Potsdam-Institut für Klimafolgenforschung

PIK

The ReMIND Integrated Assessment Model: Treatment of Renewable Energy Technologies & Insights from Model Intercomparisons

Elmar Kriegler

Snowmass Workshop on Modeling RETs in IAMs, Aug 5, 2009

ADAM project: Brigitte Knopf, Ottmar Edenhofer et al.

RECIPE project: Gunnar Luderer, Ottmar Edenhofer et al.

REMIND-Team: Nico Bauer, Gunnar Luderer, Marian Leimbach
Lavinia Baumstark, Markus Haller, David Klein,
Michael Lüken, Sylvie Ludig, Robert Pietzcker

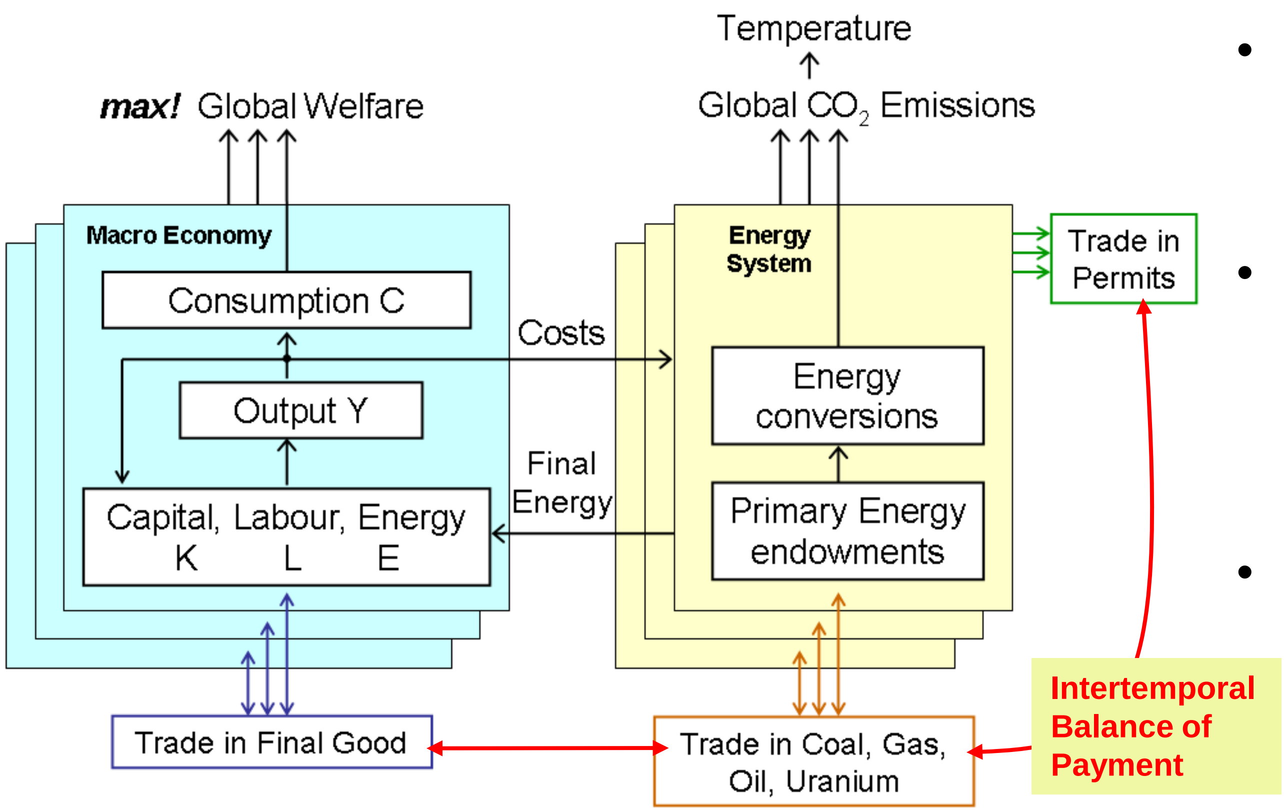
Leibniz Gemeinschaft

Potsdam Institute for Climate Impact Research
Research Domain Sustainable Solutions

Why Integrated Assessment Modeling?

- Assess implications of long term climate targets for
  - transformation of energy and other sectors
  - investment streams
  - distribution of costs of mitigating climate change
- Assess portfolio of mitigation options across
  - sectors and technologies
  - regions
  - time
- Assess mitigation portfolios and costs for
  - 1st best solution (benchmark): full when and where flexibility, all technology options
  - 2nd best cases: delayed participation, limited technology folder, …

The REMIND-R Model: Basic Characteristics



- Fully coupled macro-economy and energy system (Bauer et al., J. Comp. Mgmt. Sciences 5: 95-117,2008)
- 11 world regions, heterogeneous capital stocks in energy sector, international trade
- Regionally specific fossil fuel endowments and renewable energy potentials

Benchmark (1st best) solution: Includes full when, where, what flexibility

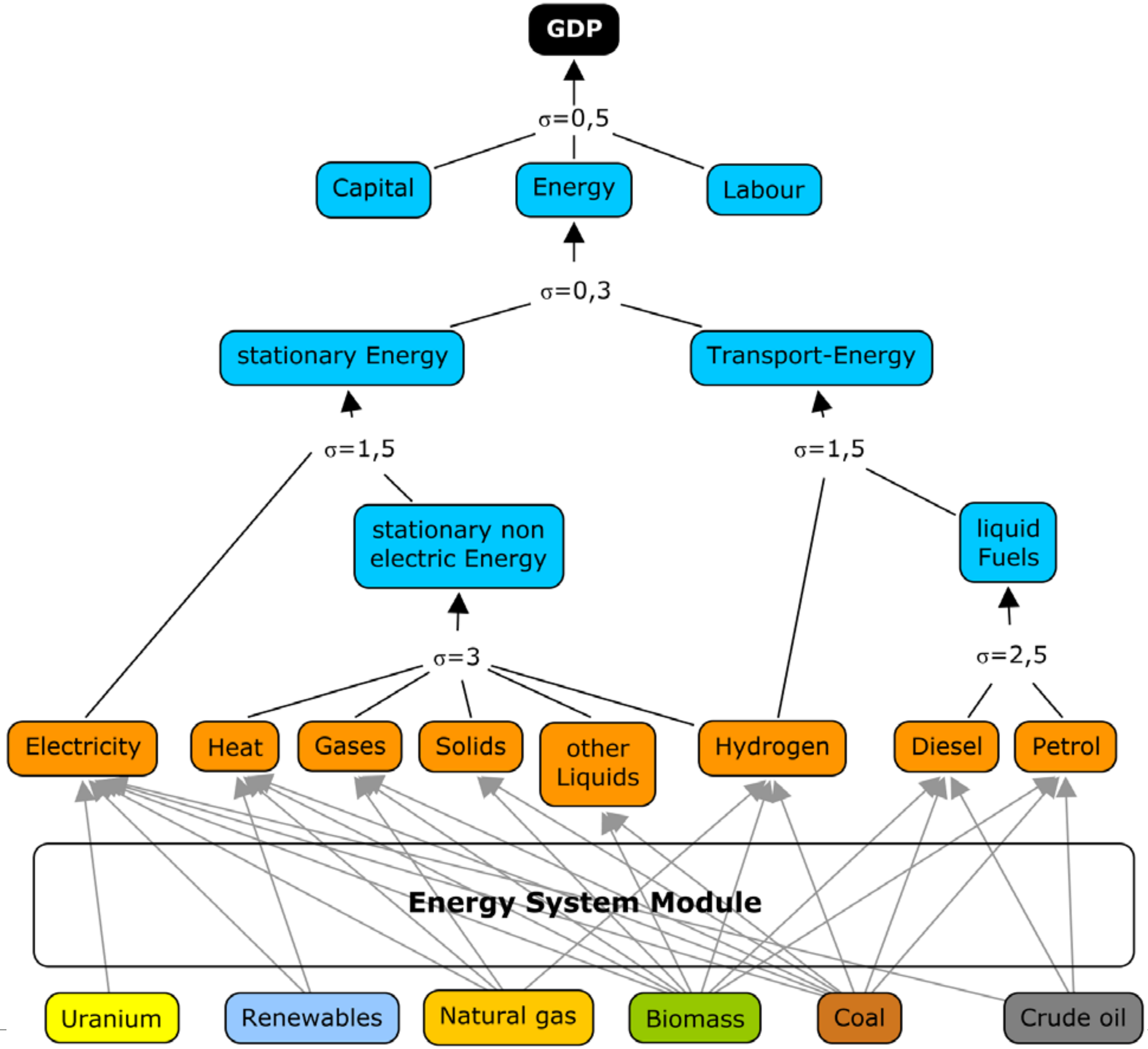
Intertemporal optimization of regional welfare

