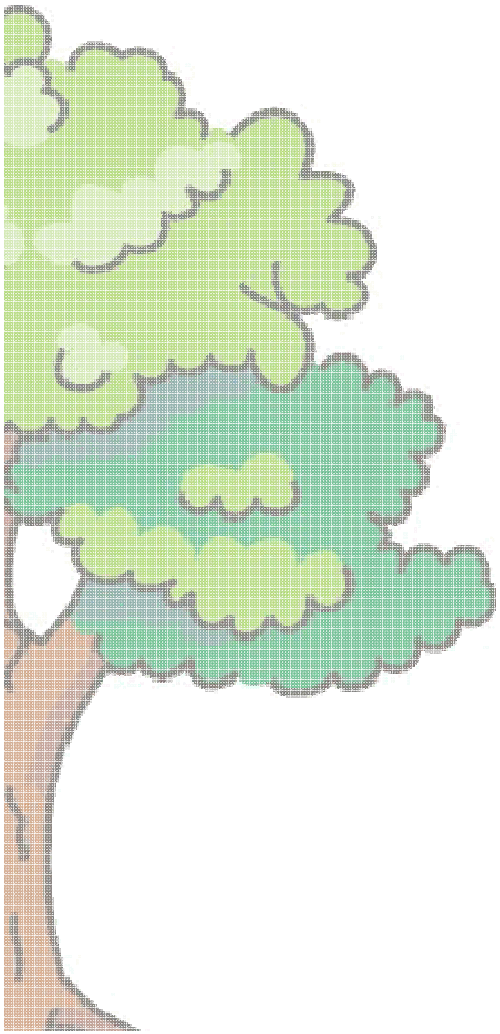
PhD disputation, TU Berlin

28 November 2014

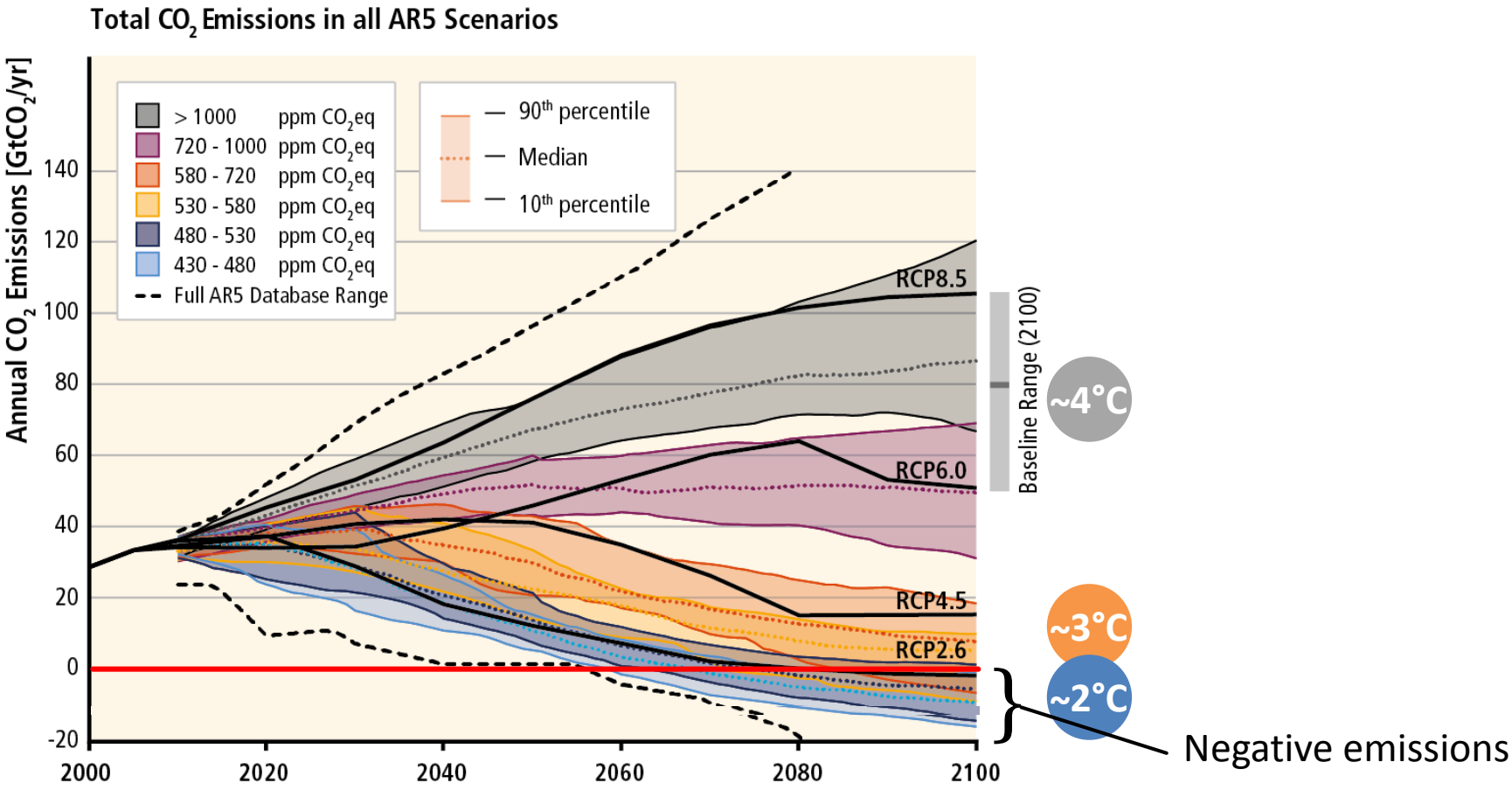


Bioenergy Markets in a Climate-Constrained World

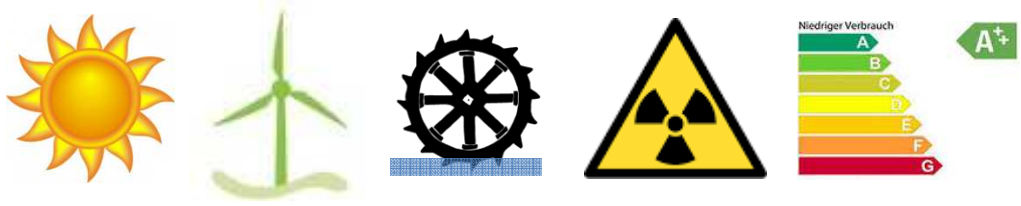
David Klein

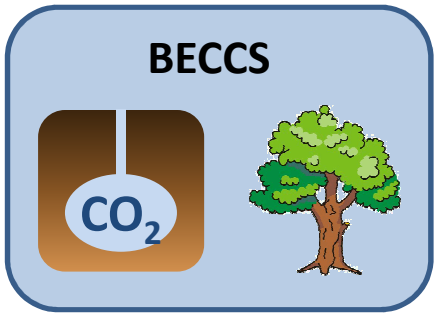
Potsdam Institute for Climate Impact Research, Germany

