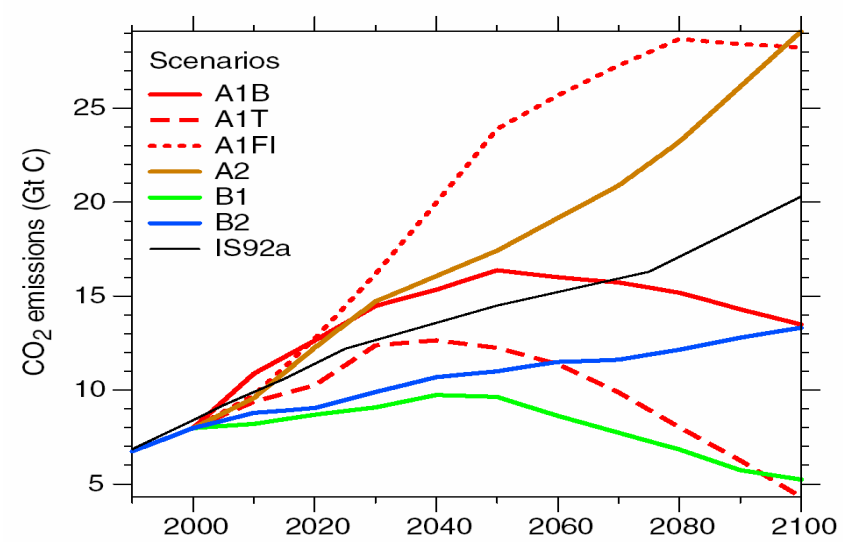
- Have future free subsidies from nature been overestimated in past analyses?
- Is there a greater risk of positive feedbacks as warming becomes larger?
- Are we making realistic estimates of the need for emissions-free energy?

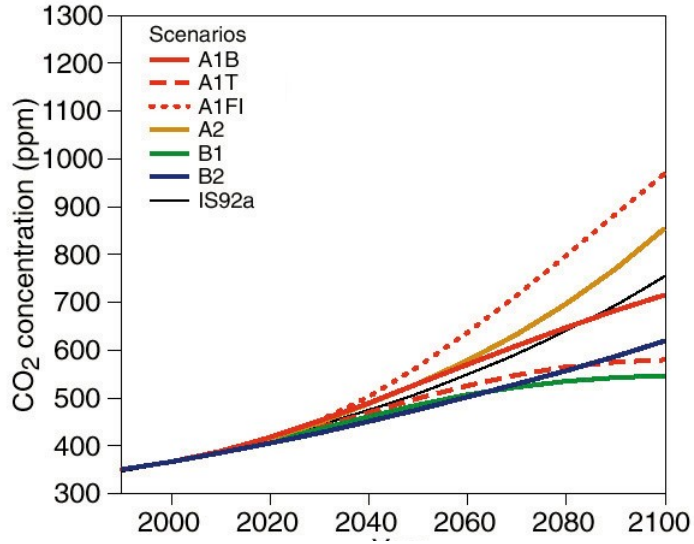
Intergovernmental Panel on Climate Change (IPCC)
A broad range of possible futures

