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Evaluation of long-term bioenergy penetration considering uncertainties in allowable carbon emissions and technology

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Acknowledgement
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Outline

- Introduction
  - Long-term mitigation under climate and socio-economic uncertainties

- Methods
  - Integrated assessment model
  - Scenarios

- Results and discussion
  - Reference scenario and middle scenario
  - Changes in biomass energy supply
  - Changes in land use change
  - Summary

Introduction

Mitigation target → **Emissions scenario** → **Socio-economic impact**
Mitigation costs
Energy, Land use
Biomass

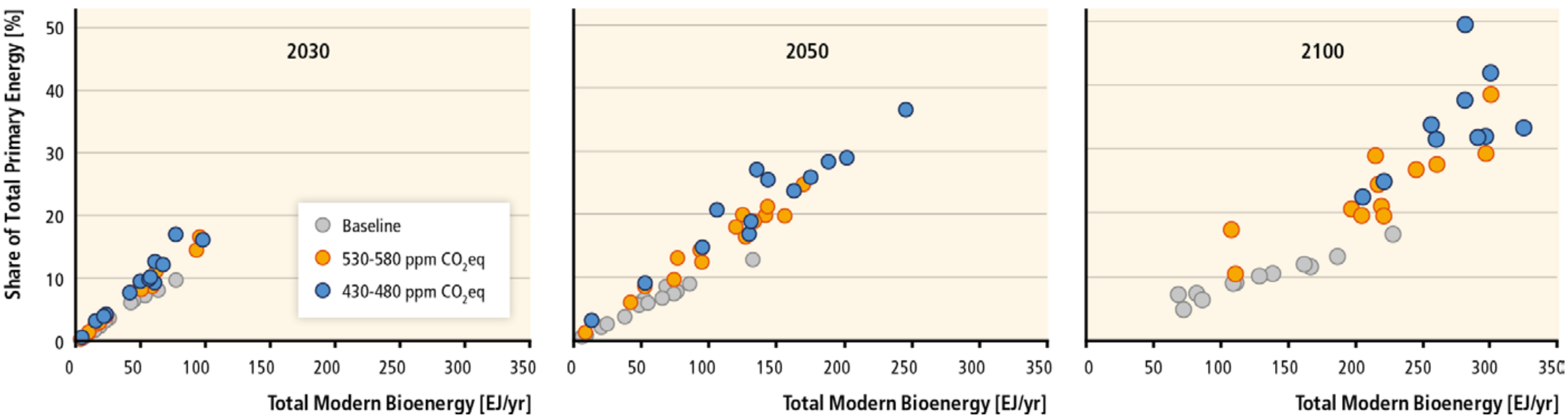
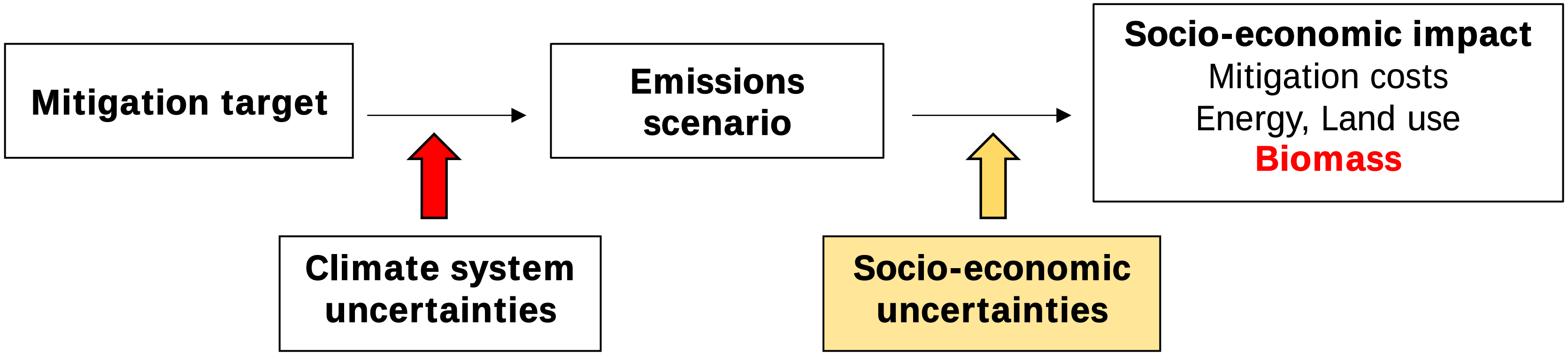
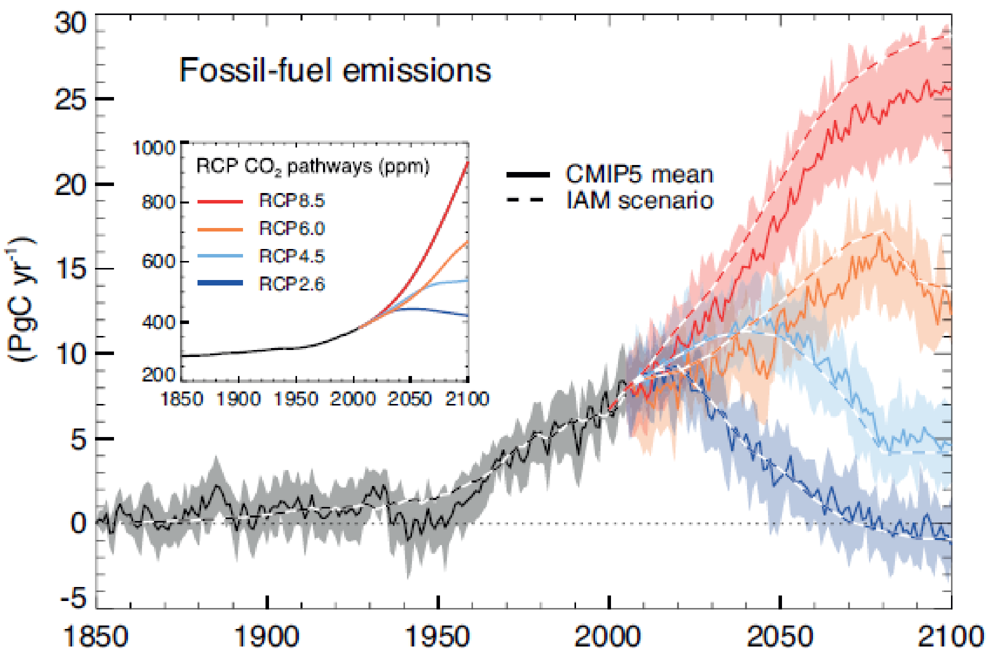


Fig 6.33 from IPCC AR5-WG3, 2014

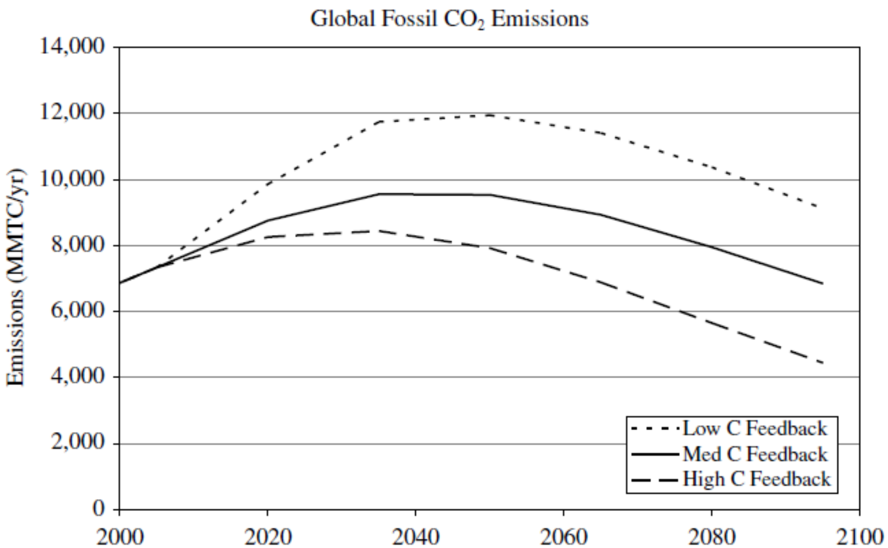
Introduction

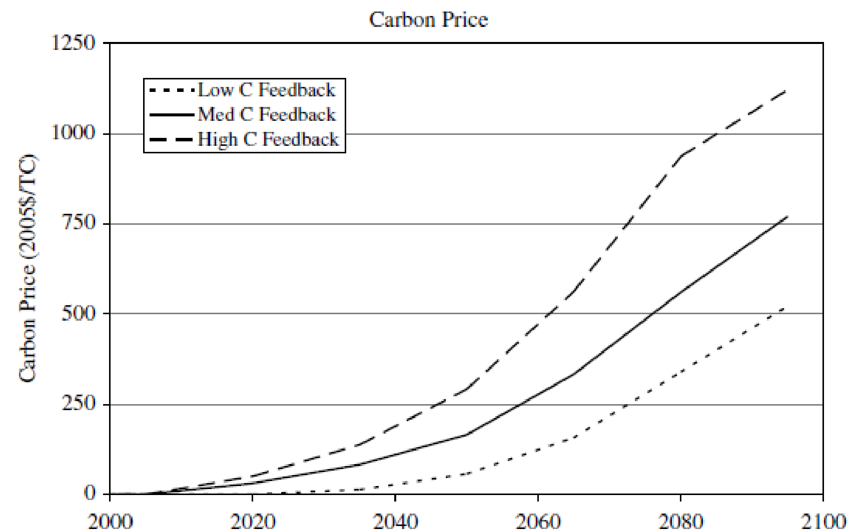




Compatible fossil fuel emissions simulated by the CMIP5 models for the four RCP scenarios. Time series of annual emission (PgC yr–1). (Figure TS.19 in IPCC AR5, 2014)

