Interaction of Agriculture and Energy in Global Greenhouse Gas Mitigation Scenarios

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*The views expressed are the author's and should not be attributed to the Economic Research Service or USDA

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Overview

- Global Scenarios for Policy Analysis
  - Representative Concentration Pathways (RCPs)
  - Current Energy Modeling Forum (EMF) study
- Brief History of Future Agricultural Resources Model (FARM)
- Model structure and data
  - CGE Framework
  - GTAP 7 Data and Aggregation
- Sample results (Global electricity generation)
- Carbon Dioxide Capture and Storage (CCS)
- CCS with bio-electricity
- Sample results (US electricity generation)

Representative Concentration Pathways

- Replacement for SRES scenarios used in IPPC 4th Assessment Report (AR4)
- Input for climate models used in IPPC 5th Assessment Report (AR5)
- Assessment of climate change impacts
- Interpretation of RCP scenarios
  - High reference scenario for emissions (RCP 8.5)
  - Medium reference scenario or high mitigation scenario (RCP 6.0)
  - Low reference scenario or intermediate mitigation scenario (RCP 4.5)
  - Low mitigation scenario (RCP 2.6)

Representative Concentration Pathways

RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100.
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).

Source: Van Vuuren DP et al (2011) The representative concentration pathways: an overview. Climatic Change DOI 10.1007/s10584-011-0148-z

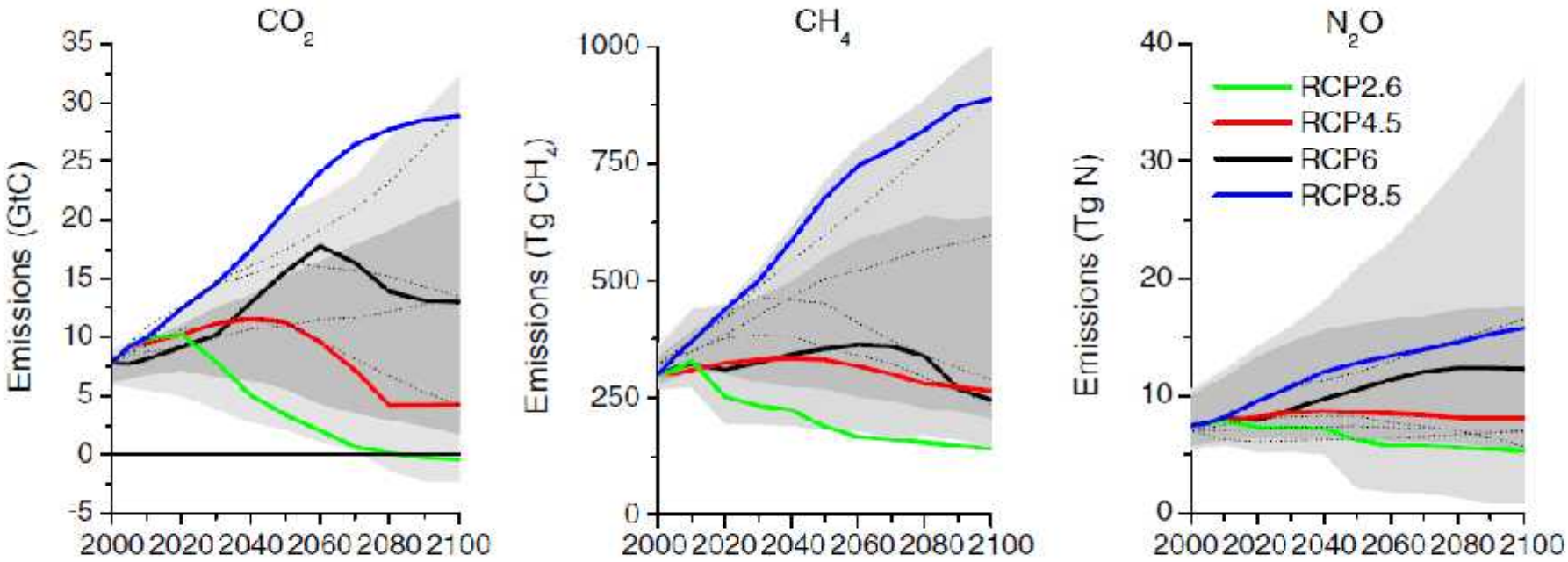


Fig. 6 Emissions of main greenhouse gases across the RCPs. Grey area indicates the 98th and 90th percentiles (*light/dark grey*) of the literature (for references, see Figure 4). The dotted lines indicate four of the SRES marker scenarios. Note that the literature values are obviously not harmonized (see text)

Source: Van Vuuren DP et al (2011) The representative concentration pathways: an overview. Climatic Change DOI 10.1007/s10584-011-0148-z

EMF-24: Technology Strategies for Greenhouse Gas Reductions and Energy Security

- "Modeling for insights, not numbers"
- Participants
  - Global scenarios (18 modeling teams)
  - U.S. scenarios (12 modeling teams)
- EMF steering group specifies a large set of scenarios that vary by policy and availability of technologies
- Modeling teams choose whether to run a "policy focus" subset or "technology focus" subset of scenarios
- Technology scenarios vary by efficiency or availability of key energy technologies
  - End-use energy efficiency
  - CO_2 Capture and Storage (CCS)
  - Nuclear energy
  - Wind and solar
  - Bio-energy potential