Intertemporal equilibrium of capital, energy and goods markets (Pareto optimum)

2nd best solutions: Implemented by adding constraints

Delayed participation, Limited availability of technologies, …

The REMIND-R Model: Energy as Production Factor



From Primary to Secondary Energy: System perspective

		Primary energy carriers						
		Exhaustible				Renewable		
		Coal	Oil	Gas	Uranium	Solar, Wind, Hydro	Geo-thermal	Biomass
Secondary energy carriers	Electricity	PC, IGCC, CoalCHP	DOT	GT, NGCC, GasCHP	LWR, *Gen IV Fast Reactors*	SPV, WT, Hydro, *CSP*	HDR	BioCHP, *BIGCC*
	H2	C2H2		SMR				B2H2
	Gases	C2G		GasTR				B2G
	Heat	CoalHP, CoalCHP		GasHP, GasCHP			GeoHP	BioHP, BioCHP
	Liquid fuels	C2L	Refin.					B2L, BioEthanol
	Other Liquids		Refin.					
	Solids	CoalTR						BioTR

Abbreviations: PC = conventional coal power plant, IGCC = integrated coal gasification combined cycle, CoalCHP = coal combined hat power, C2H2 = coal to H2, C2G = coal to gas, CoalHP = coal heating plant, C2L = coal to liquids, CoalTR = coal transformation, DOT = diesel oil turbine, Refin. = Refinery, GT = gas turbine, NGCC = natural gas combined cycle, GasCHP = Gas combined heat power, SMR = steam methane reforming, GasTR = gas transformation, GasHP= gas heating plant, LWR = light water reactor, SPV = solar photo voltaic, WT = wind turbine, Hydro = hydro power, HDR = hot-dry-rock, GeoHP = heating pump, BioCHP = biomass combined heat and power, BIGCC = Biomass IGCC, B2H2 = biomass to H2, B2G = biogas, BioHP = biomass heating plant, B2L = biomass to liquids, BioEthanol = biomass to ethanol, BioTR = biomass transformation

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	H2	C2H2		SMR				B2H2
	Gases	C2G		GasTR				B2G
	Heat	CoalHP, CoalCHP		GasHP, GasCHP			GeoHP	BioHP, BioCHP
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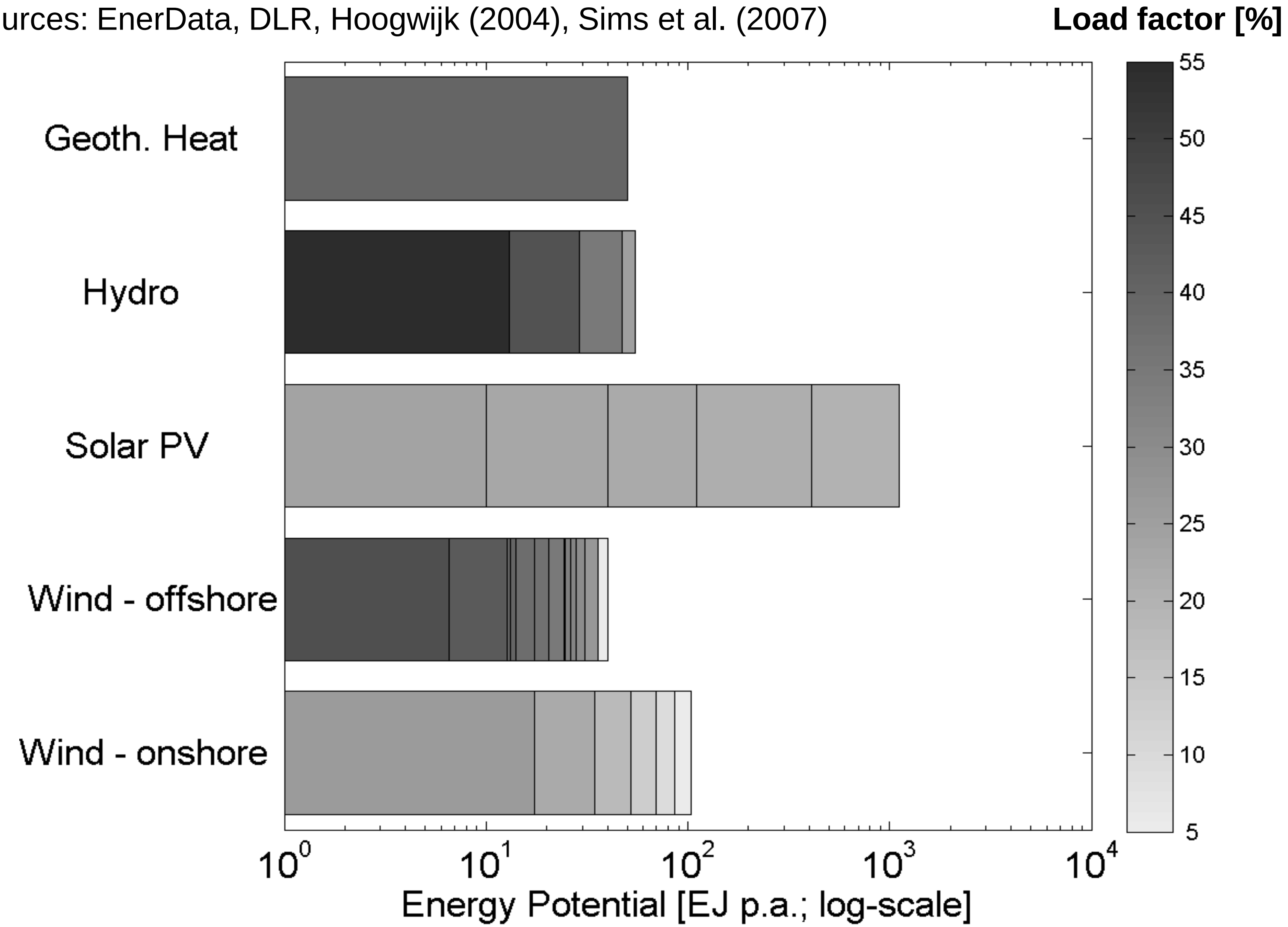
Technologies can be deployed with CCS

The REMIND-R Model: Renewable Energy Potentials

Sources: EnerData, DLR, Hoogwijk (2004), Sims et al. (2007)



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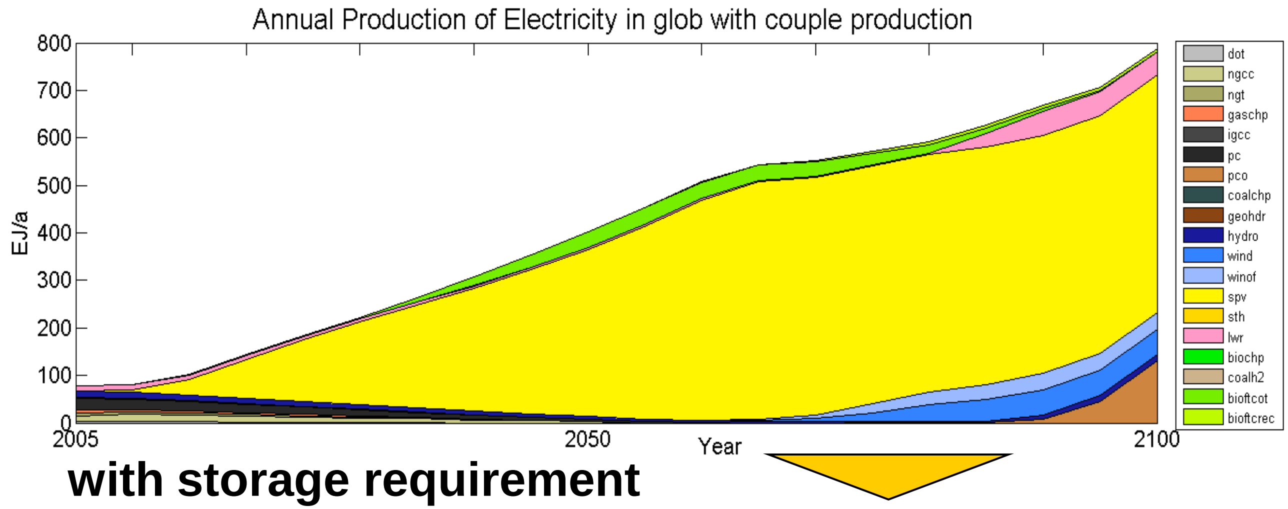
The REMIND-R Model: Grid Integration of RETs