Low-stabilization pathways include negative emissions



IPCC, 2014: AR5, WGIII, Fig. 6.7





Important assumptions

1. Carbon Dioxide Removal options

- Bioenergy with carbon capture and storage (BECCS)
- Afforestation
- Direct air capture
- Enhanced weathering

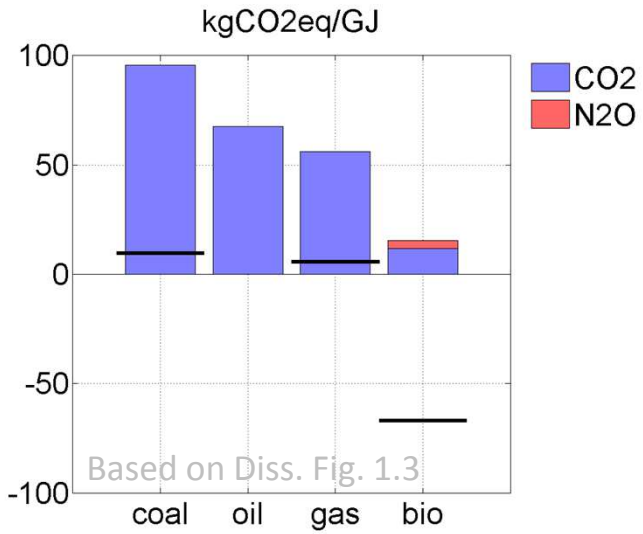
2. Ligno-cellulosic bioenergy crops

- better GHG balance than food crops
- ecologically less demanding

Properties of bioenergy

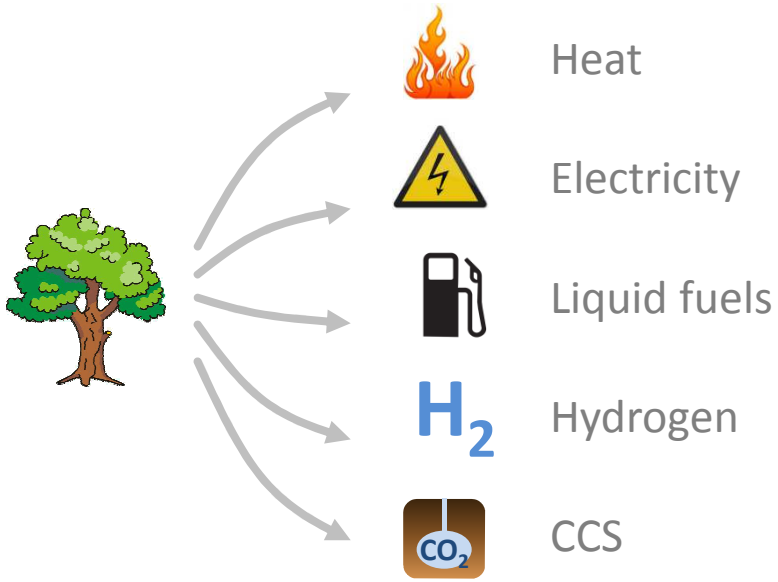
Advantages

- **low GHG intensity**
- **negative emissons**
- **versatility**
- dispatchable
- tradable



Important drawbacks

- **LULUC emissions**
- **requires fertile land**
- food competition
- biodiversity loss
- water consumption
- pre-mature technol.

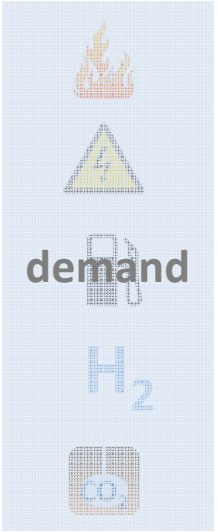


Research questions

What is the potential contribution of bioenergy to climate change mitigation
considering its potential to provide negative emissions?

climate policy

- What is the **global supply** of modern biomass?
- How does **climate policy affect bioenergy supply**?
- What are potential implications for the landuse system?



- **Why, when, and how** is bioenergy deployed under climate policy?

Versatility
&
negative emissions

- economic drivers of demand
- willingness-to-pay for bioenergy
- technology choice
- intertemporal allocation

Papers

Literature review

Can Bioenergy Assessments Deliver?

*Creutzig, F.; von Stechow, C.; **Klein, D.**; Hunsberger, C.; Bauer, N.; Popp, A.; Edenhofer, O. (2011), Economics of Energy and Environmental*

Landuse implications

The economic potential of bioenergy for climate change mitigation with special attention given to implications for the land system

*Popp, A.; Dietrich, J.P.; Lotze-Campen, H.; **Klein, D.**; Bauer, N.; Krause, M.; Beringer, T.; Edenhofer, O. (2011), Environmental Research Letters*

Technology study

Bio-IGCC with CCS as a long-term mitigation option in a coupled energy-system and land-use model

***Klein, D.**; Bauer, N.; Bodirsky, B.; Dietrich, J.P.; Popp, A. (2011), Energy Procedia*

The global economic long-term potential of modern biomass in a climate-constrained world

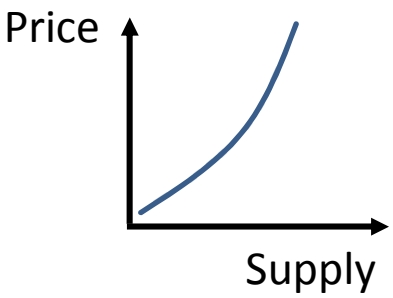
***Klein, D.**; Humpenöder, F.; Bauer, N.; Dietrich, J.P.; Popp, A.; Bodirsky, B.; Bonsch, M.; Lotze-Campen, H.; (2014), Environmental Research Letters.*

The value of bioenergy in low stabilization scenarios: an assessment using REMIND-MAgPIE

***Klein, D.**; Luderer, G.; Kriegler, E.; Strefler, J.; Bauer, N.; Leimbach, M.; Popp, A.; Dietrich, J.P.; Humpenöder, F.; Lotze-Campen, H.; Edenhofer, O. (2013), Climatic Change*

supply price

$ = ?



Bioenergy supply curves – Why?

