Ecosystem sustainability of 2°C scenario using BECCS

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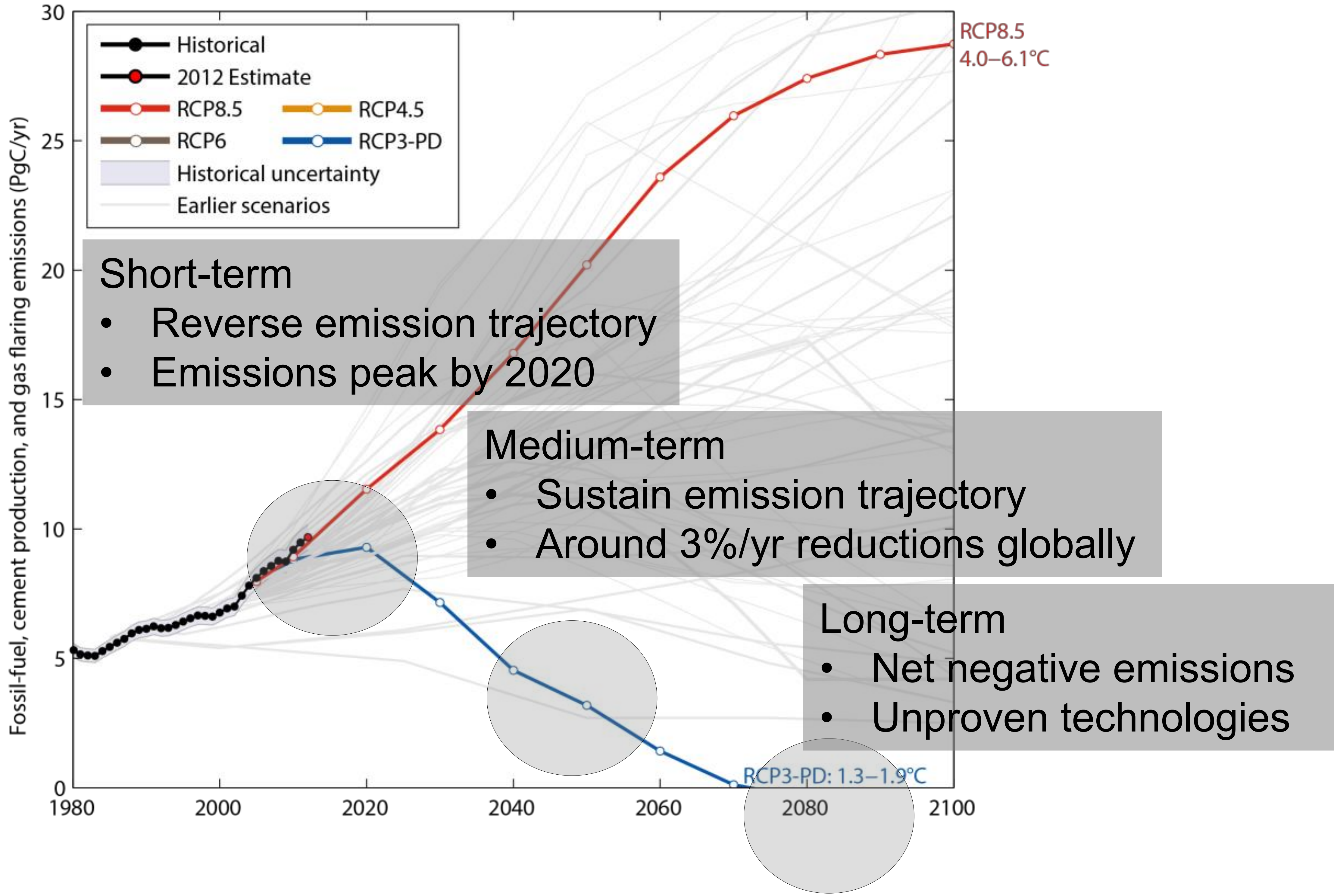
Outline of today's talk

- Background
- Review of global potential of bioenergy in the future scenarios, and quick look of RCP2.6's land-use
- Bottom-up estimate of achievable BECCS in RCP2.6's land-use scenario with dedicated bioenergy crops (1st and 2nd generation)
- Evaluation of sustainable BECCS in Japan

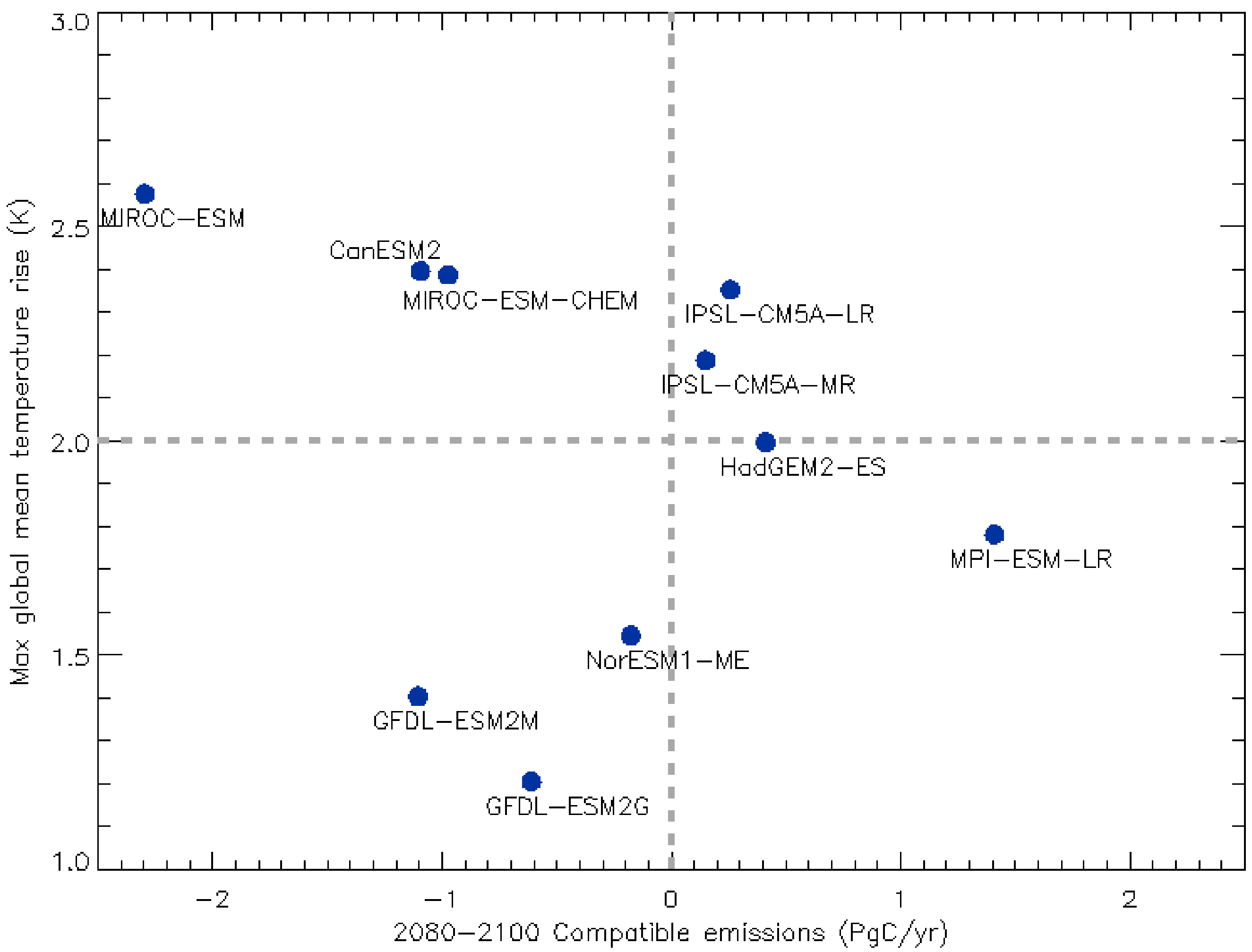
Challenges to keep below 2ºC

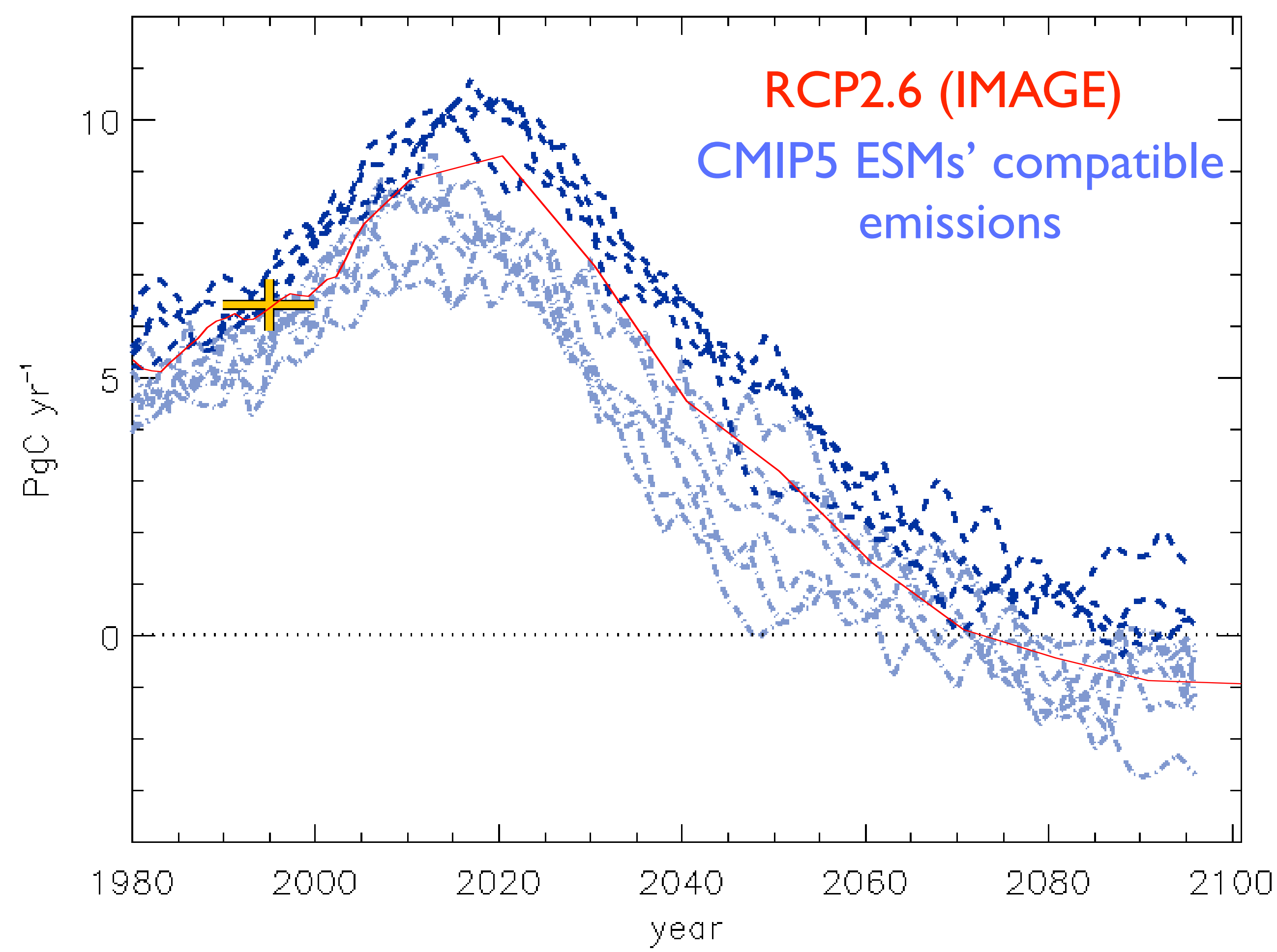
An emission pathway with a "likely chance" to keep the temperature increase below 2ºC has significant challenges



Source: Peters et al. 2012a; Global Carbon Project 2012

2℃, negative emissions in RCP2.6 by CMIP5 Earth System Models





Jones et al., 2013

- 6 out of 10 CMIP5 ESMs require negative fossil fuel emissions.
- Still large uncertainty exists due to the climate sensitivity, carbon-concentration and carbon-climate feedbacks, land-use implementation, and model representation of current carbon stock.

Also, large uncertainties exist in the deployment of BECCS

- Possible contribution of BECCS depends on the potential and societal acceptance of large scale bioenergy production and CCS.
- For bioenergy, large uncertainties in technology development, carbon neutrality, effects on food security, biodiversity, water scarcity, and soil degradation; sustainability criteria needed
- For CCS, uncertainty in capture efficiency, storage capacity, societal acceptance, and leakage
- Long term response of carbon cycle to the negative emissions is also uncertain.
- Institutional and policy issue about economic incentives of BECCS

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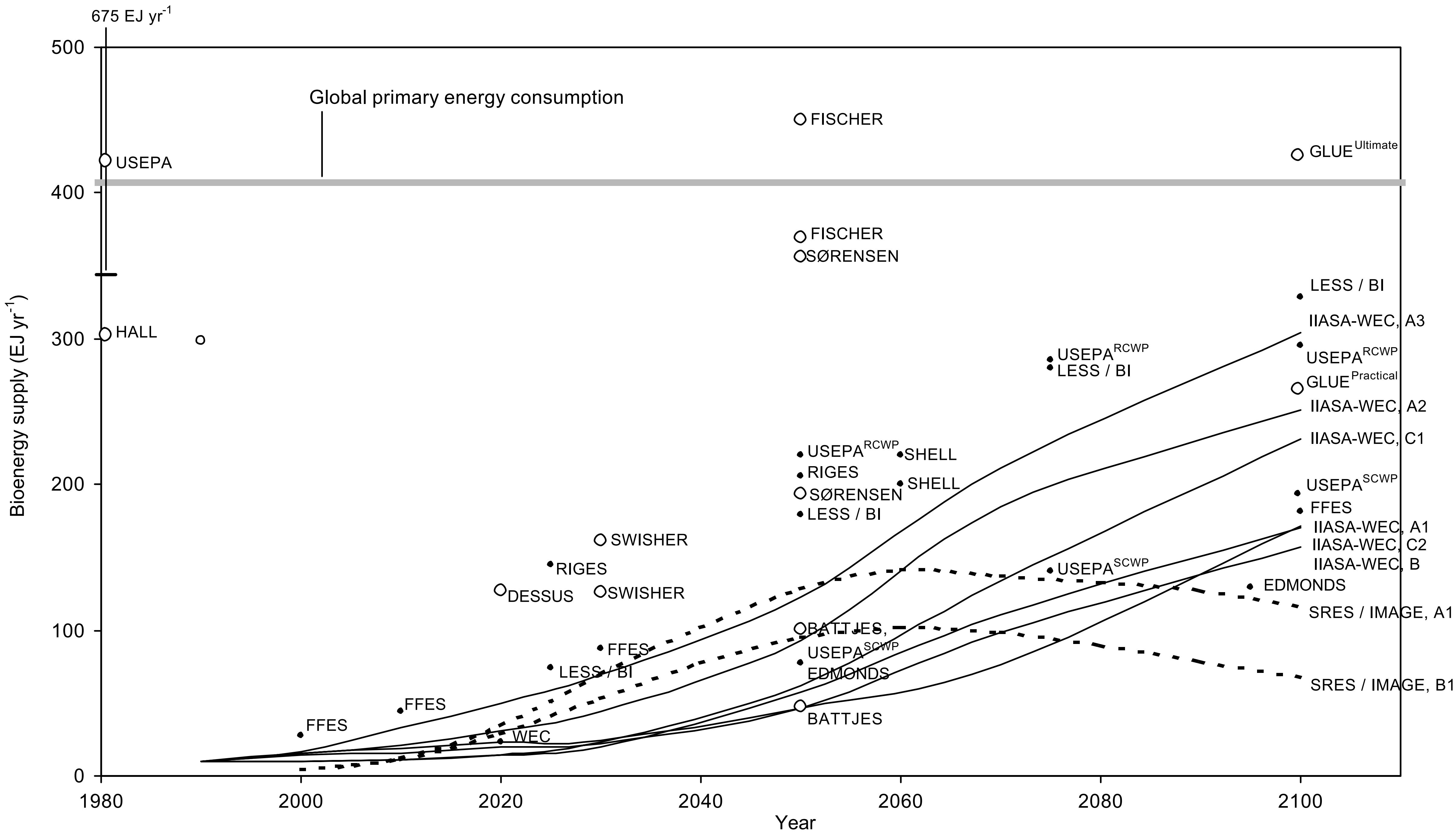
Global potential of bioenergy assumed in IAMs