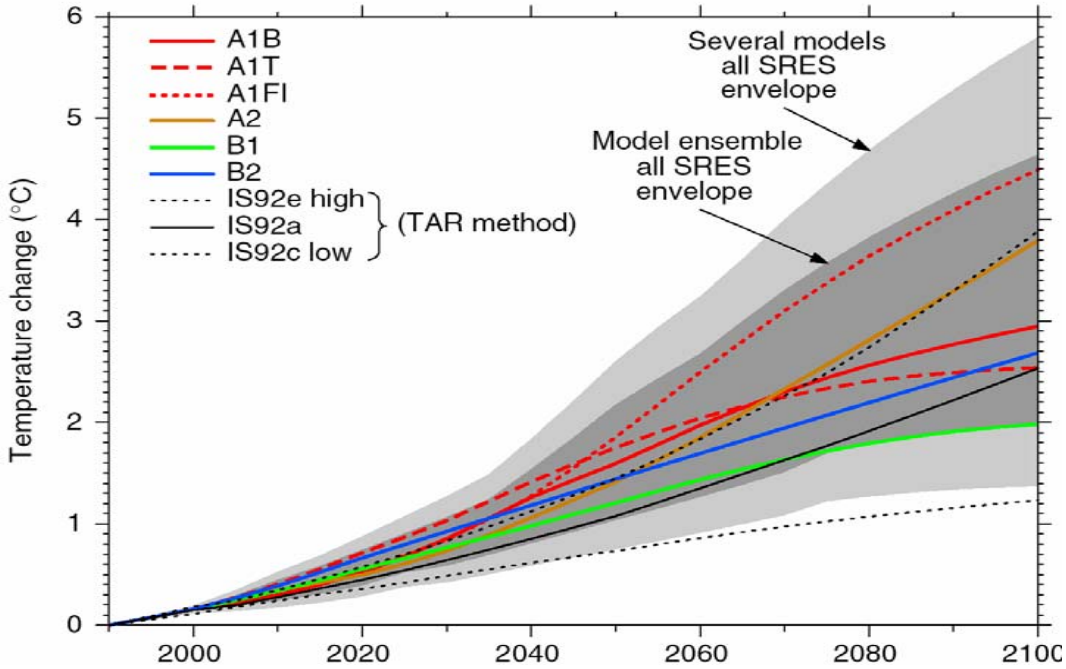


IPCC Scenarios

Lead to a range of emissions and atmospheres and warming

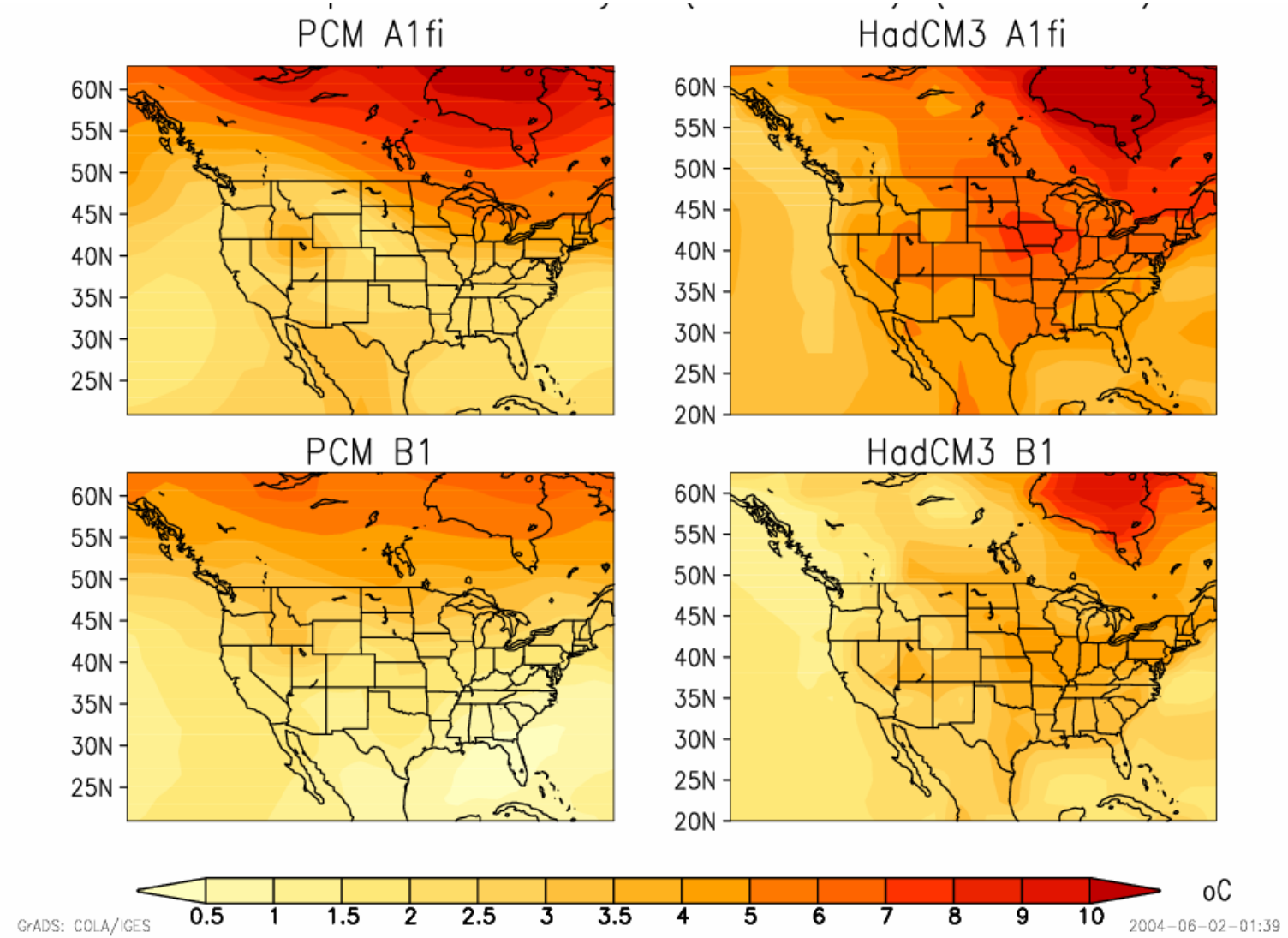




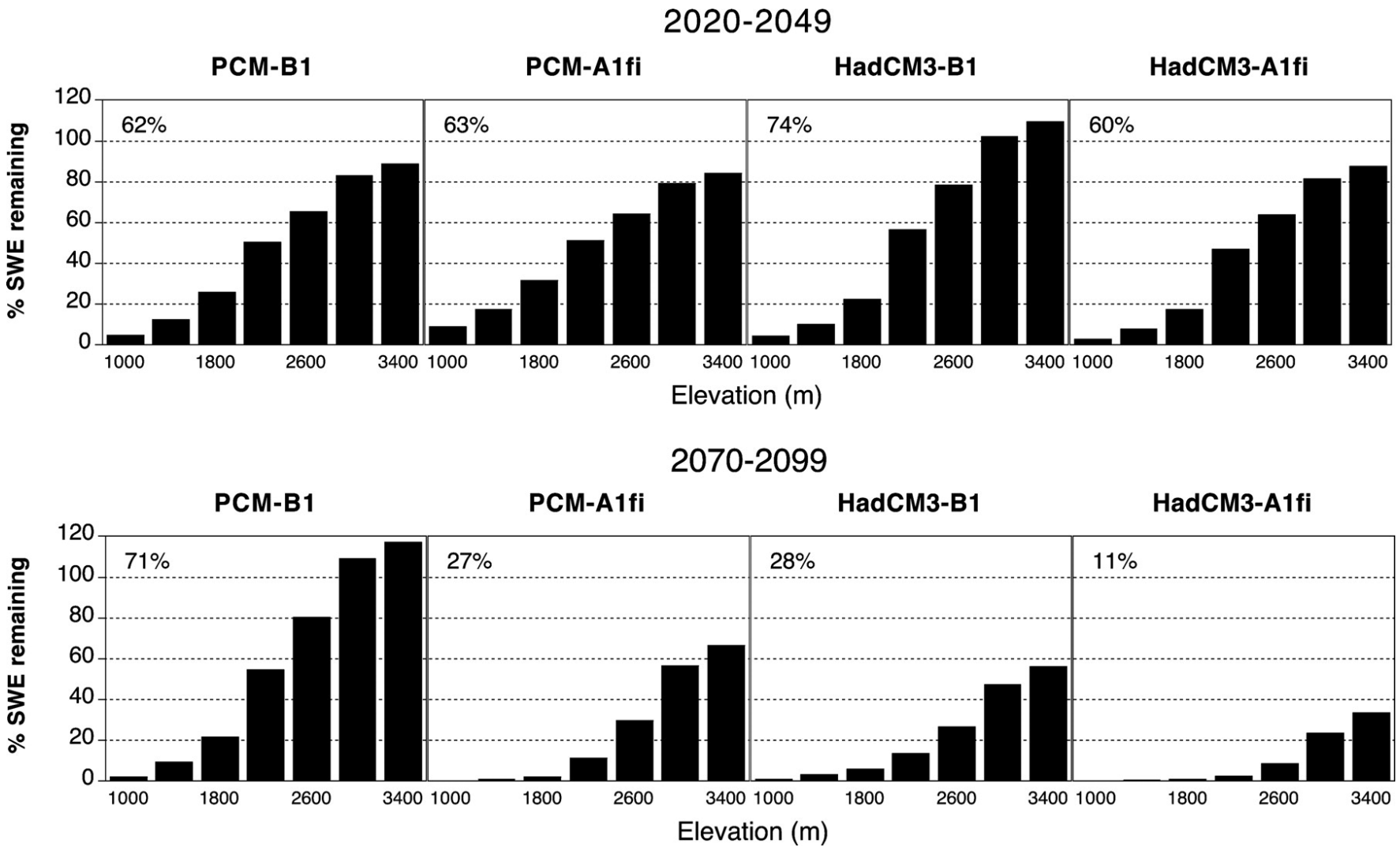


Future climate depends strongly on emissions path

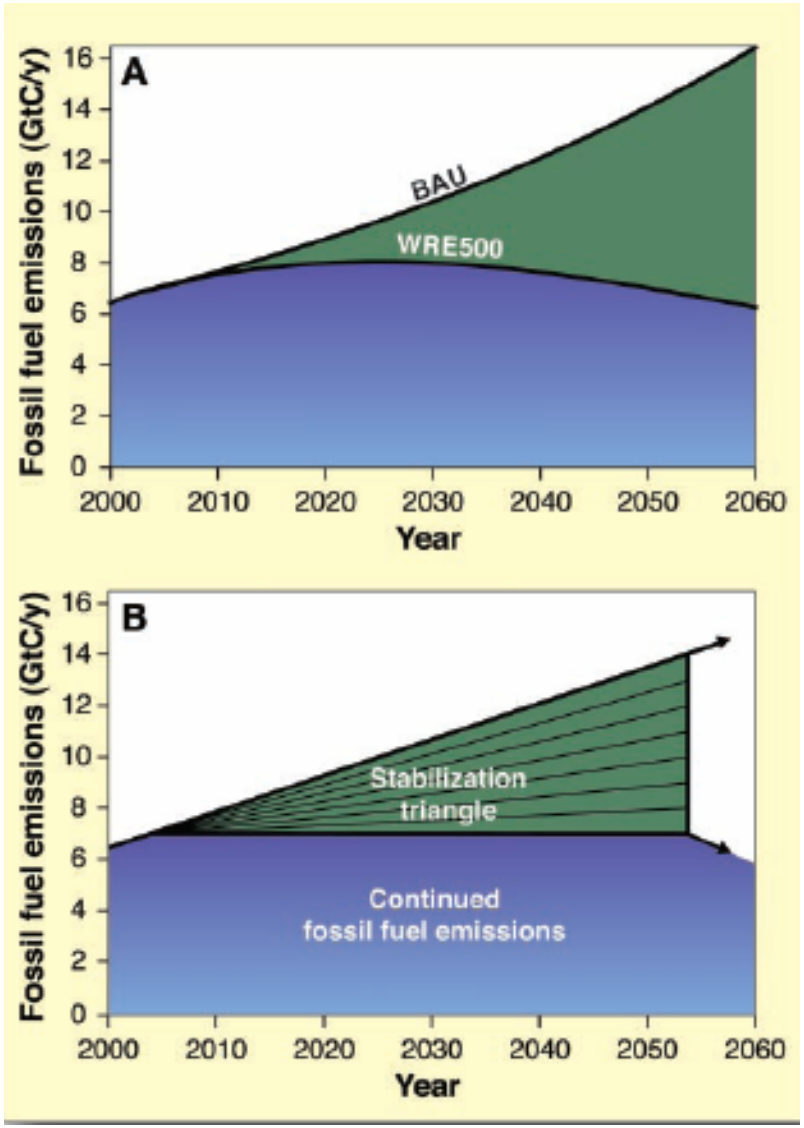
Winter temperature anomaly (2070 to 2099 – 1961 to 1990) (°C)



Snowpack (April 1)



Stabilization wedges: Solving the climate problem for the next 50 years with current technologies - S. Pacala & R. Socolow (Science, 2004)

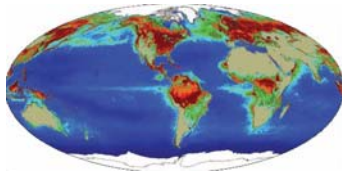


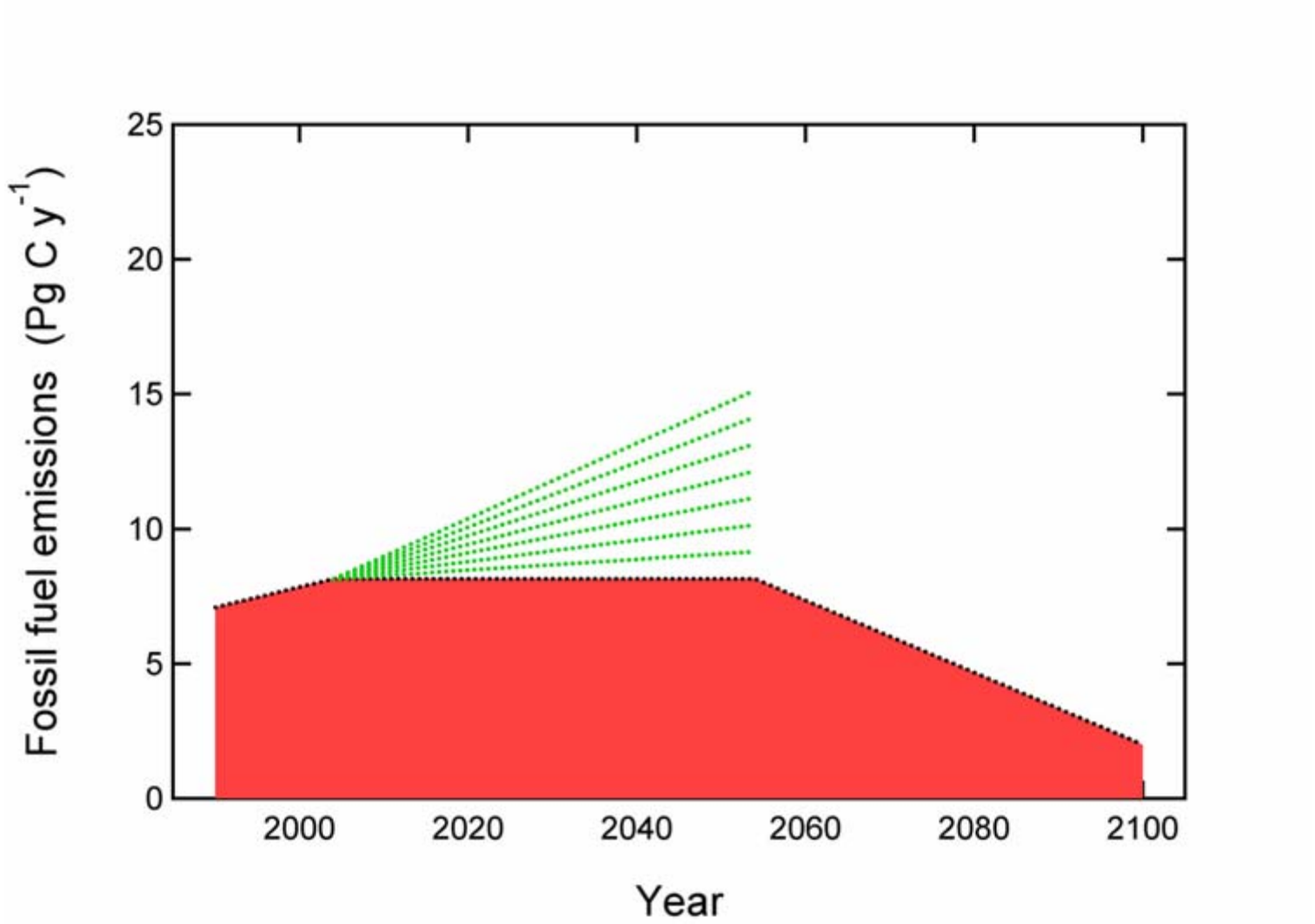
Potential Wedges from P&S

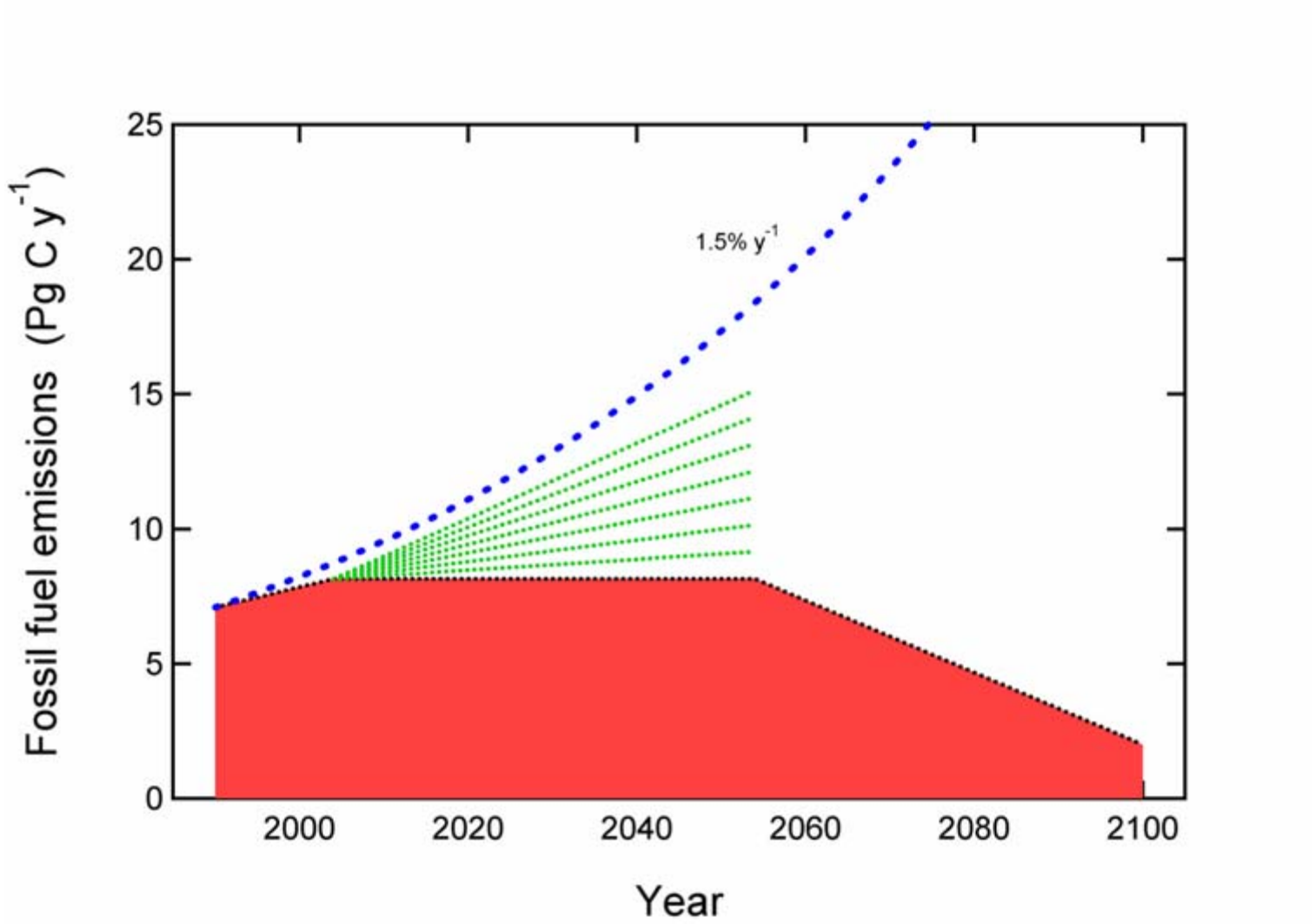
- Economy wide carbon-intensity reduction
- Efficient vehicles
- Reduced use of vehicles
- Efficient buildings
- Gas baseload power for coal baseload power
- Capture CO_2 at baseload power plant
- Capture CO_2 at H_2 plant
- Capture CO_2 at coal to synfuels plant
- Geological storage
- Nuclear power for coal power
- Wind power for coal power
- PV for coal power
- Wind H_2 in fuel-cell car for gasoline in hybrid car
- Biomass fuel for fossil fuel
- Reduced deforestation, plus reforestation, afforestation, and new plantations
- Conservation tillage