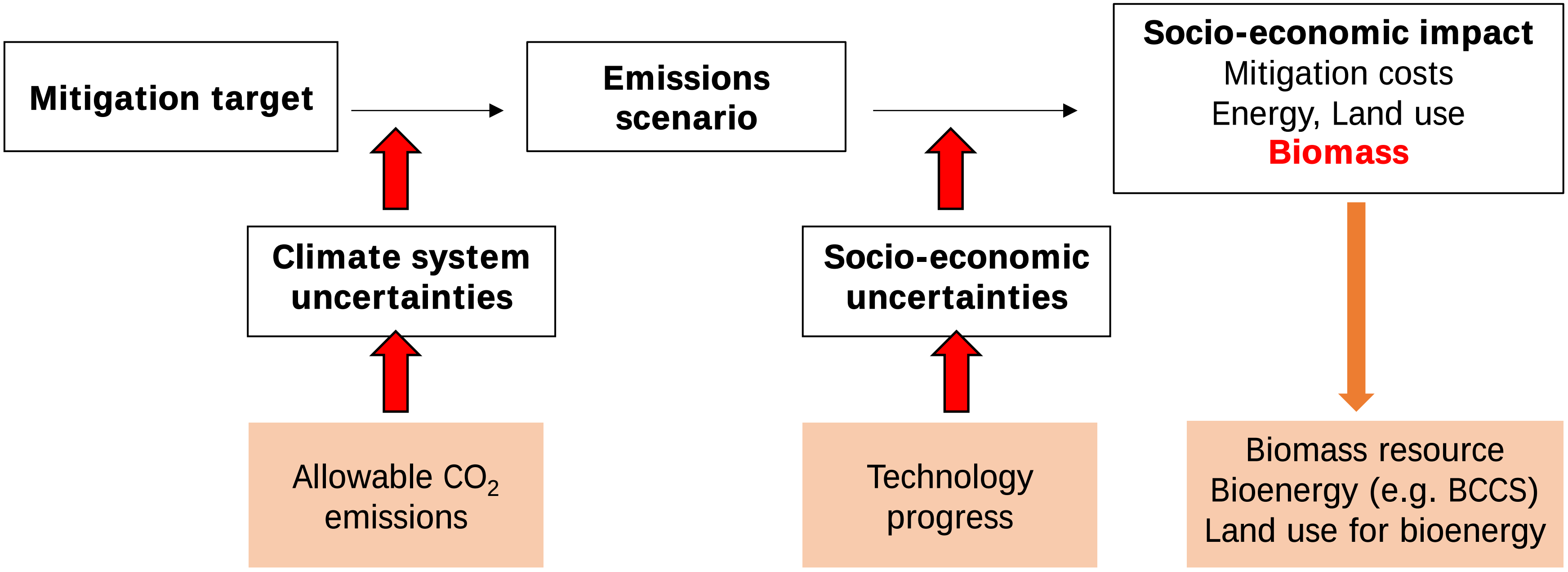
Introduction





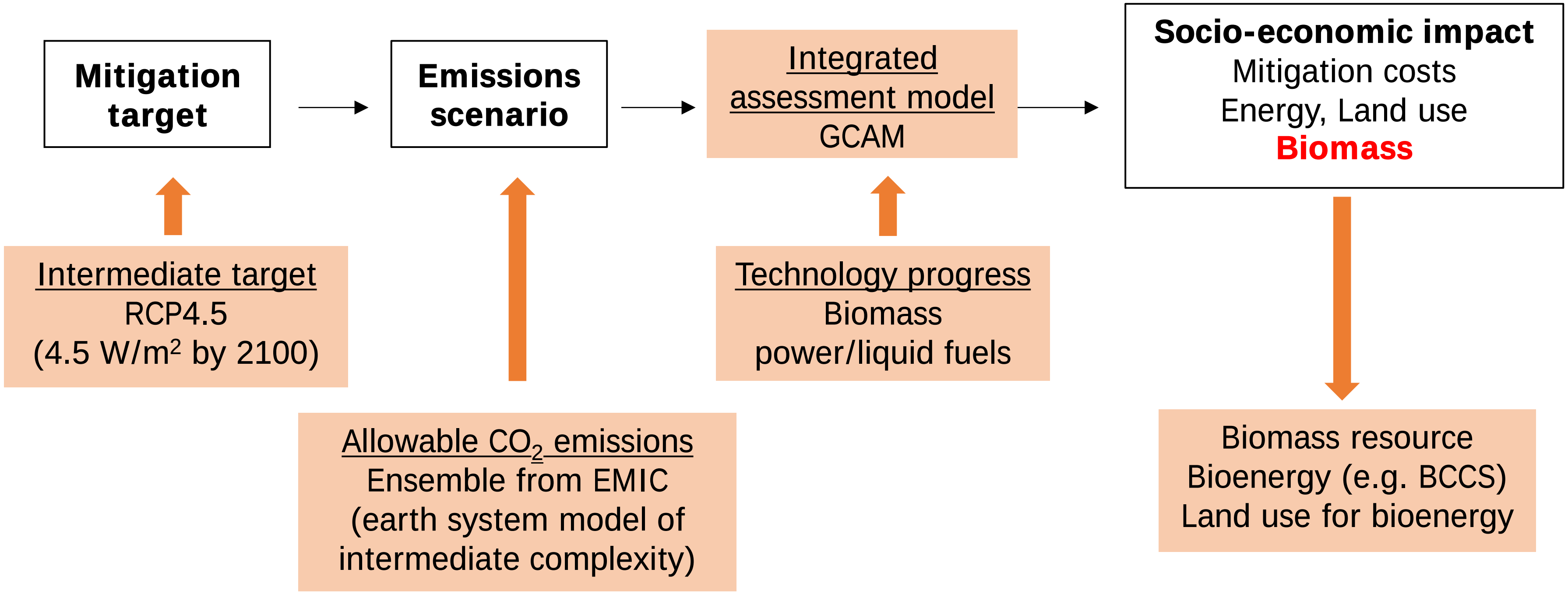
Emissions pathways and carbon price for stabilization at 550 ppmv
for three carbon cycle scenarios.
(Figure 2 and Figure 3 in Smith and Edmonds, 2006, Tellus)

Research goal



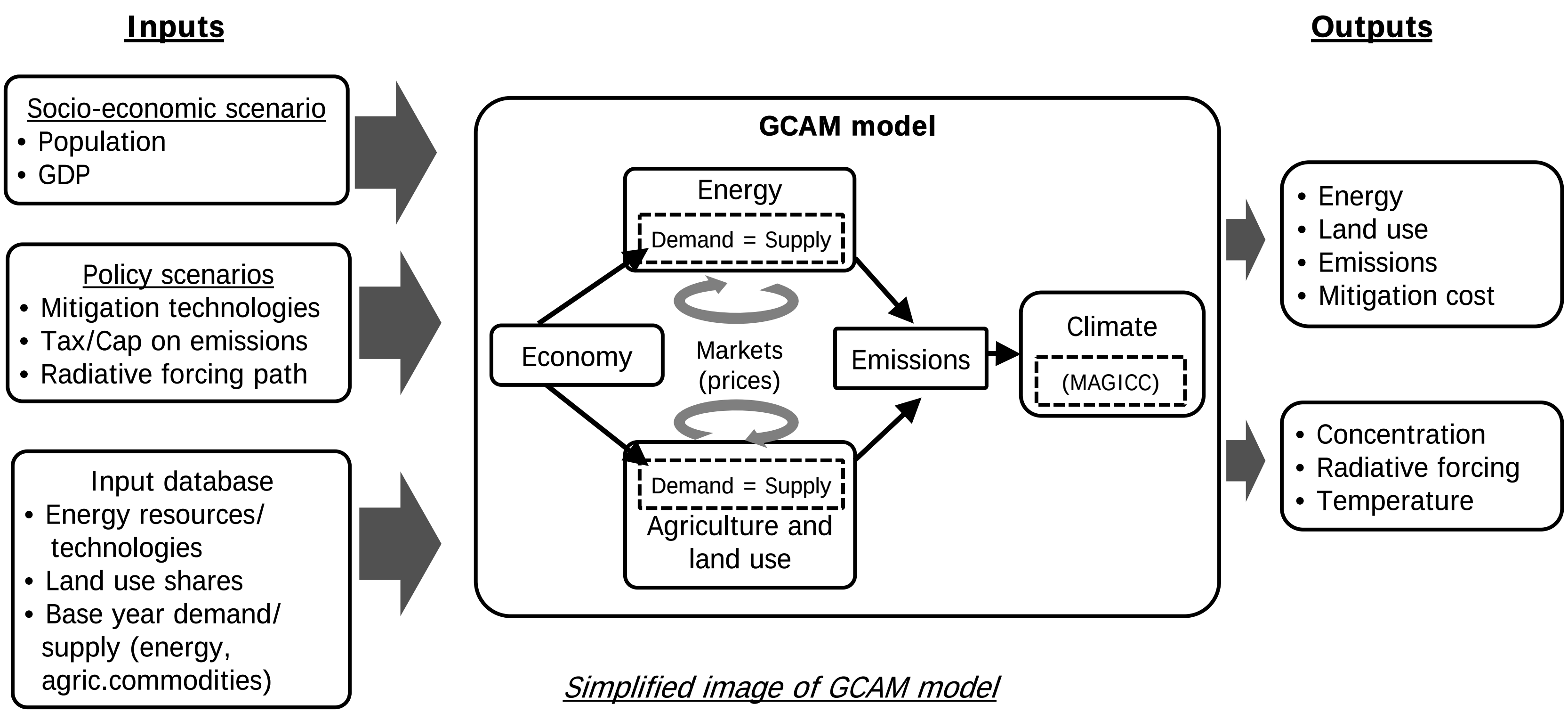
- Uncertainties in climate system (allowable CO_2 emissions) vs technology!
- Bioenergy in the long-term (2050/2100) considering mitigation target under uncertain CO_2 emissions path.
- Implications for bioenergy resource use (energy potential), land use change (i.e. compromise food and other LU).