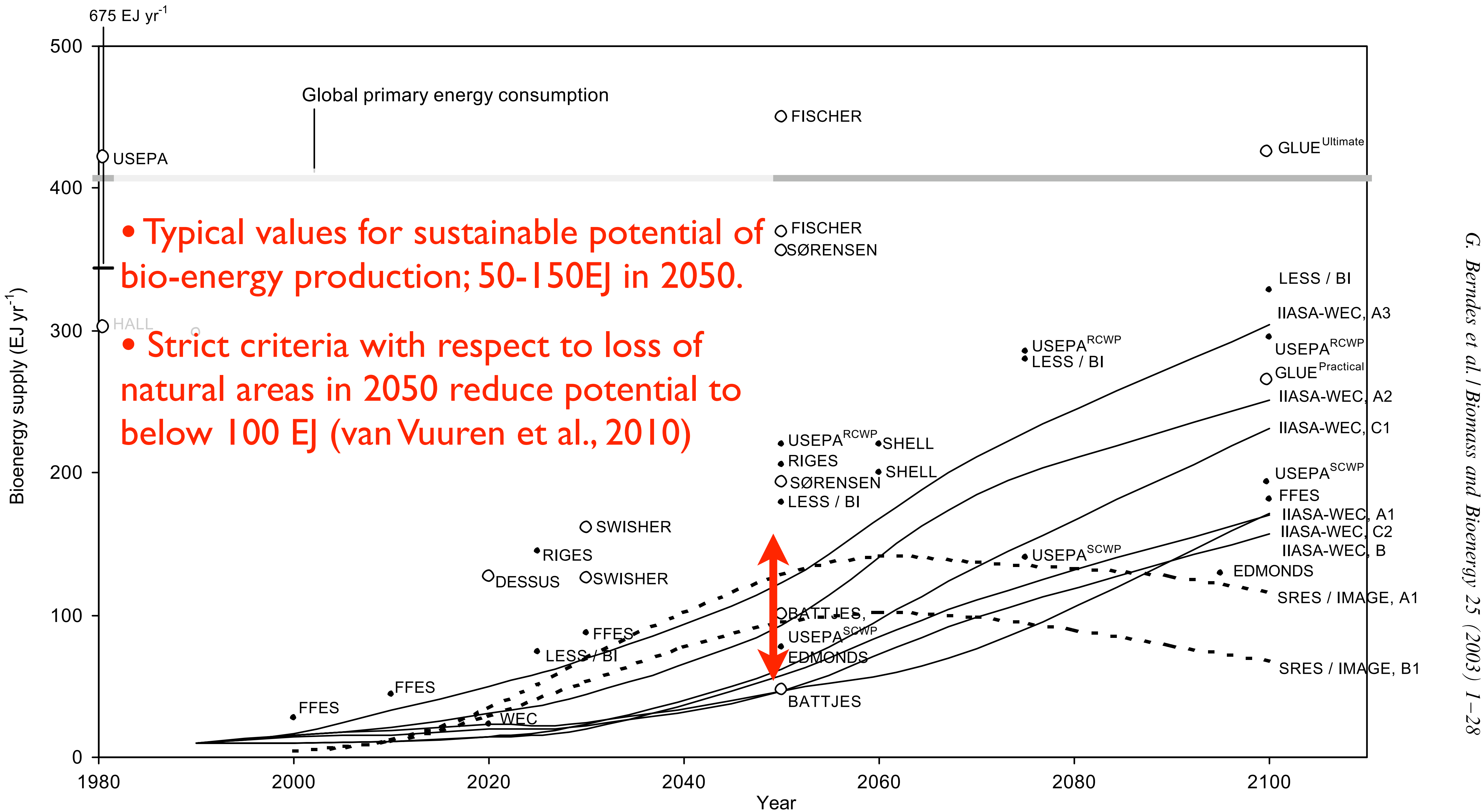
G. Berndes et al. / Biomass and Bioenergy 25 (2003) 1–28

Fig. 2. Potential biomass supply for energy over time. Resource-focused studies are represented by hollow circles and demand-driven studies are represented by filled circles. USEPA and HALL, who do not refer to any specific time, are placed at the left side of the diagram. IIASA-WEC and SRES/IMAGE are represented by solid and dashed lines respectively, with scenario variant names given without brackets at the right end of each line. The present approximate global primary energy consumption is included for comparison. (The global consumption of oil, natural gas, coal, nuclear energy and hydro electricity 1999–2000 was about 365 EJ yr^{-1} [43]. Global biomass consumption for energy is estimated at 35–55 EJ yr^{-1} [44–46].)

Berndes et al., 2003

Global potential of bioenergy assumed in IAMs

- Typical values for sustainable potential of bio-energy production; 50-150EJ in 2050.
- Strict criteria with respect to loss of natural areas in 2050 reduce potential to below 100 EJ (van Vuuren et al., 2010)



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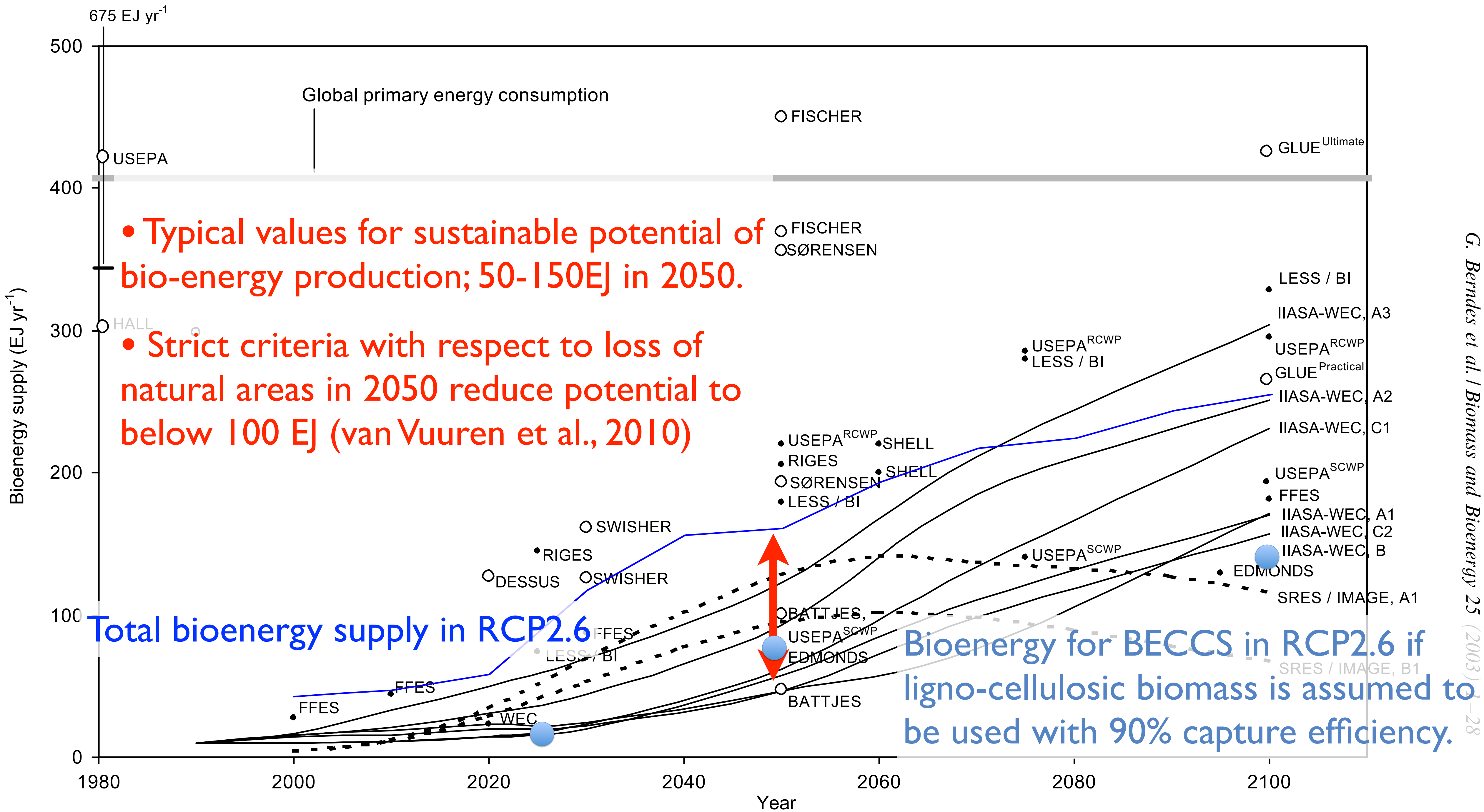

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Assumed land use and yield in the future energy crops

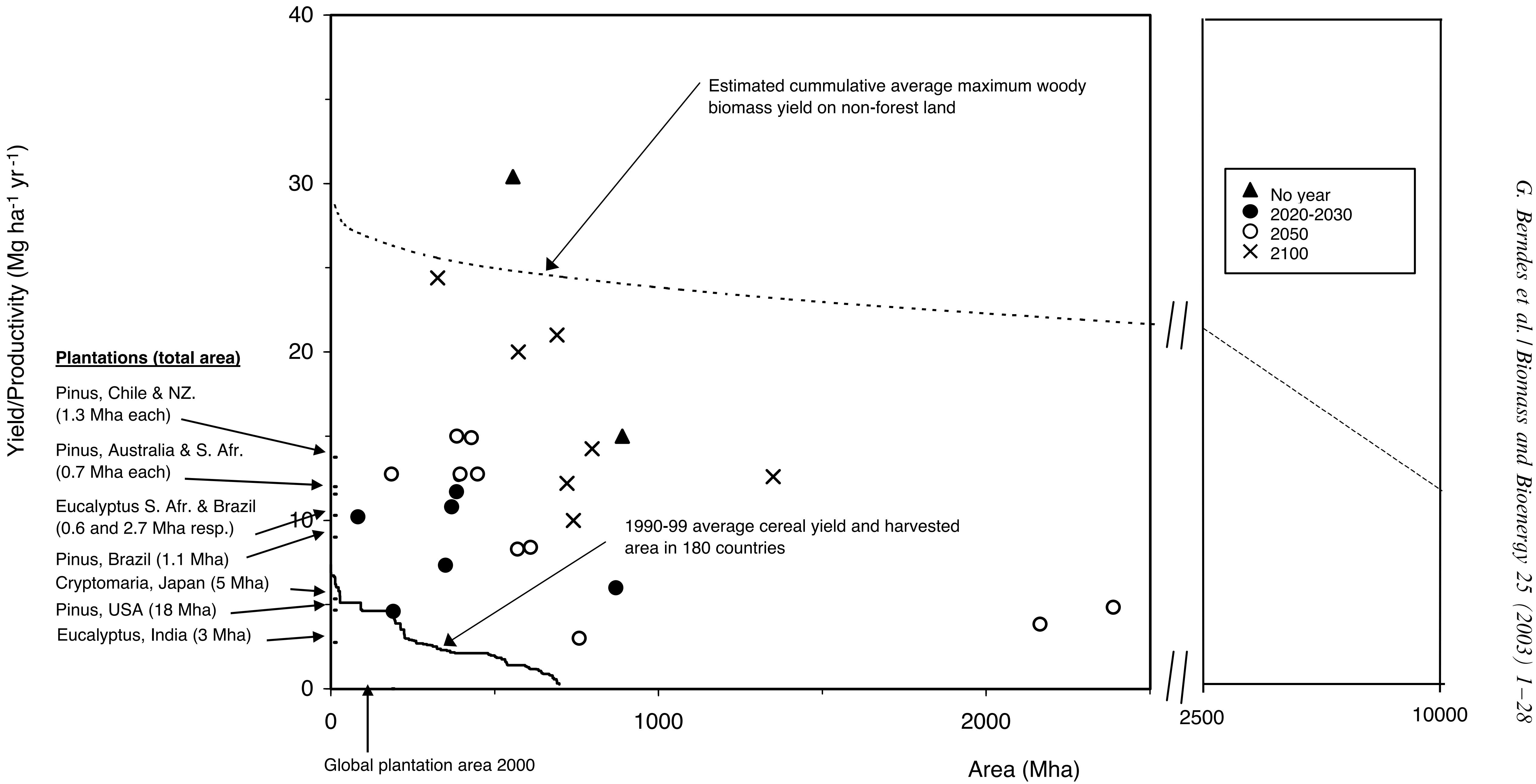

Fig. 6. Land use and yield levels in future energy crops production. Dots represent suggested plantation area and average yield levels in the studies. Lines represent suggested maximum woody biomass yield on non-forest land, and harvested area and yields in global cereal production. The global tree plantation area in 2000 is indicated on the X-axis. The average yield levels for Pinus and Eucalyptus plantations in selected countries are indicated along the Y-axis. The specific yields and plantation areas used are given for each study in Appendix A.

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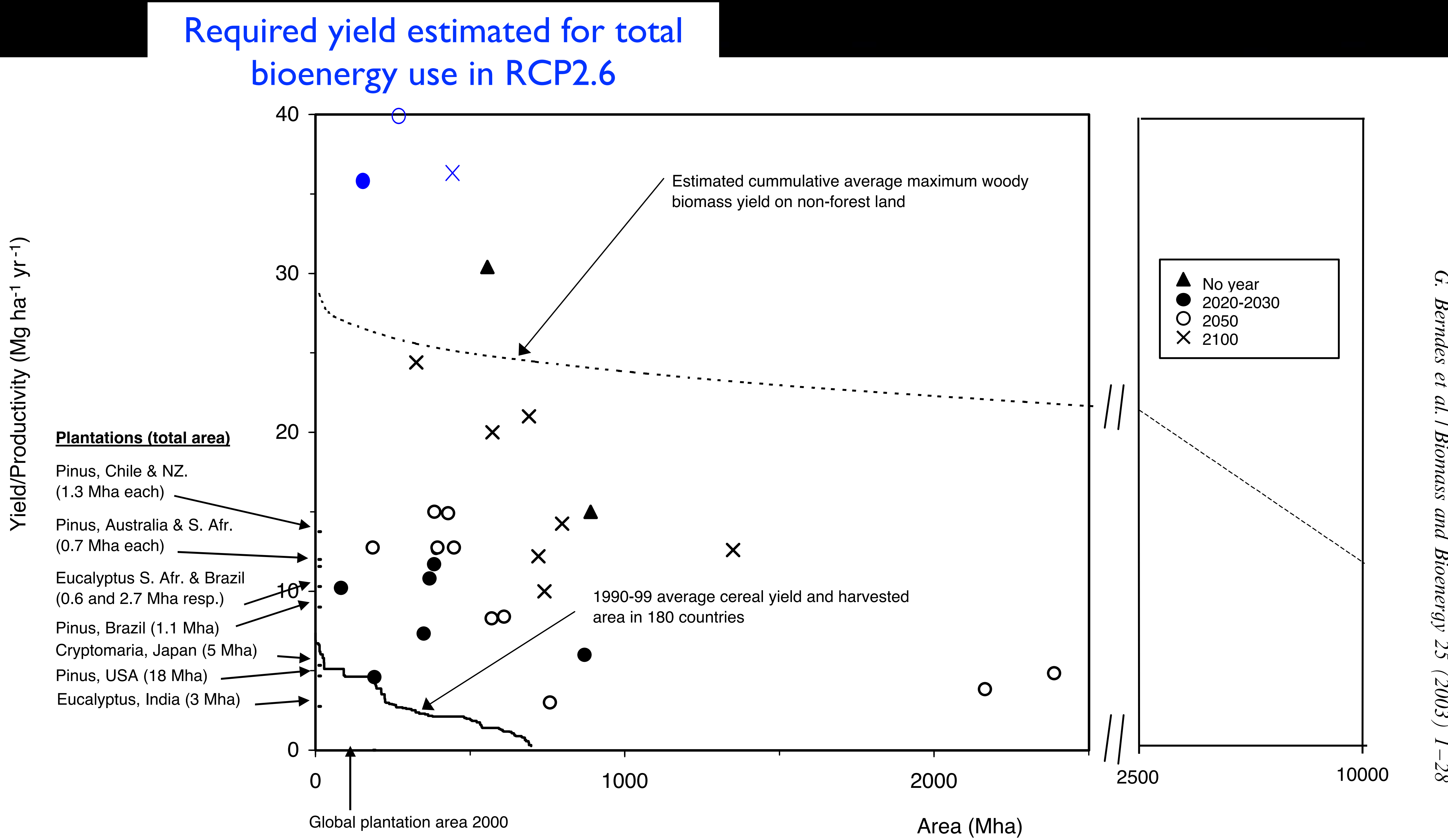