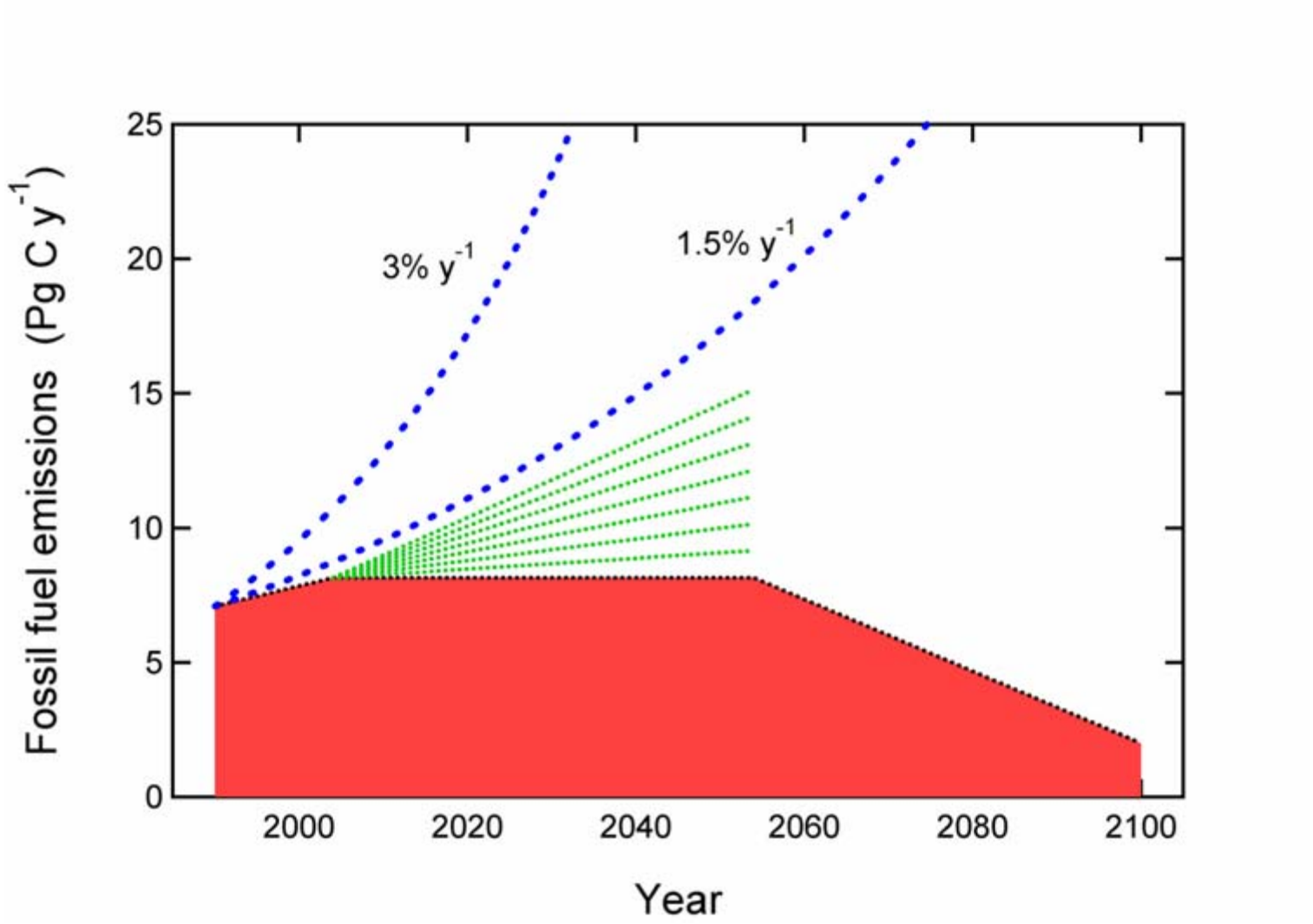
Quantitative issues?

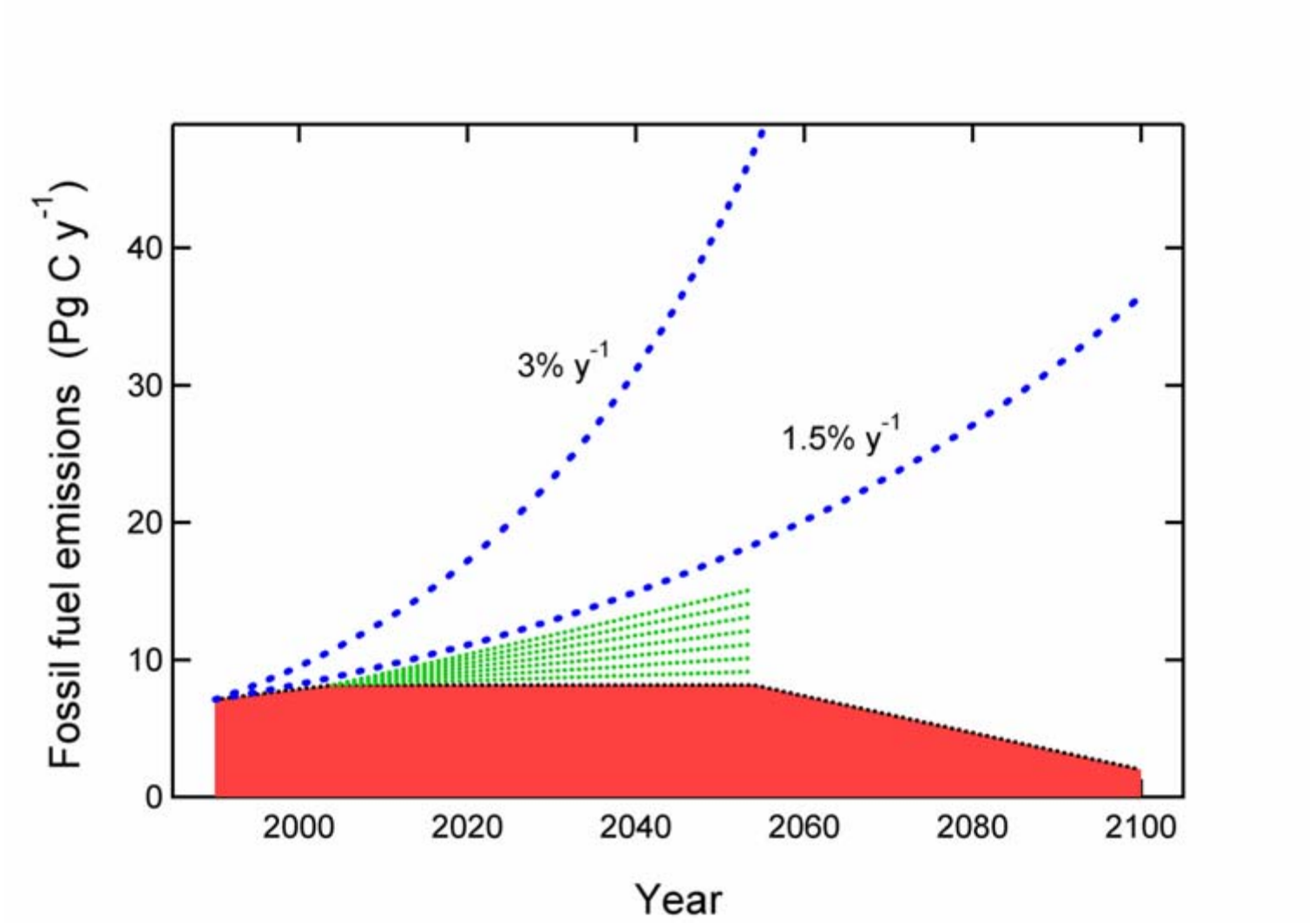
- Economic challenge of scaling wedges?
- How many wedges do we need?
  - Accounting for all forms of emissions reduction
  - Accounting for land and ocean feedbacks