Bioenergy is an important mitigation option

- bioenergy potential and costs affect overall mitigation costs

Global supply prices are under-researched

- sparse information in the SREEN and AR5

No climate policy considered so far

- deforestation is major concern about large-scale bioenergy production

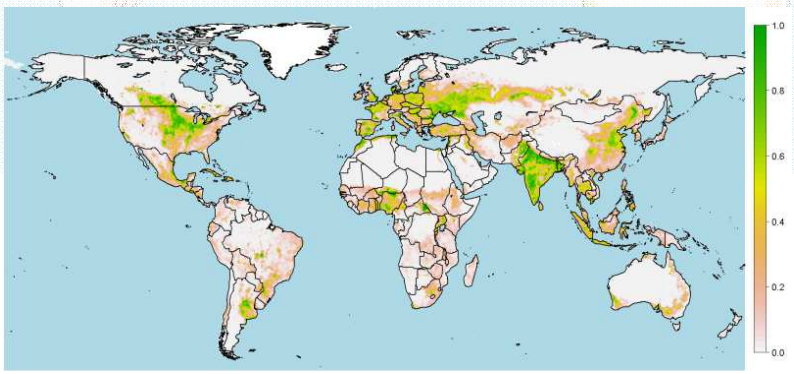
Purpose of this study

- provide supply prices
- investigate the impact of climate policy on bioenergy supply

Methods: The landuse model “MAgPIE”

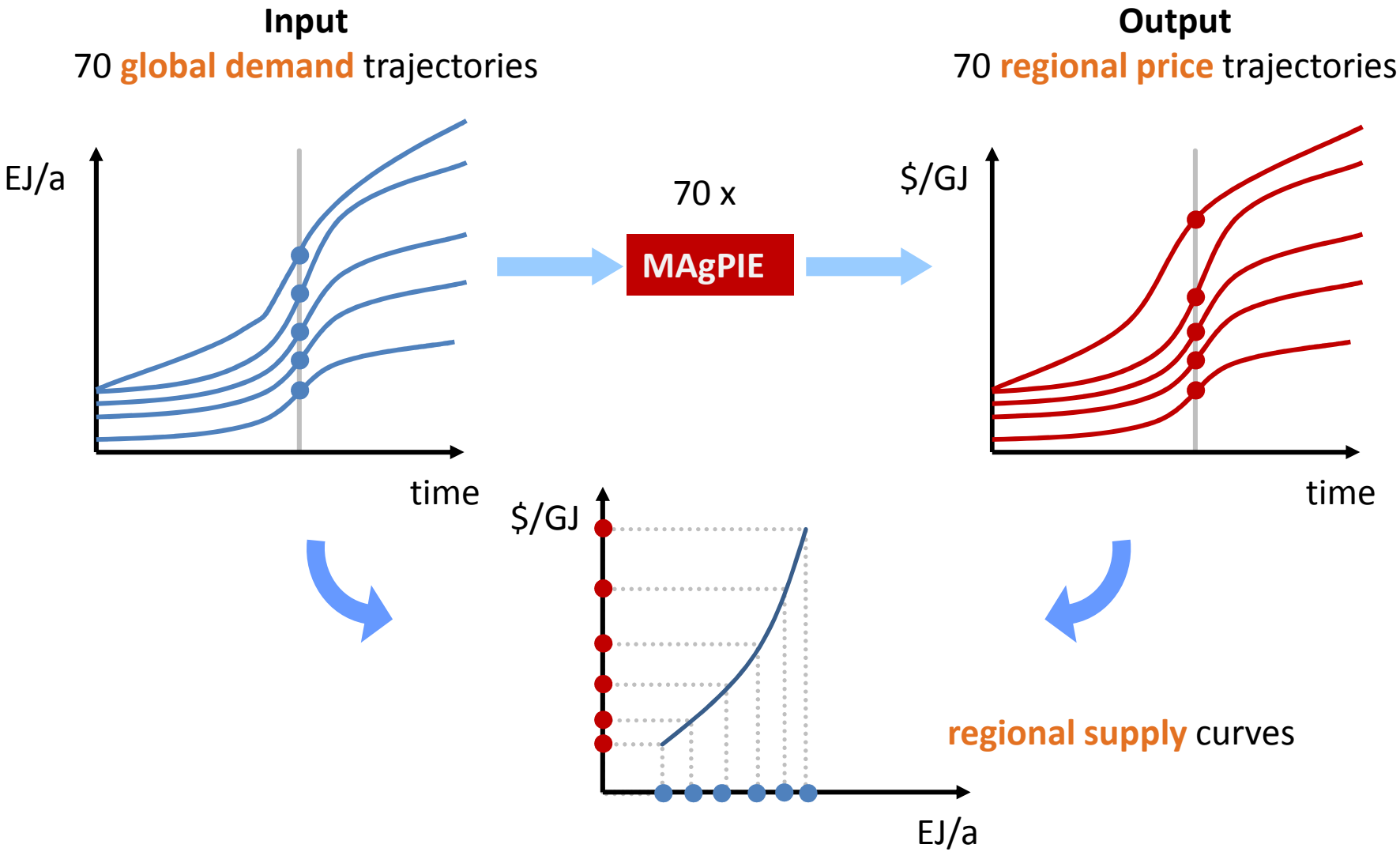
MAgPIE = Model of **Ag**ricultural **P**roduction and its **I**mpact on the **E**nvironment

- partial equilibrium, minimizes total agricultural production costs (rec. dyn.)
  - factor requirement costs (capital, labor, fertilizer, water),
  - land conversion,
  - investments into technological development,
  - GHG emission costs
- endogenous allocation: trade-off between land expansion and intensification
- shadow price for biomass
- full land-use competition with other crops