Method – Overall framework



Method - Global Change Assessment Model (GCAM)

- Integrated assessment model (IAM)
- Analysis up to 2100, partial equilibrium, energy and agriculture/land use sectors, 32 world regions.



Simplified image of GCAM model

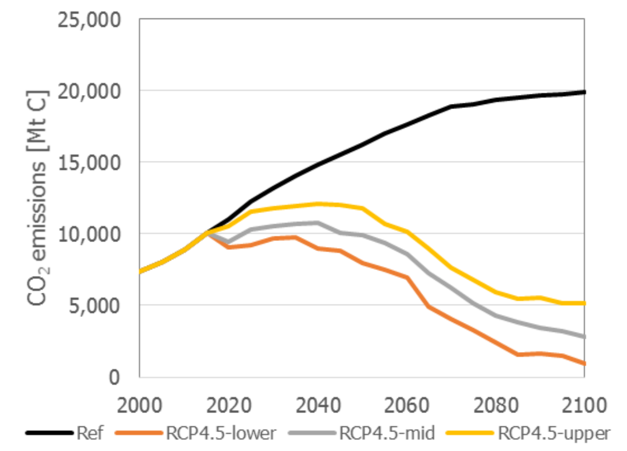
Method - Scenario setting

Socio-economics:

- SSP2: Shared socioeconomic pathways, intermediate challenges for mitigation/adaptation.

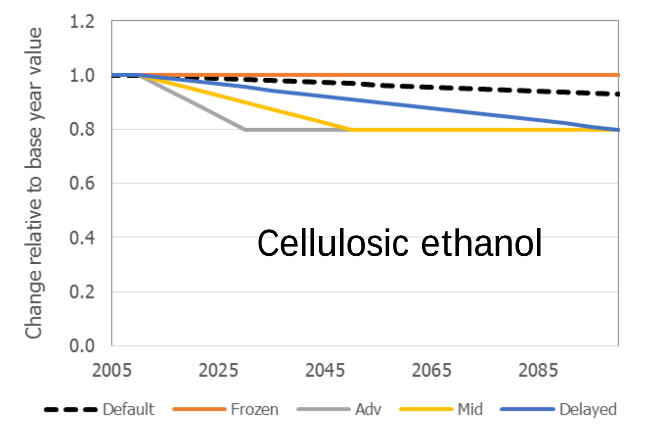
Mitigation scenarios (“RCP4.5”): radiative forcing ~4.5W/m^2 by 2100

Scenario	Description
Ref	No mitigation policy
RCP4.5-lower	allowable CO_2 emission 5th percentile of EMIC ensemble.
RCP4.5-mid	allowable CO_2 emission 50th percentile of EMIC ensemble.
RCP4.5-upper	allowable CO_2 emission 95th percentile of EMIC ensemble.



Bioenergy technology scenarios: RCP4.5-mid with assumptions on improvement in capital costs.

Scenario	Description
CapCost-Frozen	Capital cost of bioenergy technologies same as base year.
CapCost-Adv	Capital cost of bioenergy technologies decrease until 2030.
CapCost-Mid	Capital cost of bioenergy technologies decrease until 2050.
CapCost-Delay	Capital cost of bioenergy technologies decrease until 2100.



Method – Allowable CO_2 emissions

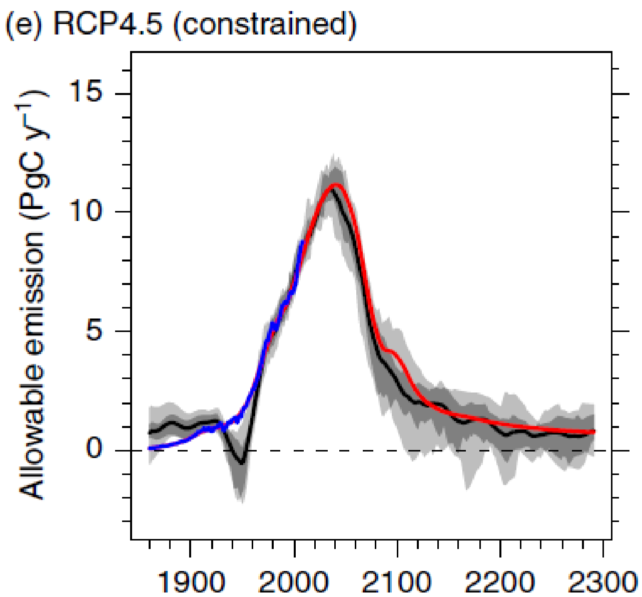
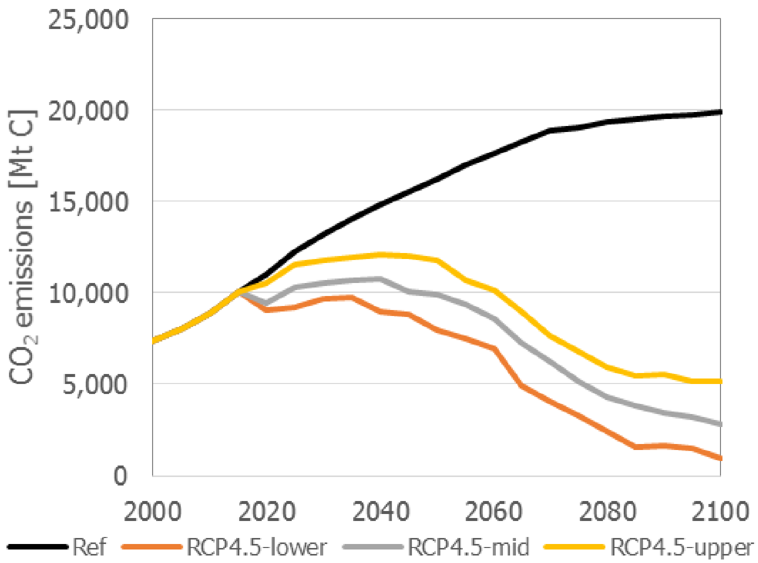


Fig 2.b) from Tachiiri et al., Tellus, 2013.



- Allowable CO_2 emissions compatible with representative concentration pathway (RCP) RCP4.5.
  - Radiative forcing target of 4.5 W/m^2 by 2100.
- Sample from experiment ensemble using earth system model of intermediate complexity (EMIC).
  - Constrained case: 5/50/95 percentiles (Lower/Mid/Upper).

Method – Climate system parameters in EMIC experiments

Table 1. Parameters perturbed in this study and the ranges considered

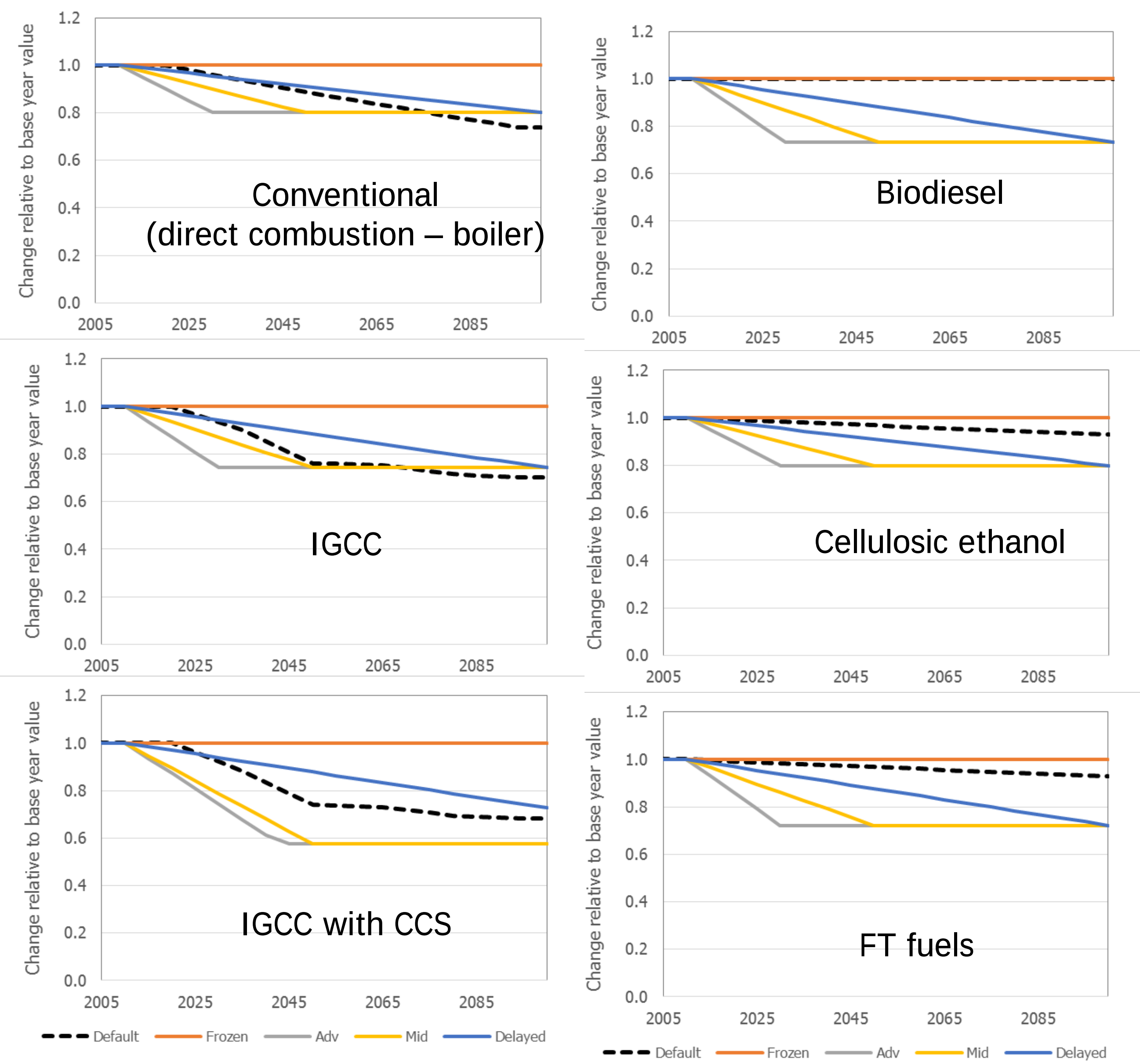
Parameter	Component	Default	Perturbation range
Climate sensitivity	Atmosphere	4.7 [b]	1–6 K†
Vertical diffusivity	Ocean	0.1–3.0 cm^2/sec*	0.3–3.0 × default
Horizontal diffusivity	Ocean	1×10^7 cm^2/sec	0.5–5.0 × default
Gent-McWilliams thickness parameter [a]	Ocean	7×10^6 cm^2/sec	$1–20 \times 10^6$ cm^2 s^{-1}
Magnitude of freshwater flux adjustment	Ocean	1.0 (ratio to the values by [c])	0.5–2.0
Wind speed used in marine CO_2 uptake	Marine carbon	3.3 m/s [b]	2.0–8.0 m/s
Maximum photosynthetic rate	Land carbon	8.0–13.5 μmolCO_2/(m^2s)**	0.8–3.0 × default
Specific leaf area	Land carbon	110–170 cm^2/(g drymatter)**	0.5–2.5 × default
Minimum temperature for photosynthesis	Land carbon	−5.0–11.0°C**	−4.5–+3.0°C of default
Coefficient for temperature dependency of plant's respiration	Land carbon	2.0 (dimensionless)	1.5–3.0
A parameter of temperature dependency of soil respiration	Land carbon	46.02 K	35–55 K
Total aerosol forcing	Forcing	(RCPs)	0.0–3.0 × RCPs††