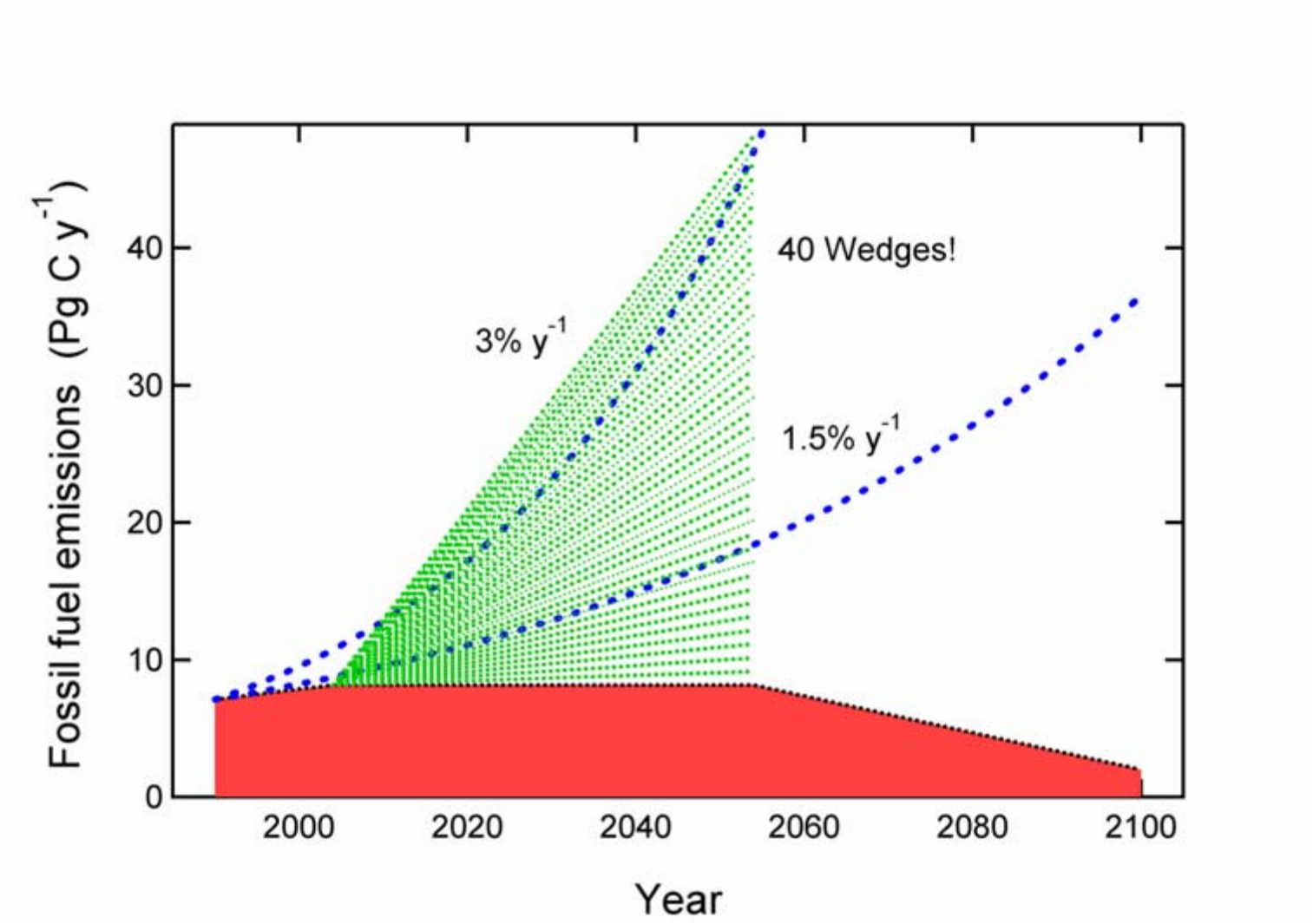


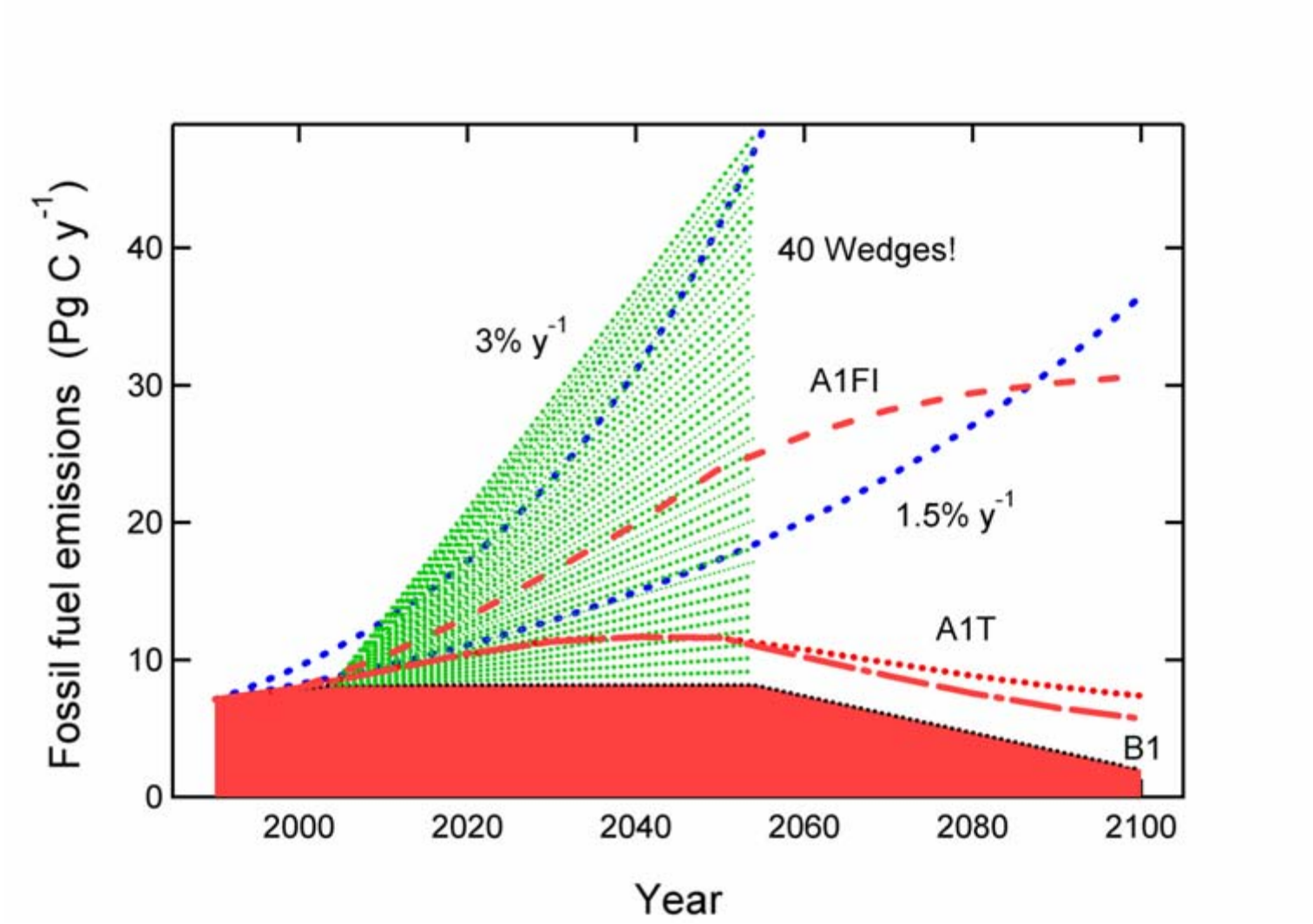

Fossil fuel emissions (Pg C y-1)
25
20
15
10
5
0
2000
2020
2040
2060
2080
2100
Year


Fossil fuel emissions (Pg C y-1)
25
20
15
10
5
0
1.5% y-1
2000
2020
2040
2060
2080
2100
Year


Fossil fuel emissions (Pg C y-1)
25
20
15
10
5
0
3% y-1
1.5% y-1
2000
2020
2040
2060
2080
2100
Year


Fossil fuel emissions (Pg C y-1)
40
30
20
10
0
2000
2020
2040
2060
2080
2100
Year
3% y-1
1.5% y-1


Fossil fuel emissions (Pg C y-1)
40
30
20
10
0
2000
2020
2040
2060
2080
2100
Year
40 Wedges!
3% y-1
1.5% y-1


Fossil fuel emissions (Pg C y-1)
40
30
20
10
0
2000
2020
2040
2060
2080
2100
Year
40 Wedges!
3% y-1
A1FI
1.5% y-1
A1T
B1

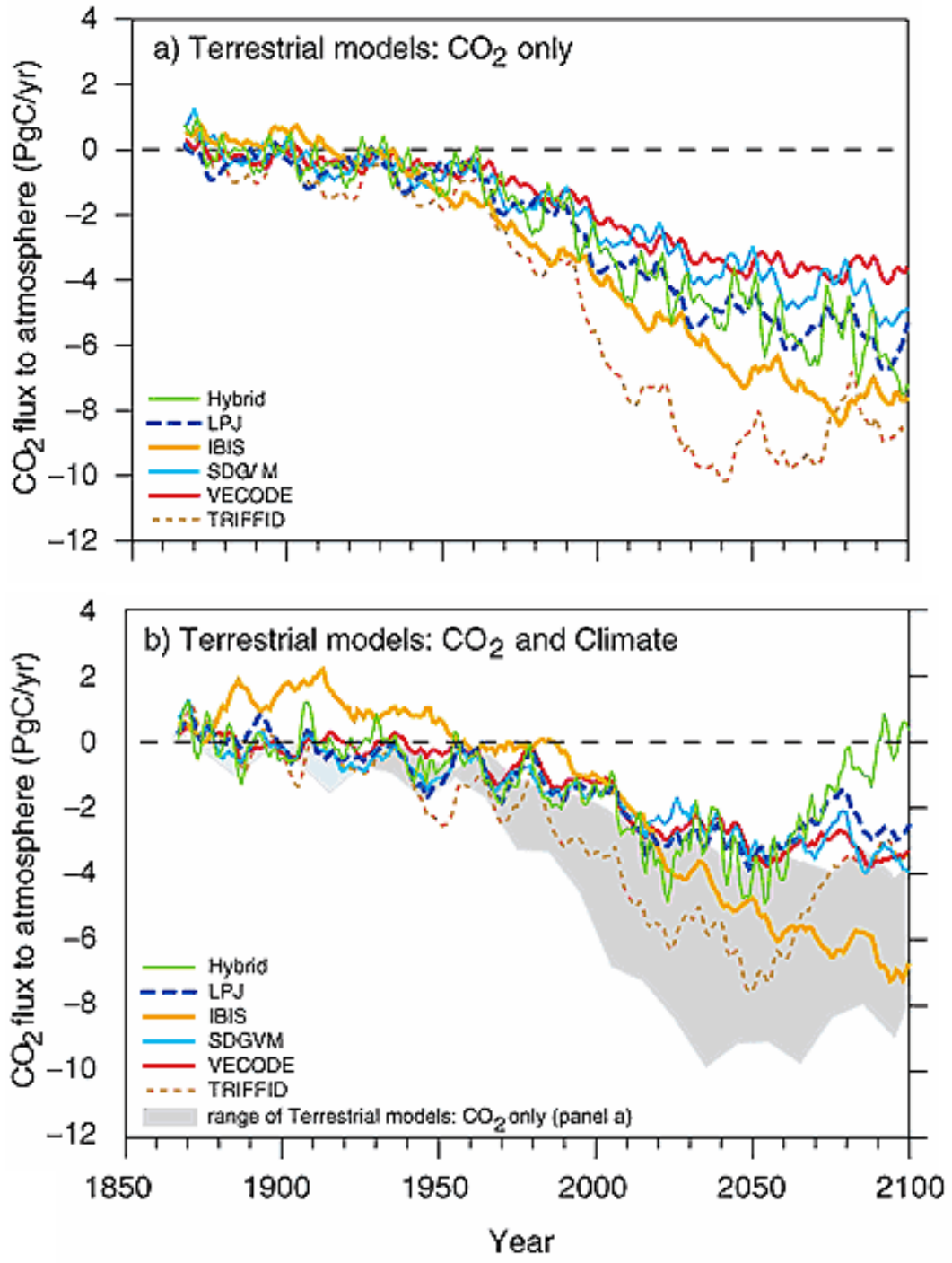
Stabilization wedges

- Many of the potential wedges will fall under endogenous efficiency improvements
- Maintaining historical pace of endogenous efficiency improvements represents a real challenge
- Necessary wedges for constant emissions could be:
  - Up to 40 at 1 Pg *C* y^{-1} in 2054
  - *A* few much larger than 1 Pg *C* y^{-1} in 2054
  - Both of the above

Global C cycle: past subsidies from nature

- Pre-industrial CO_2 = 280 ppm
- Current atmospheric CO_2 = 375 ppm
- Without subsidies, CO_2 = 500 ppm

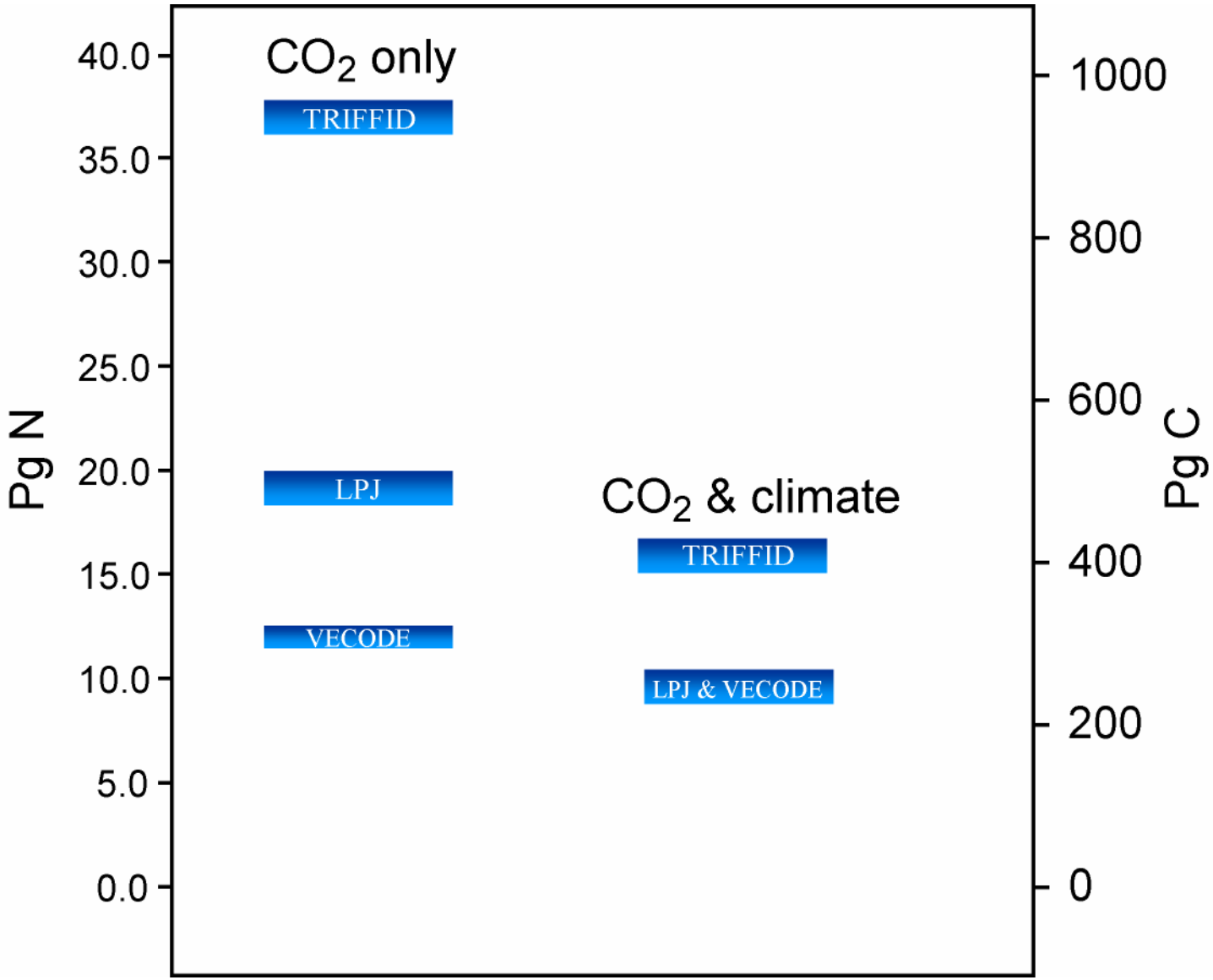
- Over the next century, models in IPCC project uncertain but large subsidies:
  - Oceans: 160 ppm
  - Land: 125 ppm