EMF-24 Global Scenarios

Technology Dimension									
	Default	**Single technologies changed**					**Conventional vs. renewable**		**Frozen technology**
Energy Intensity	Ref	Low	Ref	Ref	Ref	Ref	Ref	Low	Frozen
CCS	On	On	Off	On	On	On	On	Off	Off
Nuclear energy	On	On	On	Off	On	On	On	Off	Frozen
Wind & Solar	Adv	Adv	Adv	Adv	Cons	Adv	Cons	Adv	Frozen
Bioenergy potential	High	High	High	High	High	Low	Low	High	Frozen
Policy Dimension									
Baseline	R2G1	R2G2		R2G3	R2G4	R2G5	R2G6	R2G7	R2G8
450 CO2e	R2G9	R2G10	R2G11	R2G12	R2G13	R2G14	R2G15	R2G16	
550 CO2e	R2G17	R2G18	R2G19	R2G20	R2G21	R2G22	R2G23	R2G24	R2G25
G8	R2G26							R2G27	
Muddling through	R2G28							R2G29	

Brief History of FARM

- Legacy FARM
  - The first version of the Future Agricultural Resources Model (FARM) was constructed in the early 1990s by Roy Darwin and others at the Economic Research Service
  - By partitioning land into land classes, this model provided a unique capability among CGE models to simulate land use on a global scale
  - Early versions of the FARM model were used to simulate the impact of a changed climate or biofuel policies on global land use, agricultural production, and international trade
- New FARM
  - Planning began in 2009 with model construction in 2010
  - Adds a time dimension for analysis of alternative climate policies
  - Tracks energy consumption and greenhouse gas emissions
  - Provides a balance between greenhouse gas mitigation opportunities in agriculture and energy

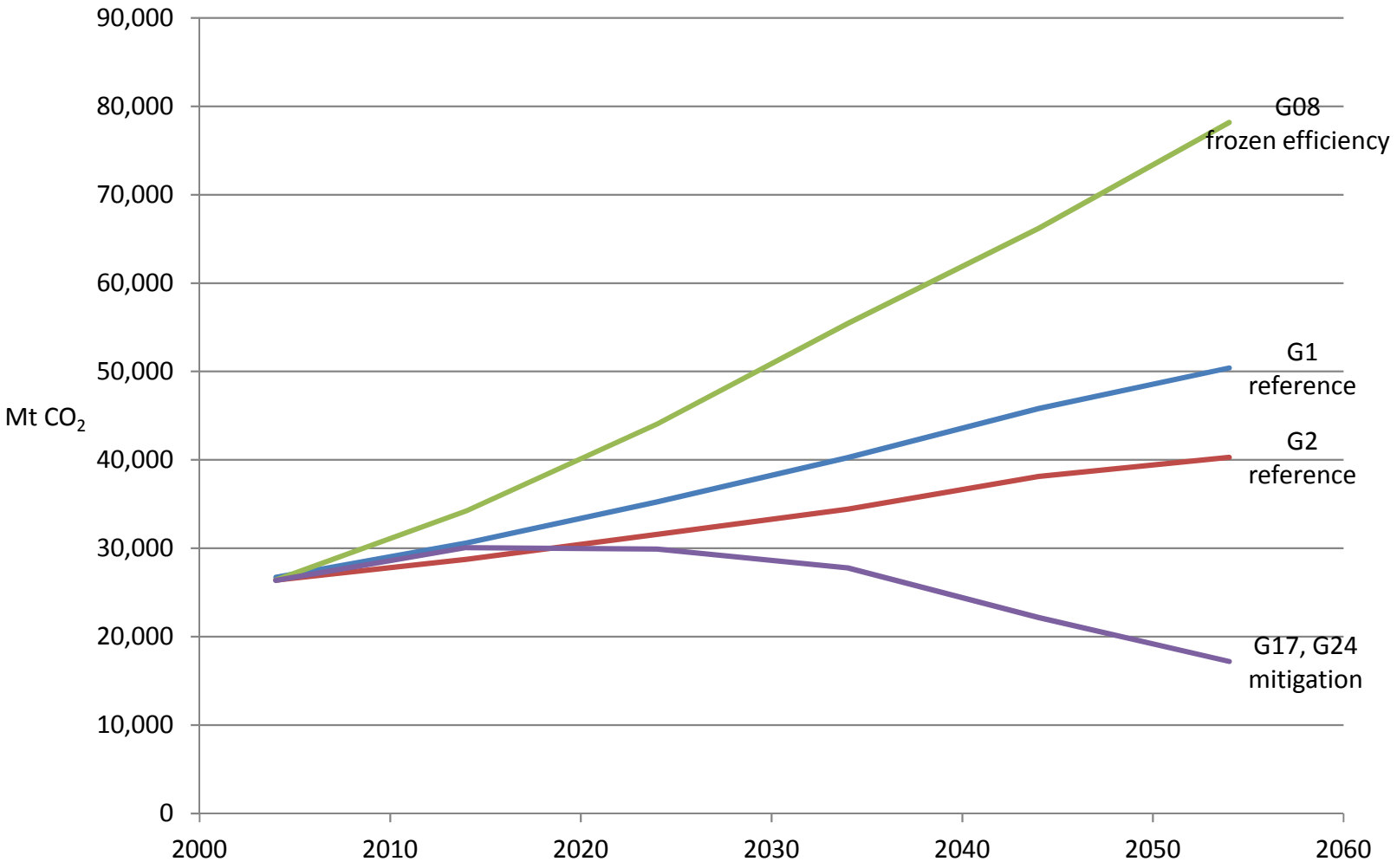
CGE Framework

- New FARM uses Tom Rutherford's GTAP in GAMS code as a starting point
  - Comparative-static global CGE model
  - Armington trade between world regions
  - Constant-elasticity-of-substitution (CES) production and utility functions
  - Fully compatible with GTAP 7 social accounts
- Major extensions for new FARM
  - Conversion from comparative-static to dynamic-recursive framework with 10-year time steps
  - Conversion of consumer demand from CES to Linear Expenditure System (LES)
  - Production system allows joint products
  - Introduction of land classes for agricultural and forestry production
  - Introduction of electricity generating technologies