Model assumptions:

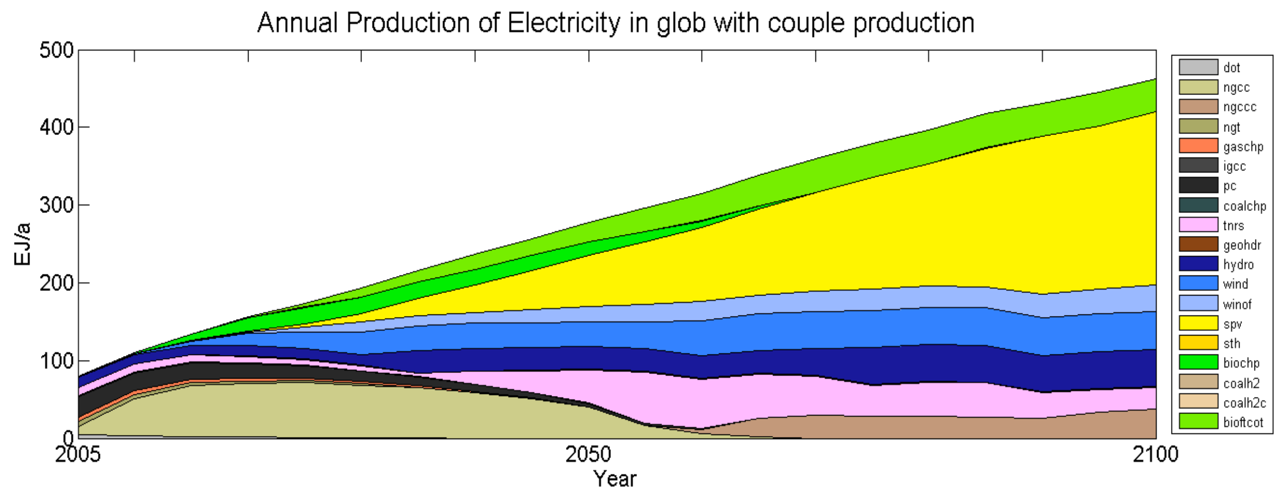
1. Fluctuations grouped into three categories:
- day-night (flow batteries, 80% efficient storage),
- week-long (CAES, 40% efficient storage)
- seasonal (enough capacity for each season)

2. For fluctuating sources (wind, PV), storage requirement is calculated from generation share G

without storage requirement



with storage requirement



Reference for techno-economic parameters of storage: Chen, H., et al. (2009) Progress in Natural Science 19, 291-312

RECIPE model intercomparison

IAM intercomparison complemented by bottom-up sector studies and policy instrument analysis

- 3 participating models:
  - REMIND-R (PIK: O. Edenhofer, N. Bauer, M. Leimbach, G. Luderer)
  - IMACLIM-R (CIRED: J.-C. Hourcade, H. Waisman, O. Sassi)
  - WITCH (CMCC: C. Carraro, V. Bosetti, E. de Cian, M. Tavoni)
- Default policy target: 450 ppm CO_2 only
- Focus on second best scenarios:
  - delayed participation
  - limited technology availability
- Funding institutions: WWF and Allianz

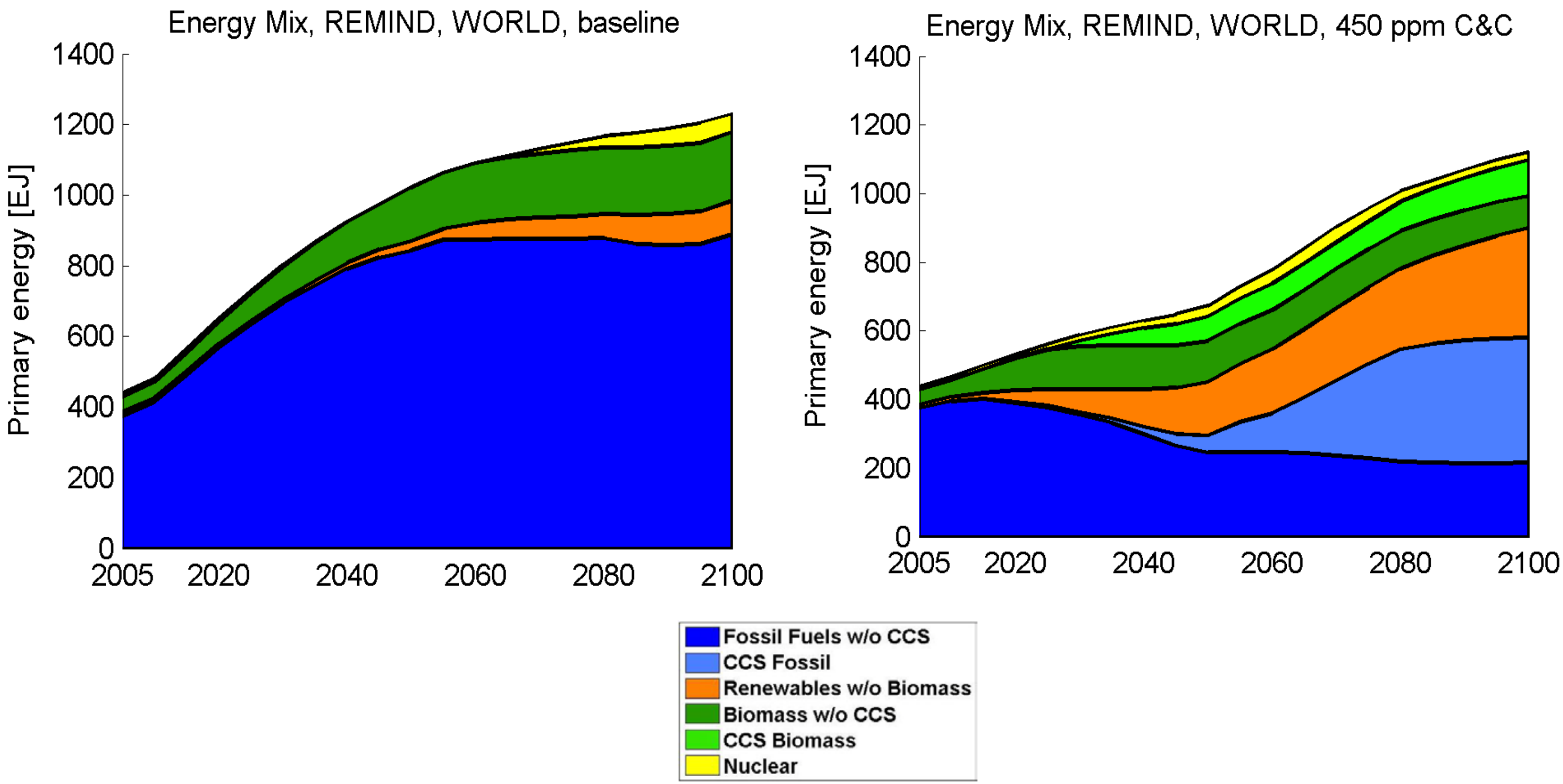
References:

• Edenhofer, Carraro, Hourcade, Neuhoff, Luderer, Flachsland, Jakob, Popp, Steckel, Strohschein, Bauer, Brunner, Leimbach, Lotze-Campen, Bosetti, de Cian, Tavoni, Sassi, Waisman, Crassous-Doerfler, Monjon, Dröge, van Essen, del Rio (2009) RECIPE: The Economics of Decarbonization – Synthesis Report. Forthcoming.
• Luderer, G. ,V. Bosetti, J. Steckel, H. Waisman, N. Bauer, E. de Cian, M. Leimbach, O. Sassi, M. Tavoni (2009): The Economics of Decarbonization: Model comparison results. RECIPE Working Paper. Forthcoming: http://www.pik-potsdam.de/recipe.