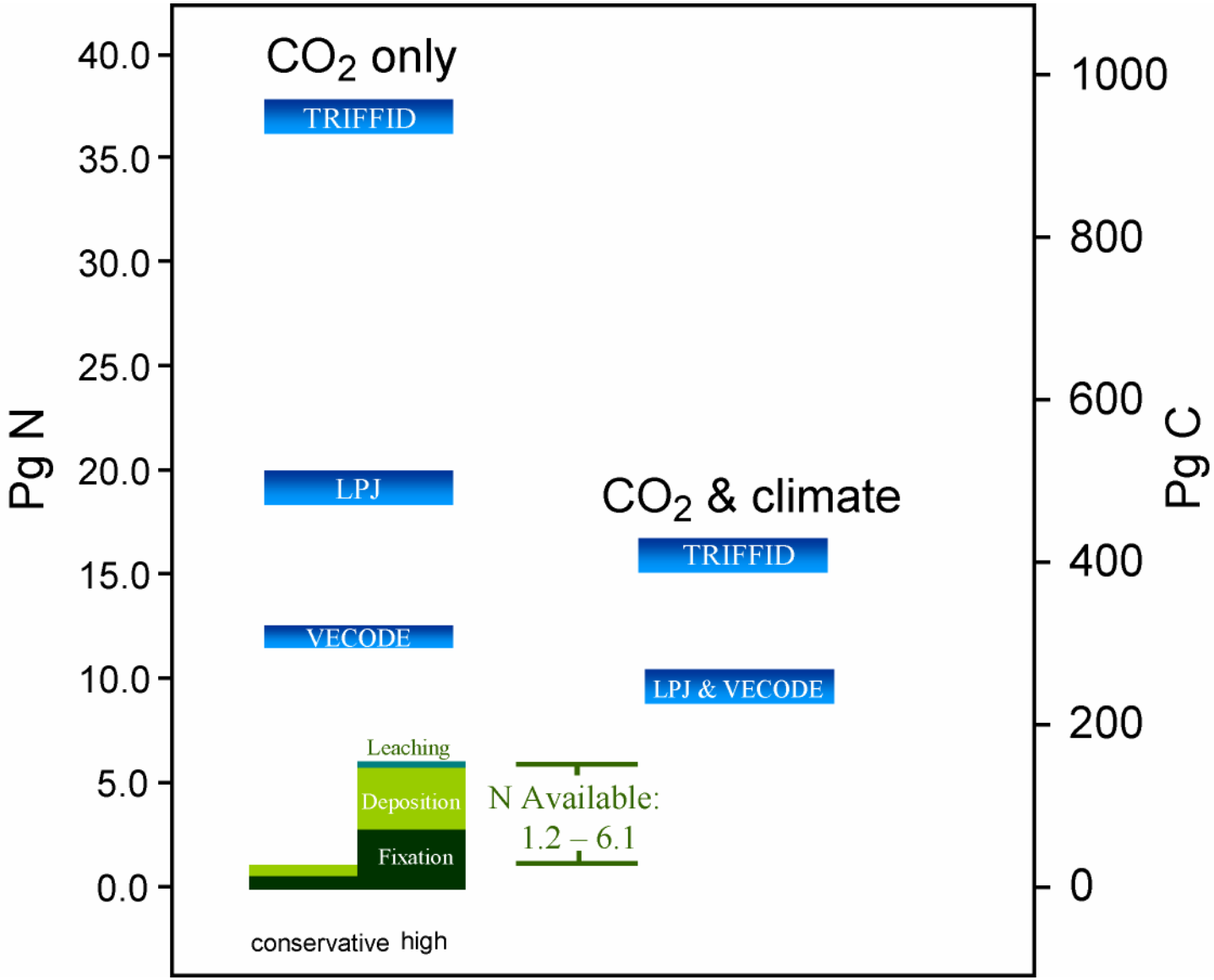

a) Terrestrial models: CO_2 only
CO_2 flux to atmosphere (PgC/yr)
4
2
0
−2
−4
−6
−8
−10
−12
Hybrid
LPJ
IBIS
SDGVM
VECODE
TRIFFID
b) Terrestrial models: CO_2 and Climate
CO_2 flux to atmosphere (PgC/yr)
Hybrid
LPJ
IBIS
SDGVM
VECODE
TRIFFID
range of Terrestrial models: CO_2 only (panel a)
1850
1900
1950
2000
2050
2100
Year

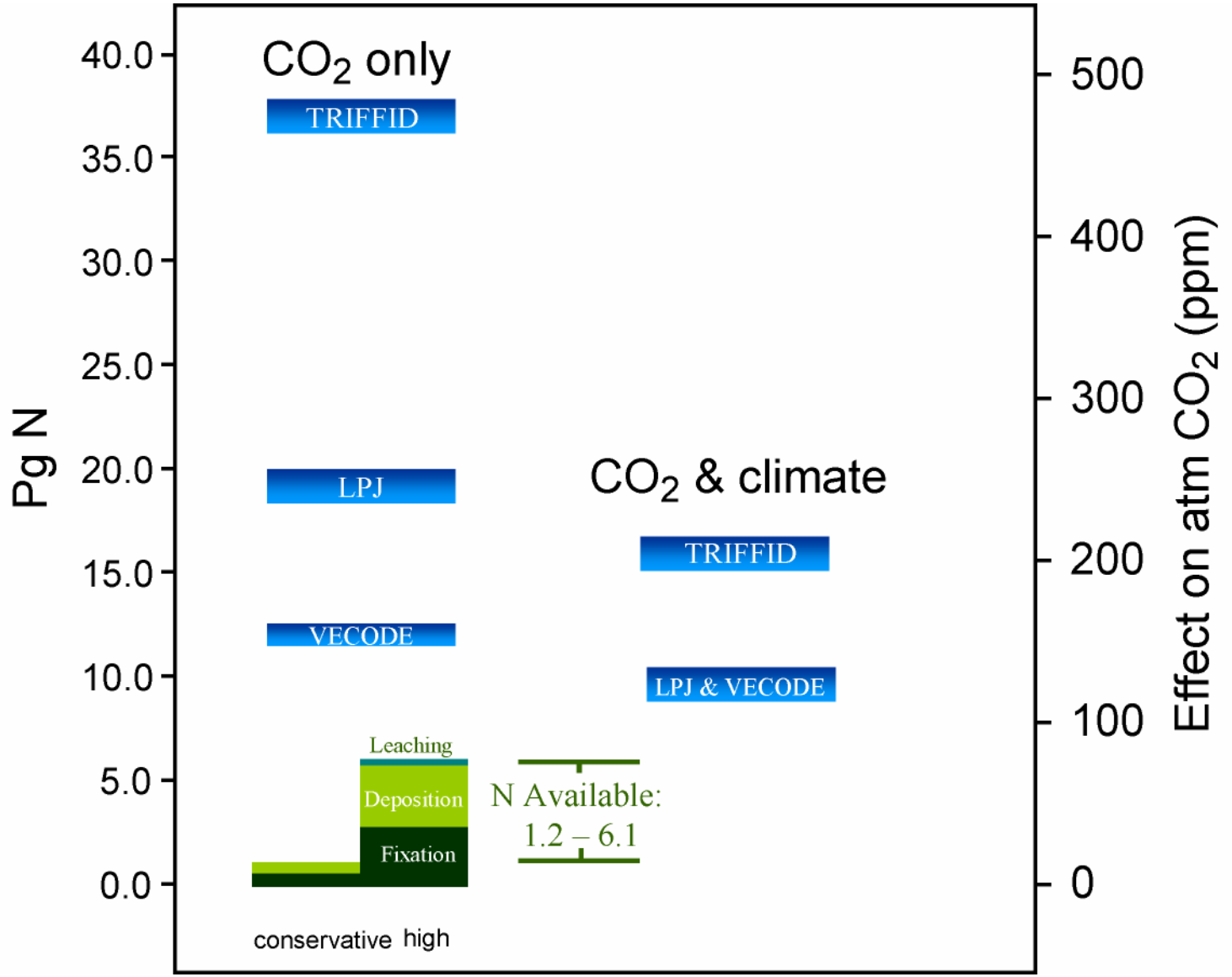
CO_2 fertilization of NEP

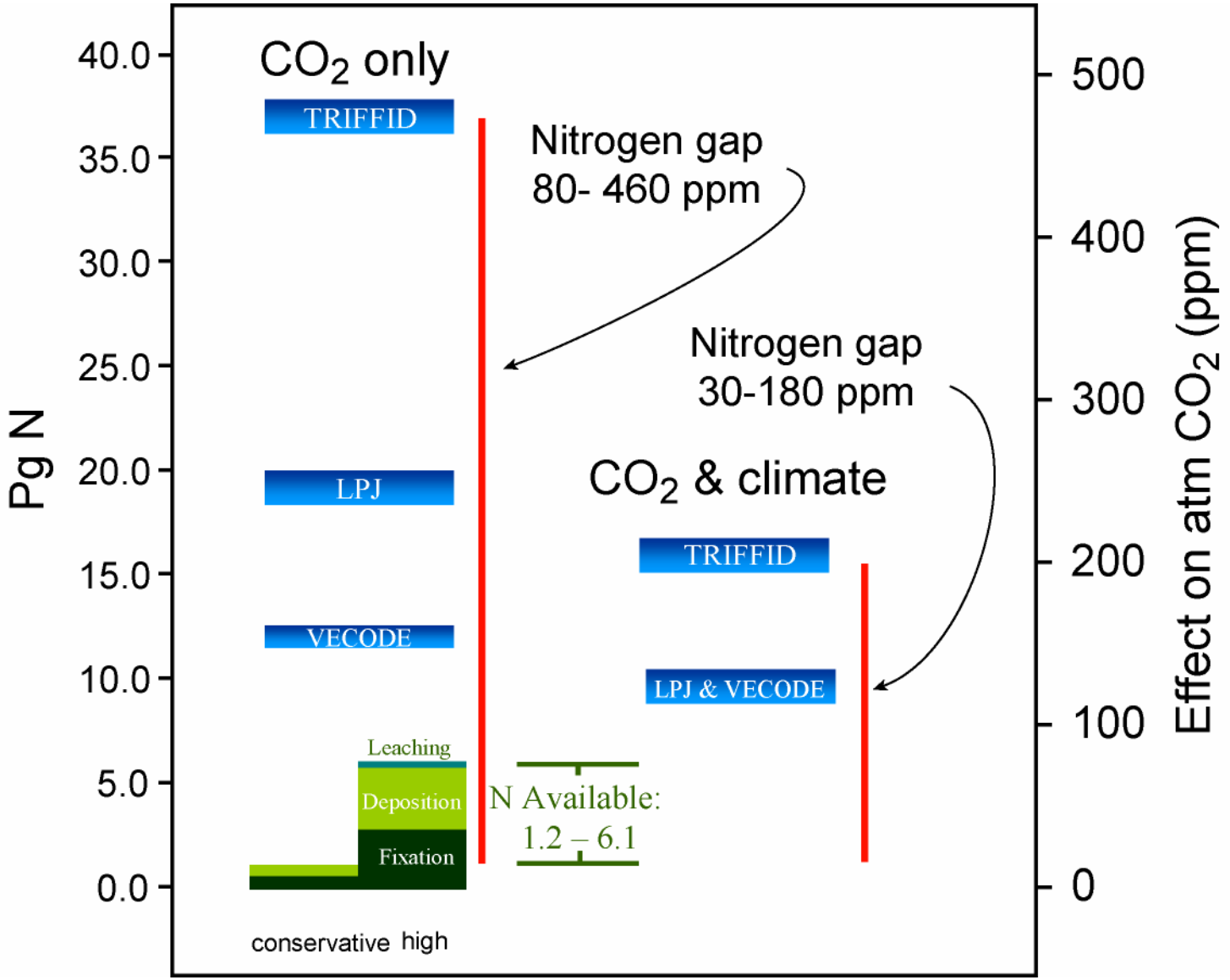
- Modest CO_2 fertilization in empirical studies
- Constraint from N gives optimistic upper bound for fertilization
- Estimate global increase in N availability
  - (2000-2100)
- Compare with standard models for CO_2 fertilization

- Hungate et al. 2003 Science


CO_2 only
TRIFFID
LPJ
VECODE
CO_2 & climate
TRIFFID
LPJ & VECODE
Pg N
Pg C
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1000
800
600
400
200
0

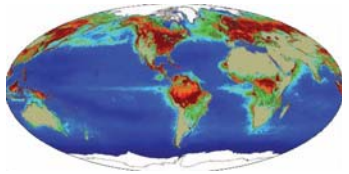

CO_2 only
TRIFFID
LPJ
VECODE
CO_2 & climate
TRIFFID
LPJ & VECODE
Leaching
Deposition
Fixation
N Available:
1.2 – 6.1
conservative
high
Pg N
Pg C
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1000
800
600
400
200
0


CO_2 only
TRIFFID
LPJ
VECODE
CO_2 & climate
TRIFFID
LPJ & VECODE
Leaching
Deposition
Fixation
N Available:
1.2 – 6.1
conservative
high
Pg N
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
500
400
300
200
100
0
Effect on atm CO_2 (ppm)


CO_2 only
TRIFFID
LPJ
VECODE
Leaching
Deposition
Fixation
conservative
high
Nitrogen gap
80- 460 ppm
Nitrogen gap
30-180 ppm
CO_2 & climate
TRIFFID
LPJ & VECODE
N Available:
1.2 – 6.1
Pg N
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
500
400
300
200
100
0
Effect on atm CO_2 (ppm)

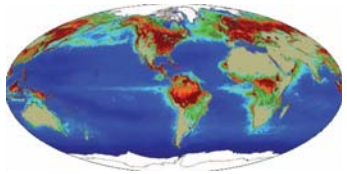
Yikes!