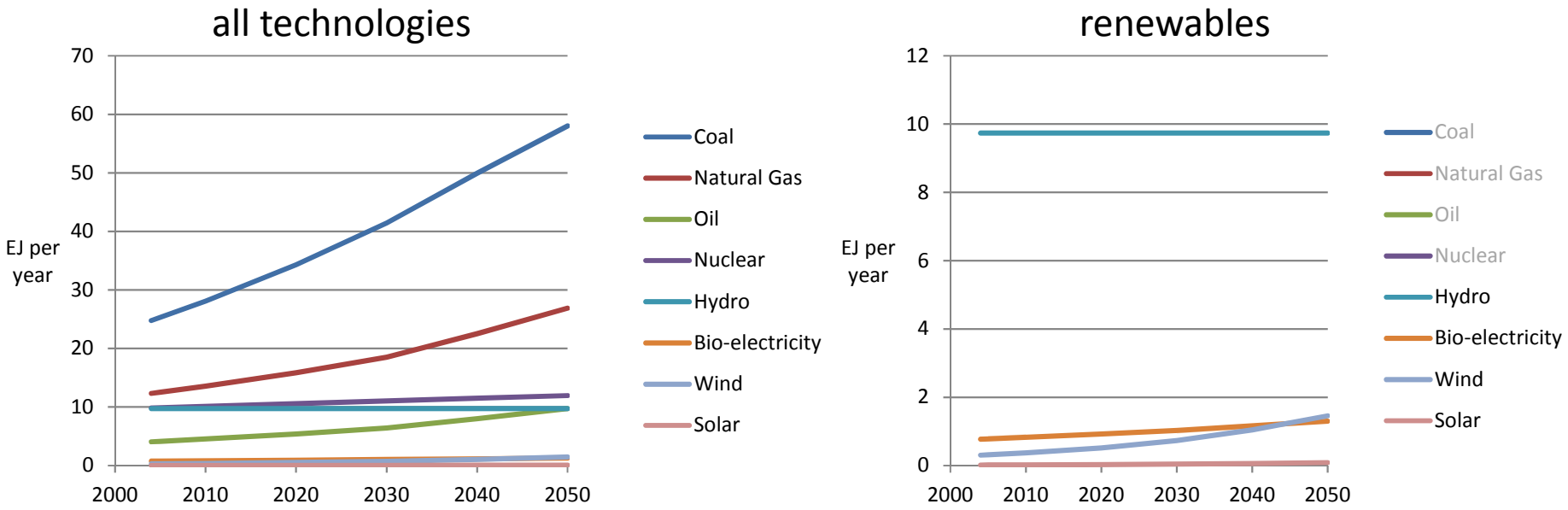
GTAP 7 Data and Aggregation

- Global Trade Analysis Project (GTAP) based at Purdue University provides social accounting matrix (SAM) for year 2004
  - GTAP coverage includes 113 world regions and 57 commodities
  - Data include bilateral trade for all commodities
  - GTAP version 8 will have a 2007 base year
- Aggregation for EMF-24
  - 15 world regions: usa, japan, westEU, eastEU, othOECD90, russia, othREF, china, india, indonesia, othAsia, midEastNAf, subSahAf, brazil, othLatAmer
  - 25 GTAP production sectors: 5 energy carriers (coal, oil, natural gas, refined petroleum, electricity); 11 agricultural sectors; forestry; 6 industries; transportation; services
  - 6 electricity generation technologies: coal, gas/oil, nuclear, hydro, wind/solar, bio-electricity (using IEA data)
  - New sectors: biomass, optionCCS, household transportation, household energy services
- GTAP provides other types of data
  - Energy consumption in million tons of oil equivalent (mtoe)
  - Land rents for each region across 18 agro-ecological zones (AEZs) aggregated within each FARM region to 6 land classes
  - Production of forest products