Methods: Constructing the supply curves

Measuring the price response of MAgPIE to bioenergy demand



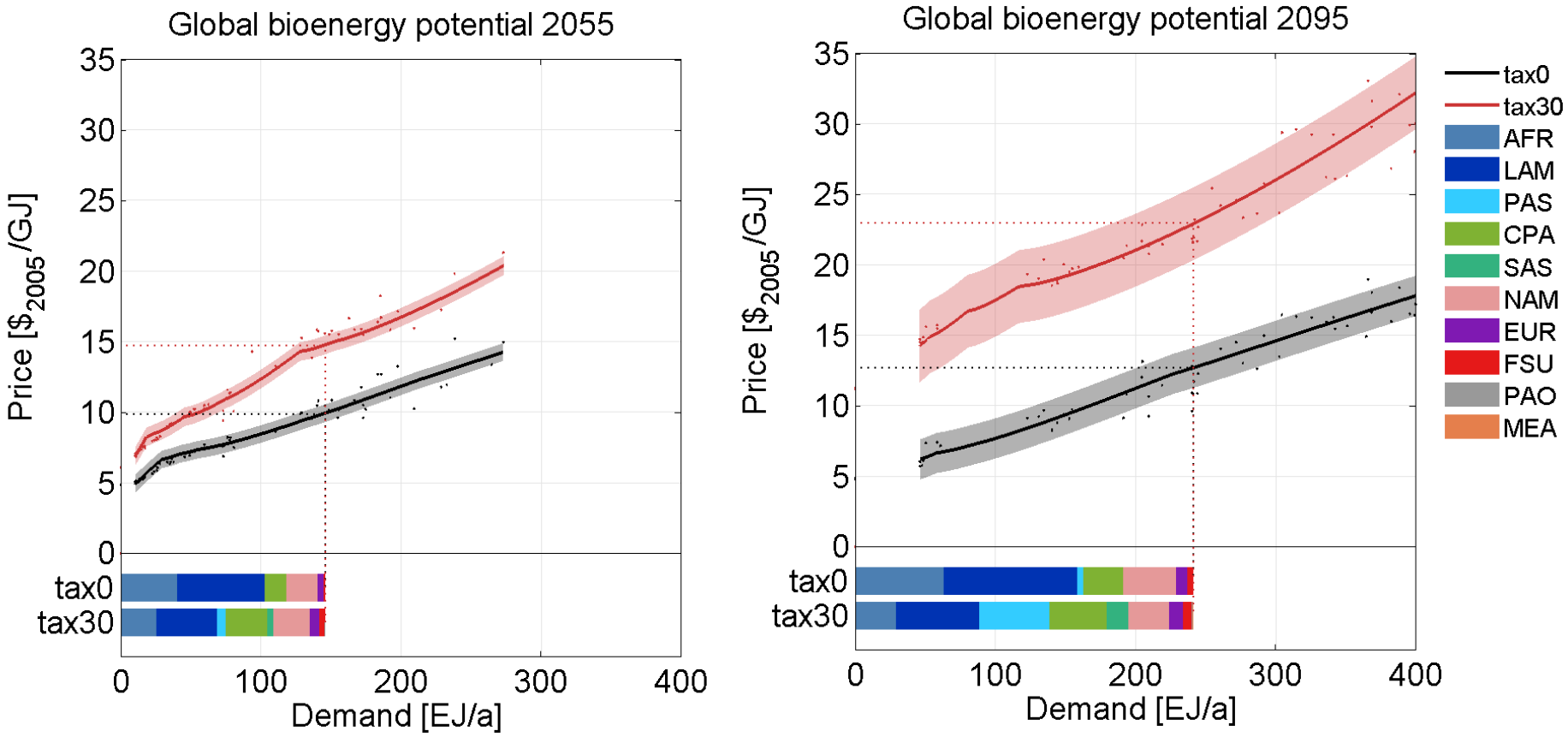
Scenarios

Two climate policy scenarios:

tax0	tax30
no GHG prices	exponentially increasing GHG price (~ 2°C) 2020: 30 $/tCO2 2055: 165 $/tCO2 2095: 1165 $/tCO2 CO2, N2O, CH4

Tax on CO_2 from deforestation only,
not on emissions from converting natural vegetation.

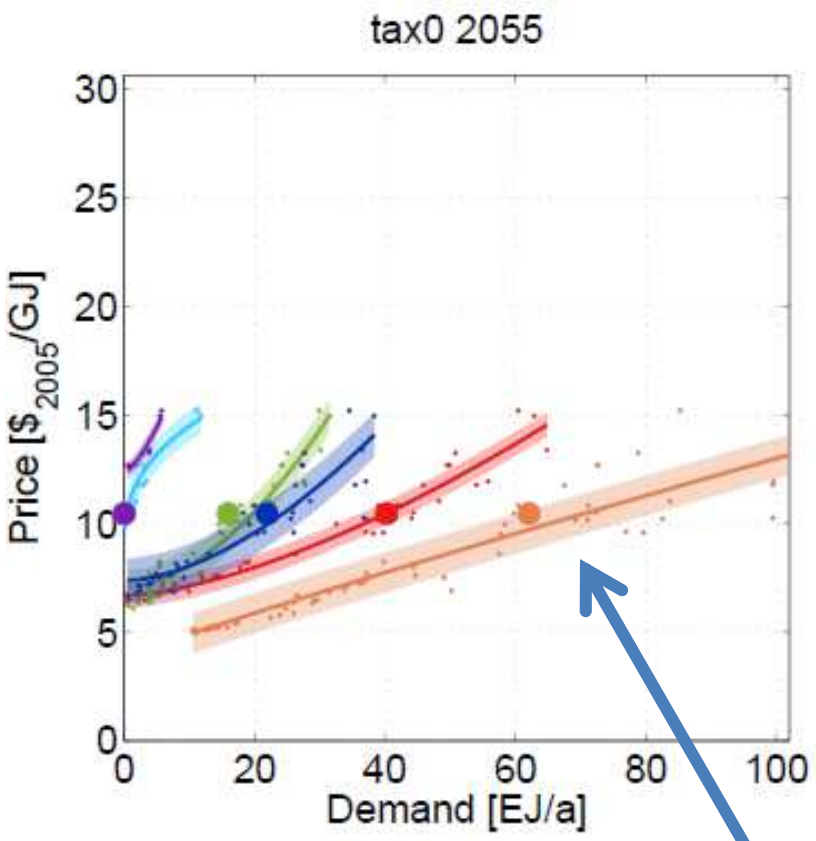
Results: Globally aggregated supply curves

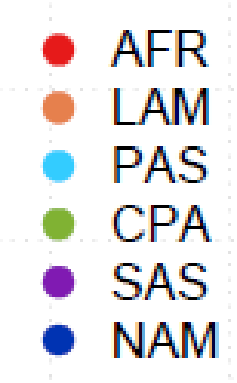


- GHG tax increases bioenergy prices by ~ 5 $/GJ in 2055 and 10 $/GJ in 2100
- Without tax: major suppliers are tropical regions with access to fertile forest land
- GHG tax shifts bioenergy production from AFR and LAM to PAS, CPA, SAS