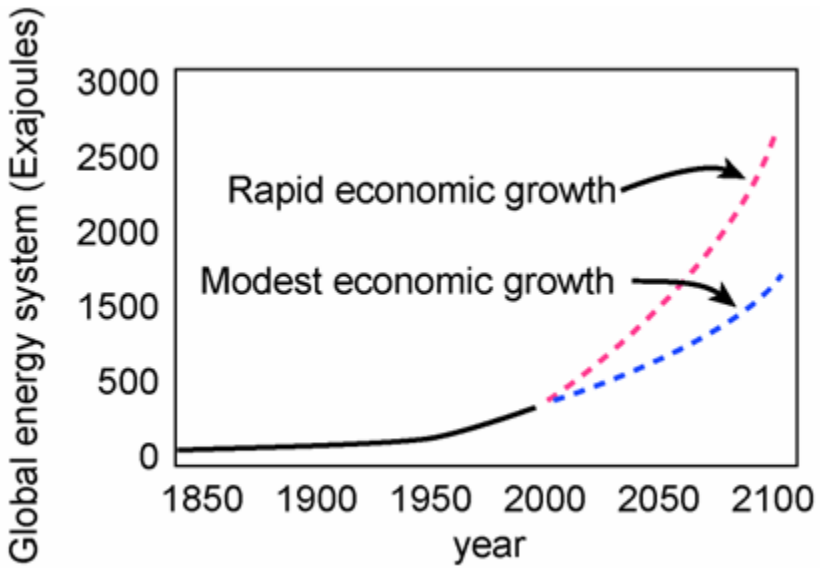
- Existing models may over-estimate century-scale CO_2 uptake on land
  - Perhaps by up to 360 Pg or 180 ppm
  - Probably $\frac{1}{2}$ compensated by oceans

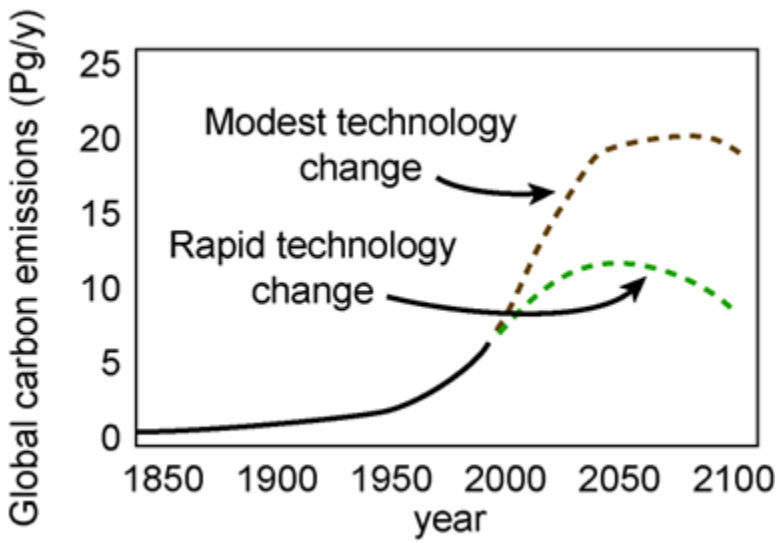


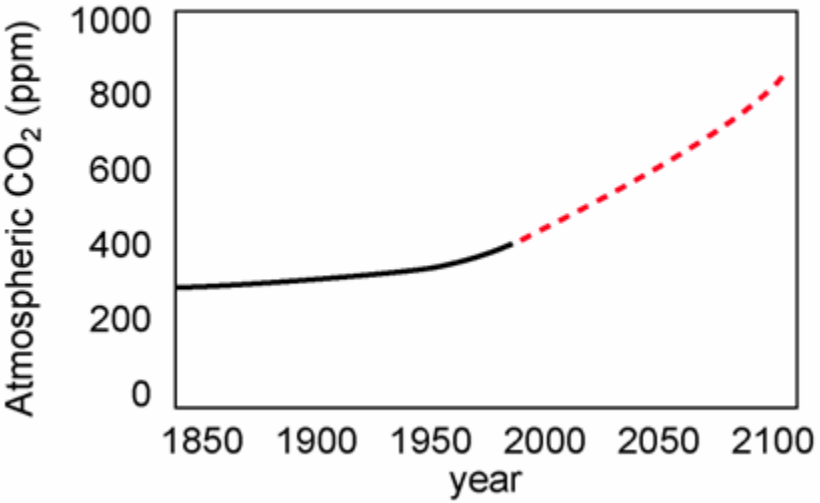
Why have we overestimated CO_2 fertilization?

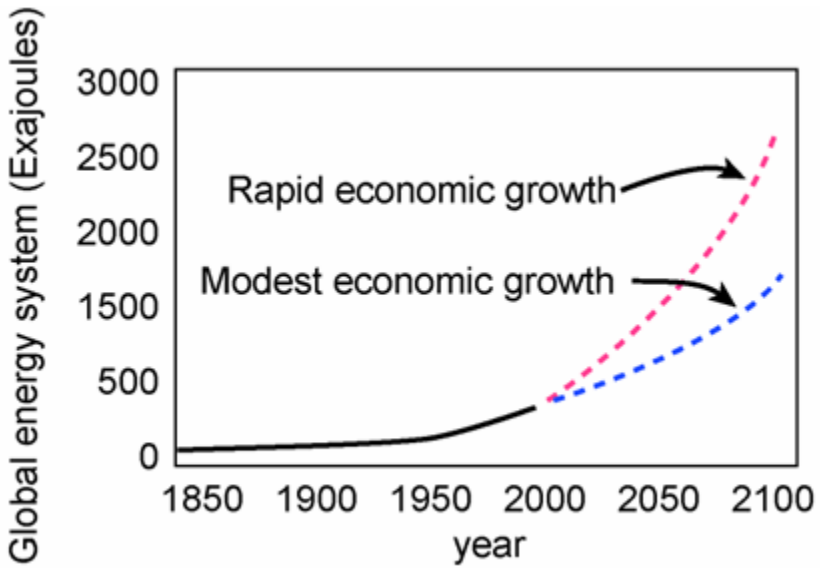
- Unrealistic early experiments
  - Fast-growing plants
  - Abundant resources
  - Focus on aboveground NPP
- IPCC rules
  - Other sinks masqueraded as CO_2 fertilization
    - Regrowth
    - Overestimated deforestation
    - Forest thickening
    - Landfills and sediments

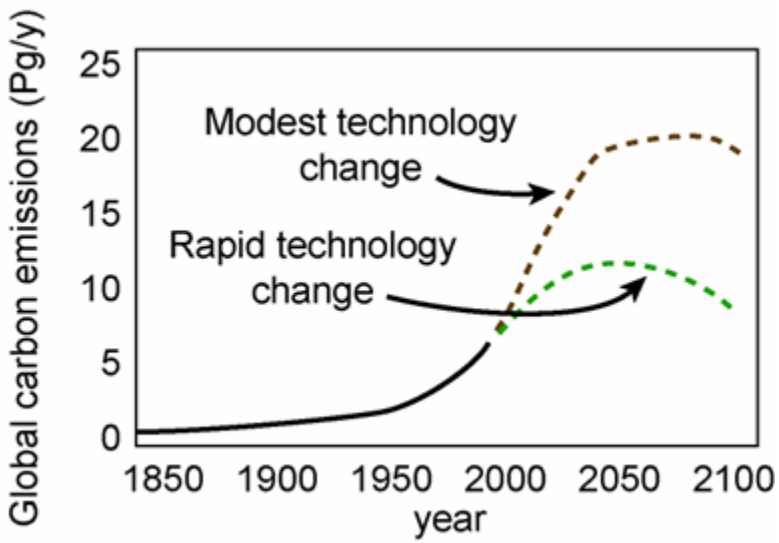


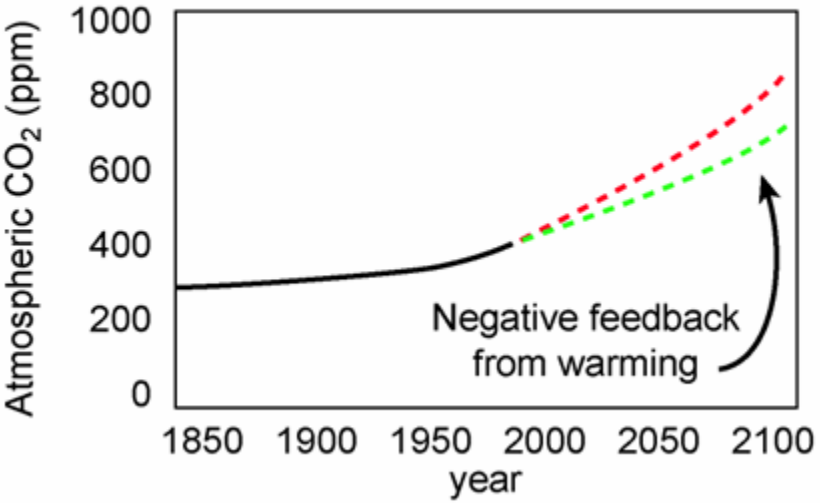

Global energy system (Exajoules)
3000
2500
2000
1500
500
0
Rapid economic growth
Modest economic growth
1850
1900
1950
2000
2050
2100
year

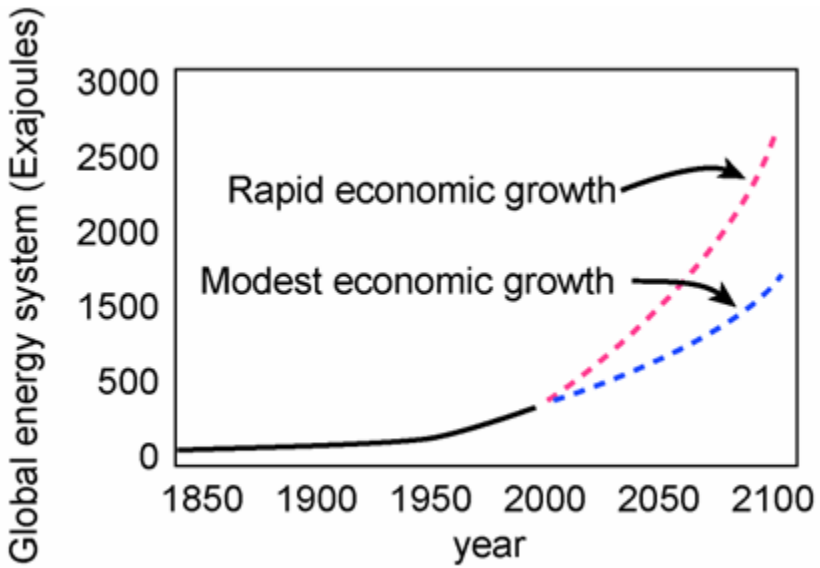

Global carbon emissions (Pg/y)
25
20
15
10
5
0
Modest technology change
Rapid technology change
1850
1900
1950
2000
2050
2100
year