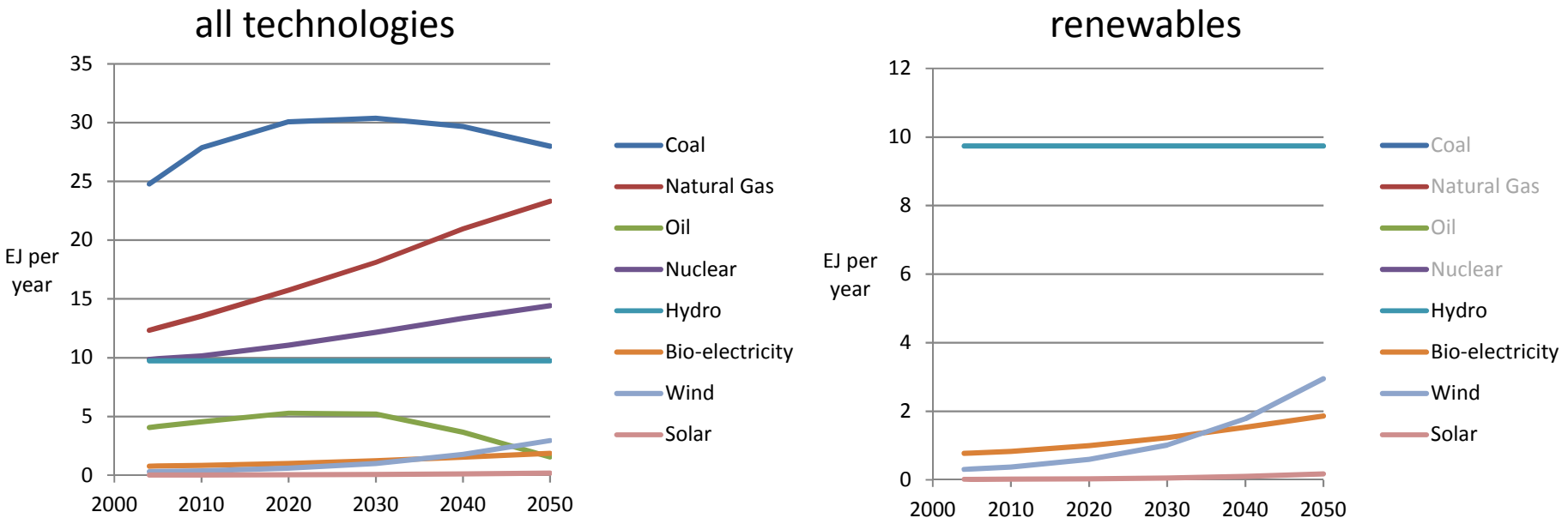
Global CO_2 Emission Scenarios



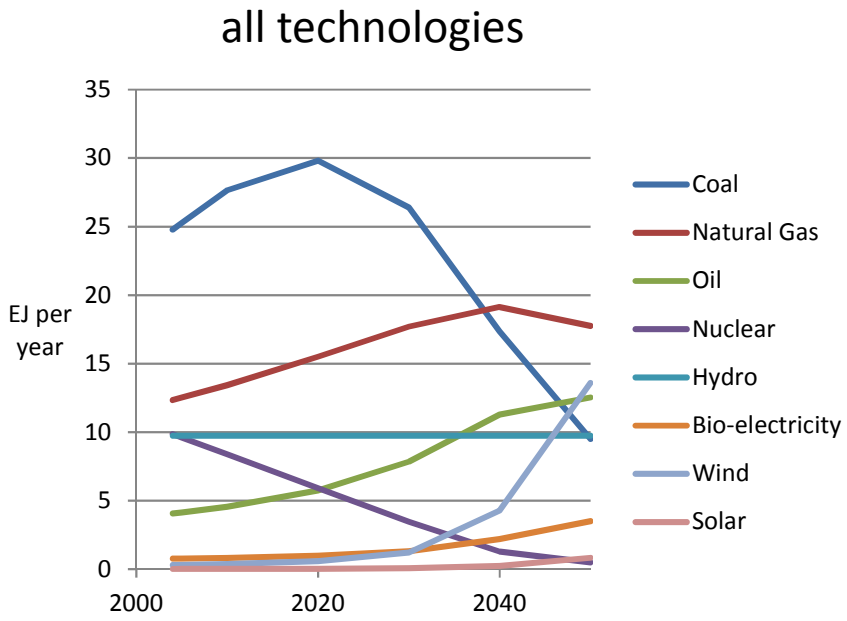
Global Electricity Generation (reference G1)

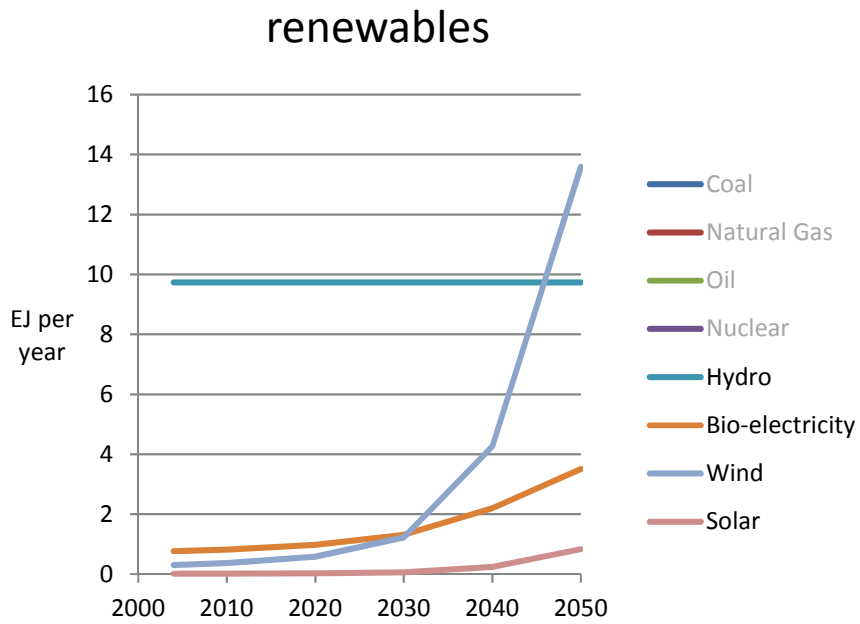


Global Electricity Generation (mitigation G17)