Results: Transformation of the Energy System

REMIND

Baseline | **450 ppm CO_2**



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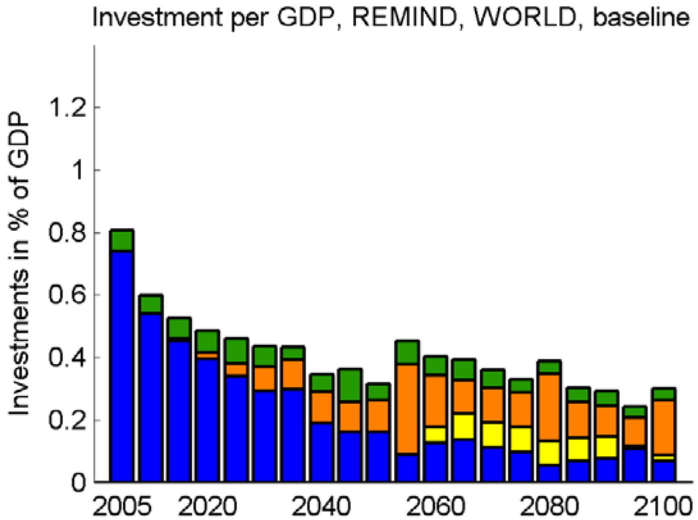
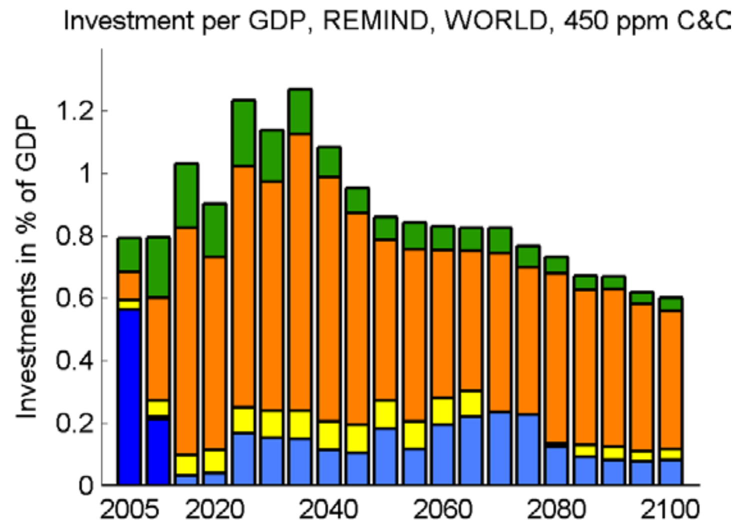
Energy System Investments (REMIND)

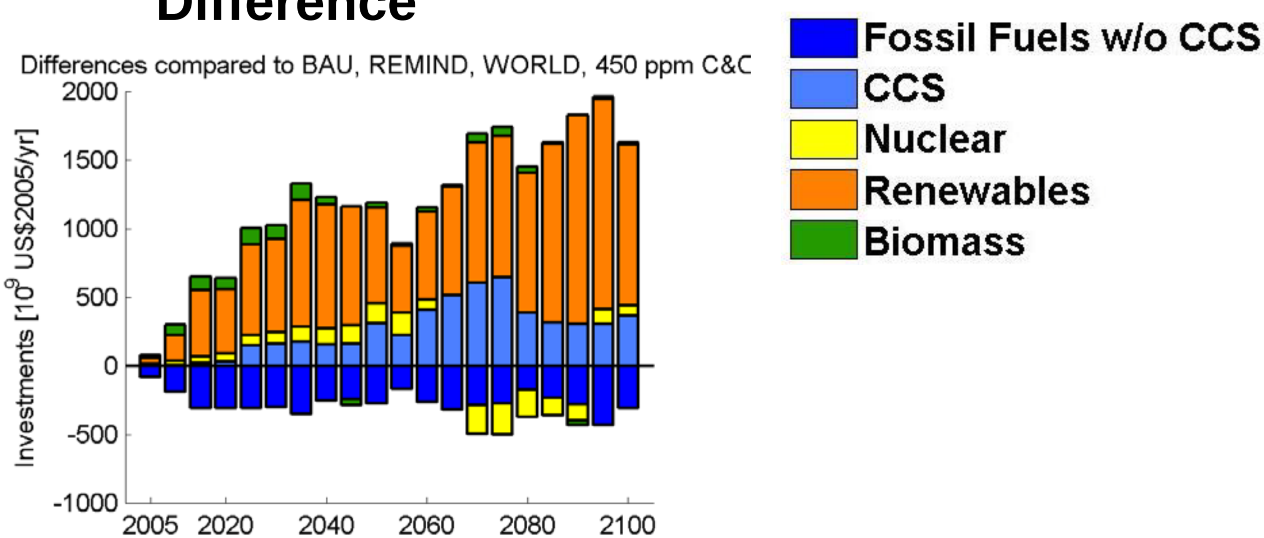
Baseline



450 ppm CO_2

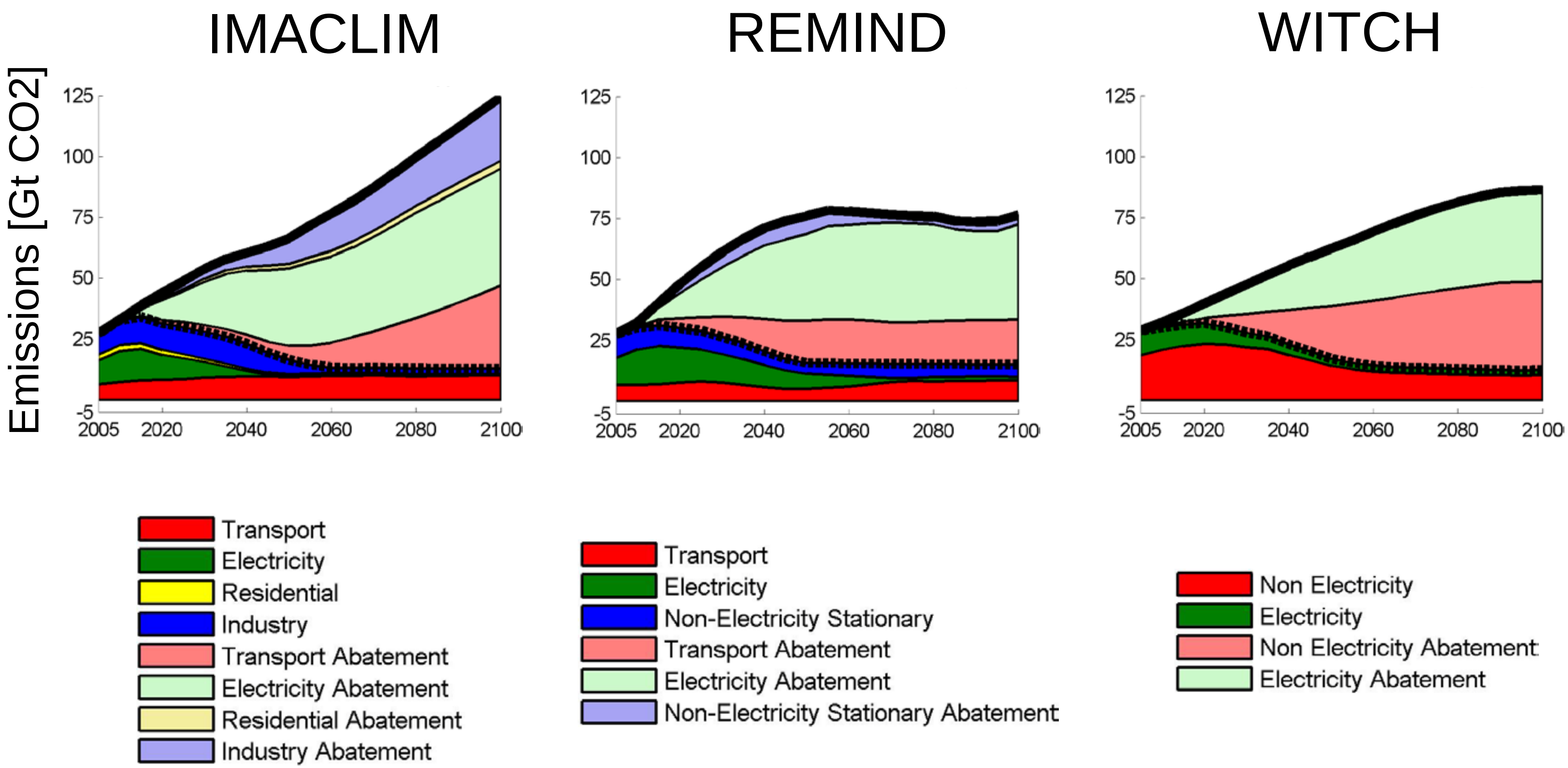


Difference



Mitigation Per Sector: “Dynamic Sectoral Wedges”

