Overview of the PIK
REMIND-MAgPIE-LPJml
integrated assessment framework

Elmar Kriegler, Wolfgang Lucht

The World in 2050 Workshop
IIASA, 11 March 2015
# IAM TEAM AT PIK

<table>
<thead>
<tr>
<th>Energy</th>
<th>Nico Bauer, Gunnar Luderer, Christoph Bertram, Jerome Hilaire, Antoine Levesque, Ioanna Mouratiadou, Michaja Pehl, Robert Pietzcker, Jessica Strefler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>Alexander Popp, Hermann Lotze-Campen, Anne Biewald, Benjamin Bodirsky, Florian Humpenöder, Ulrich Kreidenweis, Christoph Müller, Miodrag Stefanovic, Isabelle Weindl</td>
</tr>
<tr>
<td>Economy</td>
<td>Marian Leimbach, Franziska Piontek, Anselm Schultes, Niklas Roming, Gregor Schwerhoff</td>
</tr>
<tr>
<td>Model operations</td>
<td>Jan Philipp Dietrich, Lavinia Baumstark, Anastasis Giannousakis, David Klein</td>
</tr>
<tr>
<td>Scientific coordination</td>
<td>Laura Delsa</td>
</tr>
</tbody>
</table>
**Model framework**

**REMIND** - global energy-economy-climate model
- Ramsey optimal growth model
- 11 economic regions
- detailed energy sector (~70 conversion techs)
- international trade (capital, emissions allowances, oil, coal, gas, biomass)

*Bauer, Baumstark, Leimbach (2012) Climatic Change*

**LPJmL** - global vegetation and hydrology model

**MAgPIE** – global land use optimisation model
- spatially explicit (0.5°), 10 economic regions
- 30 production activities (13 crops, livestock, irrigation, bioenergy, land conversion)
- internal feed balances, international trade
- endogenous land expansion
- endogenous technological change

*Lotze-Campen, Popp et al. (2008), Agricultural Economics*
Modeling the land-energy-water-climate nexus with climate change and mitigation targets as starting point

TRANSFORMATION PATHWAYS in REMIND-MAgPIE

Selected References
- Popp et al. (2011) Environmental Research Letters
Energy transformation in mitigation pathways

- Energy supply & demand changes
- Energy prices
- VRE integration
- International energy market effects
- Energy security
- Technology development & policies

Mitigation reduces fossil fuel rents.
Overcompensated by emerging carbon rent.

References
1. Pietzcker et al. (2014) Energy
2. Bauer et al. (2015) TFSC
3. Bauer et al. (2012) PNAS
4. Bertram et al. (2015) NCC
Land use transformation

- Land use changes and emissions
- Trade-offs between bioenergy, afforestation, food production\(^1,2\)
- Agricultural productivity increases\(^3\)
- Land protection regimes & reduced deforestation\(^2,4\)
- Impact of dietary changes\(^5\)
- International agricultural trade\(^6\)
- Climate impacts on land

References
1. Humpenöder et al. (2014) Environmental Research Letters
2. Popp et al. (2014) Environmental Research Letters
3. Dietrich et al. (2014) TFSC
5. Popp et al. (2010) Global Environmental Change,
Further sustainability dimensions

- Water demand of energy and agricultural sector\(^1\), Environmental flow constraints\(^2\)
- Air pollution (joint work with IIASA & PBL, e.g. in LIMITS project)
- Material flows and resource requirements (ADVANCE project)
- Nitrogen pollution\(^3\)

References
1. Bonsch et al. (2014) GCB Bioenergy

Agricultural water use
(Bonsch et al., 2014)

300 EJ/yr bioenergy in 2100
Global quantification of the food-land-water nexus (LPJmL)

(D. Gerten, W. Lucht and the LPJmL-4 team)

LPJmL4 agro-hydro-biosphere BGC model

Example: Can water management improving efficiency in productive water flows increase yield?