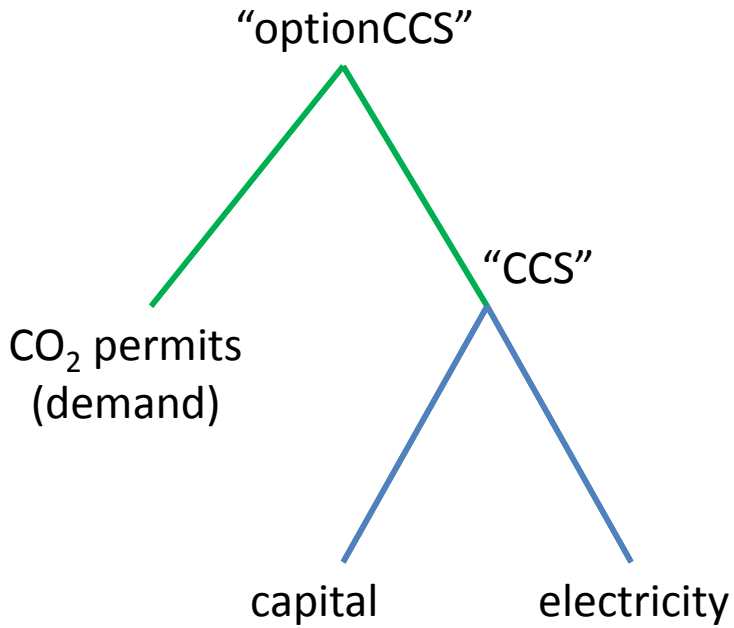
Global Electricity Generation (mitigation G24)





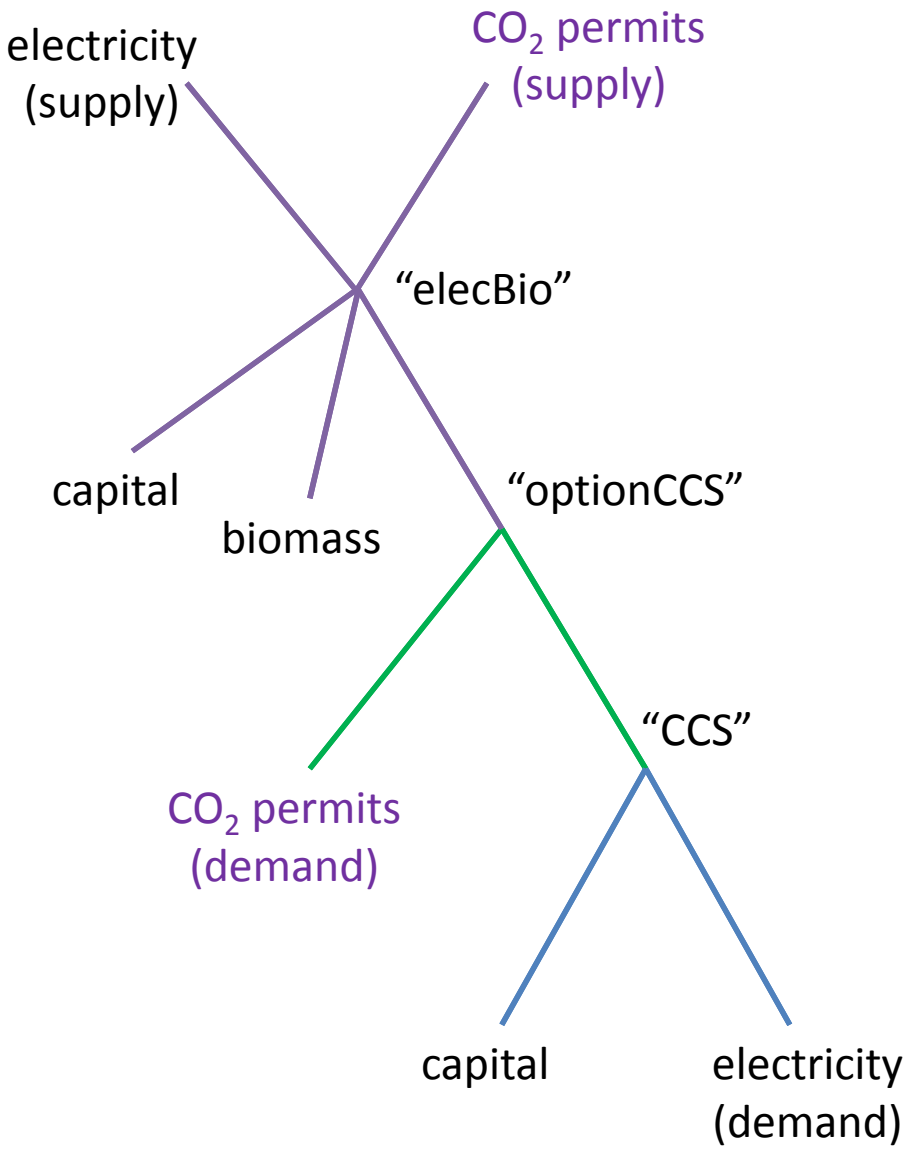
CO_2 Capture and Storage (CCS)

- CCS is a stand-alone production technology that can be used by any large point source of emissions
- Coal- and gas-fired electricity generation must purchase either CO_2 permits or CCS through a CES aggregator "optionCCS"
- "optionCCS" purchases CO_2 permits if the CO_2 price is less than cost per ton of CCS
- CO_2 price must be greater than zero as permits are an input to a CES function (benchmark CO_2 price is $1 per ton)