Sector emissions: Baseline vs. 450 ppm CO_2



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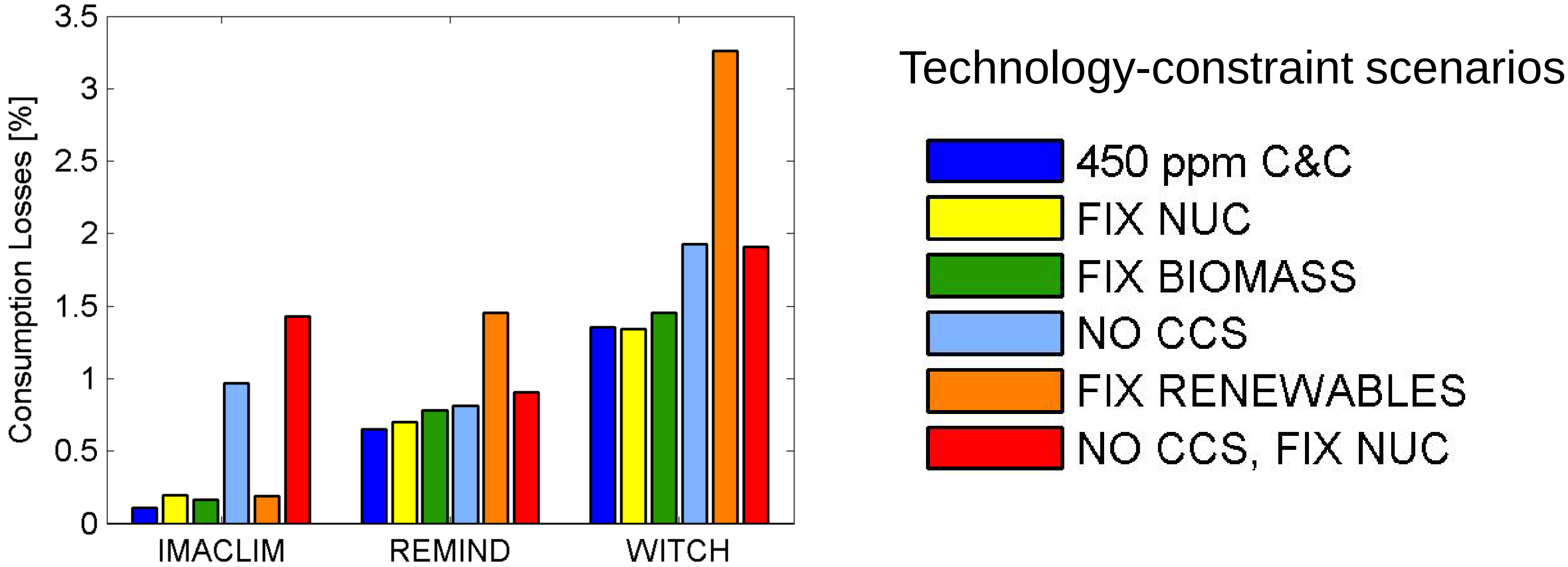
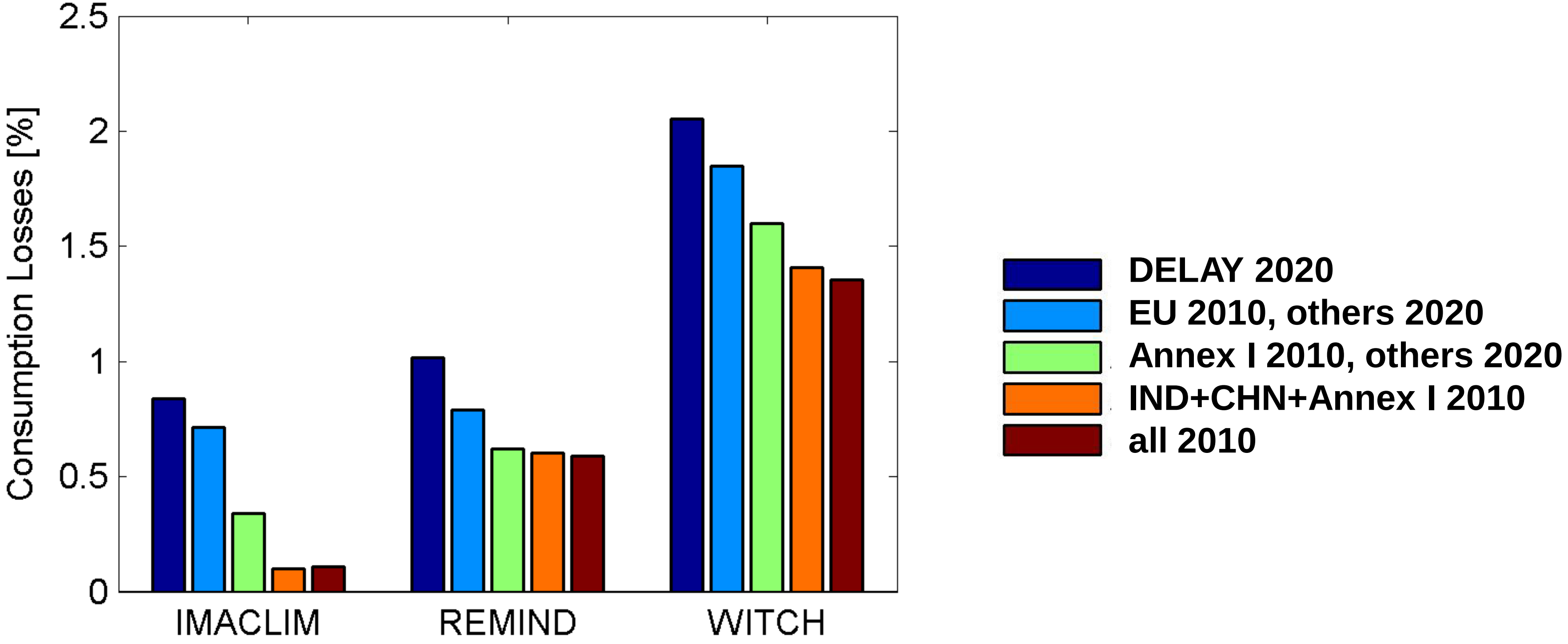
Global Consumption Losses (450 ppm CO_2)



Discounted at 3%

RECIPE: The case for early action



Discounted at 3%

Regional Modelling Comparison Project (RMCP) within ADAM

Model intercomparison on economic costs and technical feasibility of low stabilization pathways

Coordination and Compilation of Results: B. Knopf, O. Edenhofer

RMCP members:

PIK (REMIND model):	O. Edenhofer, M. Leimbach. L. Baumstark, B. Knopf
PSI (MERGE model):	T. Hal, S. Kypreos, B. Magné
U Cambridge (E3MG model):	T. Barker, S. Scrieciu
ENERDATA (POLES model):	A. Kitous, E. Bellevrat, B. Chateau, P. Criqui
PBL (TIMER):	D. van Vuuren, M. Isaac