Water management:
- Low = 10% vapour shift
- Med = 25% and rain water
- High = 50% harvesting

Potential yields +91%
max. CO₂ +47%

Figures and preliminary results: J. Jägermeyr, D. Gerten, J. Heinke et al. PIK 2014
Recent studies of the energy-land transformation

Agreement in 2015 and 2°C (LIMITS; Clim. Change Econ. 4(4)/5(1))

Global policy landscape & timing (AMPERE; Tech. For. Soc. Change 90A)

Role of Technology Availability & (EMF27; Climatic Change 123(3-4))

Role of emissions drivers (RoSE; Climatic Change)

• ca. 950 emissions scenarios
• Major contribution to IPCC AR5 report of Working Group 3

AR5 Scenario Database: https://secure.iiasa.ac.at/webapps/ene/AR5DB
Development of new scenarios for climate change research

Shared Socio-economic Pathways

SSP1: Sustainability
SSP2: Middle of the Road
SSP3: Regional Rivalry
SSP4: Inequality
SSP5: Fossil-fueled Development

Forcing level (W/m²)

- 8.5
- 6.0
- 4.5
- 2.6

Climate Policy Scenarios

Marker scenario by REMIND-MAgPIE

Courtesy: Keywan Riahi
Dynamic Systems Analysis for $t=2050$:
"Ask not what state you'll be in, but what flow you'll be in"

Can we get into the desired flow by rowing?

(1) What are the properties of the flow? What are the system properties of BAU?
(2) What is possible with rowing at time $t$?
(3) What is the robustness of the path against an interruption of rowing?

We could contribute a topological discussion of flow regimes and dilemmata faced
Considerations on TWI 2050

- Embedding mitigation pathway work in broader sustainability context is area of active work and strategic interest at PIK
  ➔ excellent fit with TWI 2050, high interest in the project

- Development of full modeling capabilities will be a multi-year multi-person project
  ➔ scope of TWI contribution somewhat contingent on timeline and availability of funding

- Large potential synergies with current SSP work by IIASA, PIK, PBL
  ➔ would be very helpful to exploit them as much as possible in TWI50

- Communication strategy of TWI 2050
  ➔ communication of model results coordinated by modeling teams
Backup Slides on Model Framework
Nitrogen pollution

Only ambitious mitigation action may reduce nitrogen pollution below critical thresholds. Even then, the risk remains that thresholds are exceeded.

Bodirsky et al. (2014), Nature Communications
## Variation of SSP input assumptions

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Parameter</th>
<th>SSP1</th>
<th>SSP5</th>
<th>SSP 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td>Population growth (IIASA scenarios)</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Economy</strong></td>
<td>GDP growth (OECD scenarios)</td>
<td>Very High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Convergence of per capita income (OECD scenarios)</td>
<td>Fast</td>
<td>Fast</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Convergence of capital intensities</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Resource extraction Coal/oil/gas</td>
<td>Low/low/low</td>
<td>High/high/medium</td>
<td>Medium/medium/medium</td>
</tr>
<tr>
<td></td>
<td>Solar (PV and CSP) and wind power</td>
<td>Optimistic / low cost</td>
<td>Pessimistic / high cost</td>
<td>Optimistic / medium cost</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>Fossil fuel subsidies</td>
<td>Phase out until 2030</td>
<td>Constant</td>
<td>Phase out until 2050</td>
</tr>
<tr>
<td></td>
<td>Petrol / diesel taxes</td>
<td>Convergence to 10 $/GJ by 2050</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td></td>
<td>Taxes on air pollutants</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Energy intensity</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Forest/ecosystem protection</td>
<td>High</td>
<td>Low-Medium</td>
<td>Low-Medium</td>
</tr>
<tr>
<td><strong>Behaviour</strong></td>
<td>Food demand incl food waste (Total calorie per capita)</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Per capita demand for livestock products</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Globalization/Trade</strong></td>
<td>Free trade pool (MAgPIE)</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Energy demand in SSP reference and policy cases