Parameters perturbed and where the symbols are: * and **: depth- and biome-dependent. †initially in a uniform distribution, and then weighted with a beta function (Appendix A1). ††Weighted with combination of two Gaussian functions (Appendix A2).
[a]: Gent and McWilliams (1990).
[b]: Tachiiri et al. (2010).
[c]: Oort (1983).

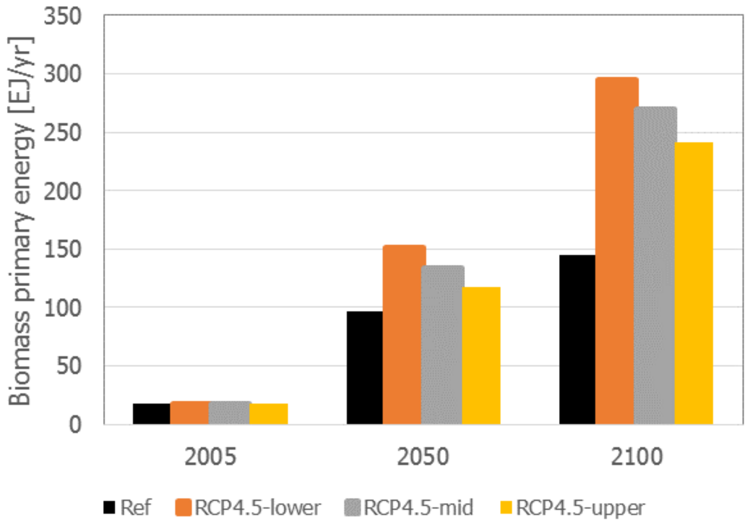
Table 1 from Tachiiri et al., Tellus, 2013.

Method - Capital cost of bioenergy technologies

- Outlook for capital cost reduction.
- International Energy Agency: Energy Technology Perspectives, World Energy Outlook.
- IPCC: special report on renewable energy.
- IRENA
- US Department of Energy: annual energy outlook.



Results - Biomass production



- Biomass supply increases considerably with more stringent emissions path (upper → lower).
- Change is within middle range of technical potential in literature.
- Change is smaller than uncertainty in technical potential.
- Share of TPES (10-25%) in middle-low range of mitigation scenarios literature (IPCC AR5).

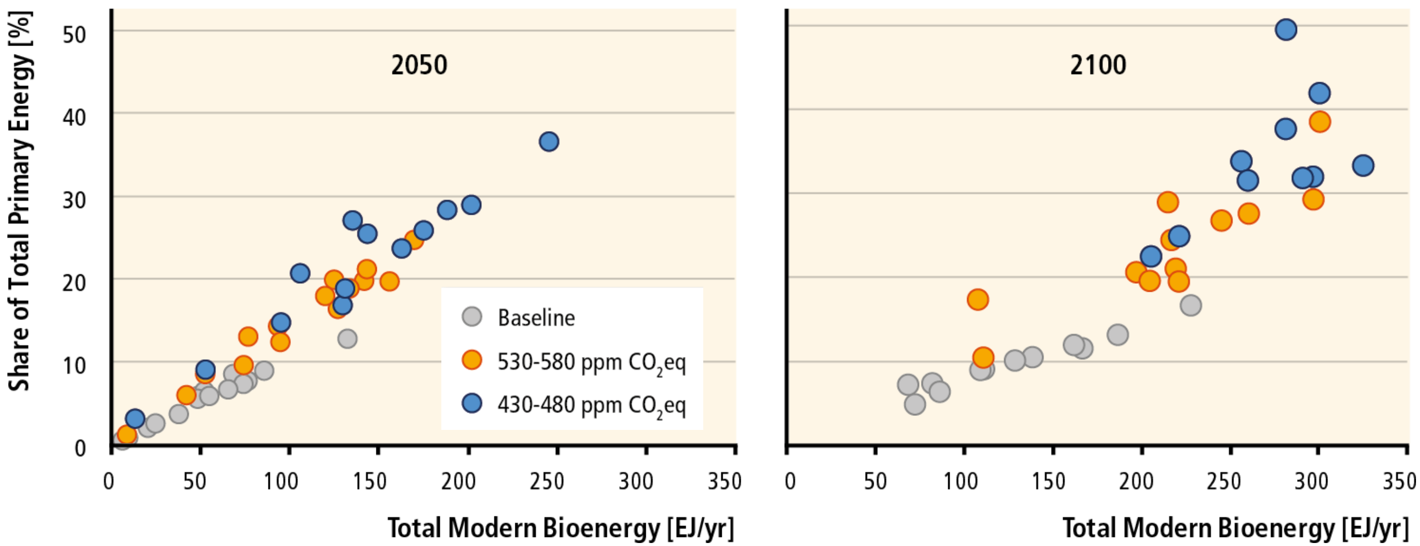
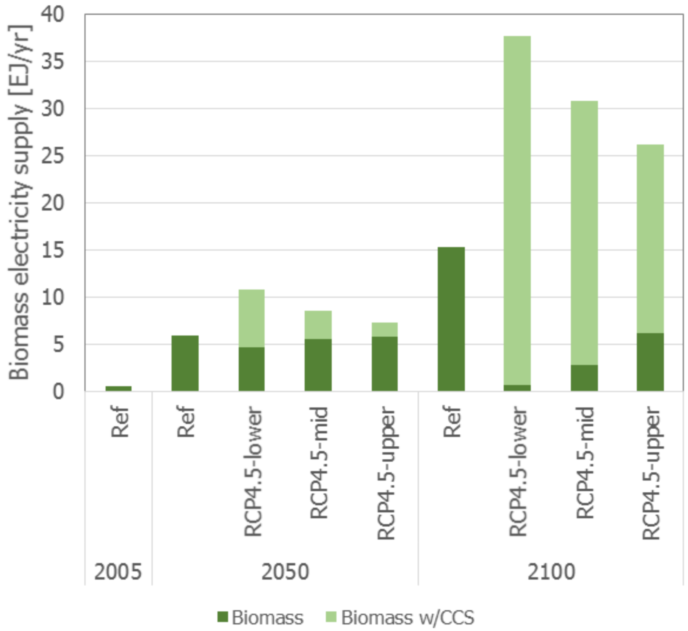


Fig 6.33 from IPCC AR5-WG3, 2014

Results - Biomass power



- Effect of emissions uncertainty on biomass power is large compared to other factors.
- Share of BECCS in electricity supply (7-11%) increases with stringency of emissions path.
- Share of BECCS in biomass power supply is in high range of literature (IPCC AR5).