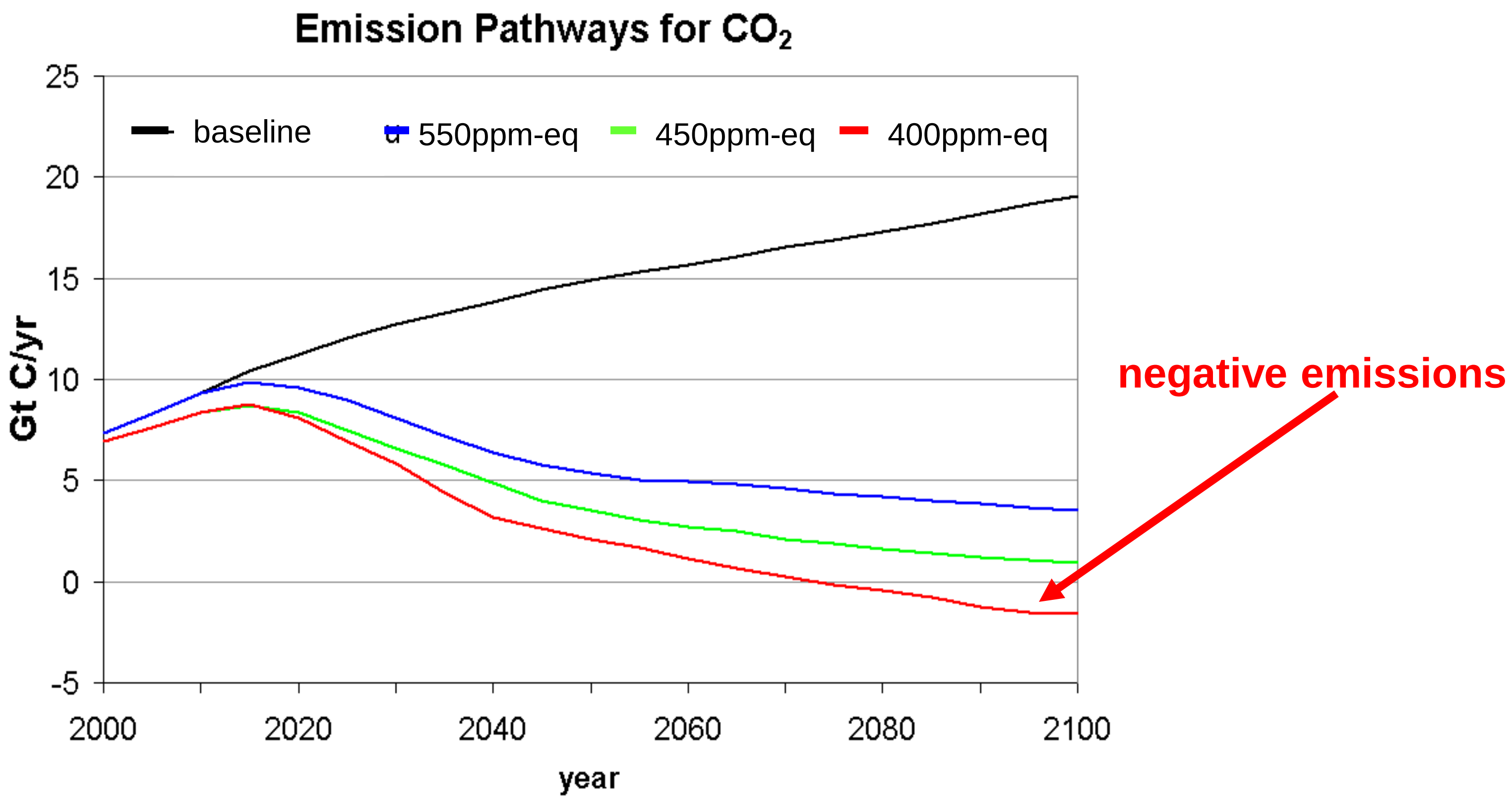
References:

• Edenhofer, Knopf, Leimbach, Bauer (Editors): A Special Issue in the Energy Journal on *The economics of low stabilisation* (2009)

• B. Knopf, O. Edenhofer, T. Barker, N. Bauer, L. Baumstark, B. Chateau, P. Criqui, A. Held, M. Isaac, M. Jakob, E. Jochem, A. Kitous, S. Kypreos, M. Leimbach, B. Magné, S. Mima, W. Schade, S. Scrieciu, H. Turton, D. van Vuuren (2009) The economics of low stabilisation: implications for technological change and policy. In M.Hulme, H. Neufeldt (Eds) Making climate change work for us – ADAM synthesis book, Cambridge University Press.

Regional Modelling Comparison Project within ADAM

- Model comparison with five energy-economy models
- 3 stabilisation targets with different probabilities to reach the 2° target: 550ppm-eq, 450ppm-eq, 400ppm-eq



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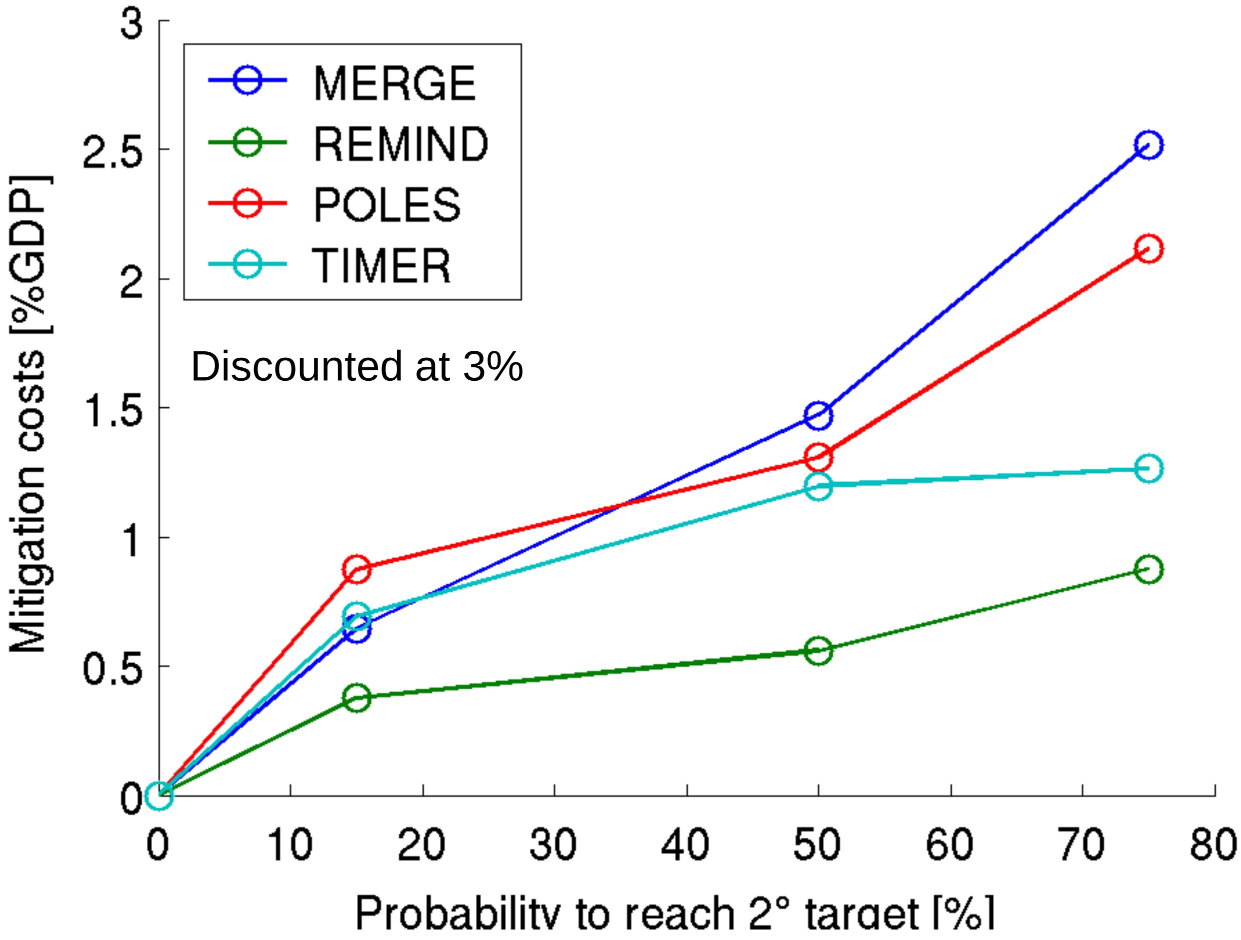
Mitigation costs of low stabilization (full flexibility)