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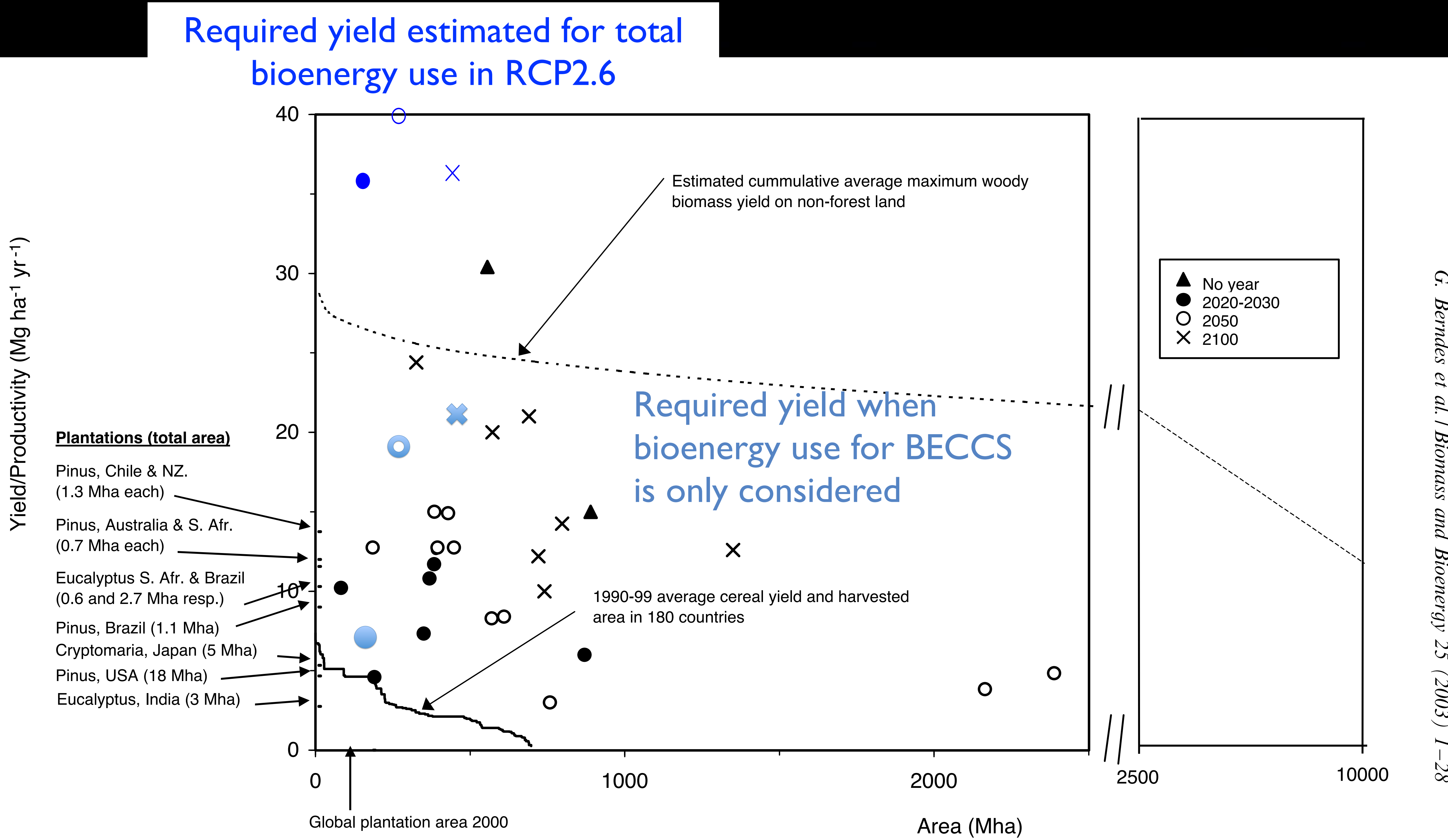

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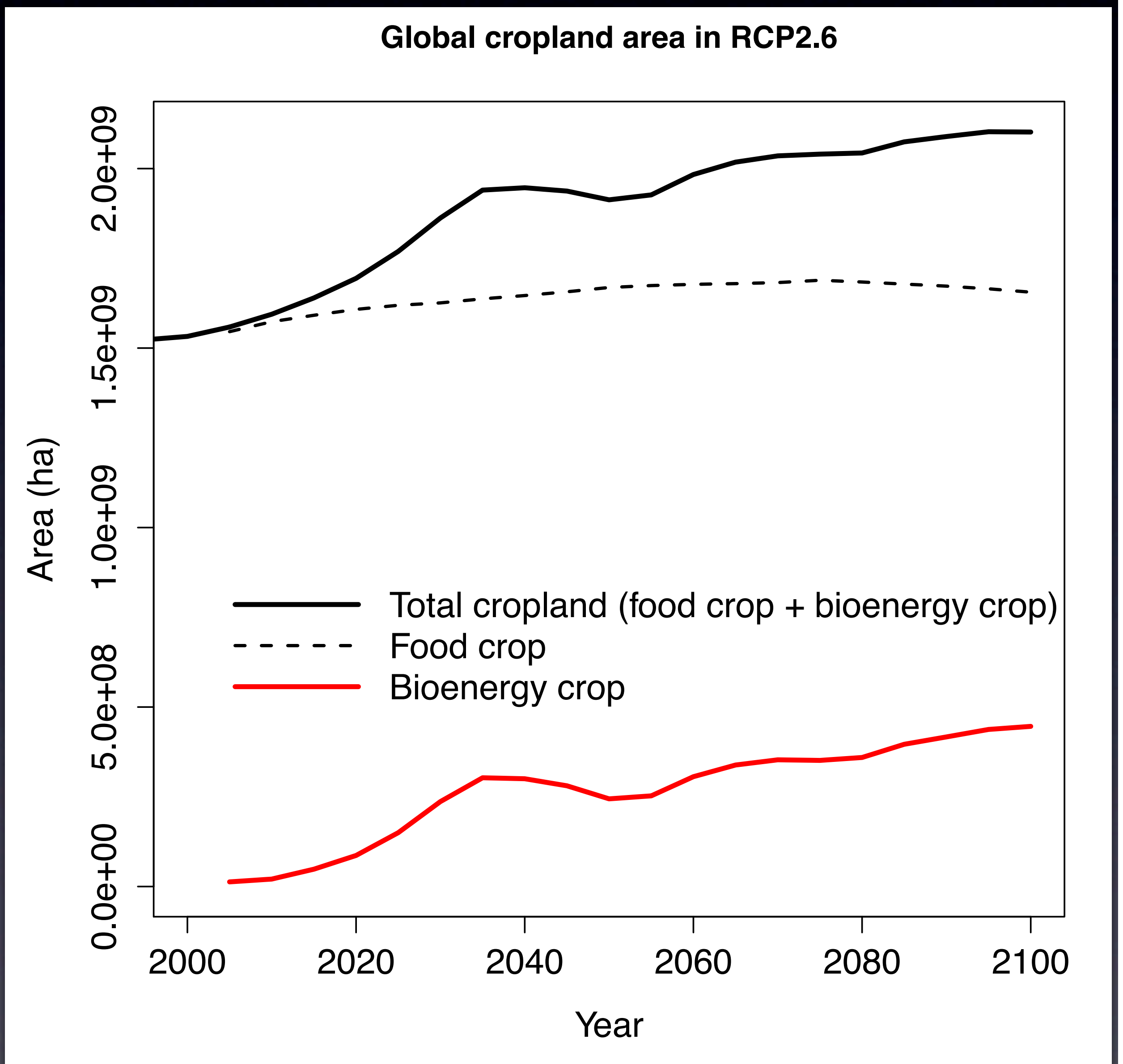
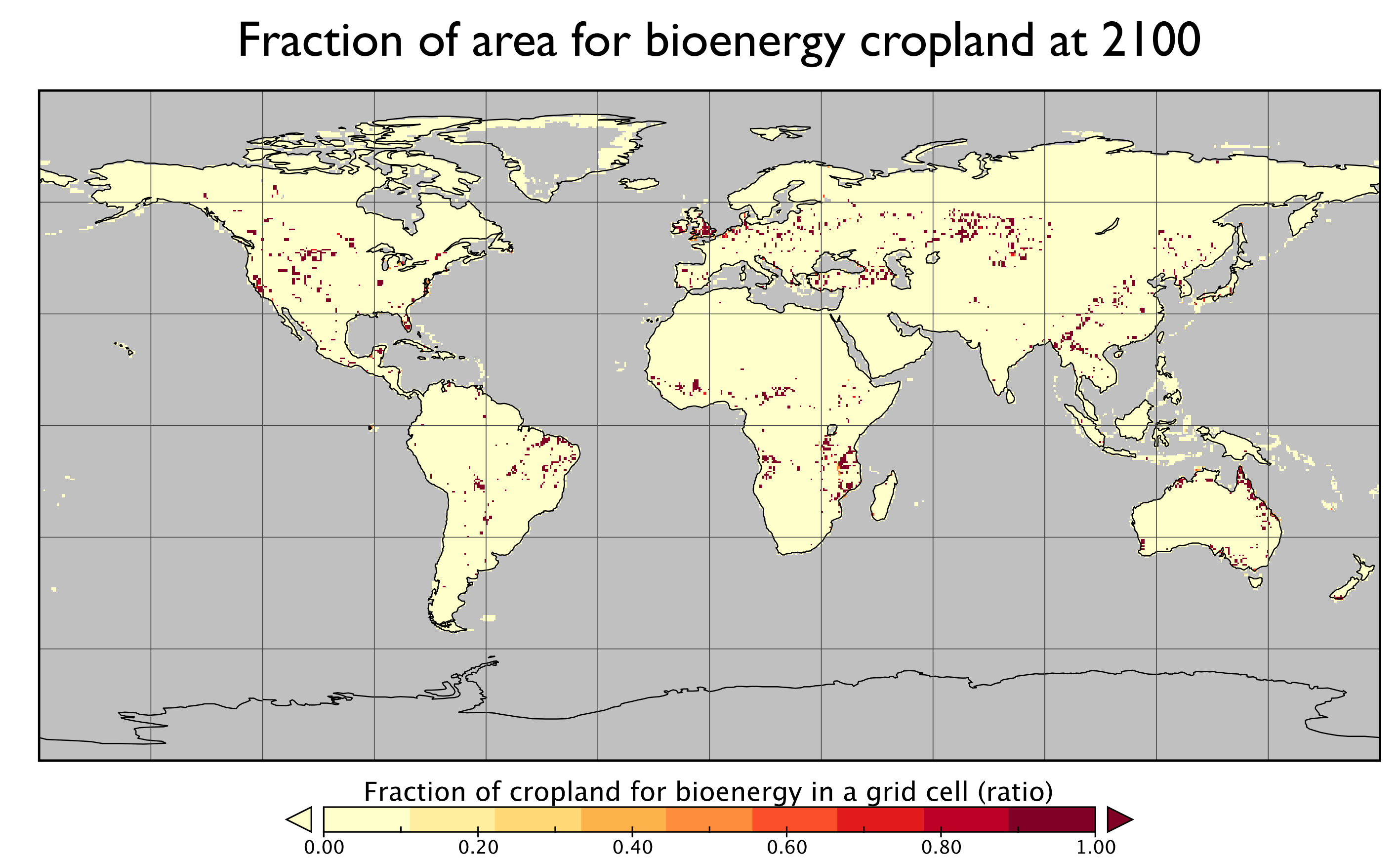
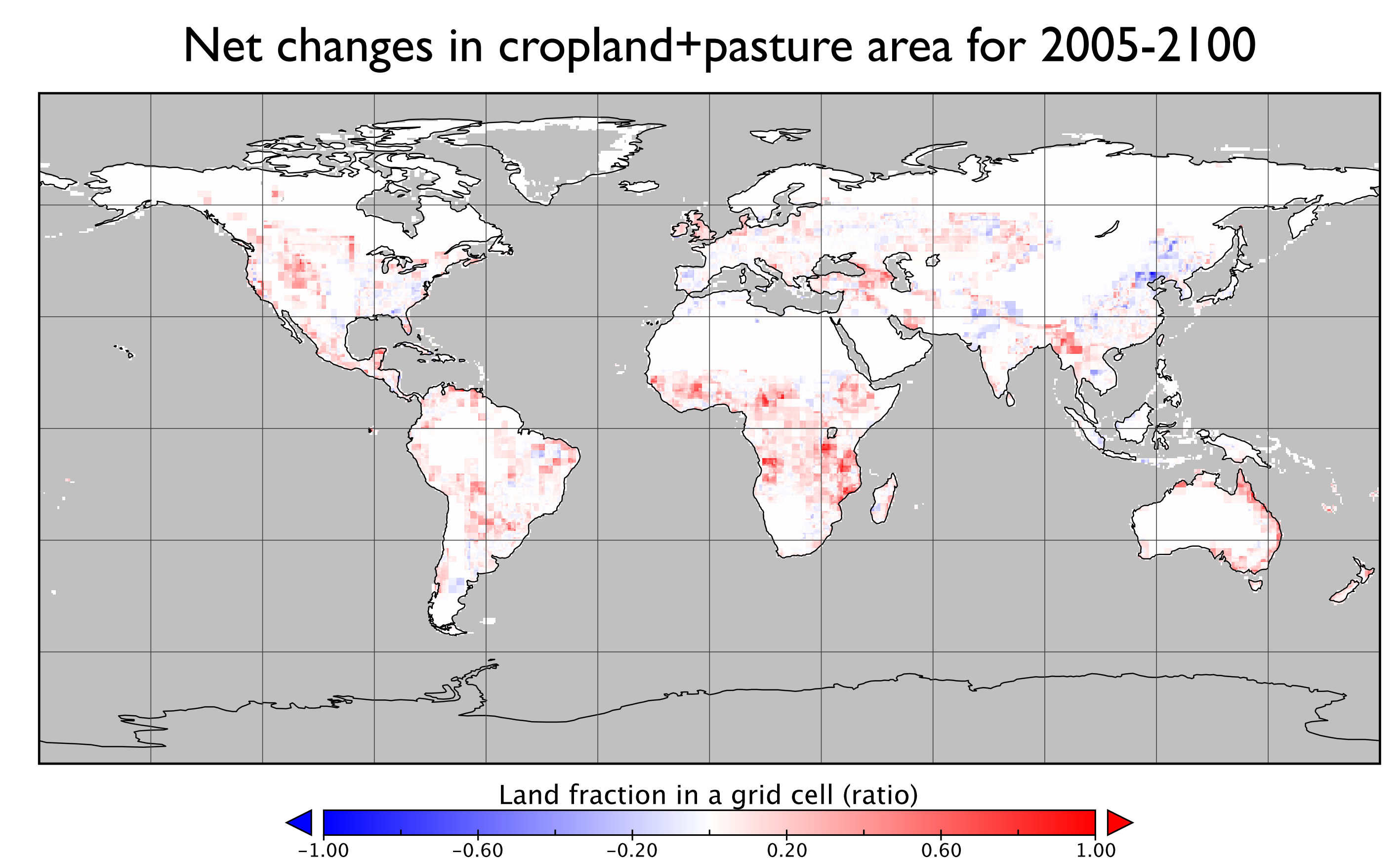
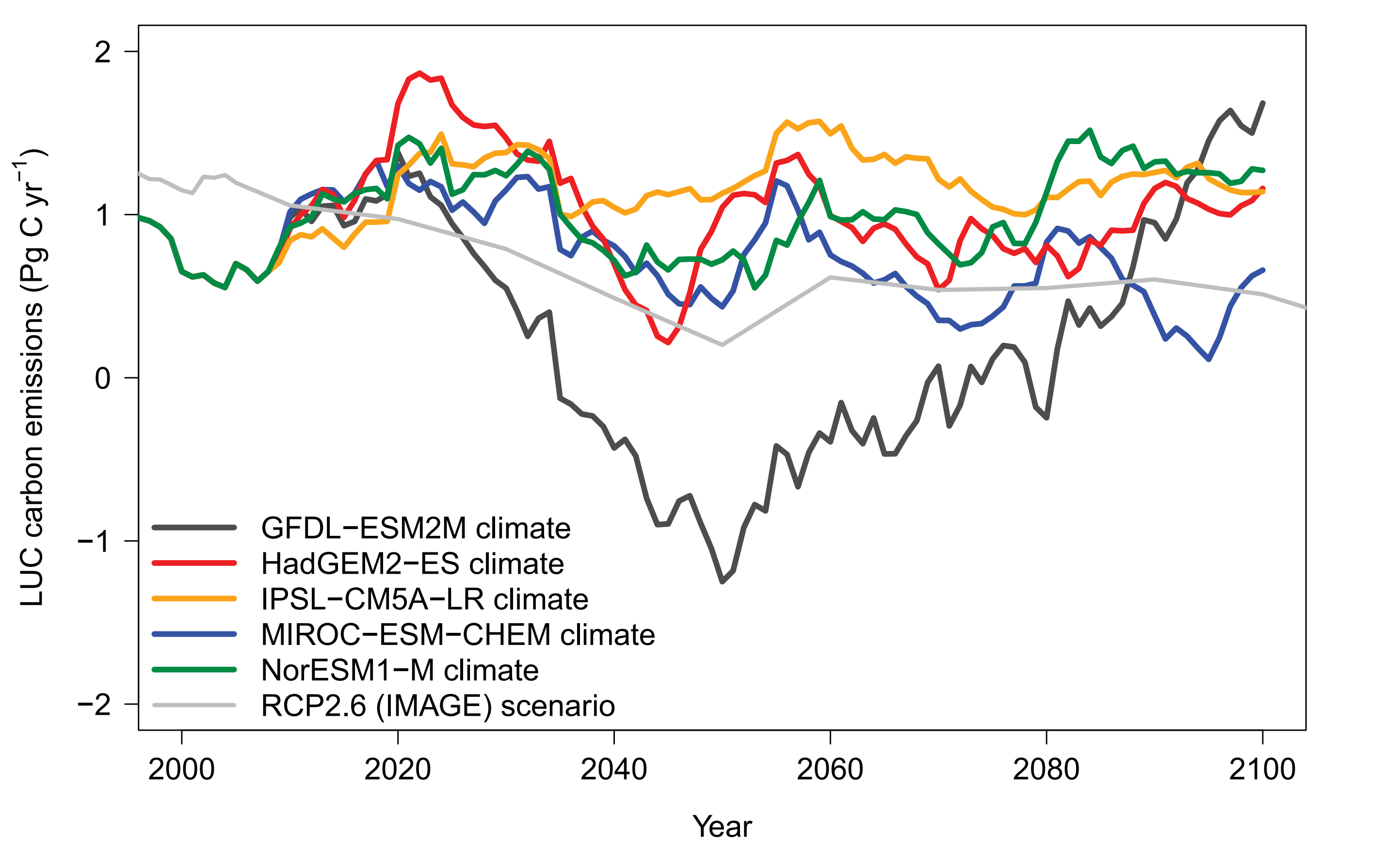
Land-use change scenario of RCP2.6







Carbon emissions from land-use change in RCP2.6



Net land-use change carbon emissions (Pg C yr^{-1}) are estimated by VISIT model using five ISI-MIP fast track climate scenarios for RCP2.6. IMAGE RCP2.6 land-use change emission scenario is shown in light gray line.