Source: Klein et al. 2014

Results: regional supply curves without and with tax



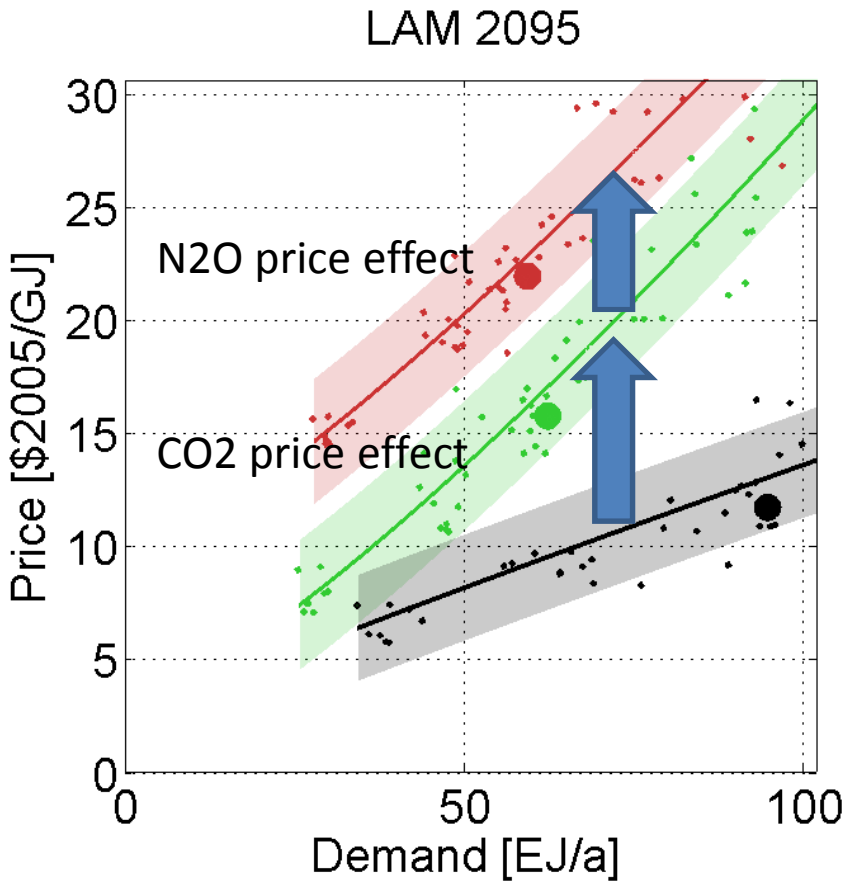


With no GHG tax major suppliers feature relative flat supply curves

Source: Klein et al. 2014

Results: The GHG tax has two price-elevating effects

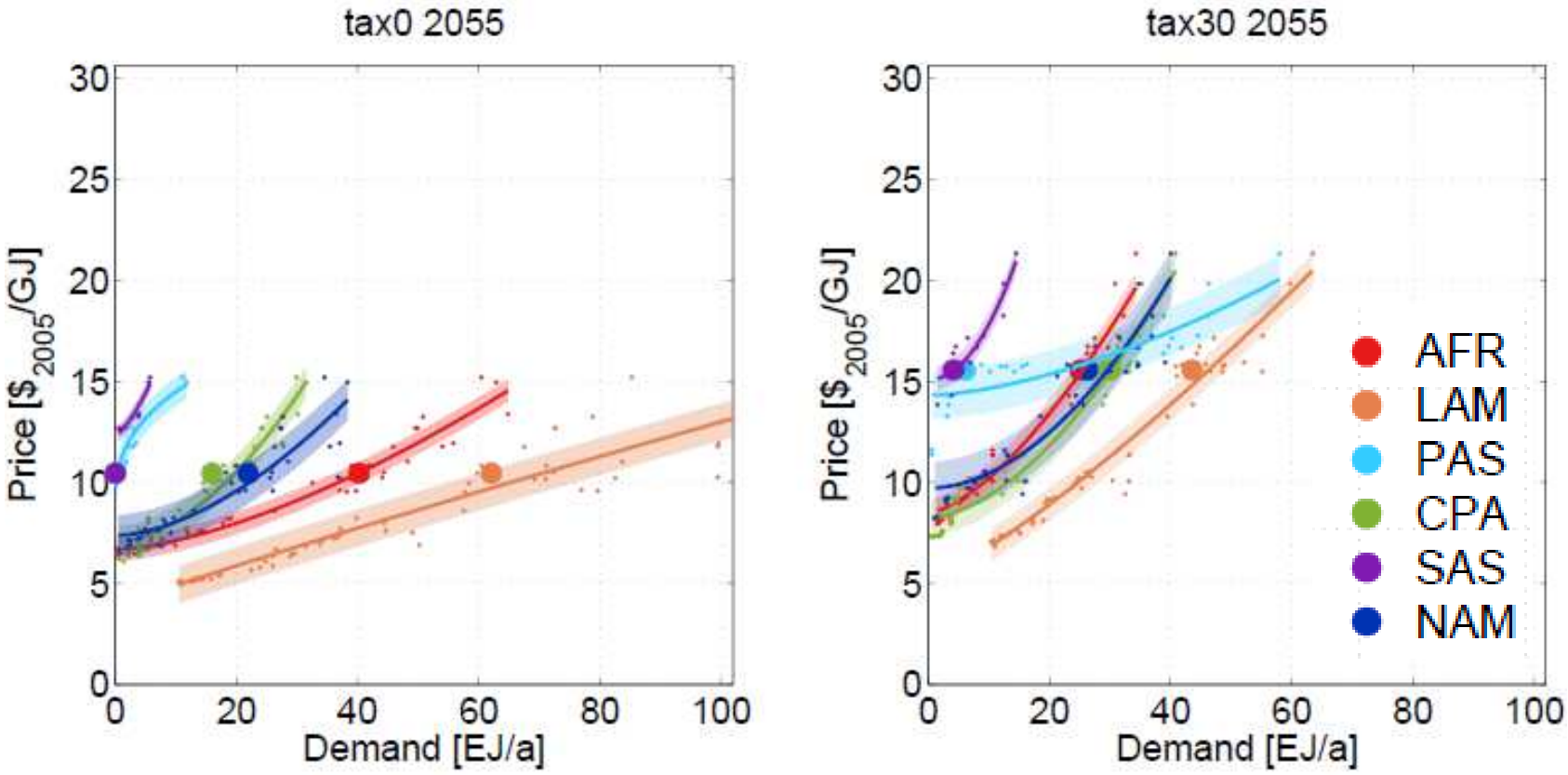
- tax0 **no GHG tax**
- tax30c **CO2 tax only**
- tax30 **tax on all GHGs**



- CO2 price effect: stops deforestation -> reduces available land -> steepens the curve
- N2O price effect: translation effect due to fertilizer emissions