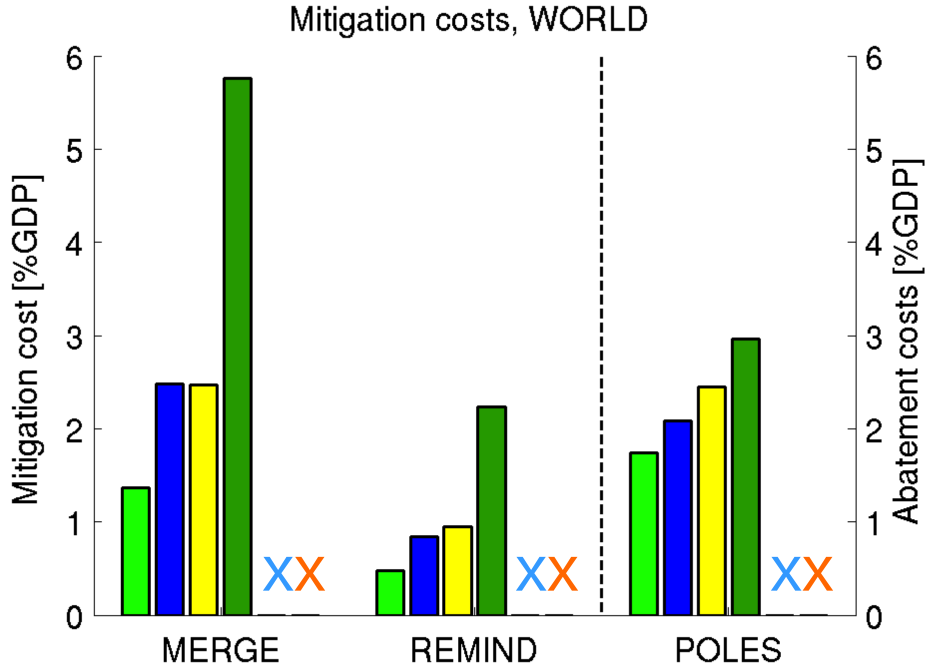


Mitigation costs for 400, 450, 550 ppm-eq plotted against probability of reaching 2°C target at these levels (median estimate from Hare & Meinshausen, 2004)

Costs & Feasibility As Function of Technology Availability

- **high biomass** potential
- **with all options**
- **no nuclear** beyond baseline
- **low biomass** potential
- **no CCS**
- **no renewables** beyond baseline

400ppm-eq

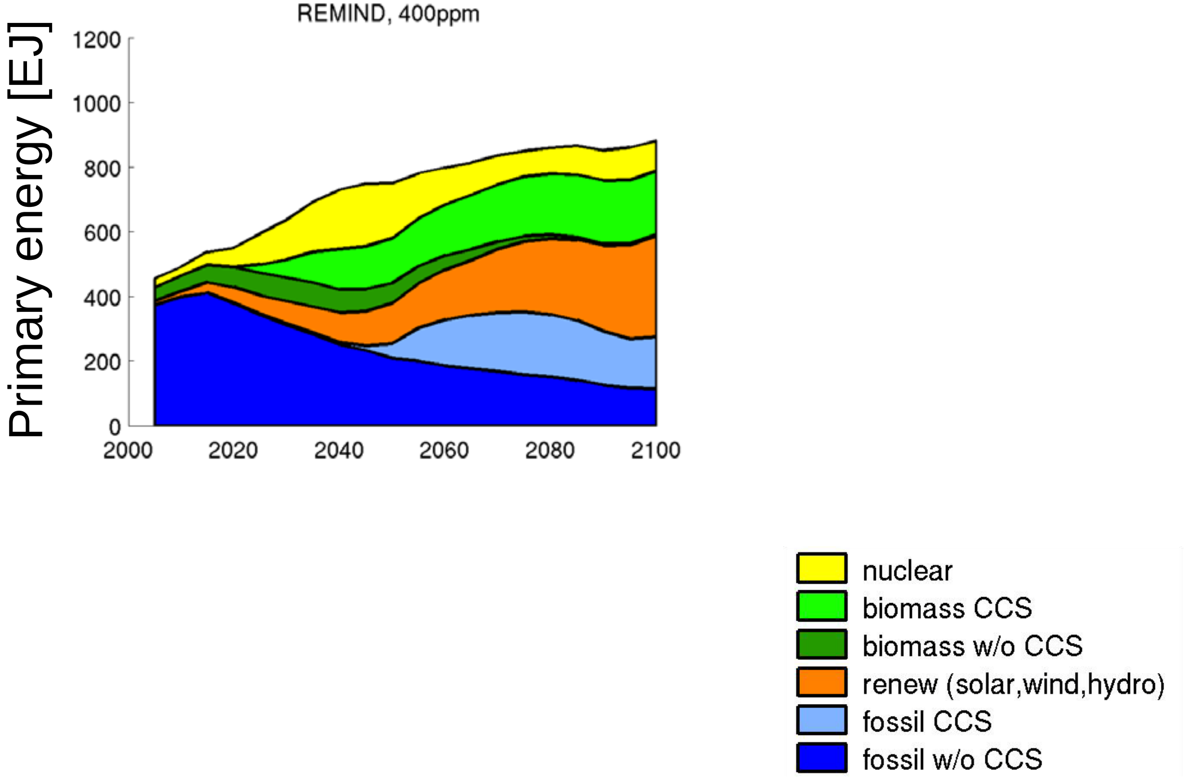


➔ 400 ppm not achievable without CCS or extension of renewables
➔ Biomass potential dominates the mitigation costs of low stabilisation
➔ nuclear is not important beyond its (high) use in the baseline

Influence of Biomass Potential

REMIND, 400 ppm-eq policy

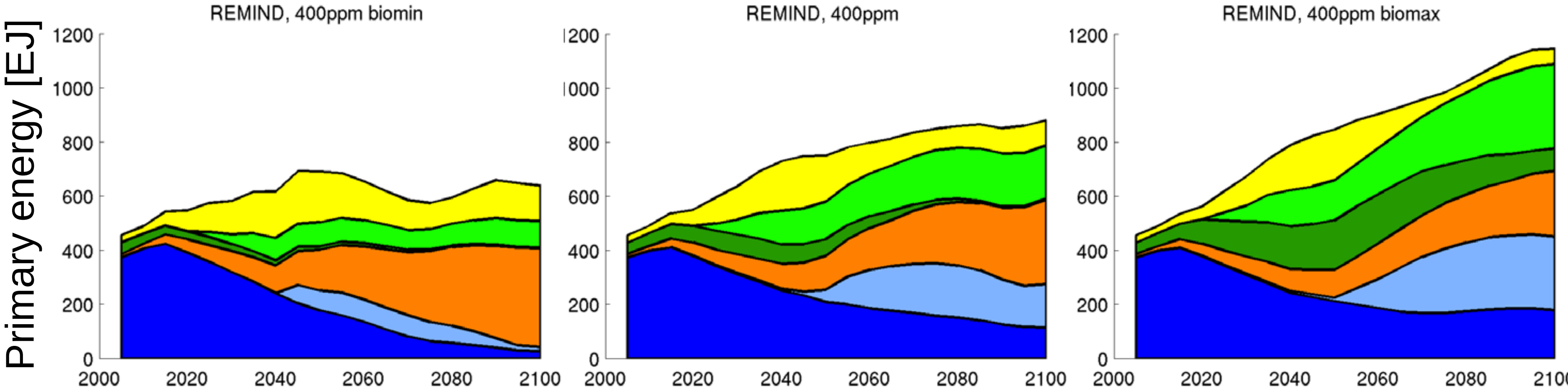
Reference: 200 EJ/yr



Influence of Biomass Potential

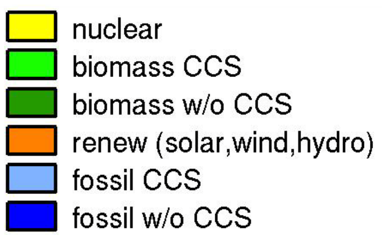
REMIND, 400 ppm-eq policy

100 EJ/yr | **Reference: 200 EJ/yr** | **400 EJ/yr**



➔ Competition between biomass+CCS with other renewables

➔ longer use of fossil energy with higher biomass potential



RMCP: Summary and Caveats

Keeping 2° with a high probability is technically and economically feasible (in the models!), but

- depends on optimistic assumption of biomass use
- relies on CCS
- assumes a full international agreement from 2010 on

Key Challenges for Treatment of RETs in IAMs

- **Better representation of grid integration costs of intermittent RETs**
  ➔ Storage, Backup, Demand management, Fluctuation balancing

- **Full integration of land use, carbon management and bioenergy**
  ➔ Debate around agricultural productivity and its future potential

- **Accounting for infrastructure and other "systemic components"**
  ➔ Path dependency, leap-frogging, cross-sectoral effects

- **Explicit inclusion of energy demand side**
  ➔ Moving from Exajoule to service units