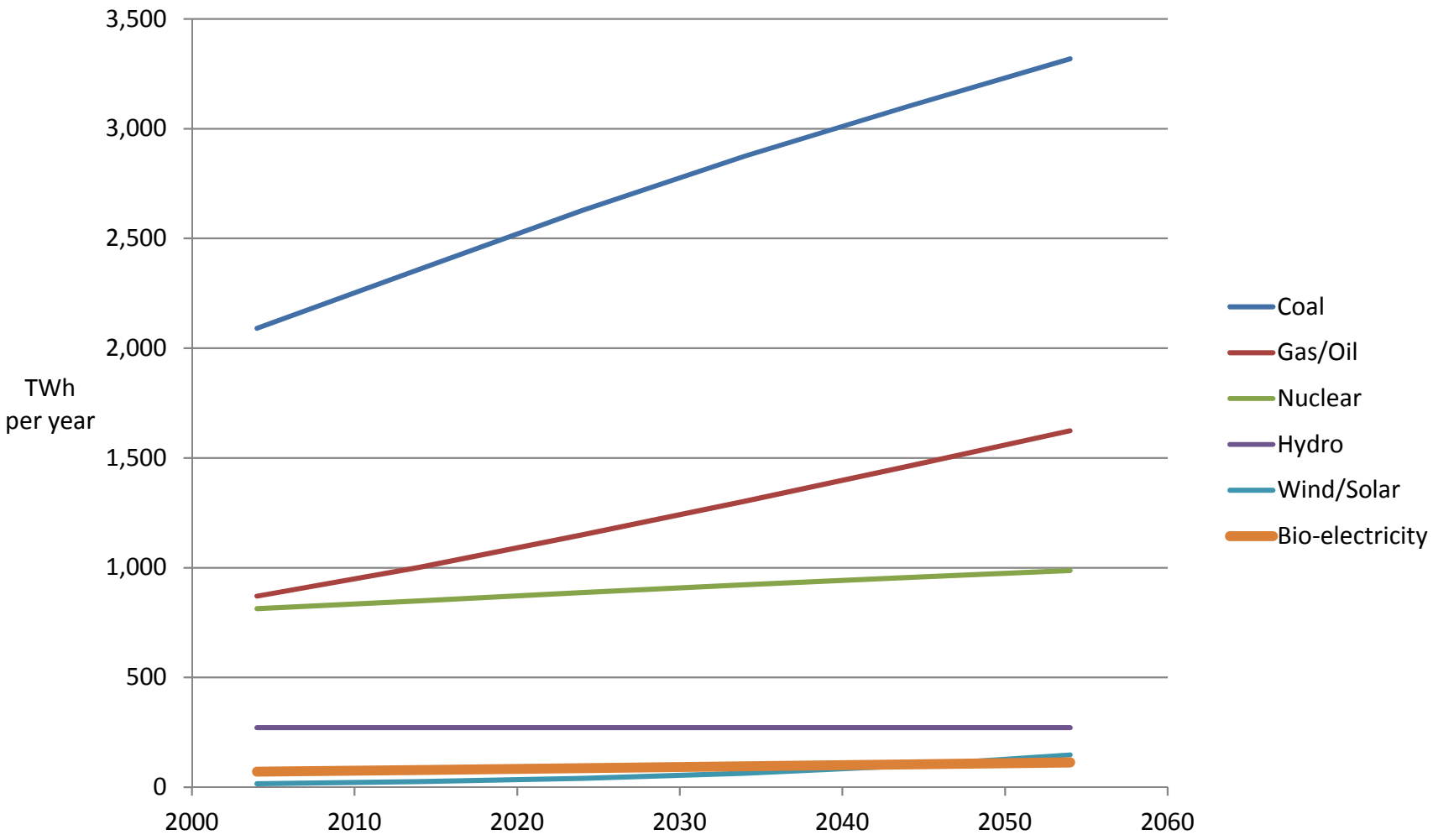


Bio-electricity with CCS

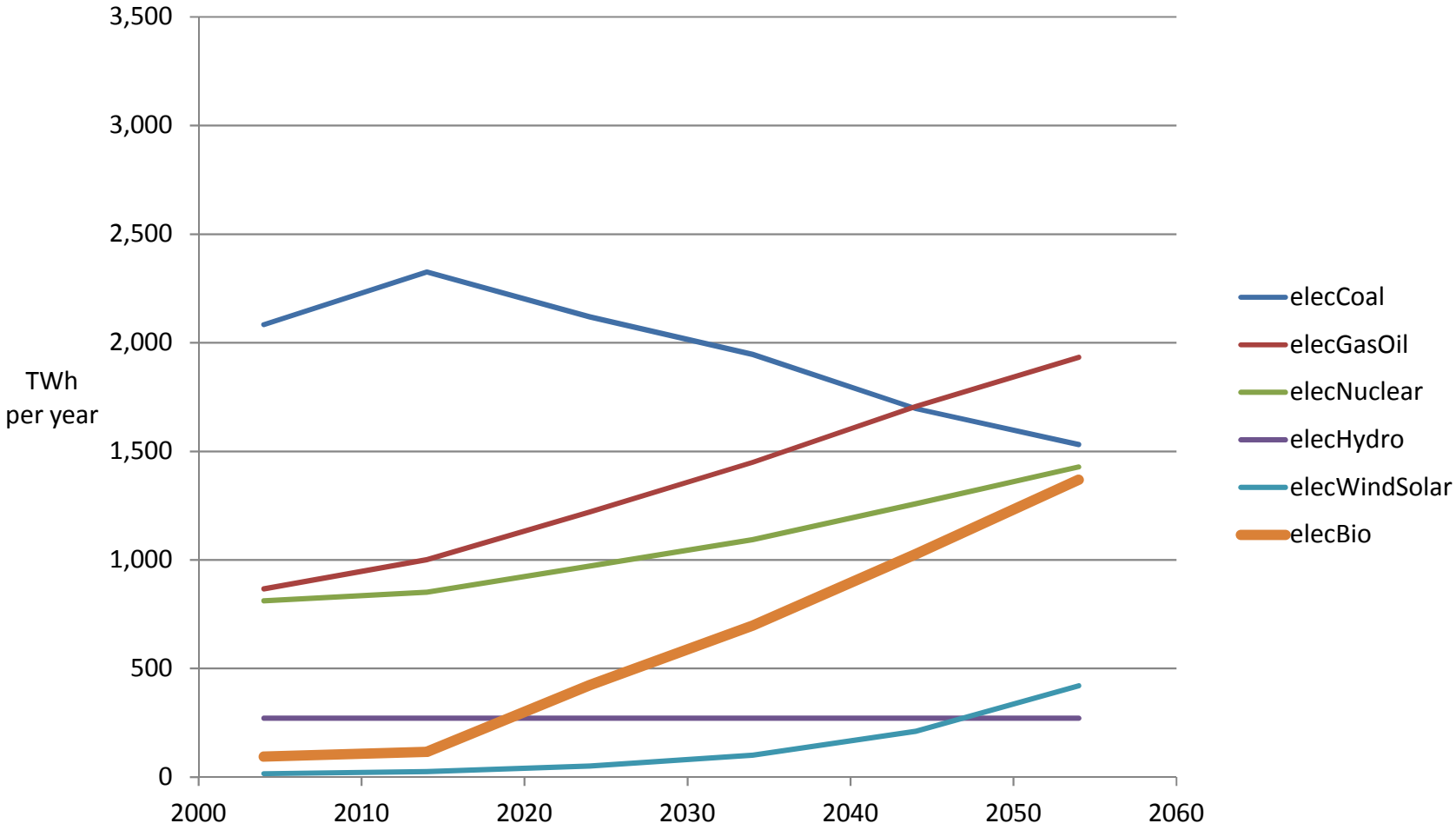
- "elecBio" generates electricity by combusting biomass for a steam turbine
- CO_2 from biomass combustion can be captured and stored if CO_2 price is high enough
- "elecBio" provides two joint products: electricity and CO_2 permits
- At low CO_2 prices, supply of permits equals demand for permits and there is no net sequestration
- At CO_2 prices high enough to drive CCS, supply of permits is greater than demand for permits
- Negative net emissions are possible if quantity of CO_2 sequestered is greater than emissions from related energy demands, such as energy needed to operate capture and storage process