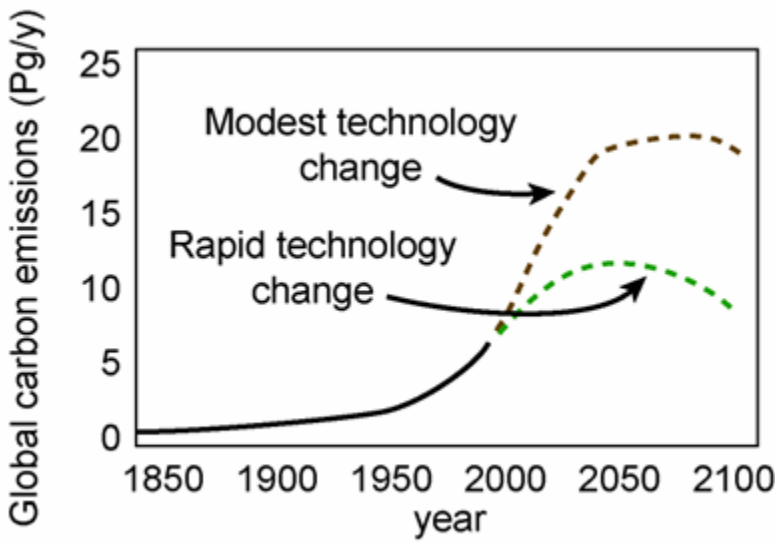

Atmospheric CO_2 (ppm)
1000
800
600
400
200
0
1850
1900
1950
2000
2050
2100
year

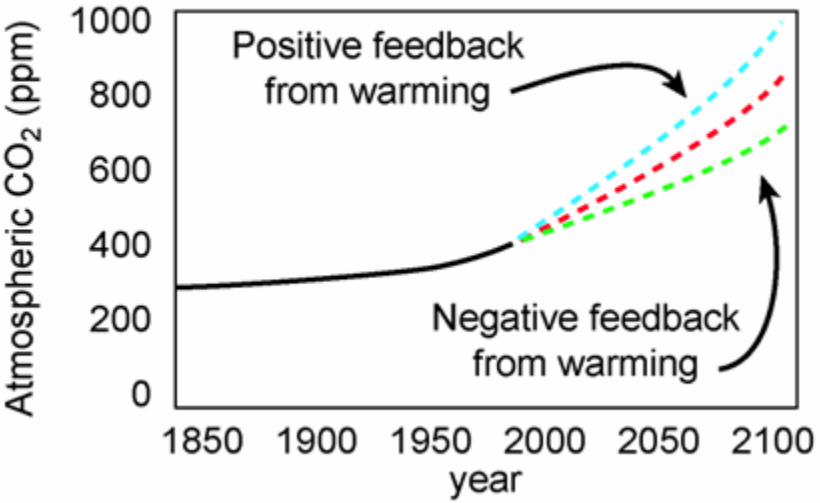

Global energy system (Exajoules)
3000
2500
2000
1500
500
0
Rapid economic growth
Modest economic growth
1850
1900
1950
2000
2050
2100
year

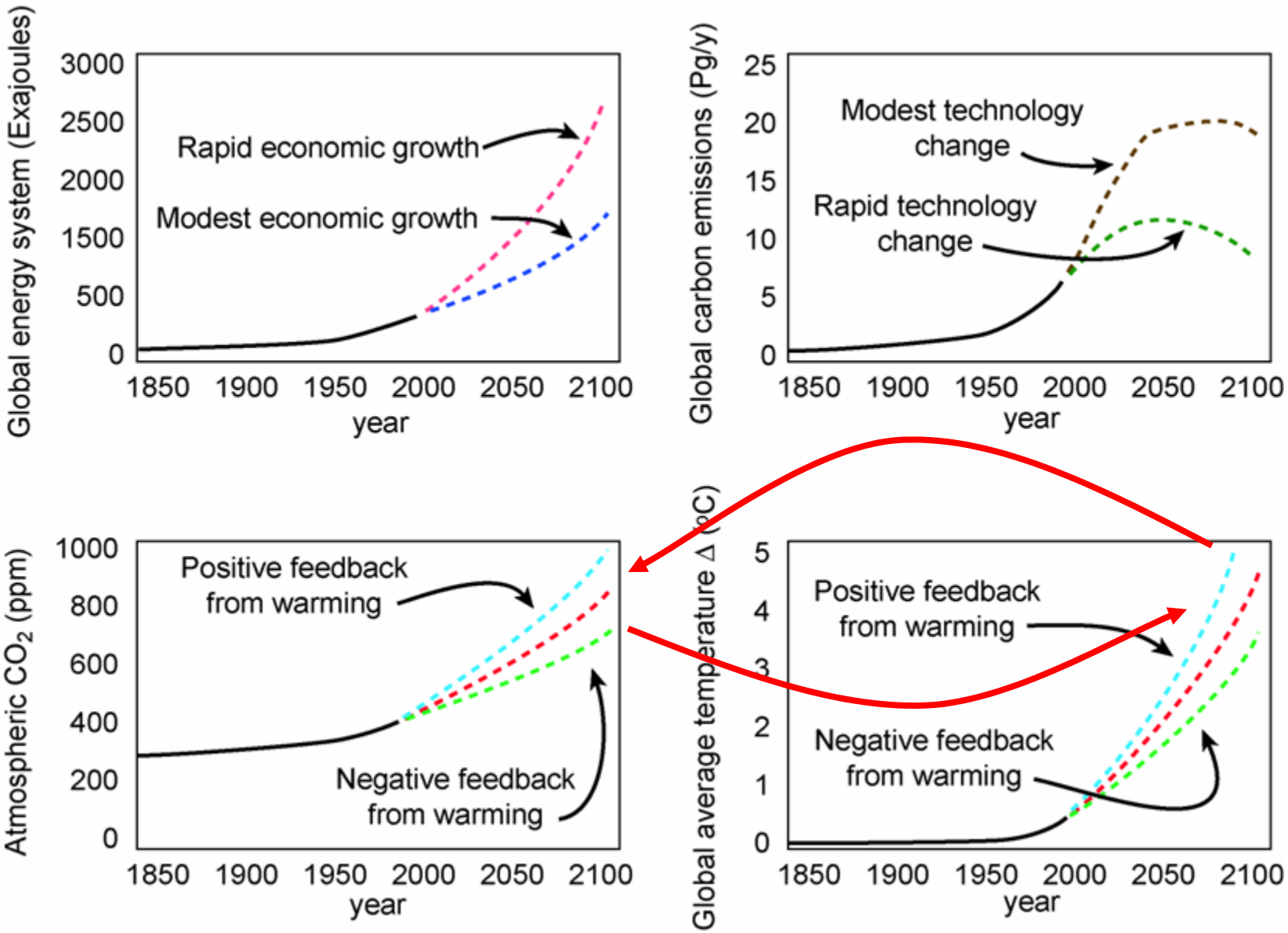

Global carbon emissions (Pg/y)
25
20
15
10
5
0
Modest technology change
Rapid technology change
1850
1900
1950
2000
2050
2100
year

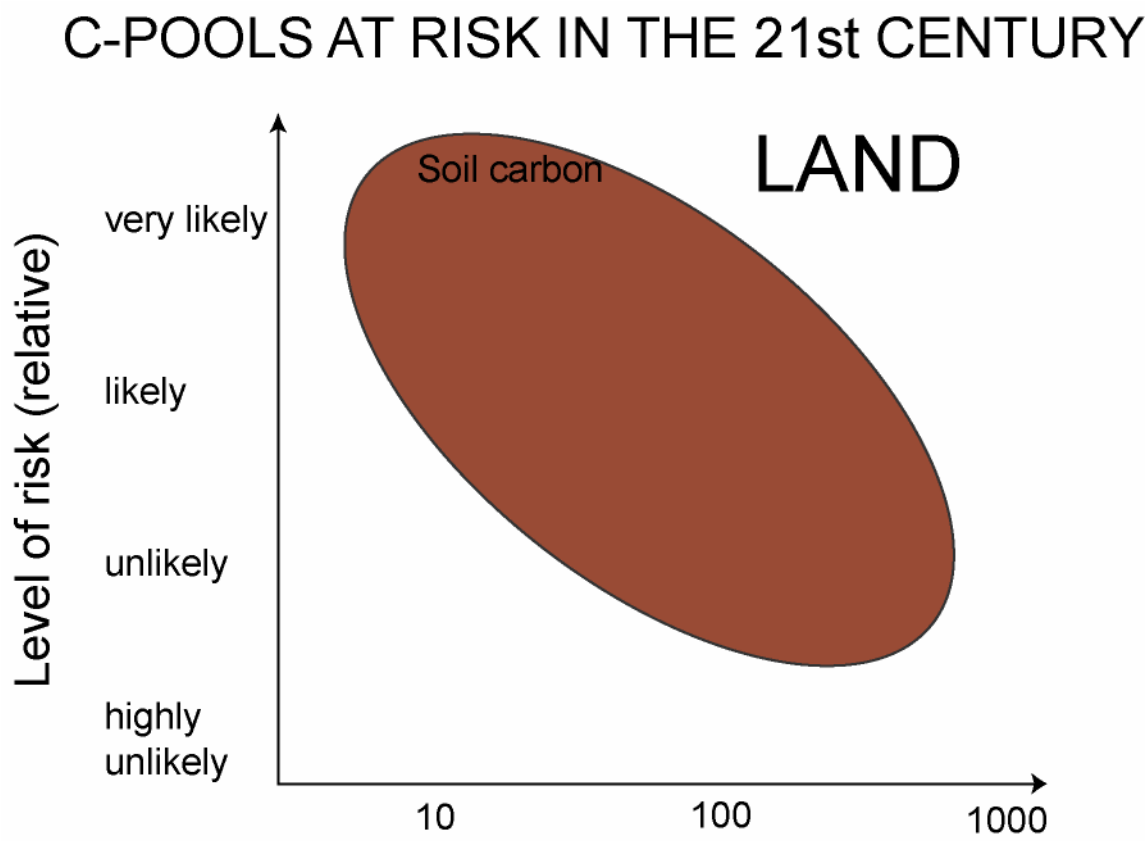

Atmospheric CO_2 (ppm)
1000
800
600
400
200
0
Negative feedback from warming
1850
1900
1950
2000
2050
2100
year


Global energy system (Exajoules)
3000
2500
2000
1500
500
0
Rapid economic growth
Modest economic growth
1850
1900
1950
2000
2050
2100
year

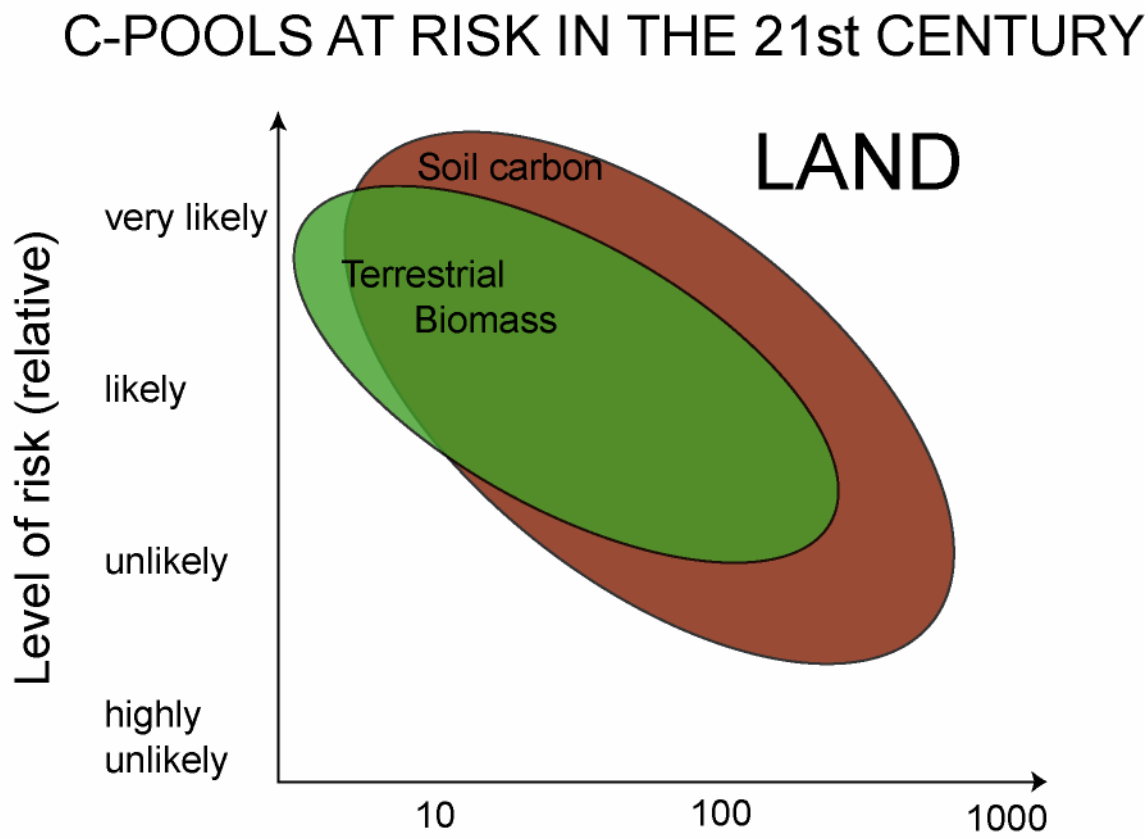

Global carbon emissions (Pg/y)
25
20
15
10
5
0
Modest technology change
Rapid technology change
1850
1900
1950
2000
2050
2100
year