Cumulative net carbon emissions from land-use change estimated by VISIT model and others

	Cumulative carbon emissions for 2006-2100 (Pg C)
VISIT (Kato and Yamagata, in review)	81 ± 34 (25-112)
CMIP5 ESMs (Brovkin et al., 2013)	67 ± 63 (19-175)
RCP2.6 (IMAGE)	60.7

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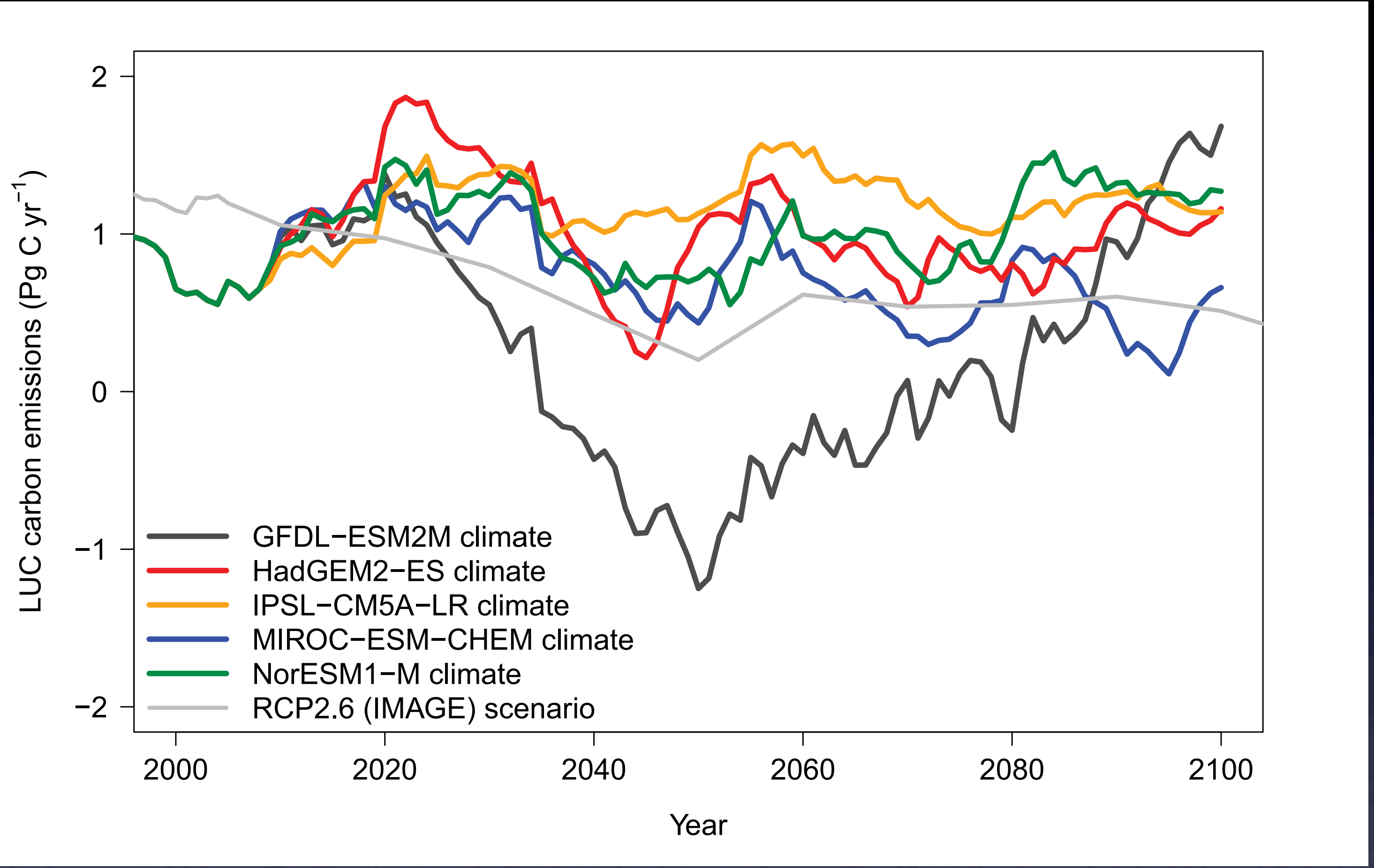

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- Even the limited cropland expansion (≃0.5 billions ha) in RCP2.6 causes non-negligible amount of carbon emissions due to the land-use change.

Land-use for sustainable low-carbon scenario with the large scale use of BECCS?

Integrated assessment models typically use top-down estimates of potential bioenergy use,

however,

bottom-up evaluation of bioenergy potential is needed to consider importance of food, water, energy, and carbon nexus.

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Integrated assessment models typically use top-down estimates of potential bioenergy use,

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bottom-up evaluation of bioenergy potential is needed to consider importance of food, water, energy, and carbon nexus.

- In this study, BECCS achievability in the constraint of the RCP2.6's land-use scenario is analyzed with
    - Conventional bioenergy crops (maize, sugarcane, sugar beet, rapeseed) with ethanol and biodiesel productions.
    - 2nd generation bioenergy crops (switchgrass, *Miscanthus* × *giganteus*) with bioSNG productions.
- Other non-BECCS bioenergy is supposed to be treated in terms of forestry and forest residues in the evaluation for now.

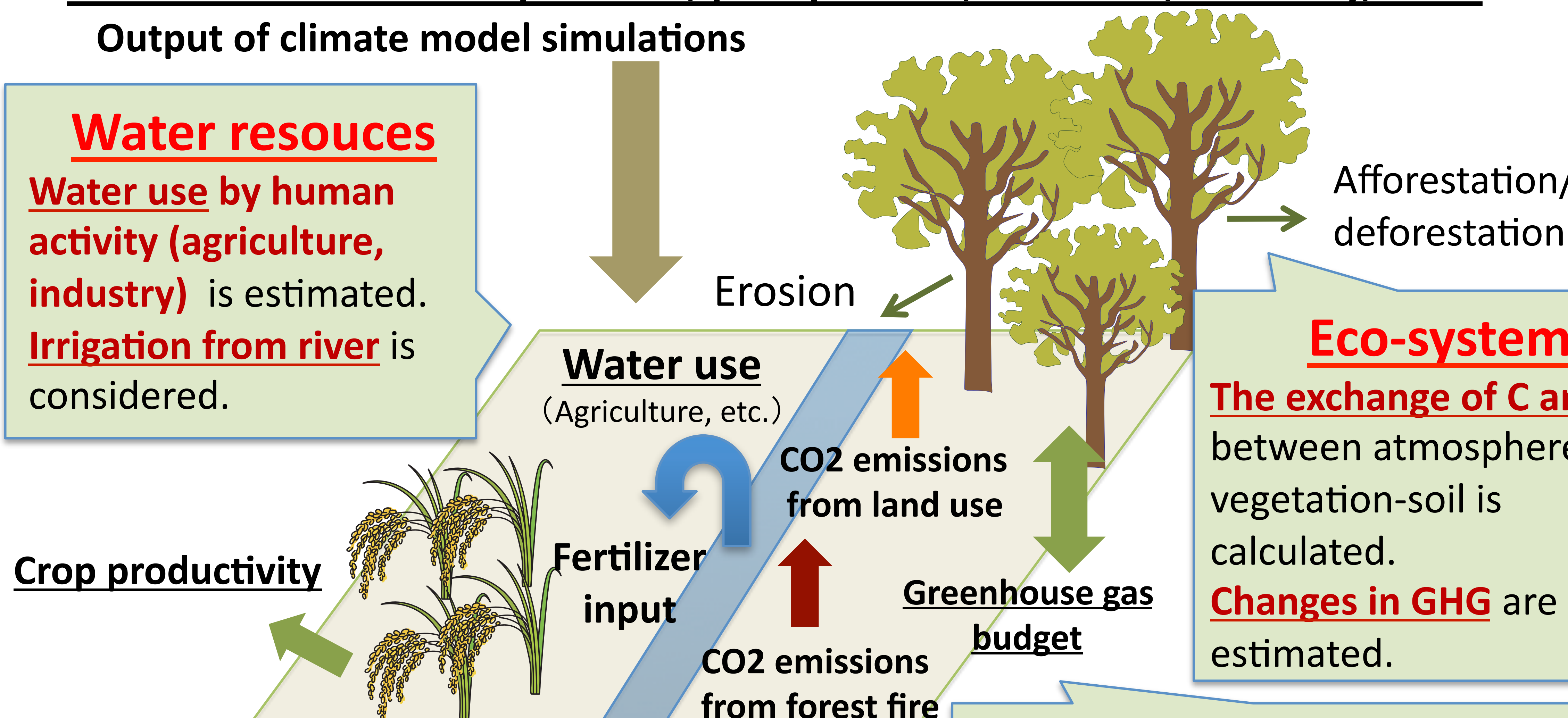
Development of "Integrated terrestrial model"

Climate data (temperature, precipitation, radiation, humidity, etc.)

Output of climate model simulations

Water resouces

Water use by human activity (agriculture, industry) is estimated.
Irrigation from river is considered.



Eco-system

The exchange of C and N between atmosphere-vegetation-soil is calculated.
Changes in GHG are estimated.

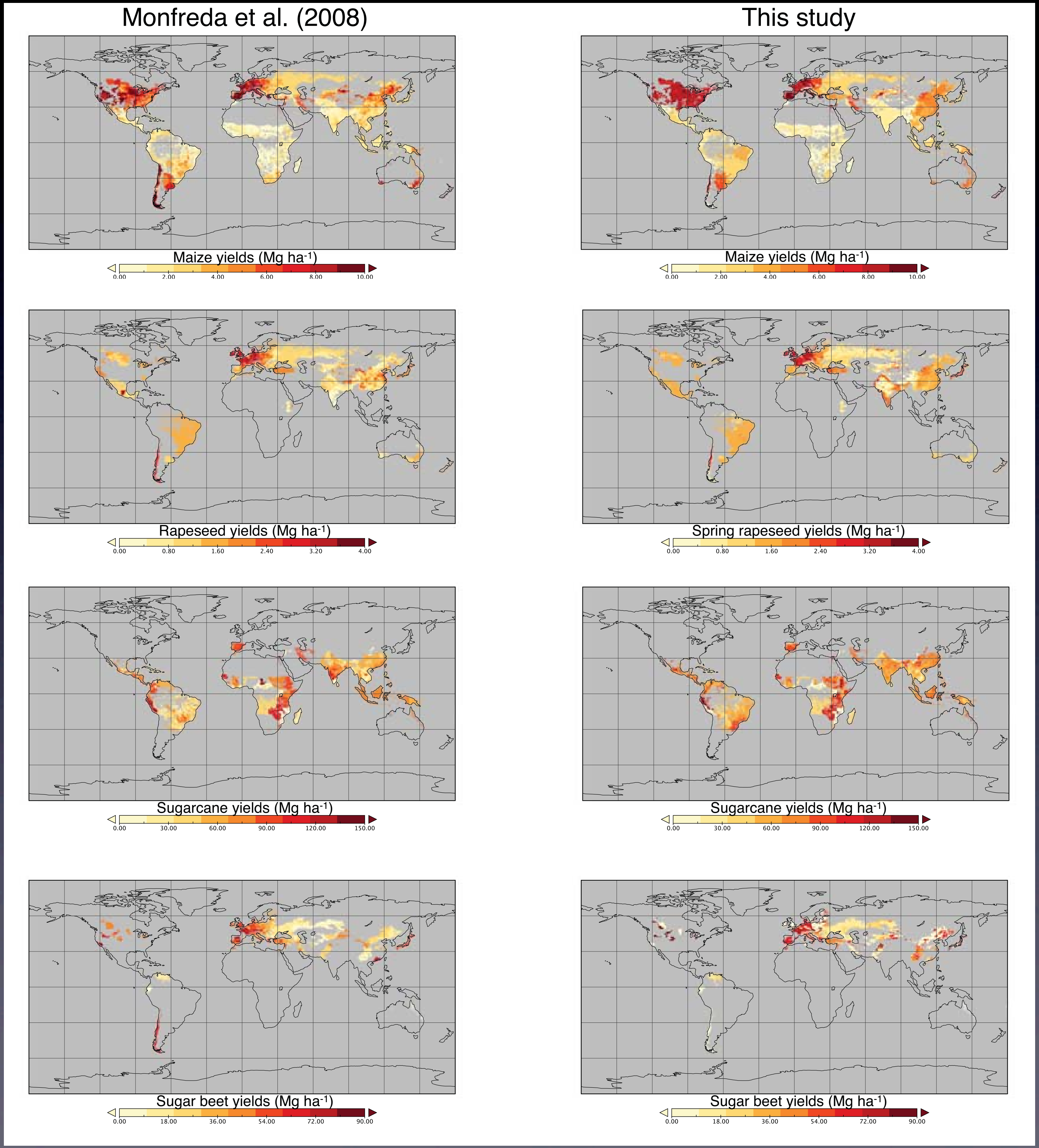
Agriculture

Crop productivity is estimated .
The production of bio-energy crop for mitigation option is considered.

Land use

Land-use change (cropland-forest) is calculated based on future socio-economic scenarios.
Economic (e.g., trade) and natural (e.g. inclination) factors are considered.

Simulation of 1st generation energy crop



Using SWAT2005, yields of the first generation bioenergy crops are simulated with globally 0.5x0.5 degree grid spatial resolution.

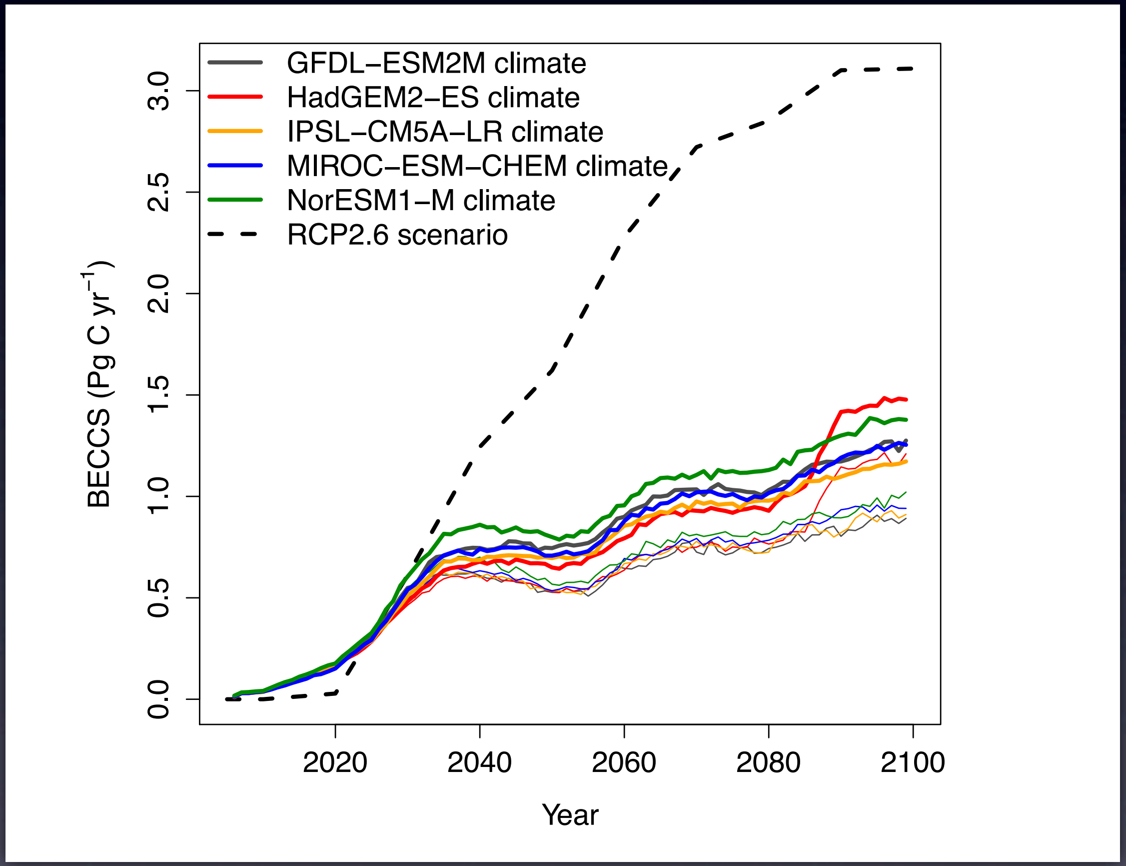
Input data of the model:

- Daily climate variables (tmin2m, tmax2m, precipitation, downward surface shortwave radiation, specific humidity, uvel10m, vvel10m)
- Nitrogen and phosphorus fertilizer input (FAOSTAT)
- Irrigated land fraction (Freydank and Siebert, 2008)
- Soil properties (ISLSCP II)
- Planting date (Sacks et al., 2010)
- Heat unit required for harvesting

Kato and Yamagata, GEC, in review

Is BECCS achievable with 1st generation bioenergy crops?