US Electricity Generation (reference G1)



US Electricity Generation (mitigation G17)
Bio-electricity with CCS



To Do List

- Non-CO_2 greenhouse gases
  - CH_4 from rice production
  - N_2O from fertilizer
  - CH_4 and N_2O from livestock
- Other biofuel pathways
  - Corn-ethanol
  - Sugar-ethanol
  - Liquid fuels from cellulosic biomass
- Land competition
  - Forest dynamics
  - Carbon emissions from land use change

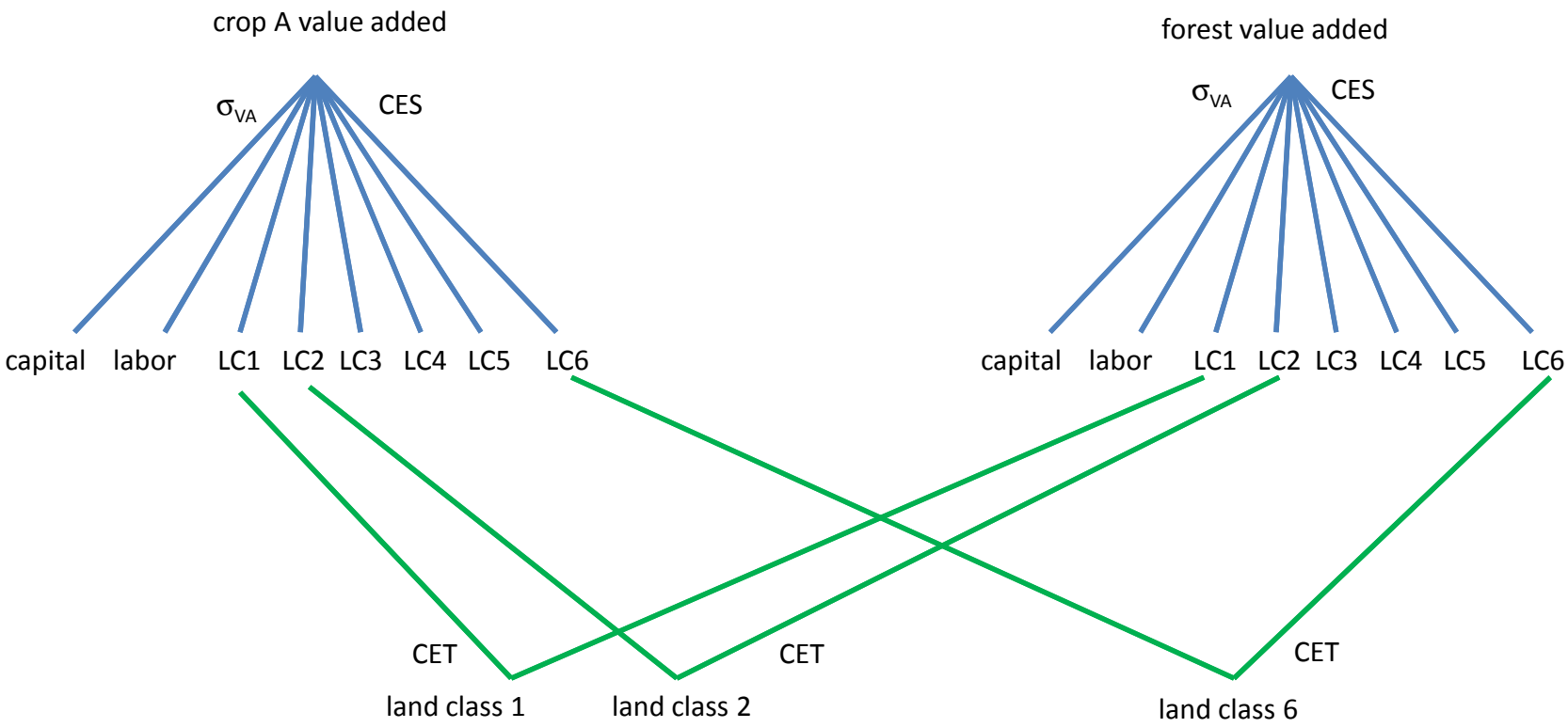
New FARM

EXTRA SLIDES

Model Classification

	U.S. only		Global coverage	
	Partial eq.	**General eq.**	**Partial eq.**	**General eq.**
Comparative static	REAP			Legacy FARM GTAP
Comparative steady-state	*REAP (with forestry)*			
Dynamic recursive				New FARM
Dynamic equilibrium (limited foresight)			GCAM (with forward market for forest products)	*New FARM (with dynamic forestry)*
Dynamic optimization	FASOM		Global Timber Model	