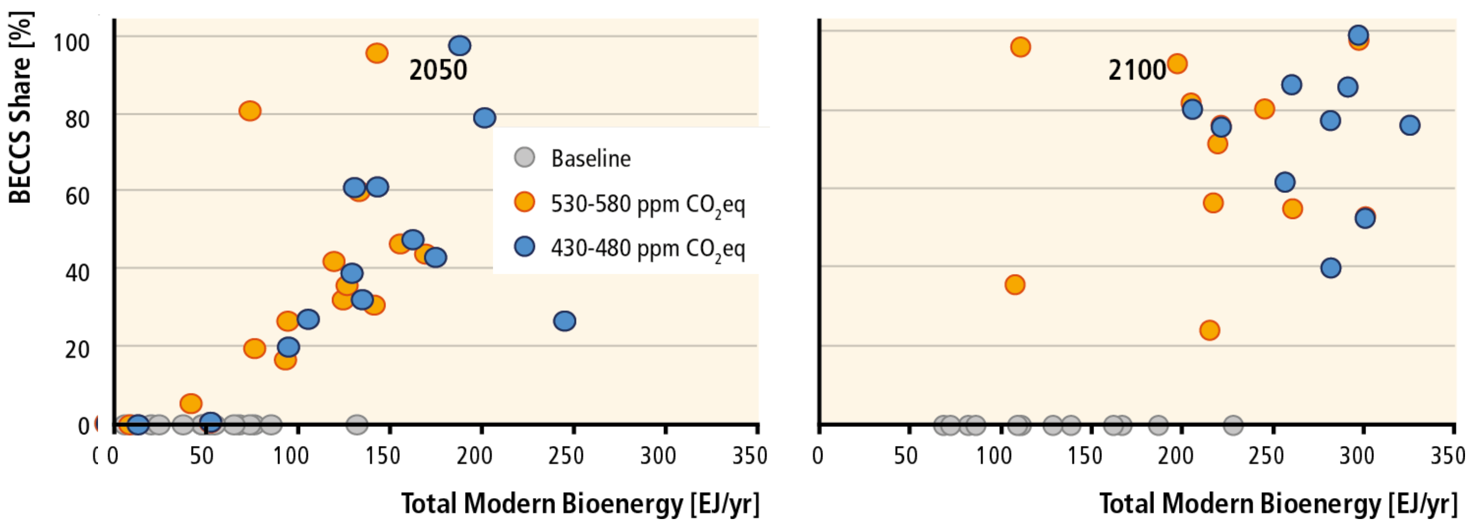
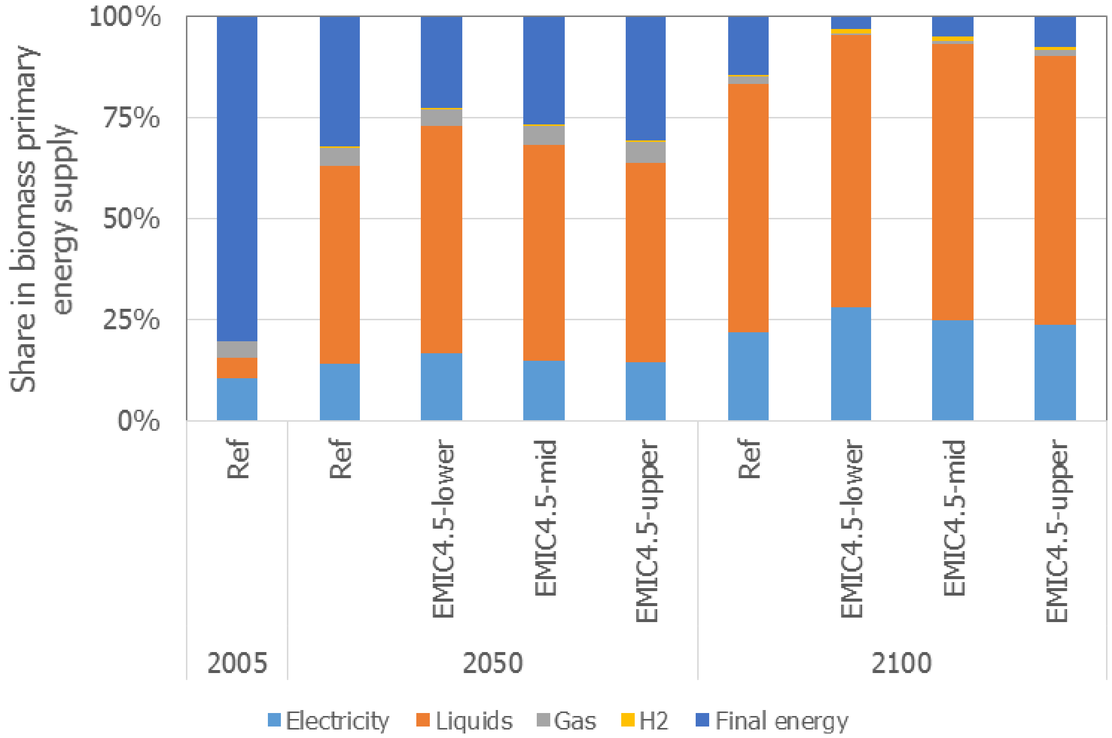