- 1st generation bioenergy crops cannot achieve the required BECCS amount for RCP2.6.



Kato and Yamagata, GEC, in review

- We find only 27-38% of required global BECCS in 2055 can be achieved, depending on the fertilizer and irrigation options under the RCP2.6 climate and land-use scenario.
- About 60% capture efficiency is assumed in the bioethanol calculations (i.e. 30% captured through fermentation process, and 30% captured in post-process fuel combustion); 90% post-process capture efficiency with biodiesel.

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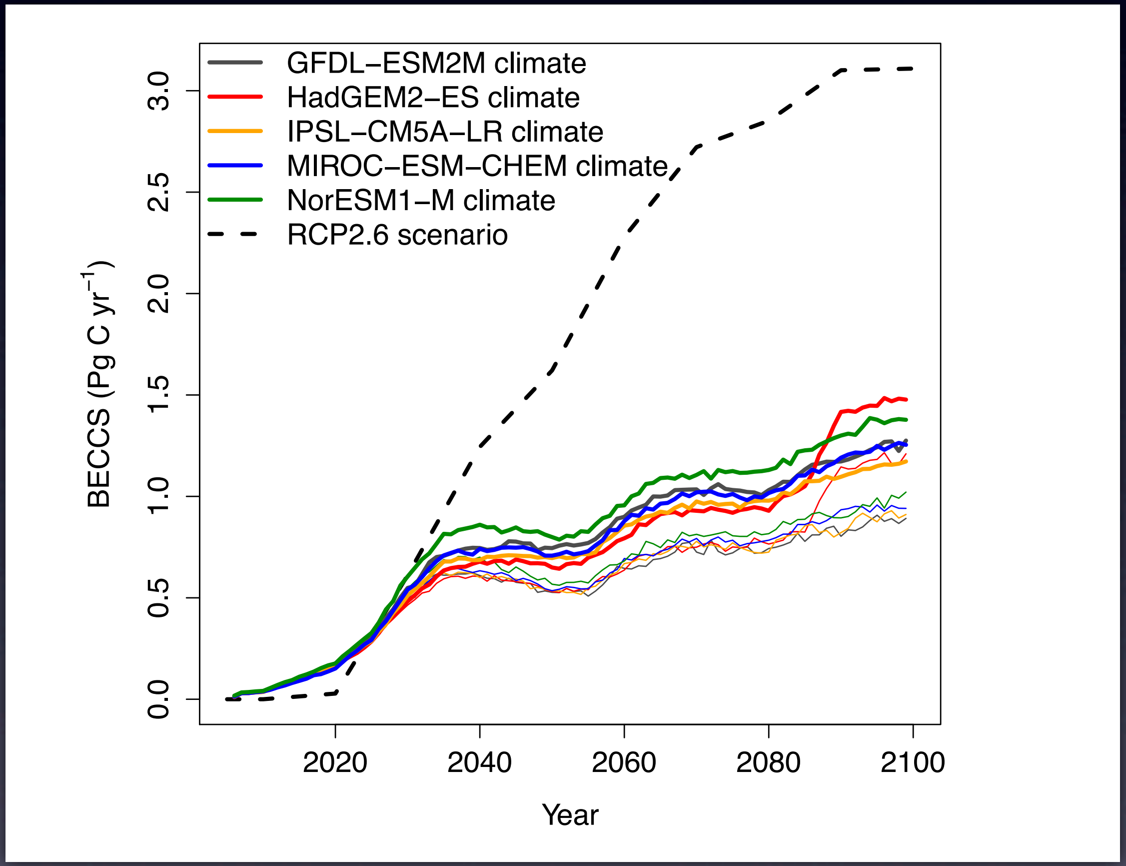

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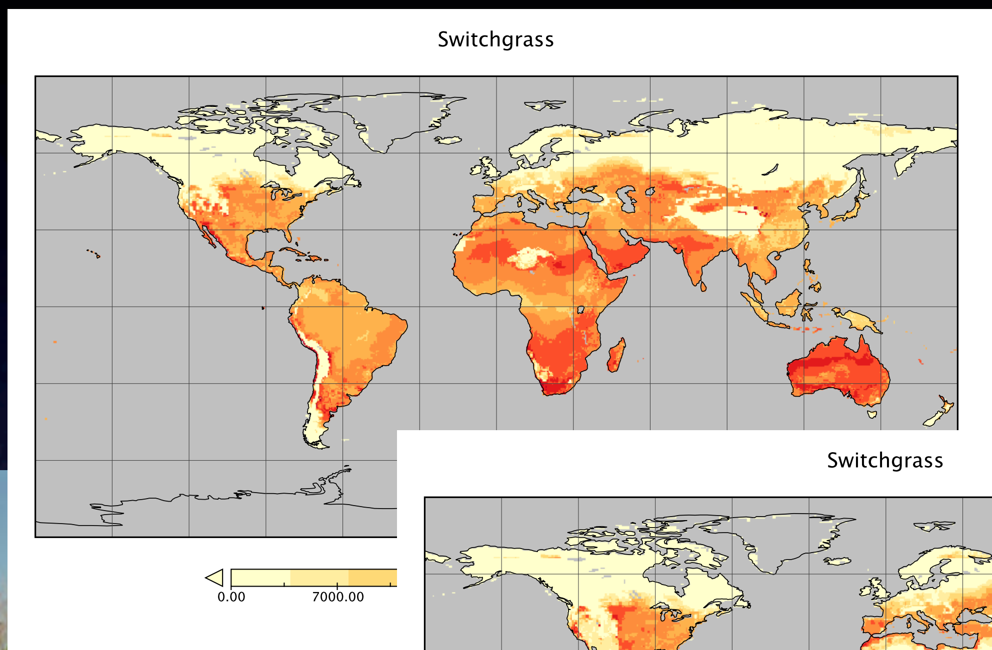
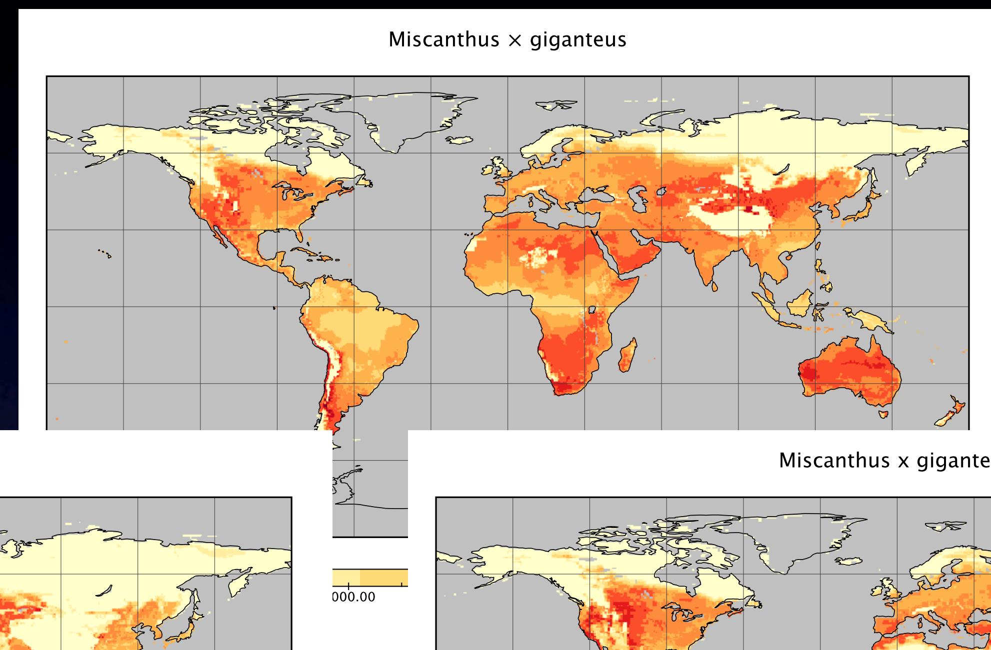
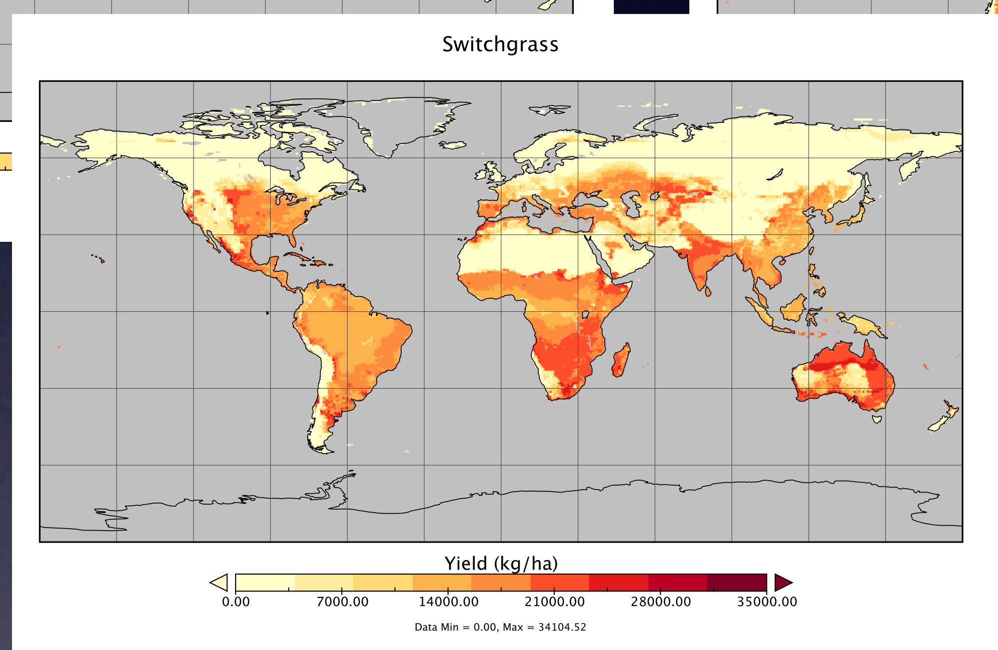
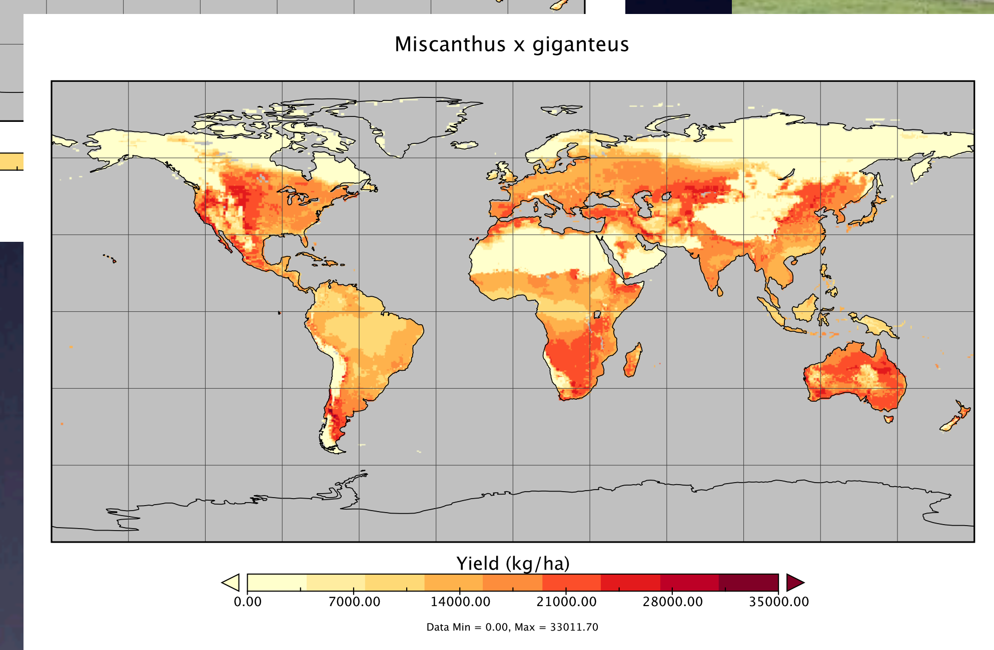
159 Pg C absorption by BECCS is assumed in RCP2.6 for 2006-2099, however, it could be achieved only 55 Pg C (34%) in no-adaptive case, and 69 Pg C (43%) in high fertilizer and irrigation use case.

Potential yield of 2nd generation bioenergy crops (switchgrass, *Miscanthus × giganteus*)



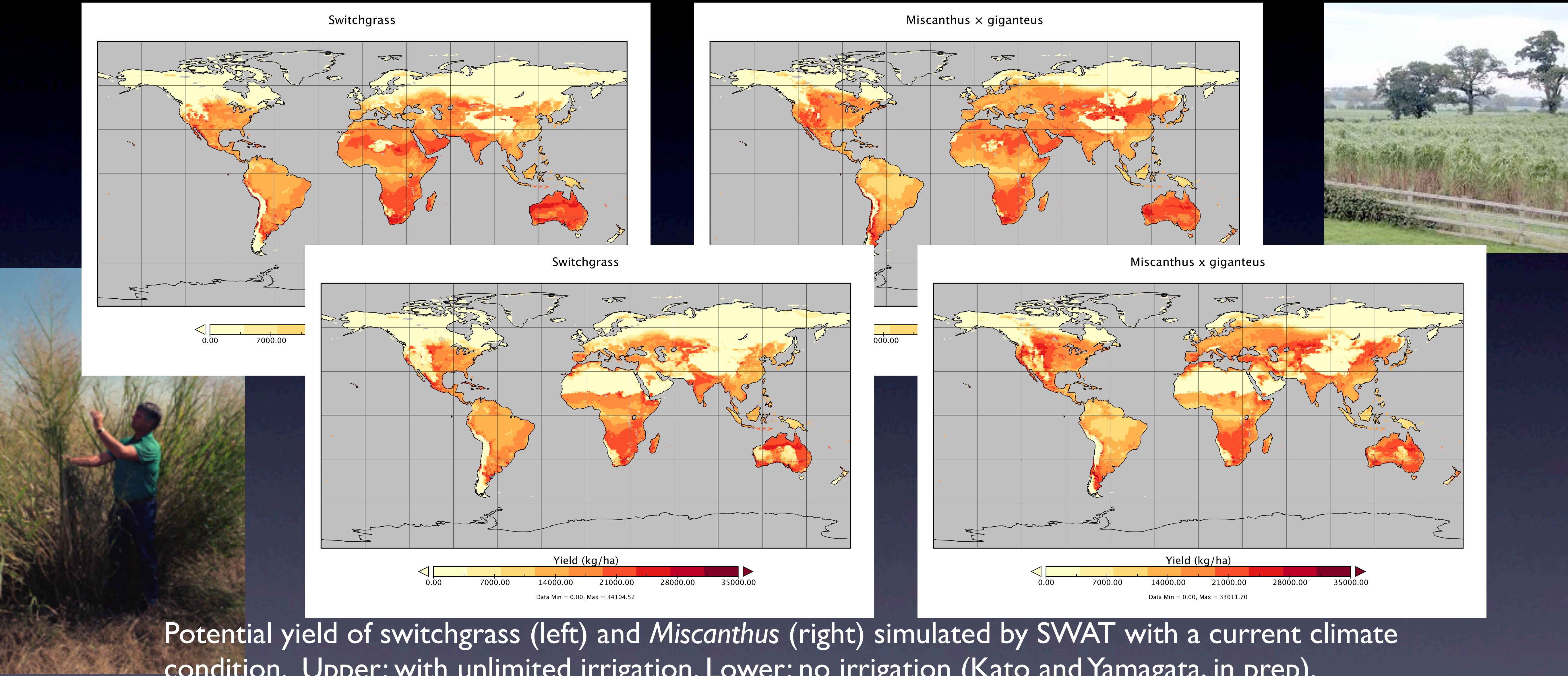






Potential yield of switchgrass (left) and *Miscanthus* (right) simulated by SWAT with a current climate condition. Upper: with unlimited irrigation. Lower: no irrigation (Kato and Yamagata, in prep).