Source: Klein et al. 2014

Results: regional supply curves without and with tax

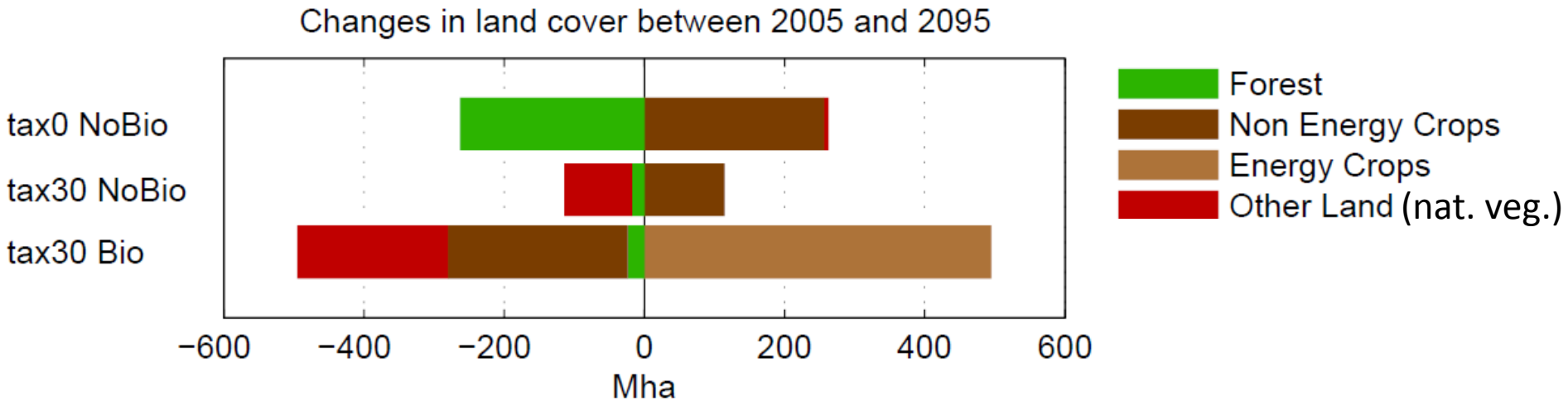


- GHG tax changes the relative position of the supply curves, since the consequences of pricing differ across regions
- Regions with no forest (CPA, PAS, and SAS) are only affected by the N2O-price effect.
- Regions that deforest in the tax0 scenario additionally show a steepening (AFR, LAM)
- PAS has access to large amounts of natural vegetation

Source: Klein et al. 2014

Results: Land use changes from 2005 to 2095

- Results from a medium demand scenario selected as a sample out of the full portfolio (240 EJ in 2095)



- Carbon tax effectively protects forests
- Compensated by intensification and conversion of nat. veg. (no emission costs)
- Bioenergy production is realized by further intensification and expansion into nat. veg.

Source: Klein et al. 2014

Conclusion 1: Supply

- The bioenergy prices start **above 5 $/GJ** (emerge under full land-use competition)
- **Climate policy** significantly **increases supply prices**

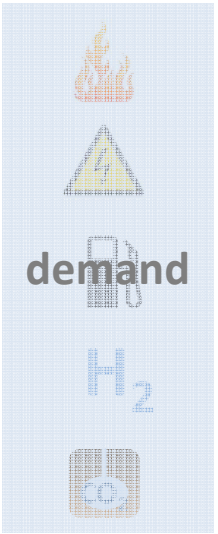
- Combination of **carbon tax & large-scale bioenergy** causes substantial pressure
- **Deforestation is stopped**
- It dramatically **reduces land available** for food production
- **Requires strong intensification**
- **Threatens natural vegetation** and forest and that is not under emission control

Research questions

What is the potential contribution of bioenergy to climate change mitigation?

climate policy

- What is the **global supply** of modern biomass?
- How does **climate policy affect bioenergy supply**?
- What are potential implications for the landuse system?



- **Why, when, and how** is bioenergy deployed under climate policy?

Versatility
&
negative emissions

- economic drivers of demand
- willingness-to-pay for bioenergy
- technology choice
- intertemporal allocation

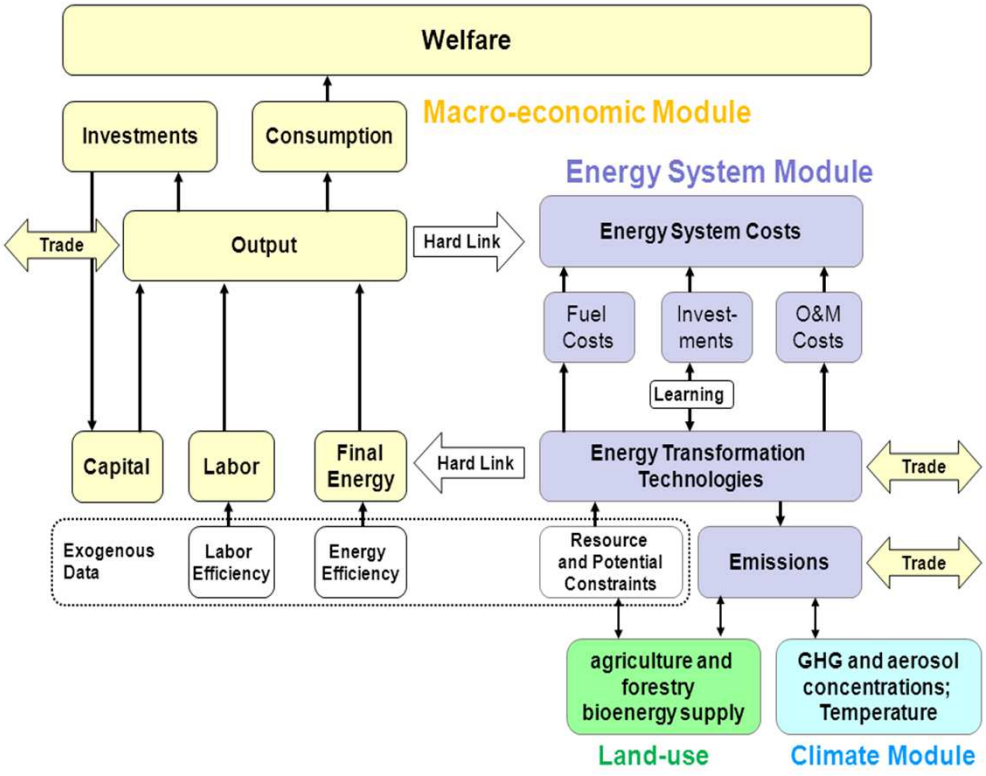
Methodology – The REMIND Model

Regional **M**odel of **In**vestment and technological **D**evelopment

- global **multi-regional** model of the energy-, economy-, and climate system
- combines a macro-economic Ramsey-type growth model with a **bottom-up energy-system** and a climate model
- computes the **general equilibrium** by maximizing the global welfare
- **intertemporal perspective with perfect foresight**
- detailed energy system