Fig 6.33 from IPCC AR5-WG3, 2014

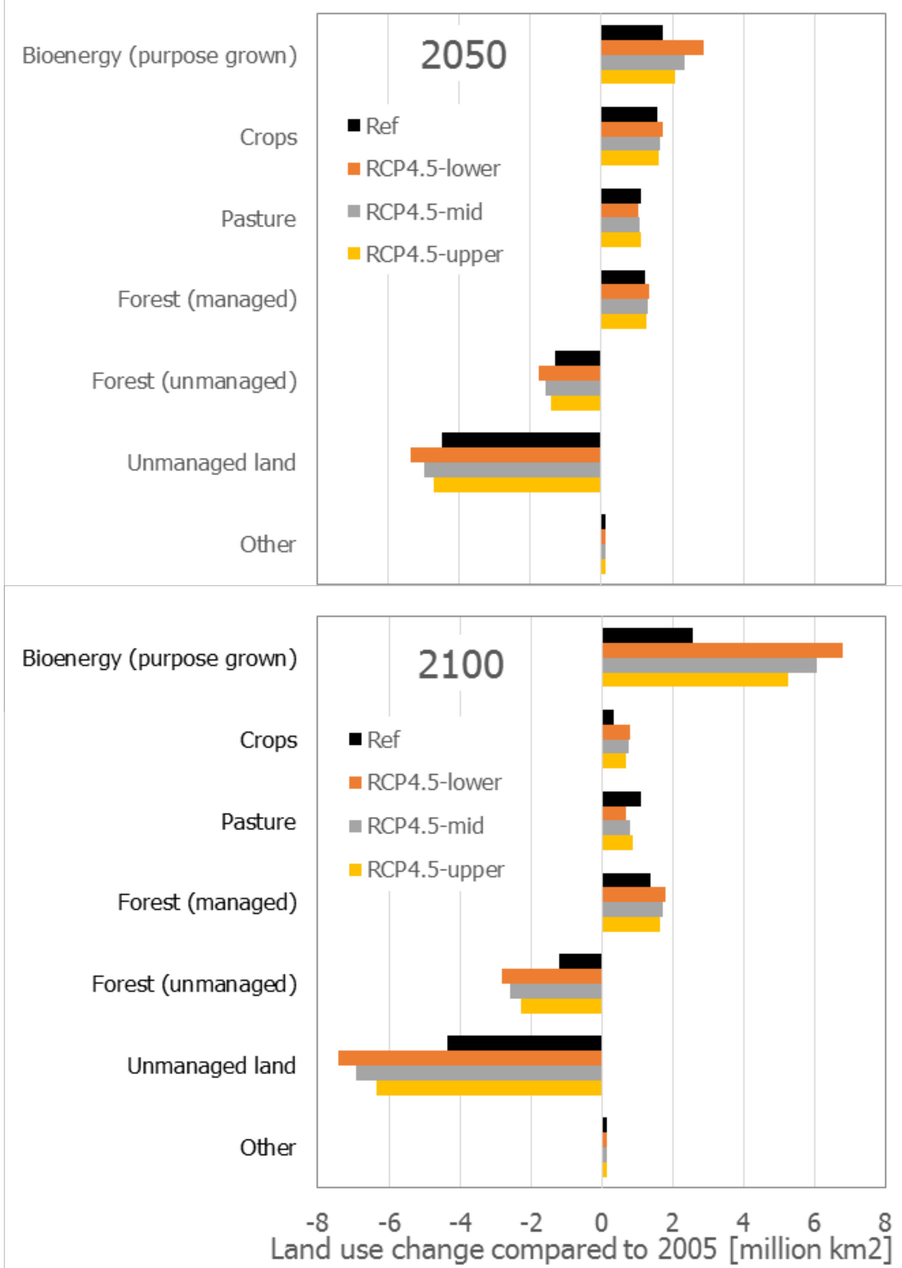
Results - Biomass supply breakdown



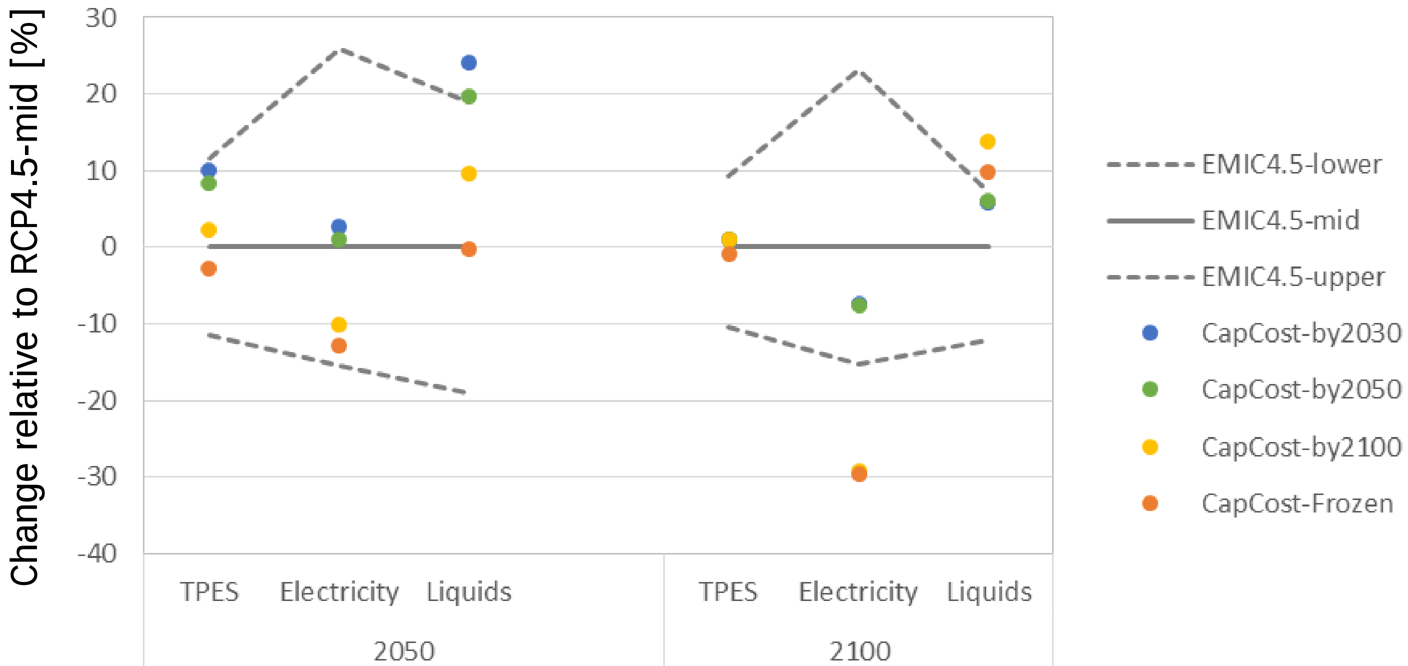
- Biomass mostly used for liquid fuel production in long-term.
- Share in total biomass primary energy supply little affected by emissions uncertainty.

Results - Land use change

- Effect of emissions uncertainty is small compared to those in energy supply.
- Land for bioenergy dedicated crops changes by 11-22%.
- Reductions in unmanaged lands.
- Higher emissions reductions induce loss of natural forest, but gains in managed forest (plantations/reforestation).
- Net change in total forest area not considerable (less than 3% of 2005 area).

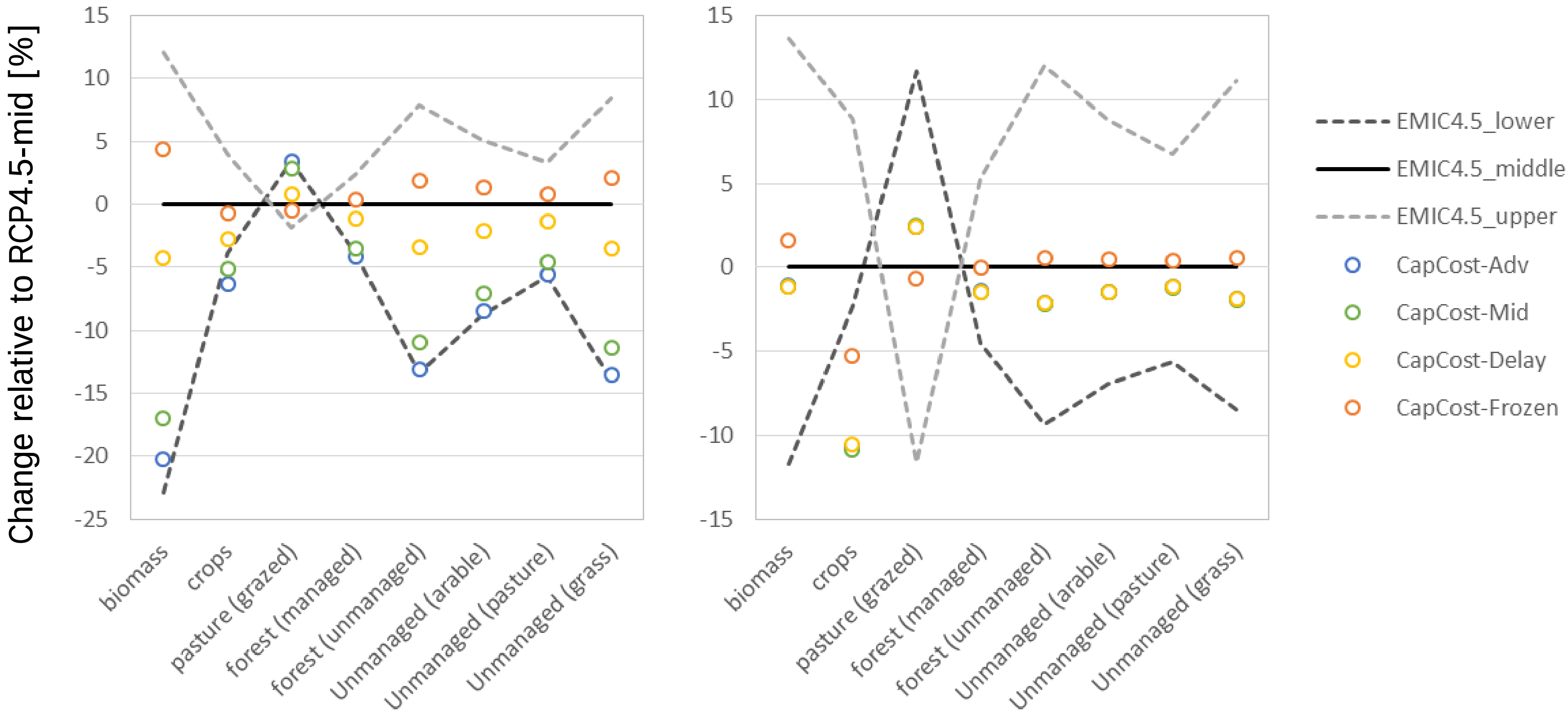


Results – Bioenergy supply



- Technology costs have positive impact in 2050.
- Cost reductions in 2100 only favors fuels.
- Uncertainty in biofuels cost comparable to that of allowable emissions.

Results – Land use change



- Compared to uncertainty in allowable emissions, uncertainty in biofuels cost has more impact for cropland.
- Changes in other land uses only considerable in 2050 for optimistic scenarios (e.g. CapCost-Adv).

Conclusion

- Evaluated the contribution of biomass energy in the long-term considering uncertainty in allowable CO_2 emissions and technology for intermediate mitigation target (RCP4.5).

- Uncertainty in emissions affects clearly bioenergy supplies (BECCS) and land for dedicated energy crops.

- Effect of uncertain allowable emissions on bioenergy tends to be greater than technology progress.
- Technology optimistic scenarios can change the picture (sp. biofuels).

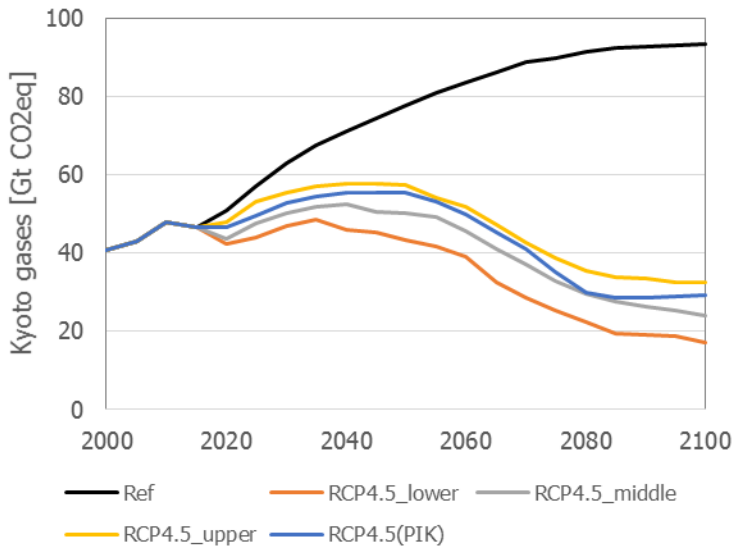
Next tasks:

- Evaluate more stringent mitigation targets (e.g. RCP2.6).
- Evaluate other uncertainties related to technology (e.g. efficiency) and other socio-economic components.
- Explore role of bioenergy-climate interactions (e.g. via land use change).

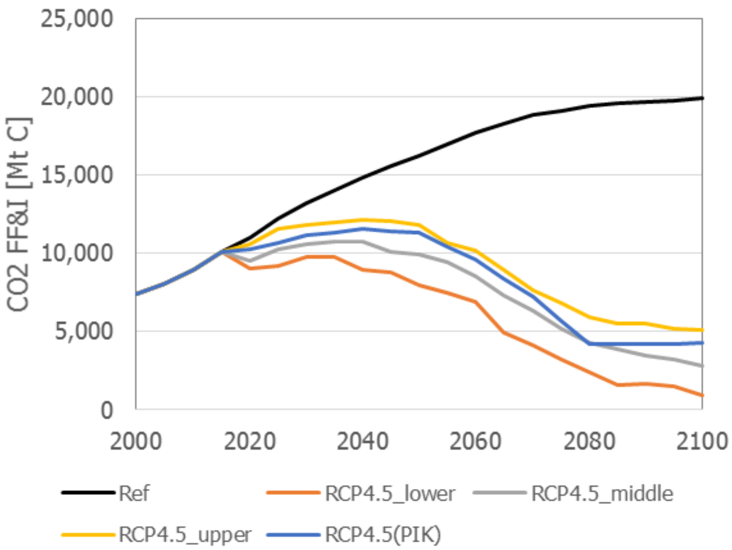
Thank you!