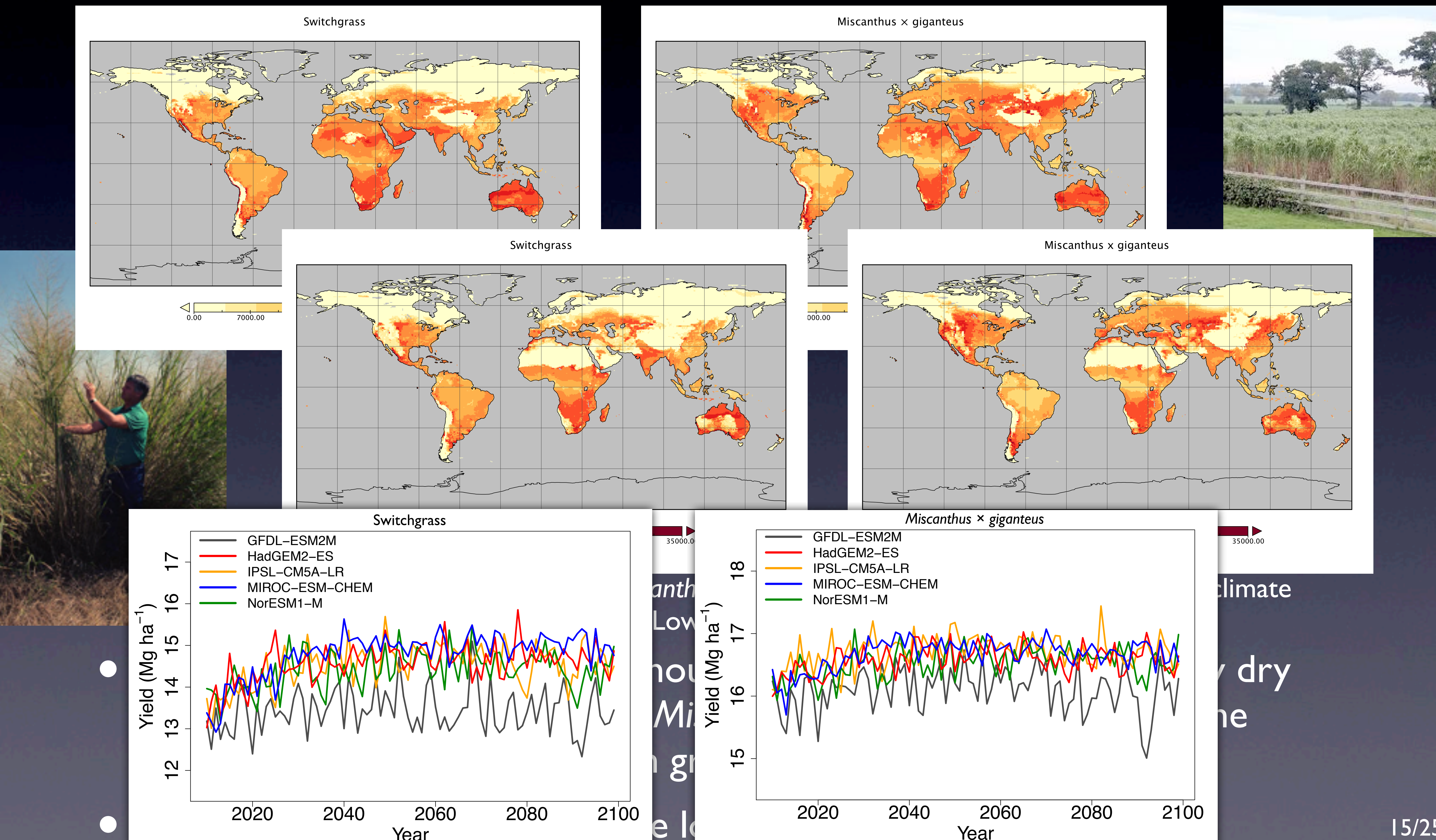
Potential yield of 2nd generation bioenergy crops (switchgrass, *Miscanthus × giganteus*)



Potential yield of switchgrass (left) and *Miscanthus* (right) simulated by SWAT with a current climate condition. Upper: with unlimited irrigation. Lower: no irrigation (Kato and Yamagata, in prep).

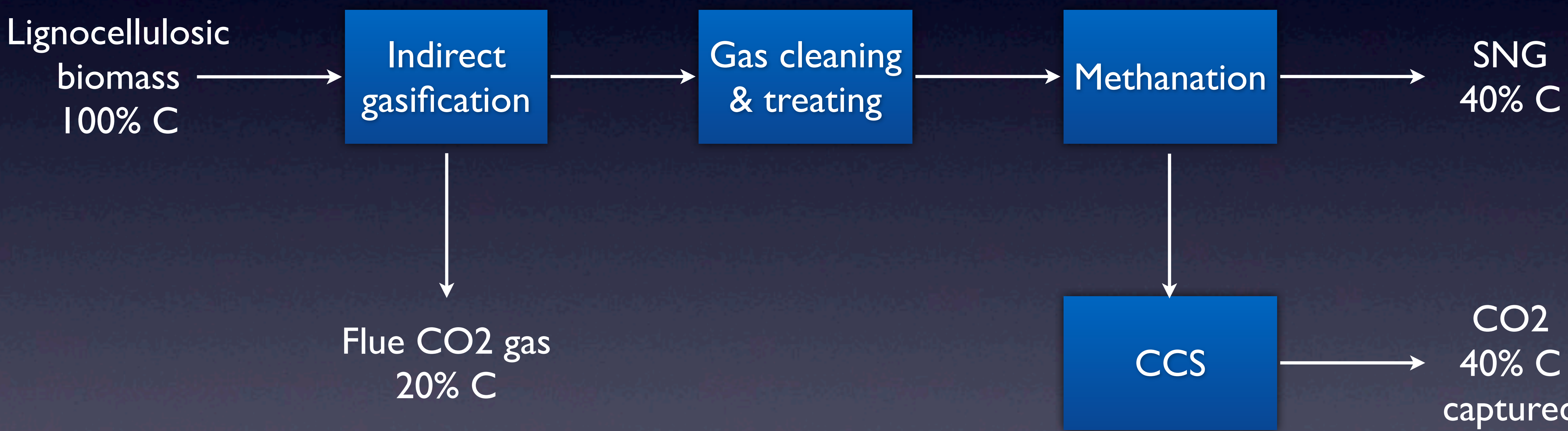
- Huge potential exists even without irrigation except for extremely dry regions (switchgrass: 13.0±7.4, *Miscanthus*: 16.0±4.8 t ha^{-1} yr^{-1} at the RCP2.6's bioenergy production grids)
- Also, fertilizer requirements are low for both crops.

Potential yield of 2nd generation bioenergy crops (switchgrass, *Miscanthus × giganteus*)



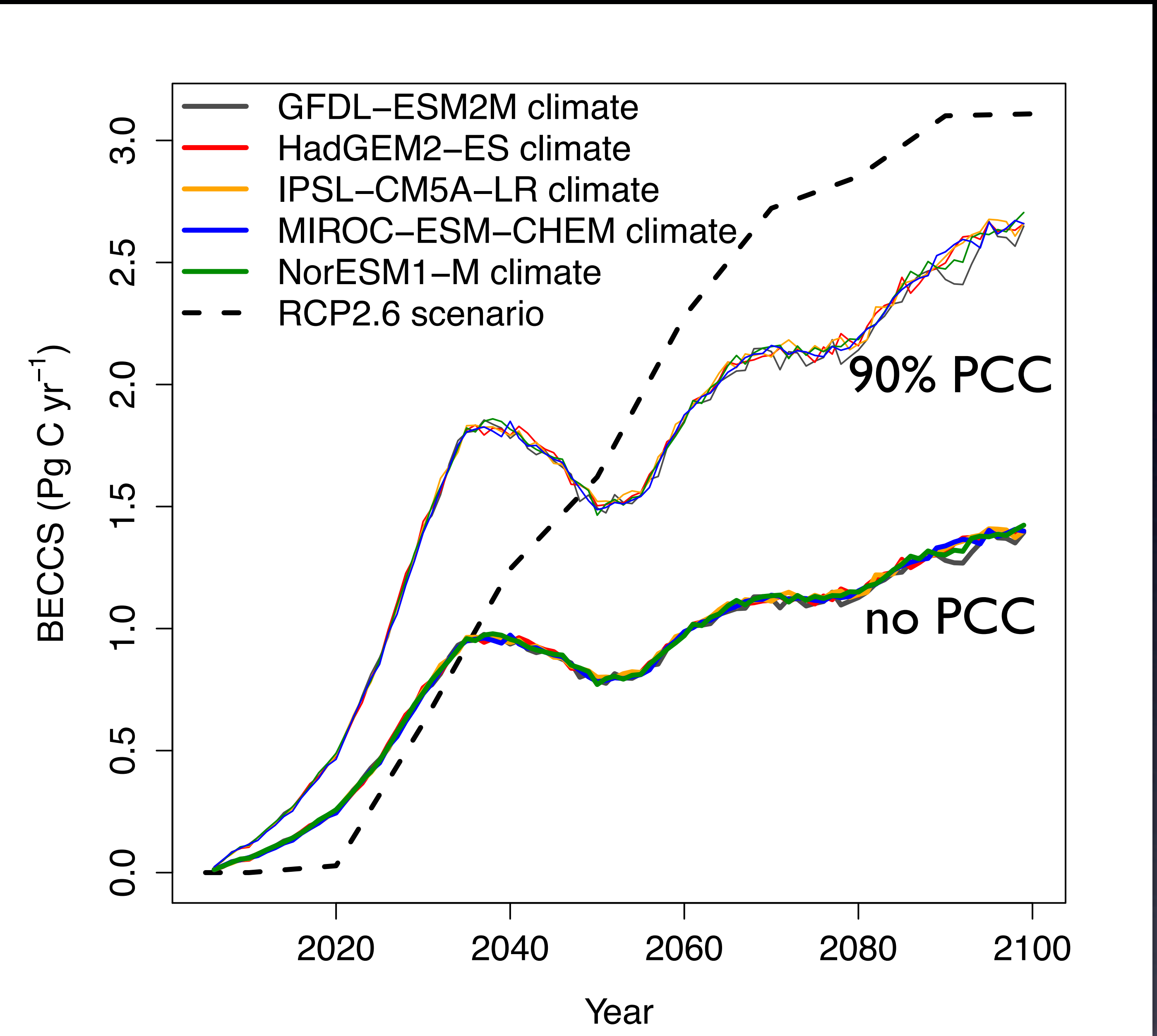
BECCS in BioSNG

- Substitue Natural Gas (SNG) processing



- CO2 abatement costs for BioSNG is competitive with CCS in fossil fired power plants (Carbo, 2011): Avoidance cost amount 62€/ton CO2.

Is BECCS achievable with 2nd generation bioenergy crops?

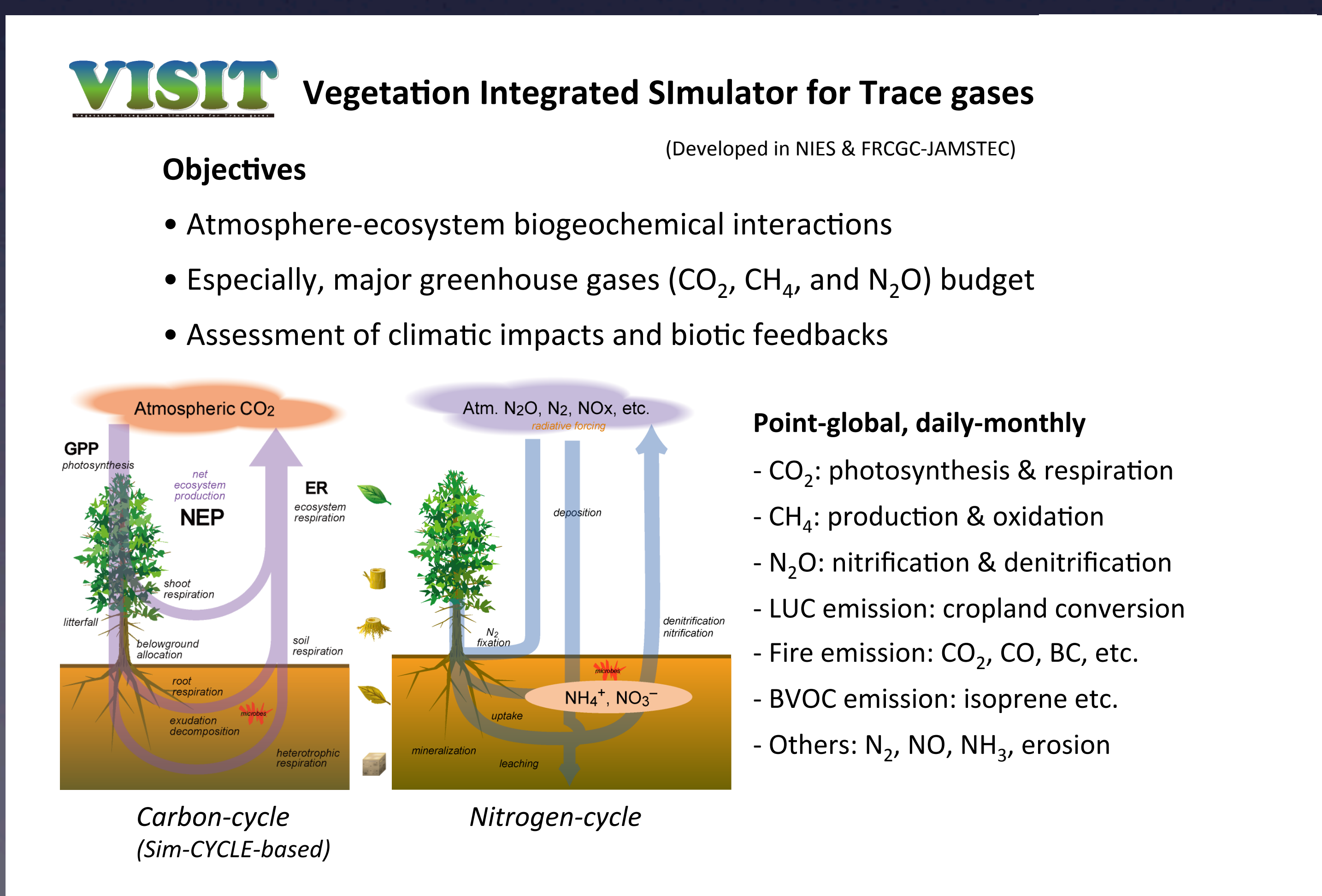


- With 2nd generation biofuel, required BECCS for RCP2.6 can be marginally achieved when 90% post-combustion capture (PCC) technology is deployed.
  - 90% PCC case: 76% capture efficiency is assumed in the calculation (i.e. 40% captured in pre-combustion process, and 36% captured post-process fuel combustion).

It could be achieved 80 Pg C BECCS (half of the required BECCS) without PCC, and 116 Pg C with 45% PCC, and 152 Pg C with 90% PCC.

Woody biomass and residues

- What amount of the sustainable woody biomass can be used for the bioenergy?
    - Estimating sustainable and practical woody biomass production limits using inventory and/or VISIT model (process-based ecosystem model) in term of carbon budget
    - Also need to consider limitation related to the spatially explicit condition, such as location of power plant, logistical cost, ...