- **Wider sustainability context**

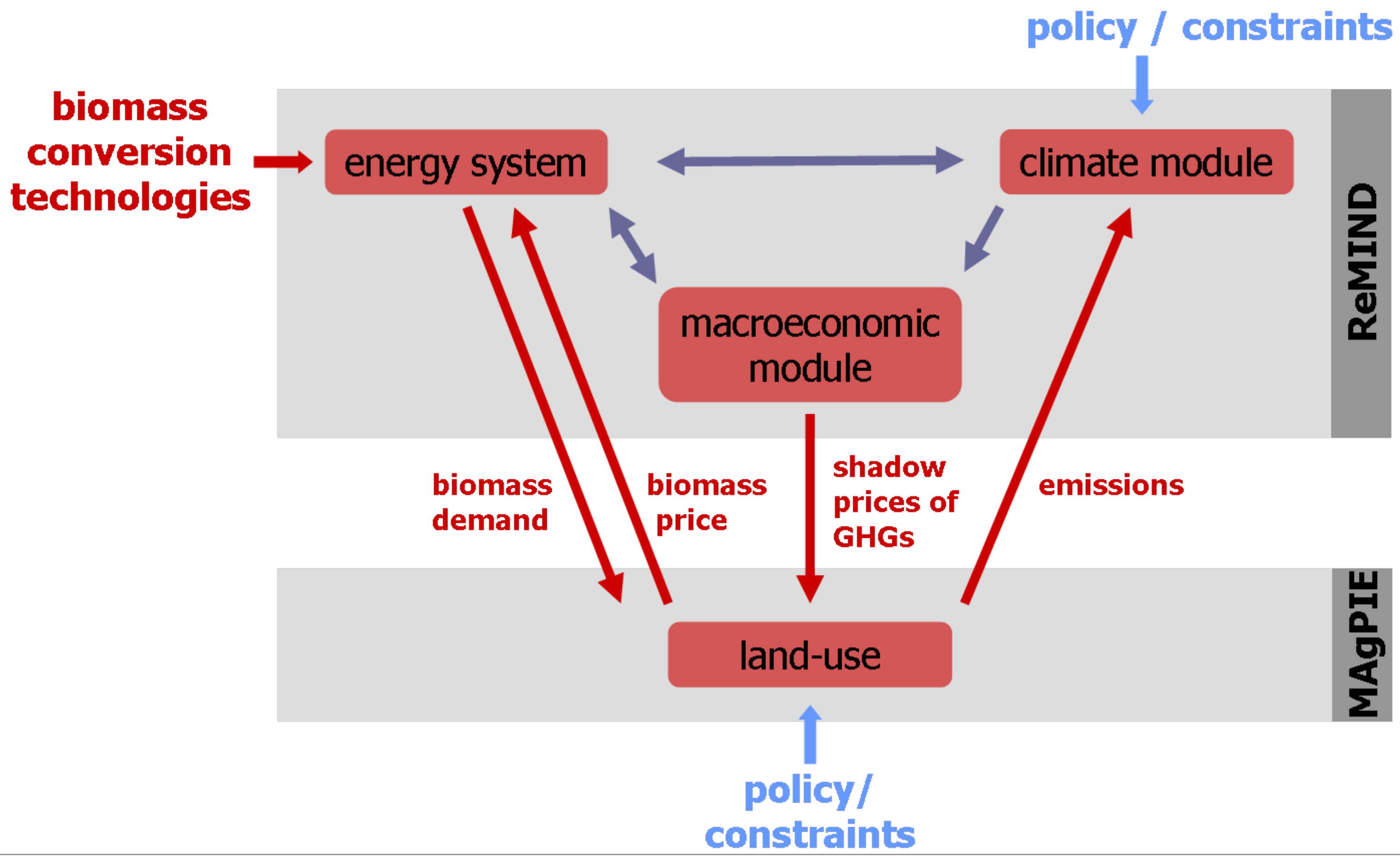
  ➔ development and climate policy, "metabolic" co-benefits and disbenefits (resource and waste streams), bottlenecks

  These are challenges of "bridging scales" (temporal, spatial and sectoral resolution).

REMIND approach to including land use dimension

Soft coupling with grid-based agro-economic model MagPIE

(Lotze-Campen, H., Müller, C., Bondeau, A., Rost, S., Popp A., Lucht, W. (2008) *Food demand, productivity growth and the spatial distribution of land and water use: a global modelling approach*. Agricultural Economics, 39, 325-338.)

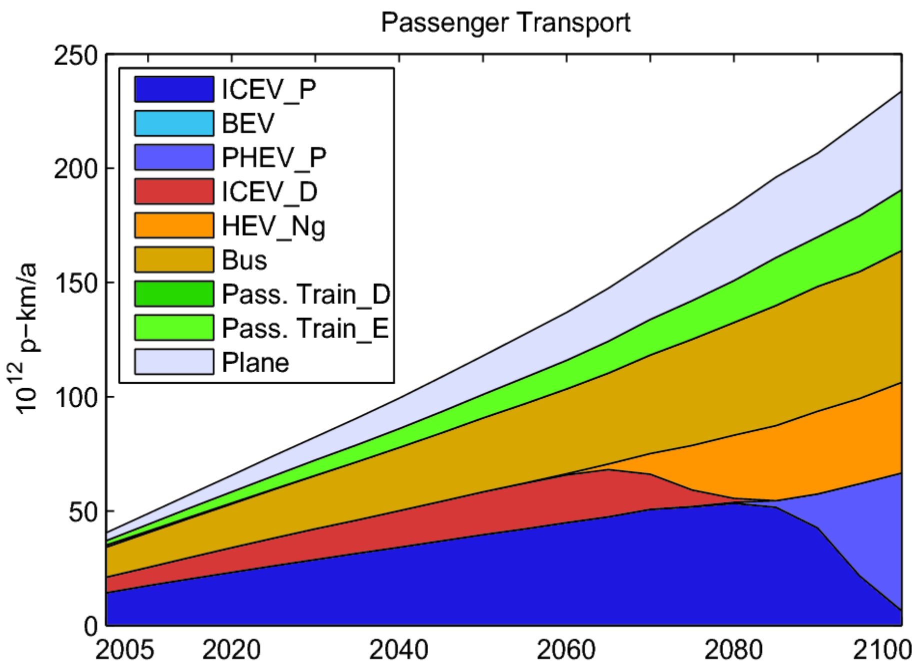


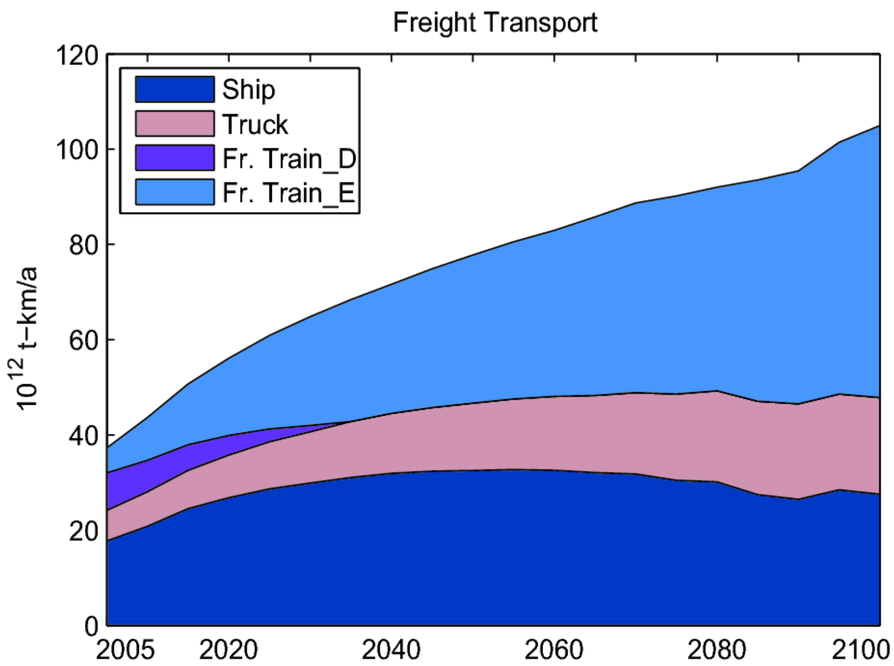
REMIND approach to modeling services

First steps taken for modeling the transport sector: Vehicle technologies and transport modes resolved in a one-world region REMIND version.

Transport services (in ton-km & person-km) included in production function

Policy scenario for reaching 2ºC target





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Leimbach, M., (2007) *Technological spillovers within multi-region models: Intertemporal optimization beyond the Negishi approach.* Economic Modelling, 24, 272-294.

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Leimbach, M., Bauer, N., Baumstark, L., Edenhofer, O. (2009) *Mitigation costs in a globalized world. Climate policy analysis with REMIND-R*. Environmental Modeling and Assessment, in press

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