Representation of landuse sector

- bioenergy supply curves, N2O emission factor
- emission baselines from MAgPIE (subject to MAC)
- -> direct and indirect bioenergy emissions are fully accounted for



Scenario definition

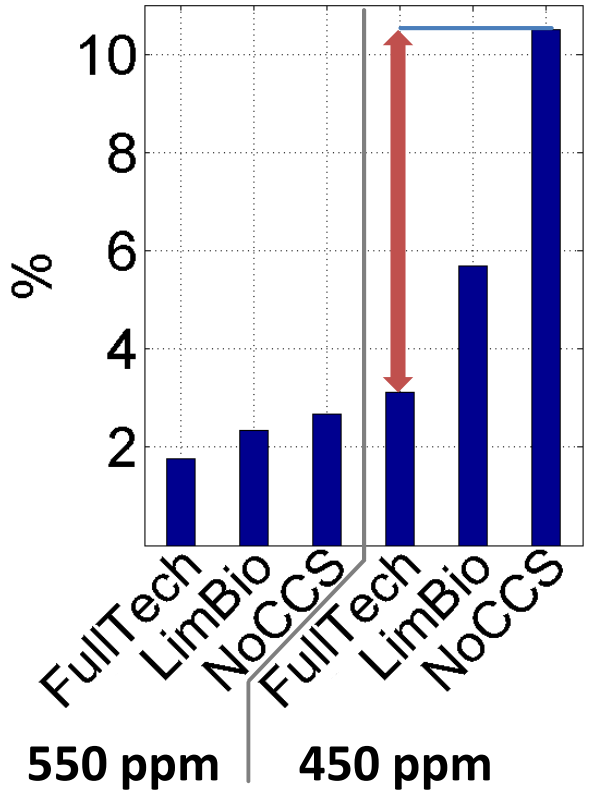
Major uncertainties about main factors that determine bioenergy deployment

- availability of advanced **conversion technologies** including CCS
- future **development of the landuse system** (unsufficient technological progress)
- negative side effects: food-competition, biodiversity, water consumption

	FullTech	NoCCS	LimBio
	CCS ✓ 300 EJ	CCS ✗ 300 EJ	CCS ✓ 100
Baseline			
450 ppm CO_2eq			
550 ppm CO_2eq			

BECCS has high option value for low-stabilization

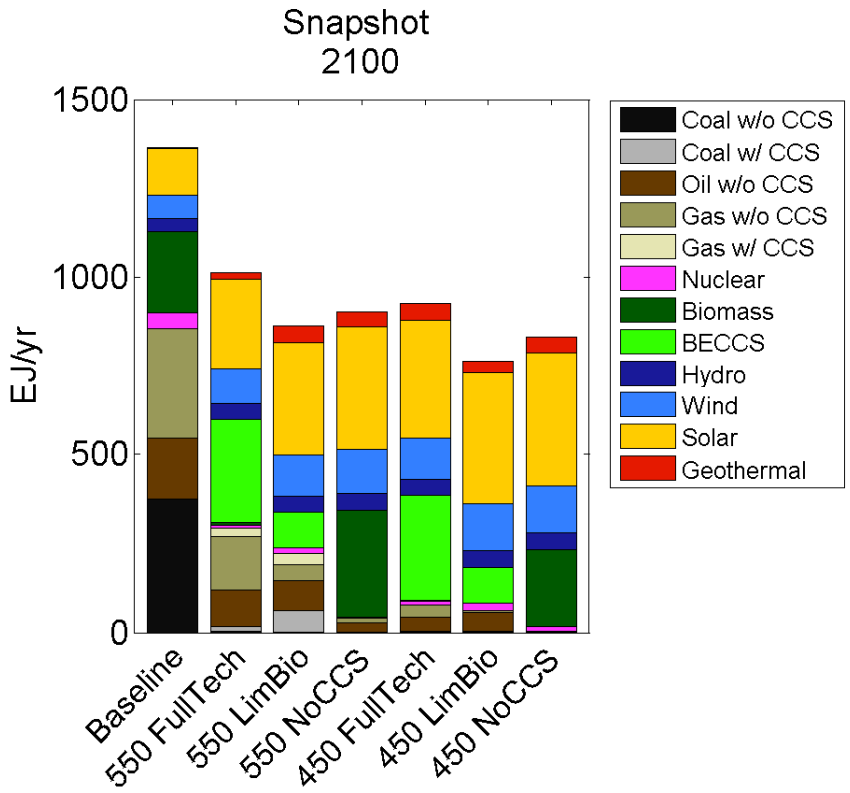
Cumulated consumption losses relative to baseline scenario



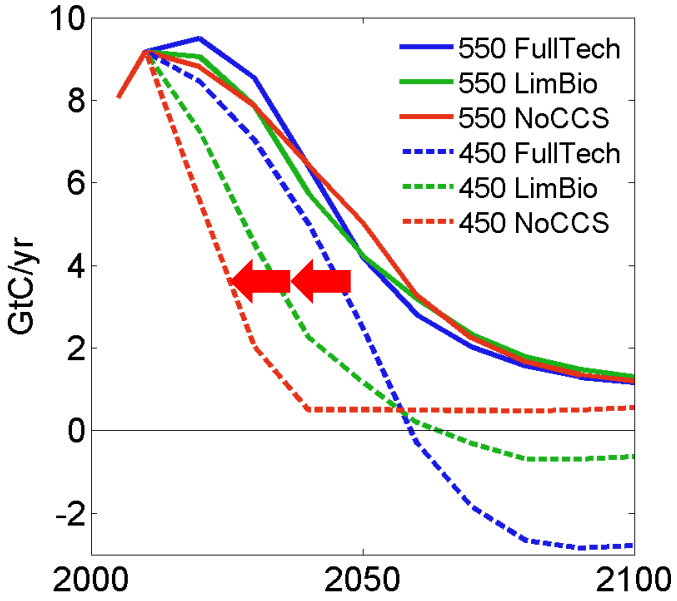
Source: Klein et al. 2013

Global bioenergy deployment

Primary energy demand



Total energy emissions including BECCS

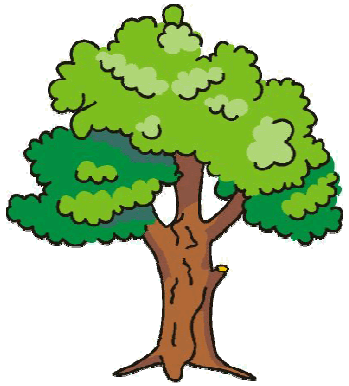


- earlier and higher cumulated deployment
- exclusively with CCS if available
- decarbonize the transportation sector