Land Competition



Nested CES Production

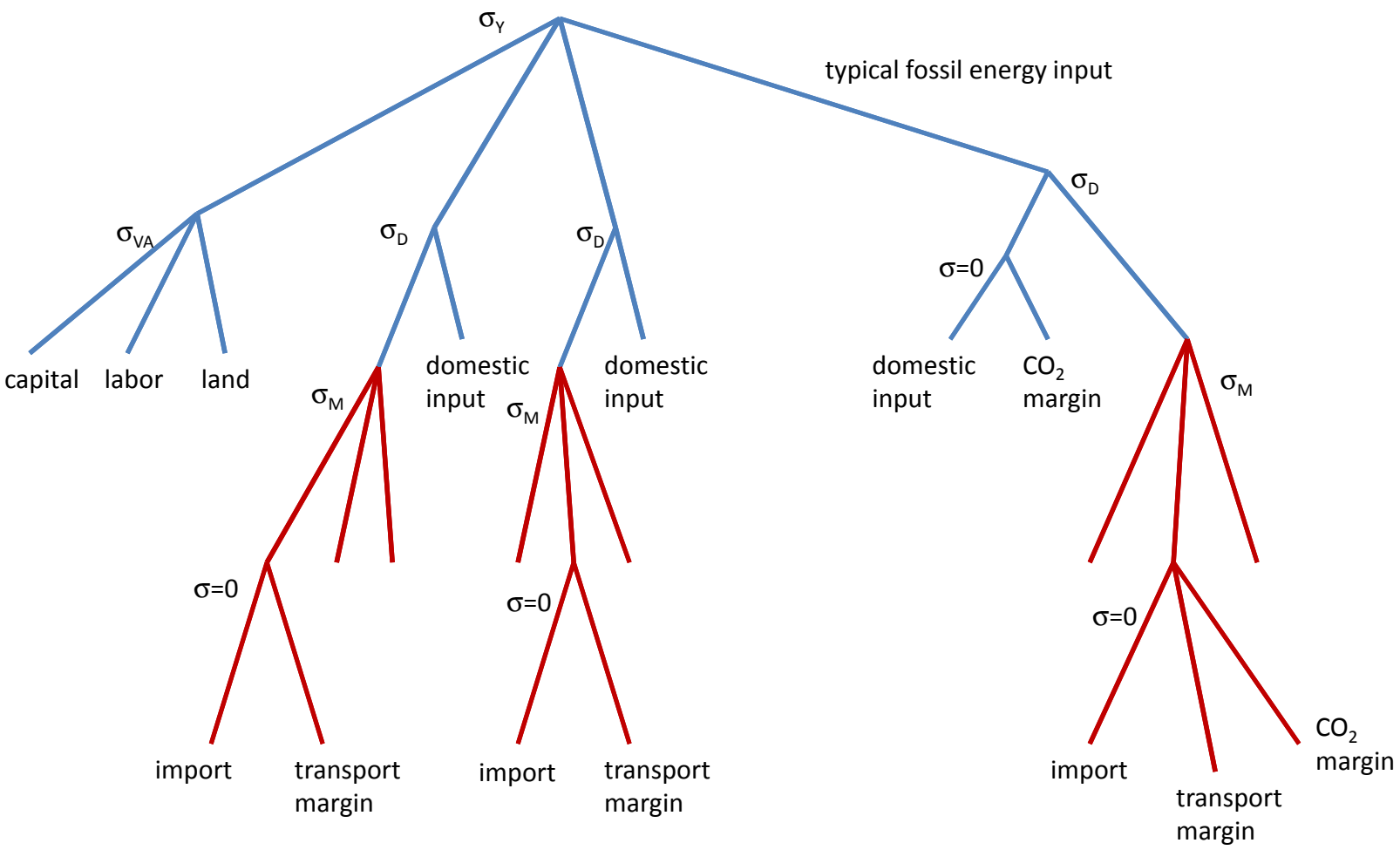


Table 2 Overview of representative concentration pathways (RCPs)

	Description[a]	Publication—IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100.	(Riahi et al. 2007)—MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100	(Fujino et al. 2006; Hijioka et al. 2008)—AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100	(Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009)—GCAM
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).	(Van Vuuren et al., 2007a; van Vuuren et al. 2006)—IMAGE

[a] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2 relative to pre-industrial levels. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents

Source: Van Vuuren DP et al (2011) The representative concentration pathways: an overview. Climatic Change DOI 10.1007/s10584-011-0148-z