Atmospheric CO_2 (ppm)
1000
800
600
400
200
0
Positive feedback from warming
Negative feedback from warming
1850
1900
1950
2000
2050
2100
year

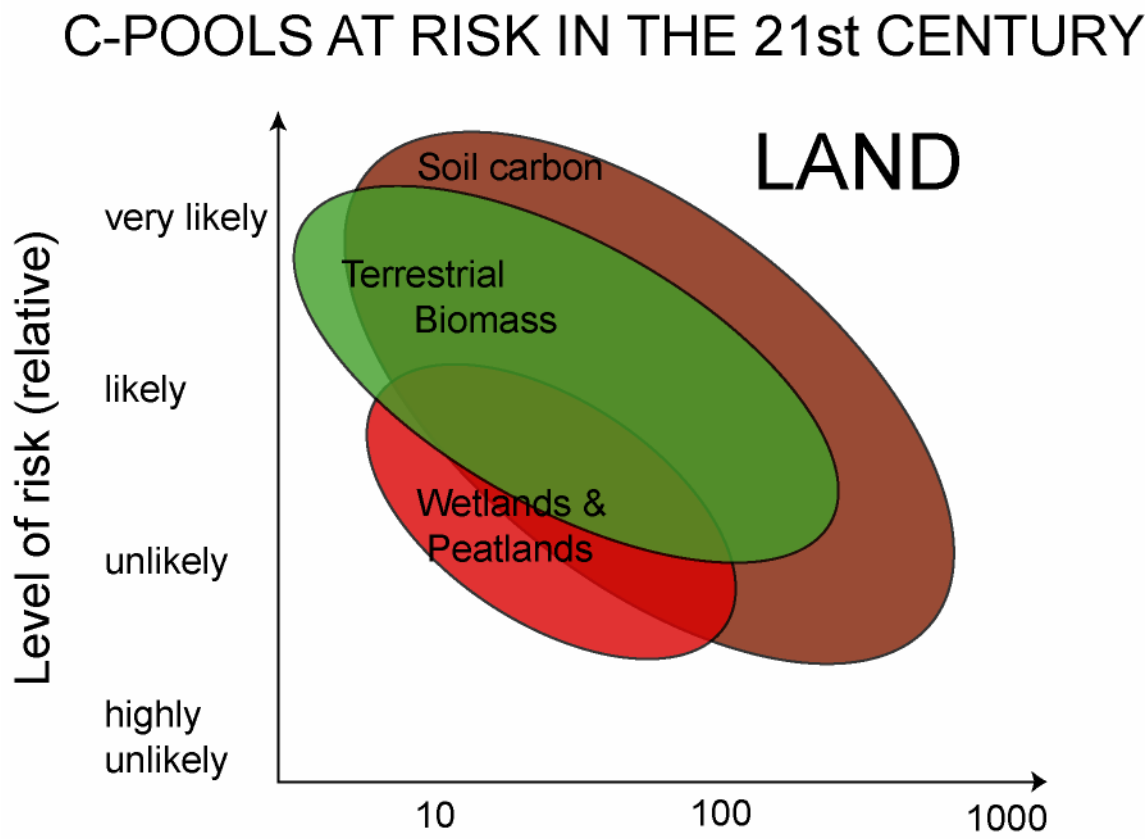

Global energy system (Exajoules)
3000
2500
2000
1500
500
0
Rapid economic growth
Modest economic growth
1850 1900 1950 2000 2050 2100
year
Global carbon emissions (Pg/y)
25
20
15
10
5
0
Modest technology change
Rapid technology change
1850 1900 1950 2000 2050 2100
year
Atmospheric CO_2 (ppm)
1000
800
600
400
200
0
Positive feedback from warming
Negative feedback from warming
1850 1900 1950 2000 2050 2100
year
Global average temperature Δ (°C)
5
4
3
2
1
0
Positive feedback from warming
Negative feedback from warming
1850 1900 1950 2000 2050 2100
year



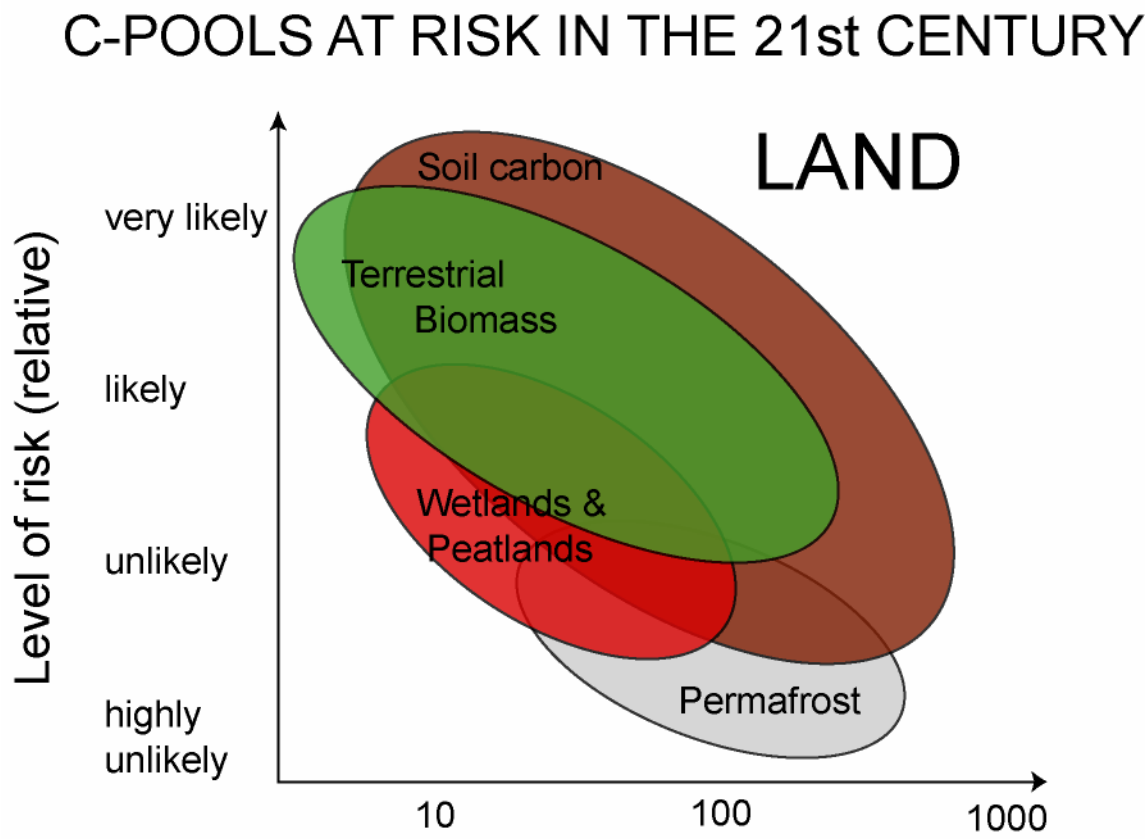
Gruber et al. SCOPE 62, 2004



Gruber et al. SCOPE 62, 2004



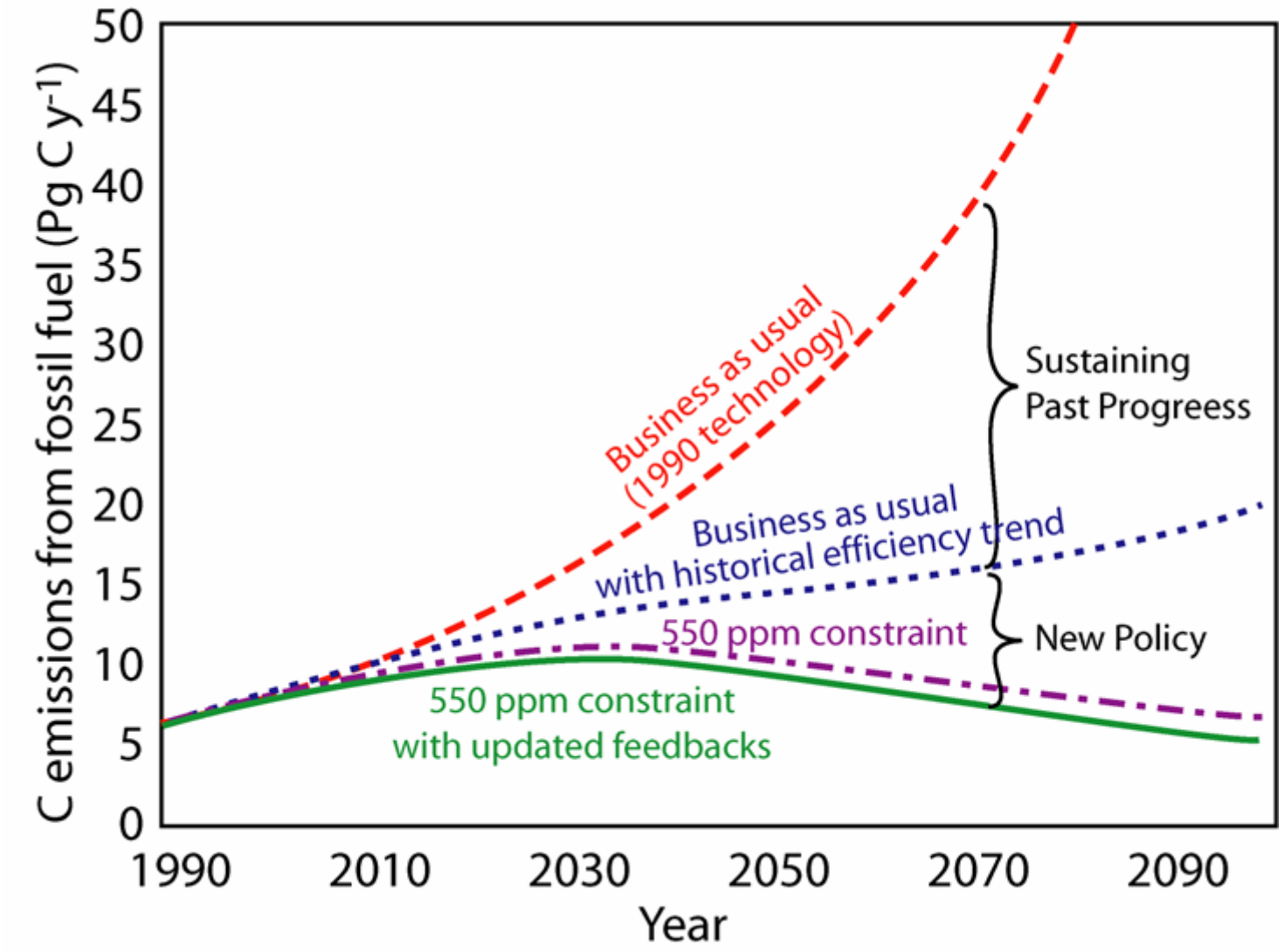
Gruber et al. SCOPE 62, 2004



Gruber et al. SCOPE 62, 2004

Land subsidies: New evidence

- Limited effects of CO_2 fertilization
  - (decreased subsidies)
- Vulnerable pools
  - (decreased subsidies or carbon losses)
- Land: New uncertainty
  - Uptake of 125 ppm
  - Release of 200 ppm
- 325 ppm is most of the range among IPCC scenarios in 2100


C emissions from fossil fuel (Pg C y-1)
50
45
40
35
30
25
20
15
10
5
0
1990
2010
2030
2050
2070
2090
Year
Business as usual
(1990 technology)
Business as usual
with historical efficiency trend
550 ppm constraint
550 ppm constraint
with updated feedbacks
Sustaining
Past Progress
New Policy

From the natural side of the C cycle

- Challenge:
  - Preserve economic growth
  - Preserve integrity of global climate

- No single solution

- Dramatically increased commitments to:
  - Conservation
  - Efficiency
  - New technologies
  - Sequestration