- maintaining short-term fossil fuel deployment induces strong demand for BECCS after 2050
- lim BECCS: intertemporal flexibility is reduced

Source: Klein et al. 2013

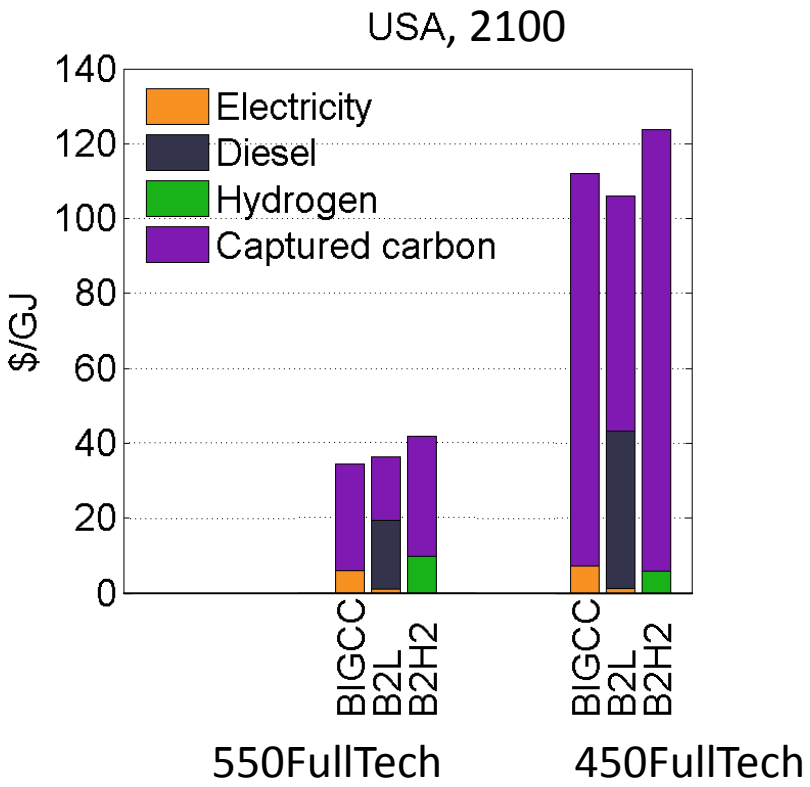
willingness to pay



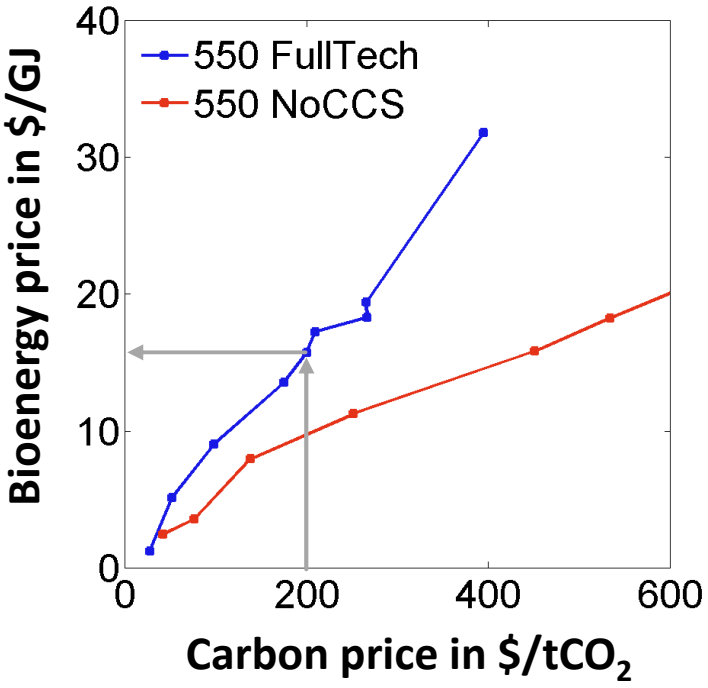
? = $

The value of bioenergy

Revenues from bioenergy conversion



Willingness-to-pay



$$p_{bio} = \frac{p_{CO2}}{\text{carbon content} \bullet \text{capture rate}}$$

- Diesel revenues are high due to fewer low-carbon alternatives in transport sector
- The value of carbon tends to dominate over the value of energy
- Driving factor for building capacities are revenues from neg. emis. rahter than energy

- Carbon content links bioenergy price to carbon price and defines the willingness-to-pay

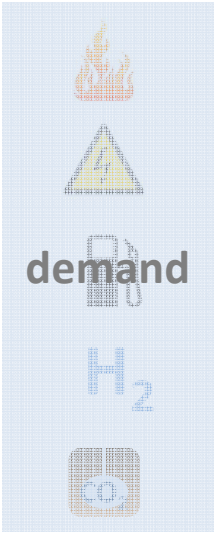
Source: Klein et al. 2013

Research questions

What is the potential contribution of bioenergy to climate change mitigation?

climate policy

- What is the **global supply** of modern biomass?
- How does **climate policy affect bioenergy supply**?
- What are potential implications for the landuse system?

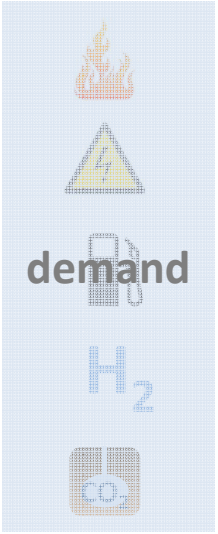


- **Why, when, and how** is bioenergy deployed under climate policy?

Versatility
&
negative emissions

- economic drivers of demand
- willingness-to-pay for bioenergy
- technology choice
- intertemporal allocation

Conclusions



- Low-stabilization is **hard to achieve without negative emissions**
- **BECCS is a crucial** mitigation option
- Maintaining short-term emissions relies on **long-term availability of BE *and* CCS**

- Bioenergy is predominantly used to **decarbonize the transport sector**
- **Carbon value tends to exceed energy value**
- Strong need for negative emissions induces **high willingness-to-pay** for BE
- Investment in technologies that woud not be built for energy production

- Ambitious climate targets (BE + CO_2 tax) put **pressure on the landuse sector**
- Bioenergy **prices increase** and **strong intensification** is required
- Threat for land that is not under emission control
- The **political decision** which land to put under carbon taxation **defines how much land is accessible** for the supply of bioenergy and food

Inofficial conclusion

Bioenergy with CCS is the only technology
that can turn today‘s energy transformation challenges
into far-future landuse problems.

Thank you
for your attention