SSP1

SSP2

SSP5

Reference

450ppm

Preliminary results
Cell-specific share of total agricultural land (crop & pasture)

SSP1-bau - 2095

Preliminary results
Cell-specific share of total agricultural land (crop & pasture)

SSP5-bau - 2095

Preliminary results
Quick introduction to the models: ReMIND

Macro Economy

- Welfare

 Investments

- Consumption

Output

- Capital
- Labour

Final energy

Labour efficiency

Energy efficiency

Labour efficiency

Energy efficiency

Exogenous Data

- Energy system costs
- Energy transformations and conversion technologies
- Fuel costs
- Investment costs
- Operation and Maintenance costs

Emissions

Ressource and potential constraints

Learning by doing

Trade

Climate module

Quick introduction to the models used: ReMIND

ReMIND Energy System / Macro Interface
Quick introduction to the models used: ReMIND

ReMIND regions

USA - USA
EUR - EU27
JAP - Japan
CHN - China
IND - India
RUS - Russia
AFR - Sub-Saharan Africa (excl. Republic of South Africa)
MEA - Middle East, North Africa, central Asian countries
OAS - Other Asia (mostly South East Asia)
LAM - Latin America
ROW - Rest of the World (Canada, Australia, New Zealand, Republic of South Africa, Rest of Europe).
MAgPIE – a global land use optimisation model

- spatially explicit (0.5°), 10 economic regions
- 30 production activities (13 crops, livestock, irrigation, bioenergy, land conversion)
- internal feed balances, international trade
- endogenous land expansion
- endogenous technological change

Lotze-Campen, Popp et al. (2008), Agricultural Economics
Elmar Kriegler
Potsdam Institute for Climate Impact Research

Land use dynamics

Income vs. Food consumption

$\text{cal} / \text{cap} / \text{day}$

$k \text{cal} = 802 \times \text{gdp}^{0.142327}$  \[ R^2 = 0.66 \]

Demography

Income and diet

Socioeconomic inputs

Food demand, production costs

Crop yields
Land & Water constraints

Cereals
Sugar beets
Oilseeds
Pulses
Bioenergy

Biophysical inputs

Lotze-Campen et al. (2008), Agricultural Economics

Land use dynamics

Land use pattern

Lotze-Campen et al. (2008), Agricultural Economics
Income vs. Food consumption

\[ \text{kcal} = 802 \times \text{gdp}^{0.142327} \quad [R^2 = 0.66] \]

Low fertility, low mortality

High fertility, high mortality

Central fertility, central mortality

(Lutz et al. 2001)

Lotze-Campen and Popp, World Development Report 2010

Biophysical inputs

Socioeconomic inputs

Demography

Income and diet

Food demand, production costs

Climate change (GCM)

ECHAM4

CCSR

Crop yields

Land & Water constraints

Cereals

Sugar beets

Oilseeds

Pulses

Bioenergy

LPJ (50x50 km grid)

Agricultural productivity index (2005 = 100)

Business as usual, no climate change

With climate change

Past observations

Lotze-Campen and Popp, World Development Report 2010
LPJmL

Input:
climate, CO₂, soil, land-use

Natural vegetation

Managed grasland

Cropland

Bondeau et al. 2007, GCB

Elmar Kriegler
Potsdam Institute for Climate Impact Research
LPJmL

Agricultural yields

Bondeau et al. 2006, GCB

Carbon content

Gumpenberg, Popp et al. 2010, ERL

Run-off

Füssel, Popp, Heinke (2010)

Müller, Bondeau, Popp et al. WDR 2010

Elmar Kriegler
Potsdam Institute for Climate Impact Research
How can global models inform the negotiation process?

Mitigation scenarios for the 21st century are of value to draw the link between short term action and long term goals.

Models can provide maps of the „solution space“.

*Policy makers* can use them to navigate through this space.