Results

GHG emissions



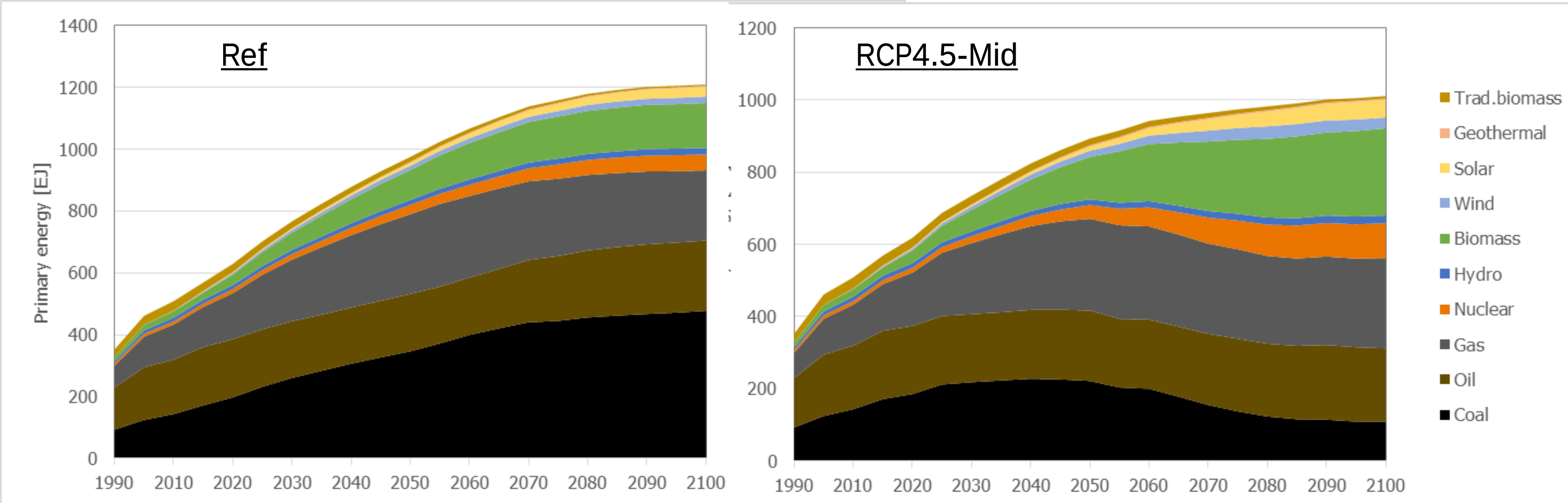
CO_2 emissions
(fossil fuel and industry)



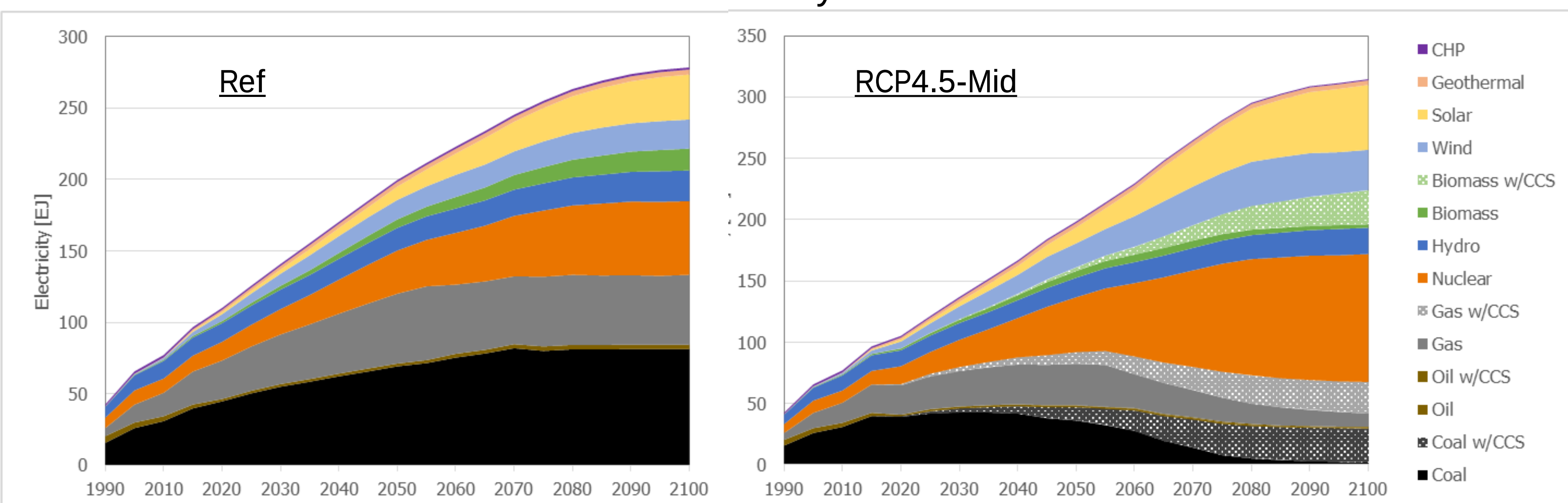
- Emissions from "standard" RCP (PIK database) are within the middle and upper percentile of EMIC ensemble.