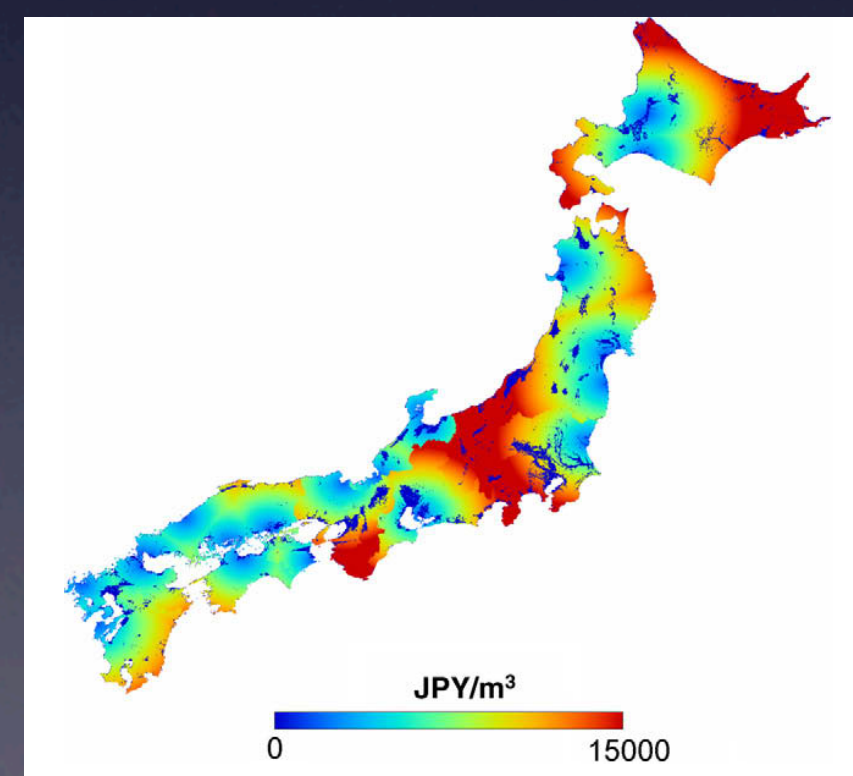


Fig. 4. Spatial distribution of wood chips production cost (rotation period is 40 years).

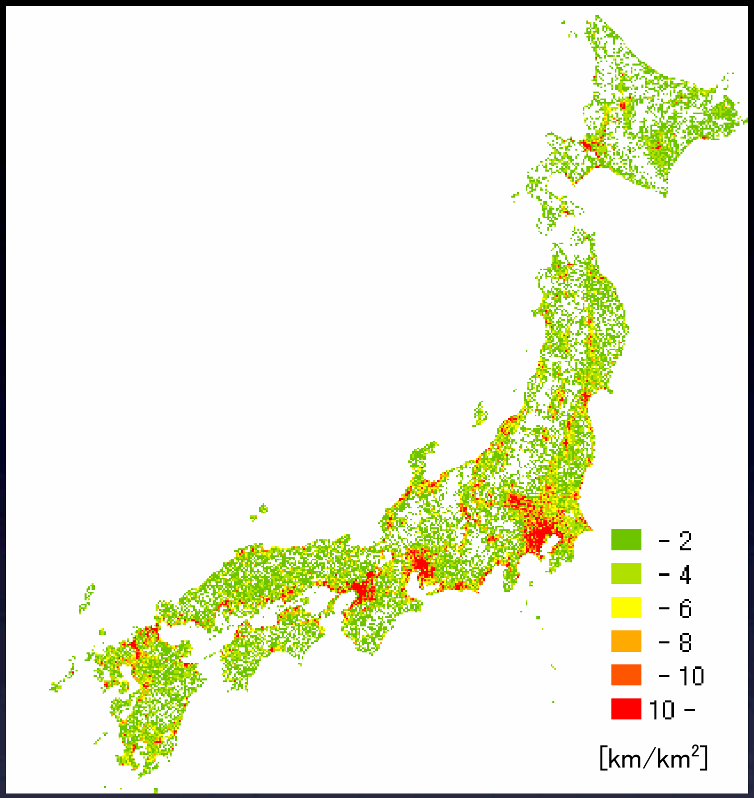
Kinoshita et al., 2010, Applied Energy

Sustainable BECCS in Japan?

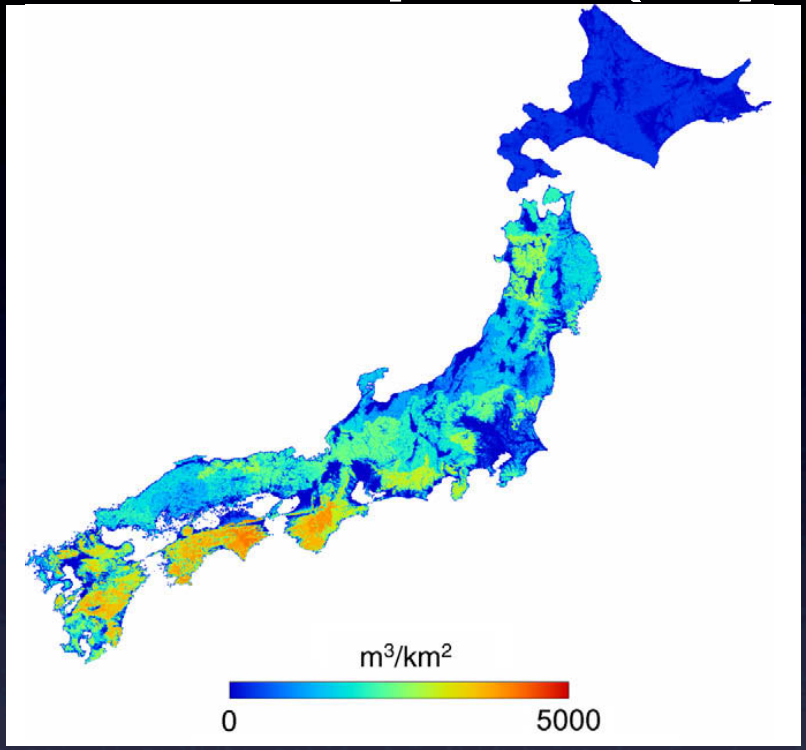
- In Japan, area used for cropland is limited, and the cost of forestry is relatively expensive.
  - Land used for cropland is 12.2% (paddy field 6.6%, other 5.6%)
  - More than 68% of Japan is covered by forests (40% plantations, 28% natural forest), but the use of woody biomass is limited because it is still not seen as economically viable.
- Current biomass energy supply in Japan: 0.85% in 2008, 0.81% in 2009, 1.91% in 2010, and 2.1% in 2011 of total primary energy supply (mostly from waste use)
- Despite the apparent limitation, BECCS potential is roughly assessed for Japan with
  - woody biomass from forestry and forest residues for co-firing in coal power plant with CCS
  - ligno-cellulosic bioenergy crops at abandoned cropland using bioSNG production
  - lignocellulosic bioenergy crops at non-used paddy field for co-firing in coal power plant with CCS

Bioenergy potential of sustainable forestry

Road density

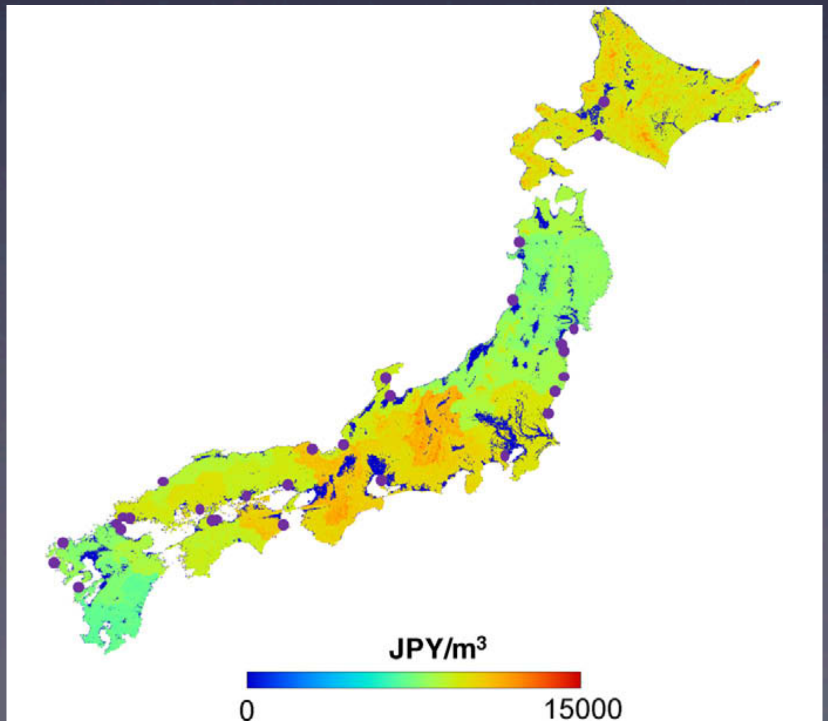


Wood chips production potential in one rotation period (40 years)



Kinoshita et al., 2010

Roundwood production cost



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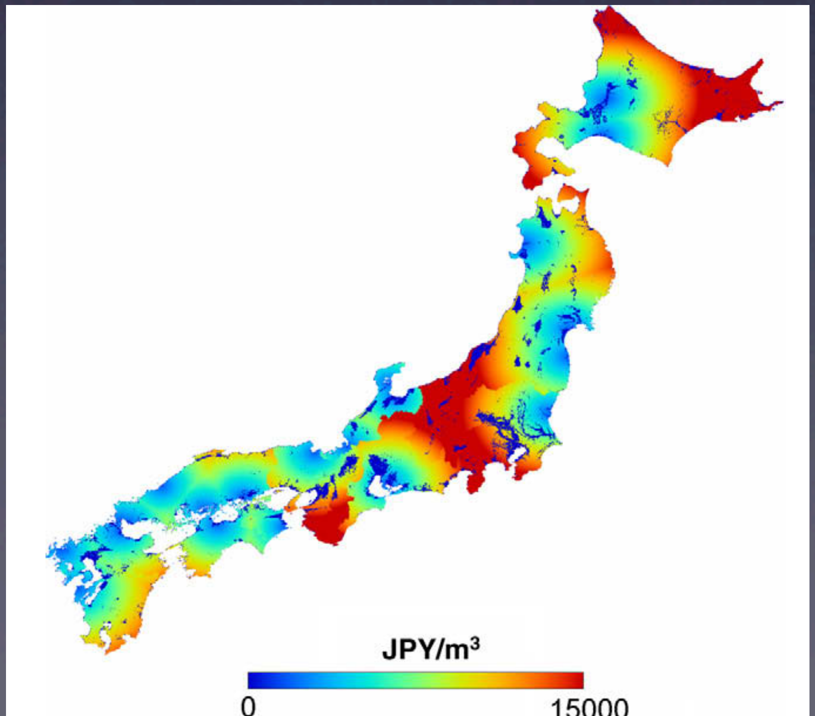
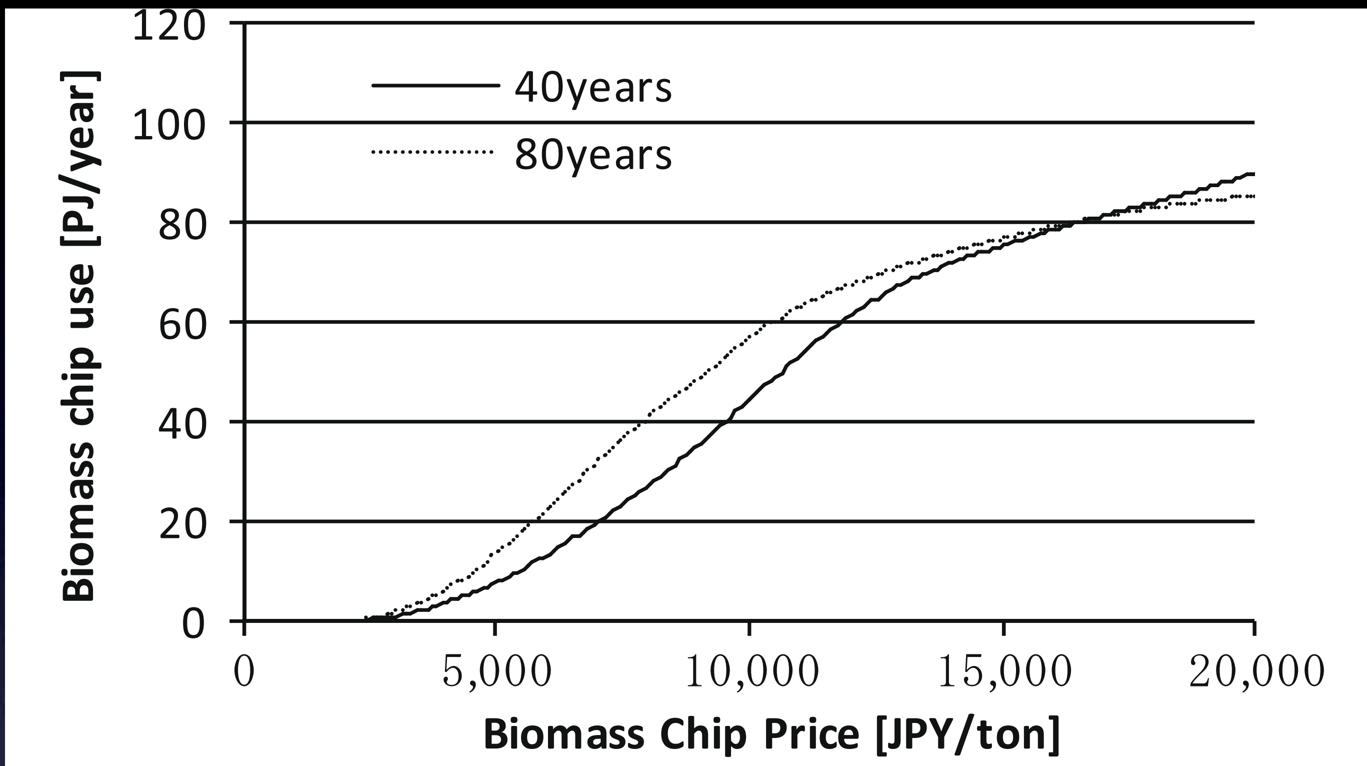
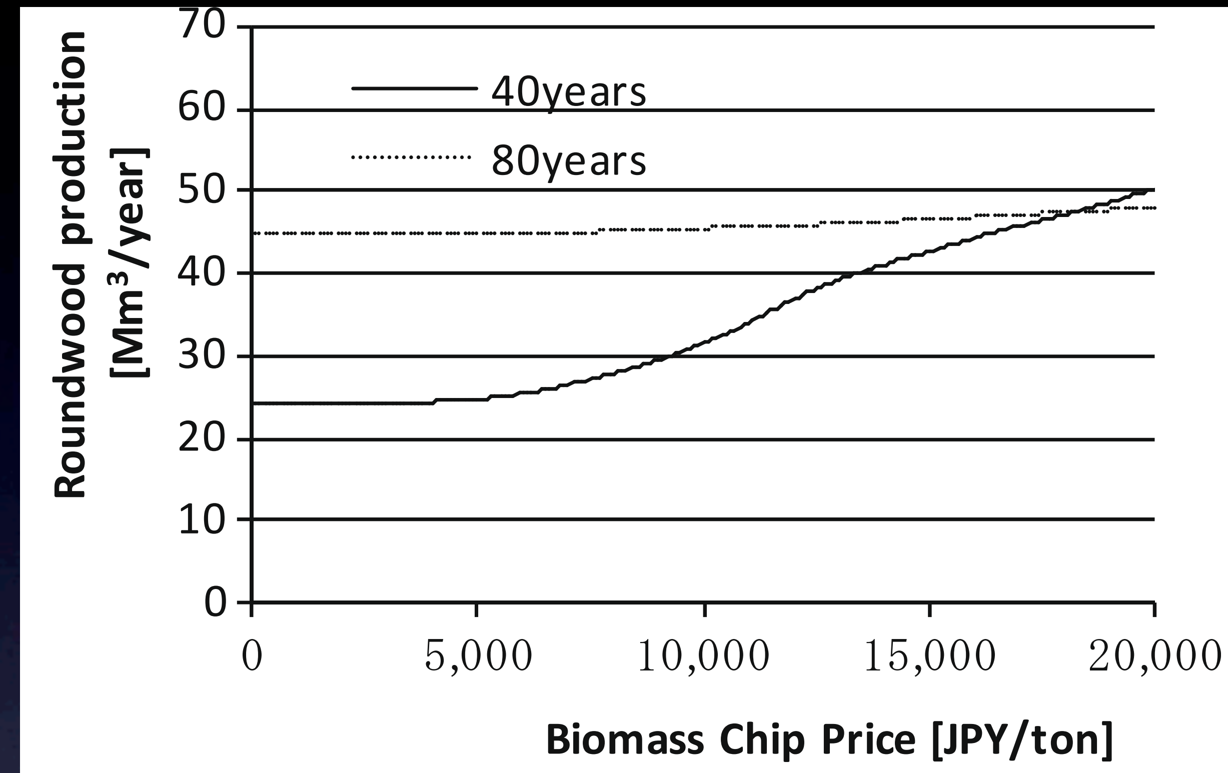