Results

Global TPES

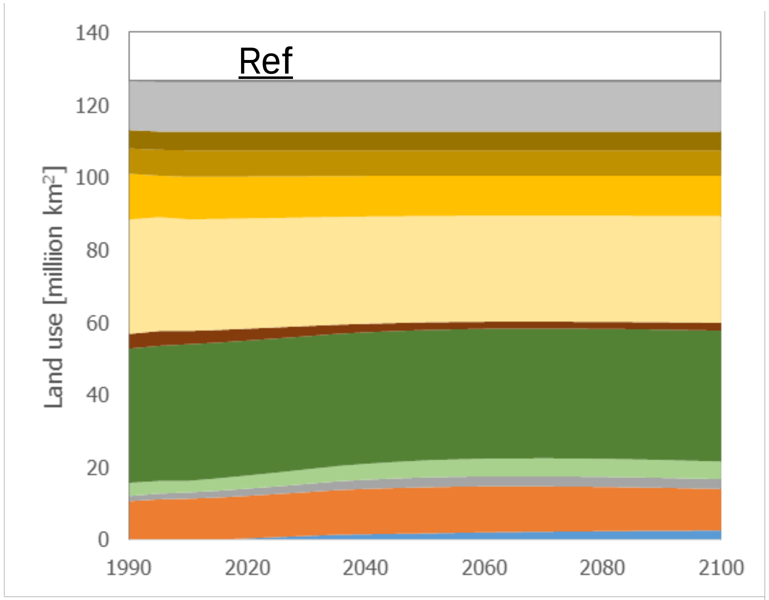


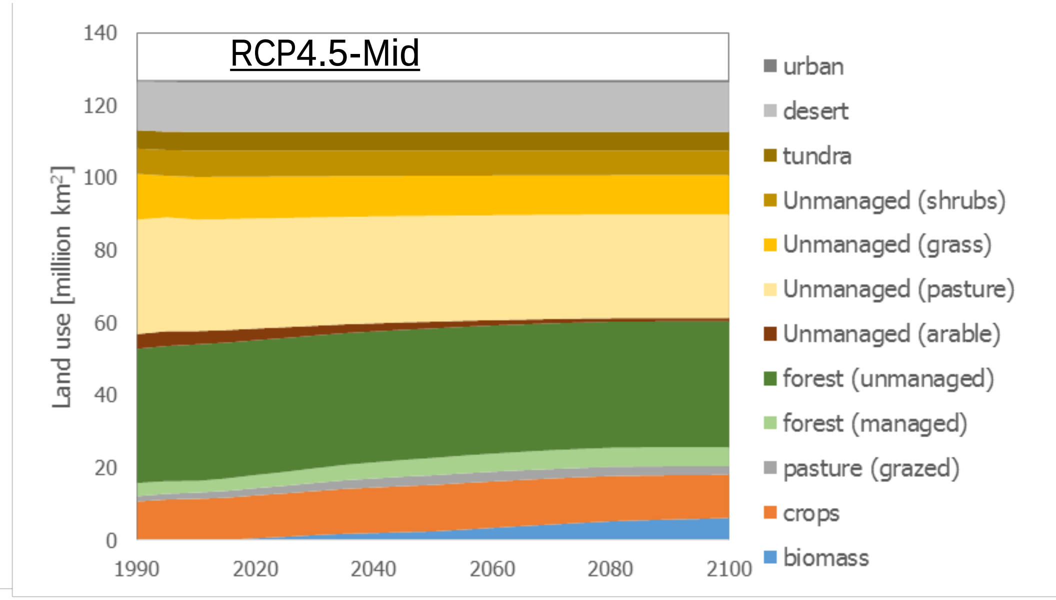
Global Electricity



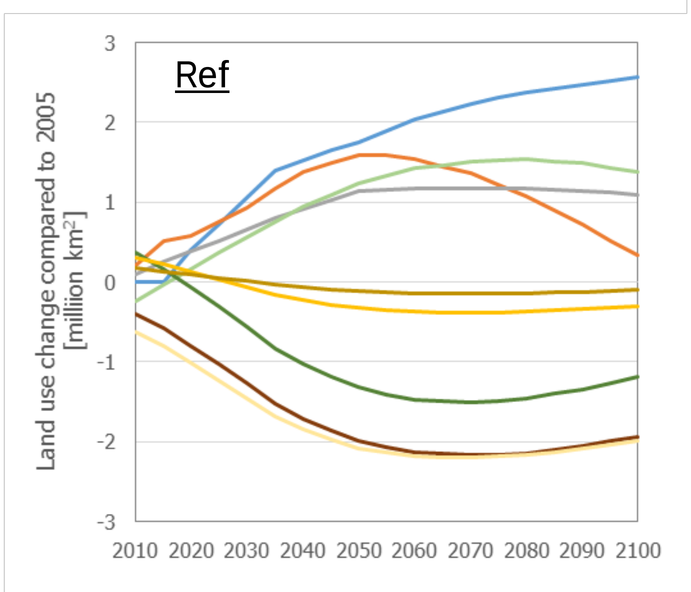
Results

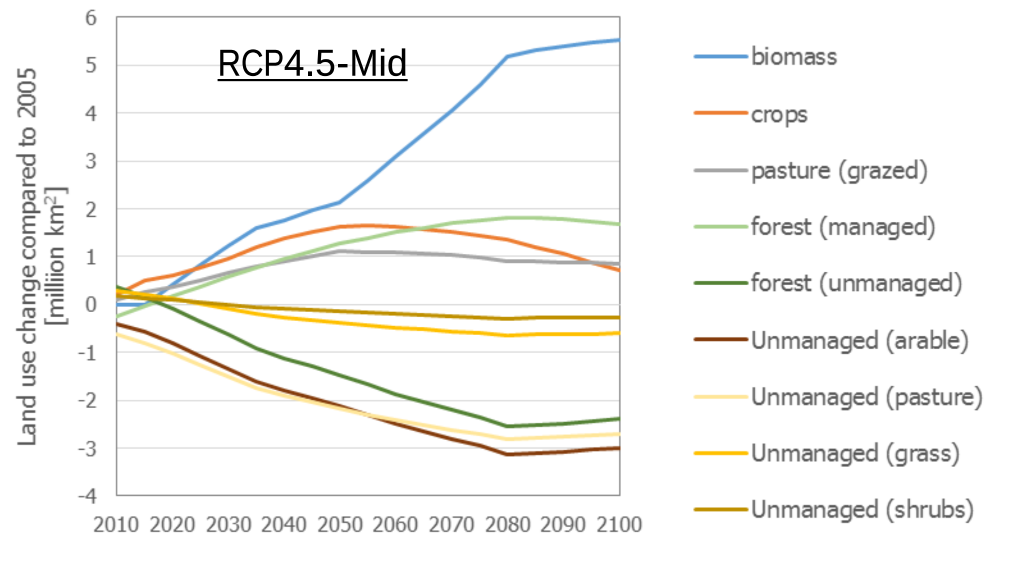
Global Land use



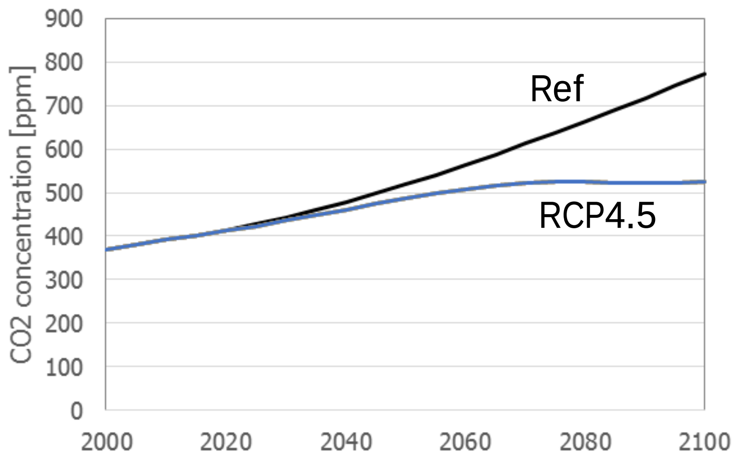


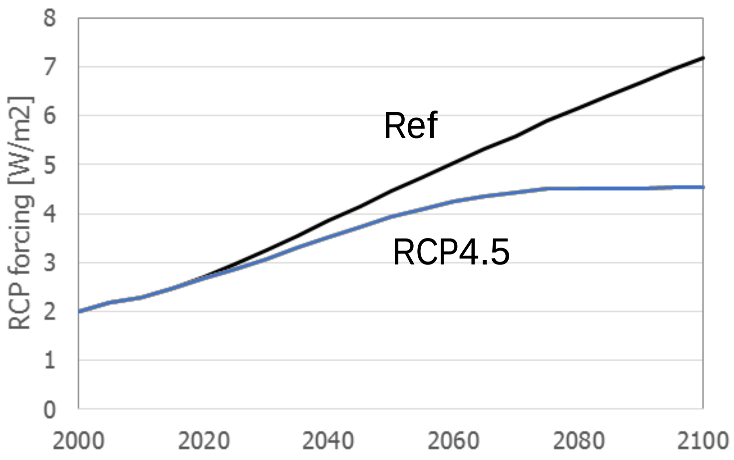
Global Land use change compared to 2005

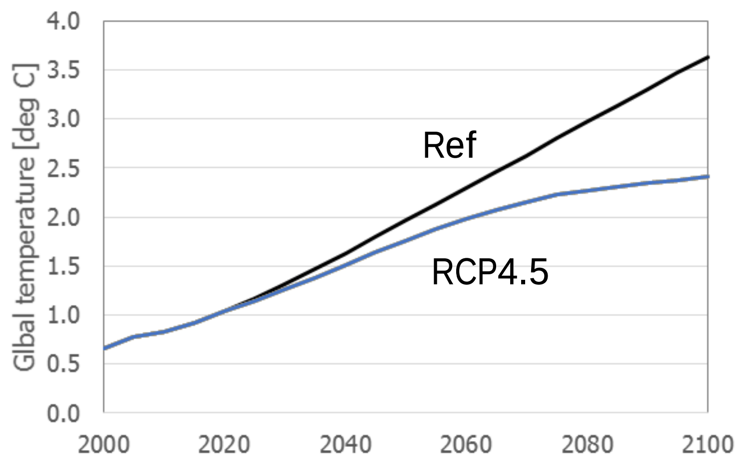




Results


CO2 concentration [ppm]
900
800
700
600
500
400
300
200
100
0
2000
2020
2040
2060
2080
2100
Ref
RCP4.5


RCP forcing [W/m2]
8
7
6
5
4
3
2
1
0
2000
2020
2040
2060
2080
2100
Ref
RCP4.5


Glbal temperature [deg C]
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2000
2020
2040
2060
2080
2100
Ref
RCP4.5

Results

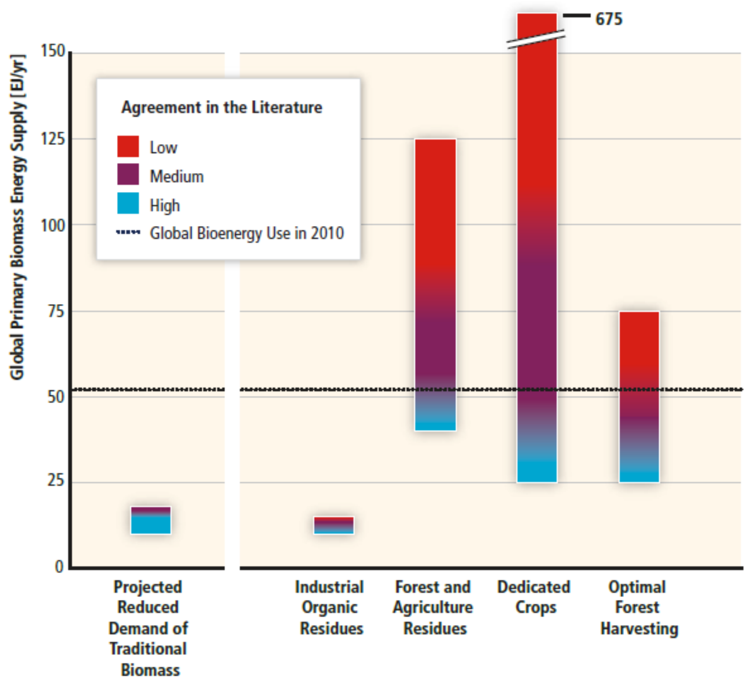
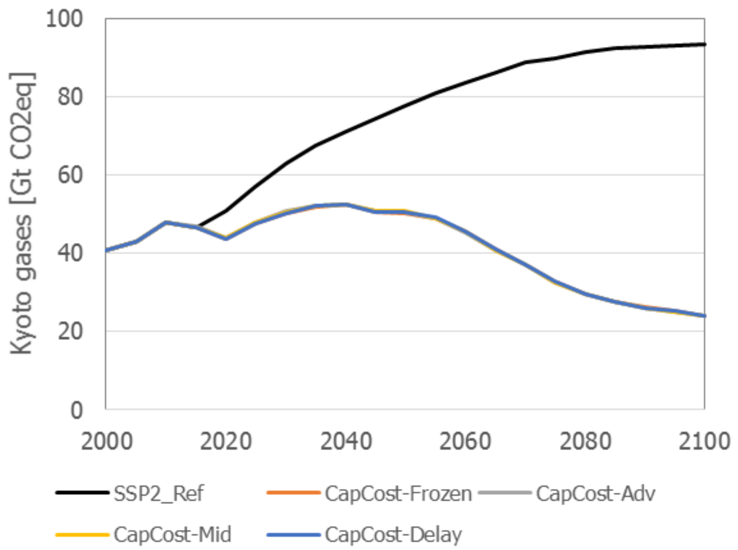


Figure 11.20 | Global Technical Bioenergy Potential by main resource category for the year 2050 | The figure shows the ranges in the estimates by major resource category of the global technical bioenergy potential. The color grading is intended to show qualitatively the degree of agreement in the estimates, from blue (large agreement in the literature) to purple (medium agreement) to red (small agreement). In addition, reducing traditional biomass demand by increasing its use efficiency could release the saved biomass for other energy purposes with large benefits from a sustainable development perspective.

Results

GHG emissions



CO_2 emissions
(fossil fuel and industry)