Potential of BECCS with sustainable forestry in Japan

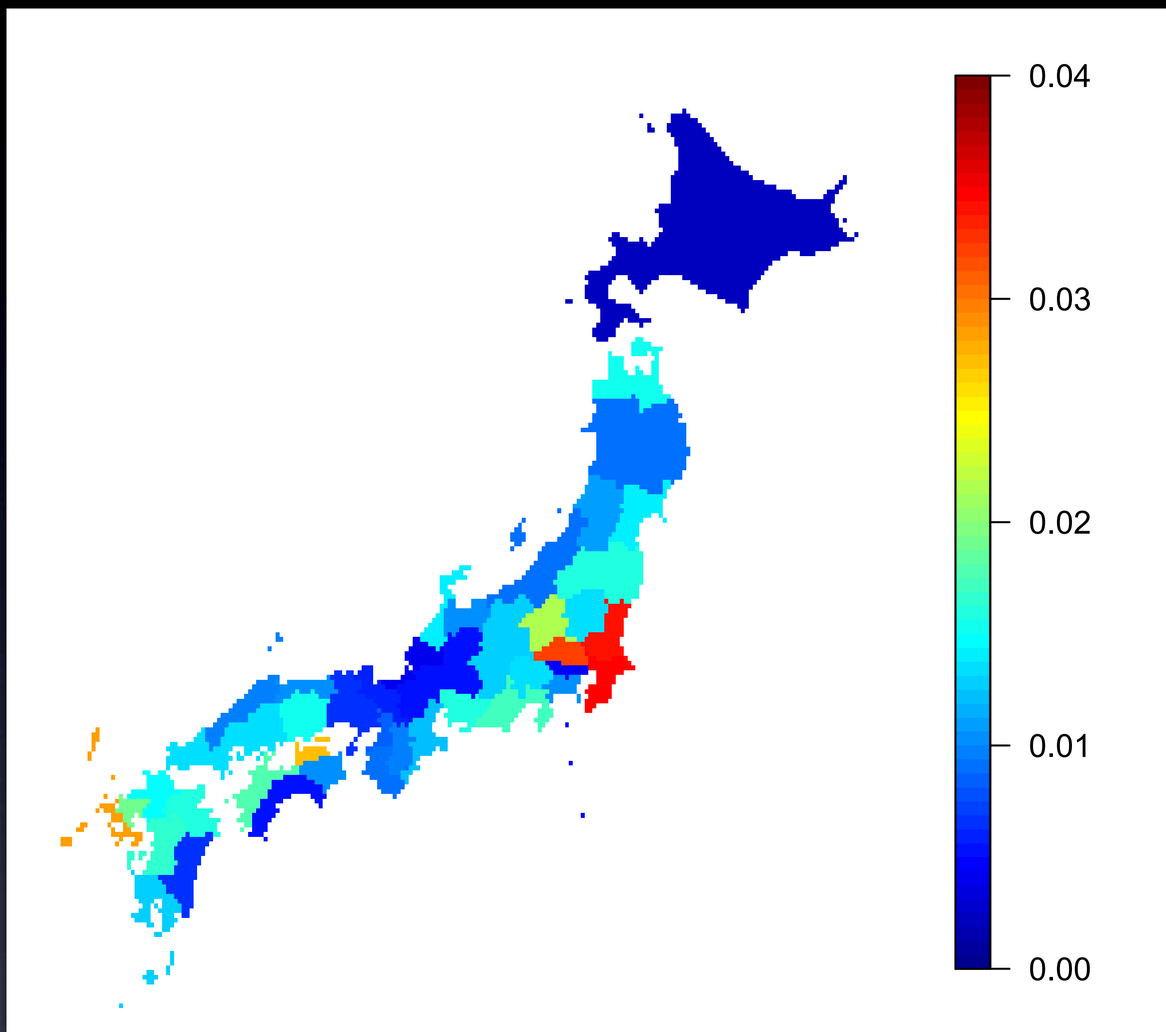




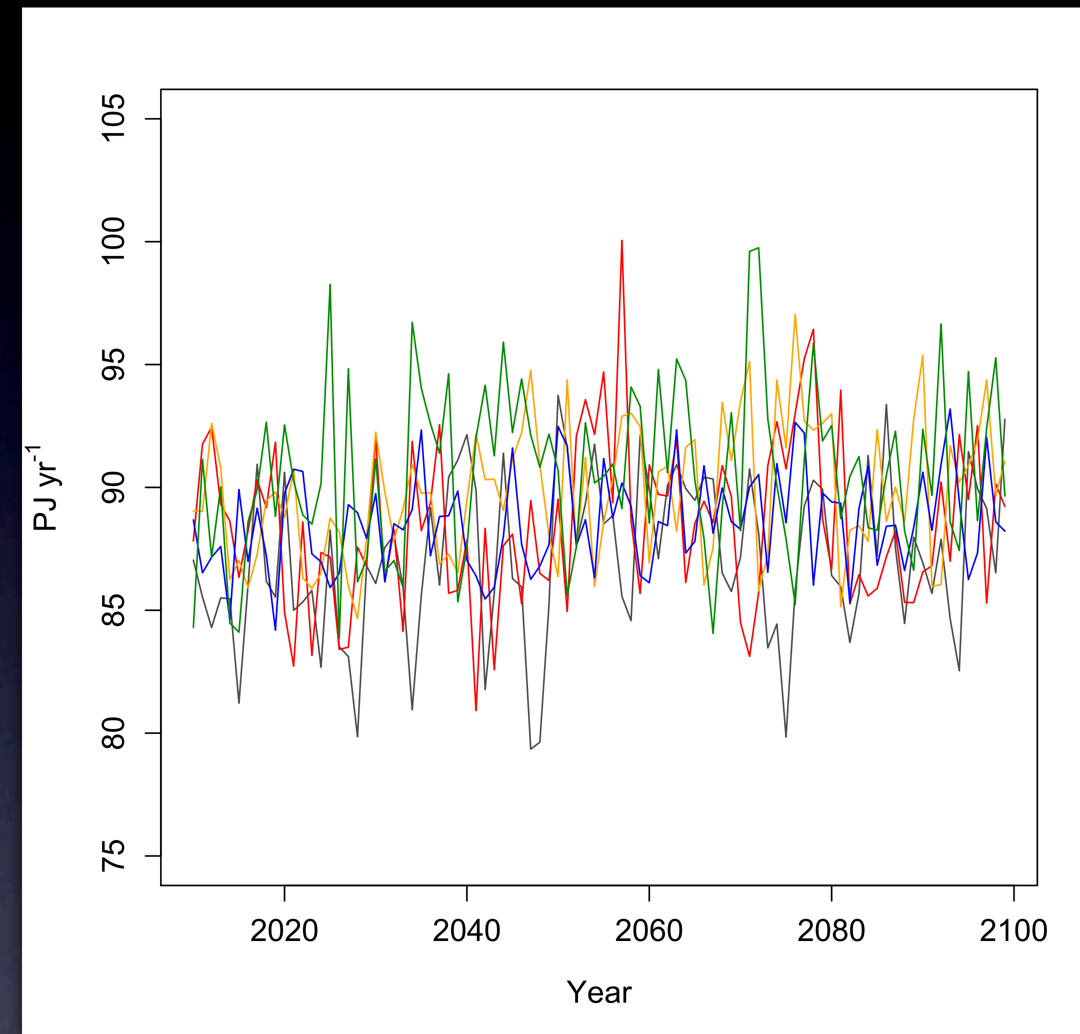
Kinoshita et al., 2010

- 15 PJ yr^{-1} can be supplied with 6300 JPY ton^{-1} from the residue of 40 years rotation period management.
  - 0.3 Mt C yr^{-1} BECCS with coal co-firing CCS
  - Additionally, 50 PJ yr^{-1} (1.0 Mt C yr^{-1} BECCS) is available when currently non-used roundwoods are also considered
  - Total BECCS: 1.3 Mt C yr^{-1} (0.4% of 2012's CO2 emissions 348 Mt C)
- Full utilization of sustainable forest residue and non-used roundwoods can achieve about 8.1 MtC yr^{-1} of BECCS (2.3 % of 2012's CO2 emissions).

Potential of BECCS with second-generation bioenergy crops in abandoned land



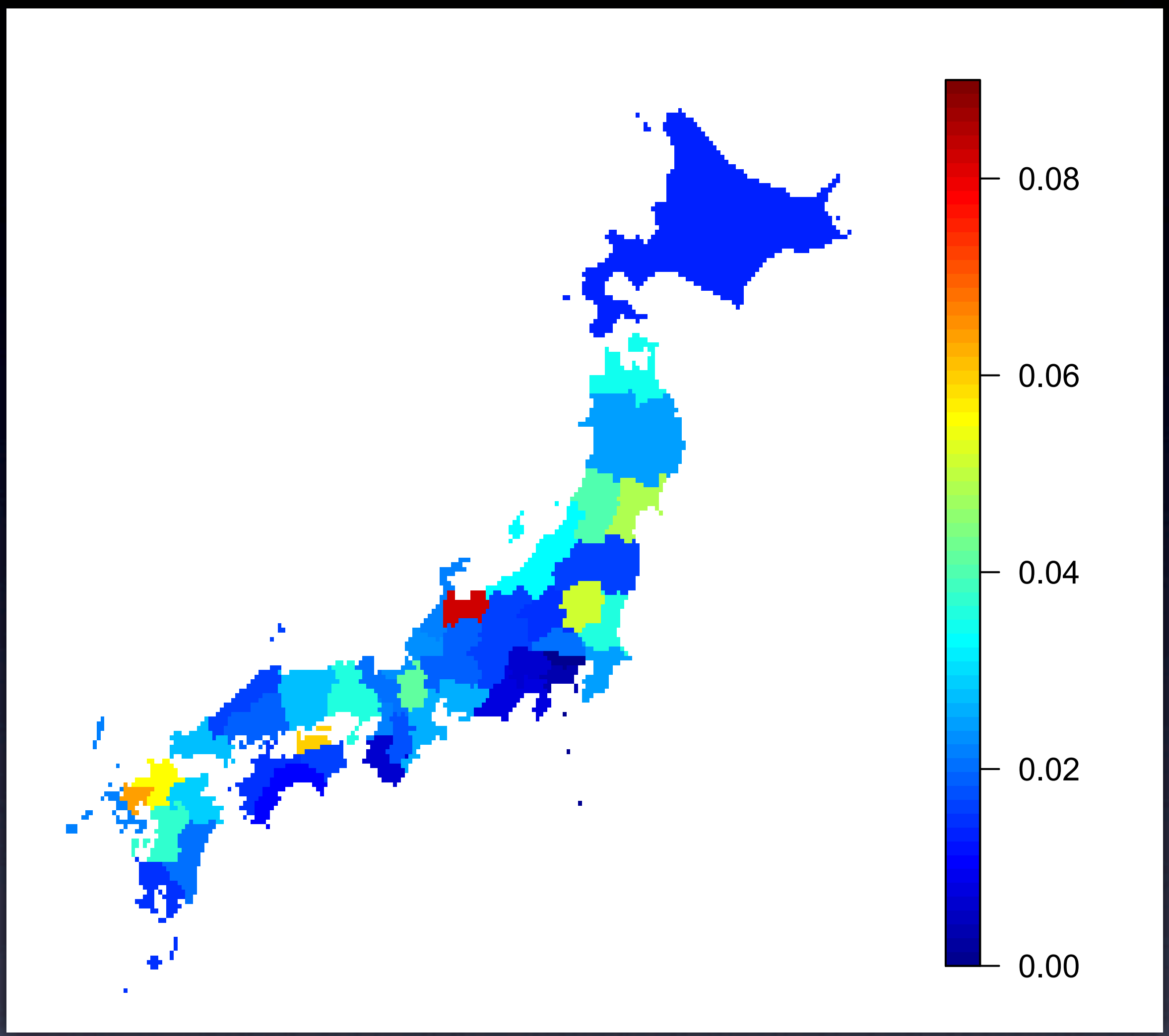
Recoverable abandoned cropland in 2010 (about 1% of total land area on average)



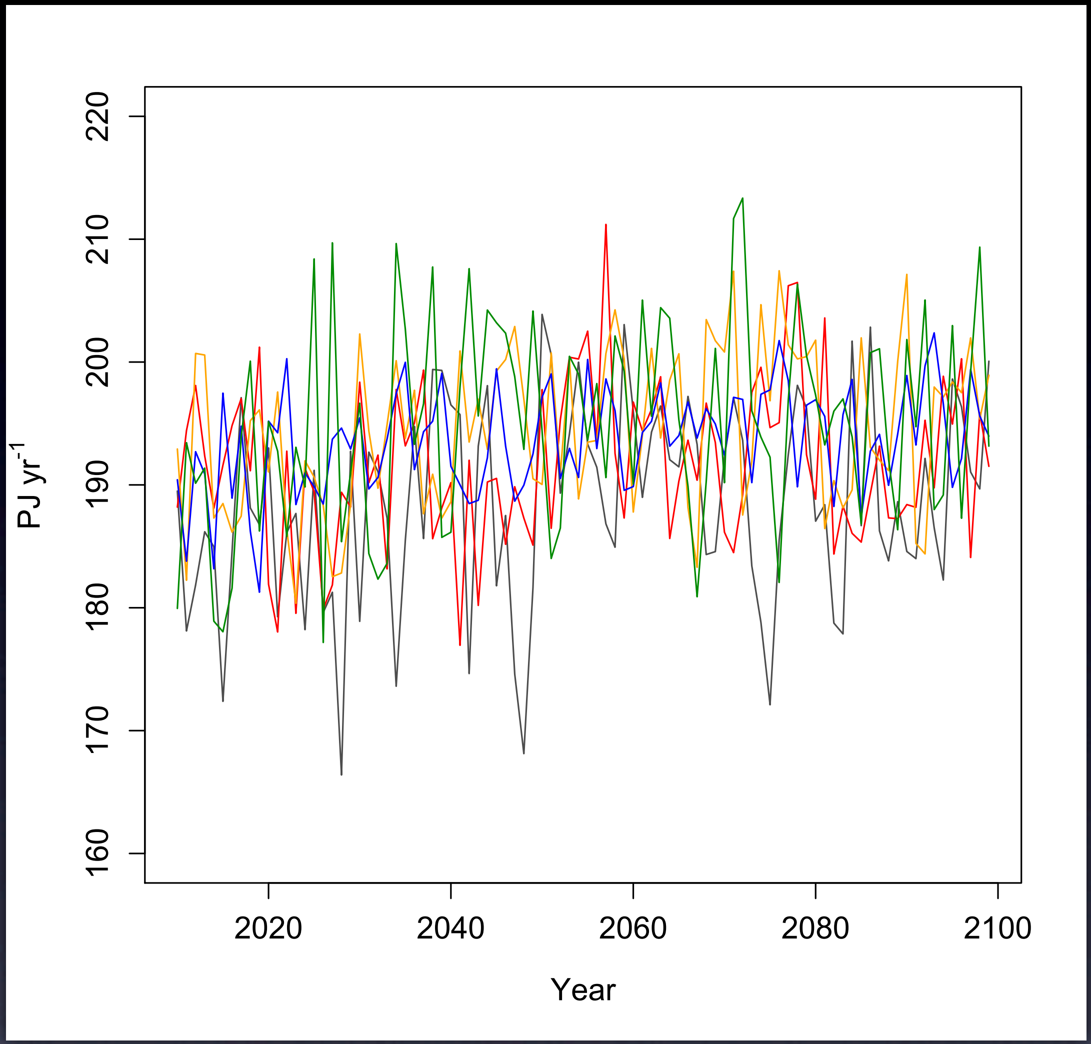
Primary energy of second-generation bioenergy crops in abandoned land: 89 ± 3 PJ yr^{-1} (0.4% of 2012's primary energy supply)

1.0 ± 0.03 Mt C yr^{-1} BECCS using bioSNG with the process gas capture (0.3 % of 2012's CO_2 emissions)

Potential of BECCS with second-generation bioenergy crops in converted paddy field



Paddy field not planted in 2010
(about 2.3% of total land area on average)



Primary energy of second-generation bioenergy crops in converted land: 193 ± 7 PJ yr^{-1}(0.9% of 2012's primary energy supply)

5.1 ± 0.2 Mt C yr^{-1} BECCS using co-firing with 90% post-combustion capture (1.5% of 2012's fossil CO_2 emissions)

Conclusions (for global 2℃ target)

- Expanding ≃0.5 billions ha cropland for bioenergy causes substantial carbon emissions by the land-use change.
- 1st generation bioenergy crops are not suitable for the large scale BECCS for 2℃ target (by its insufficient yield, conversion efficiency, and fertilizer requirement)
- 2nd generation bioenergy crops can marginally fill the required BECCS only if fully post-process combustion capture technology is deployed.
- In addition, equivalent (or even more) amount of bioenergy for BECCS is required for non-BECCS use (about 90EJ at 2050, and 120EJ at 2100) in the RCP2.6 scenario.
- Further bottom-up analysis is needed to assess the global potential of sustainable forestry and its residues use for bioenergy production.

Conclusions (for sustainable land-use in Japan)

- In Japan, 350-680 PJ yr^{-1} bioenergy is available with sustainable land-use
    - 7.4-14.2 Mt C BECCS yr^{-1} and 8.6-16.8 Mt C yr^{-1} coal emissions reduction will be achieved (4.6-8.9% reduction of 2012's CO_2 emissions).
- Other mitigation strategies are crucially needed due to the limited land for dedicated bioenergy crops and sustainable forestry.
- How to share required global BECCS among countries?