Snapshot of - REMIND-MAgPIE

Archive of REMIND-MAgPIE, version: 2.0-4.1

Contents

Reference card - REMIND-MAgPIE

The reference card is a clearly defined description of model features. The numerous options have been organized into a limited amount of default and model specific (non default) options. In addition some features are described by a short clarifying text.

Legend:

☐ not implemented

☑ **implemented**

☑ **implemented (not default option)**

About

Name and version	REMIND-MAgPIE 2.0-4.1
Model link	https://www.pik-potsdam.de/research/sustainable-solutions/models/remind; https://rse.pik-potsdam.de/doc/remind/2.1.3; https://github.com/remindmodel/remind/releases/tag/v2.1.3; https://github.com/magpiemodel/magpie/releases/tag/v4.2.1; https://rse.pik-potsdam.de/doc/magpie/4.2.1/
Institution	Potsdam Institut für Klimafolgenforschung (PIK), Germany, https://www.pik-potsdam.de.
Documentation	REMIND-MAgPIE documentation consists of a referencecard and detailed model documentation
Process state	published

Model scope and methods

Model documentation: Model scope and methods - REMIND-MAgPIE

Model type	☐ Integrated assessment model	☑ **CGE**
	☐ Energy system model	☐ CBA-integrated assessment model
Geographical scope	☑ **Global**	☐ Regional

Objective

REMIND-MAgPIE is a global multi-regional model incorporating the economy, the climate system and a detailed representation of the energy sector. REMIND-MAgPIE allows for a sophisticated analysis of technology options and policy proposals for climate mitigation. It accounts for economic and energy investments in the model regions, and interregional trade in goods, energy carriers and emissions allowances.

Solution concept	☐ Partial equilibrium (price elastic demand) ☐ Partial equilibrium (fixed demand)	☑ **General equilibrium (closed economy)** ☑ **MAgPIE: partial equilibrium model of the agricultural sector**
Solution horizon	☐ Recursive dynamic (myopic) ☐ Intertemporal optimization (foresight)	☑ **REMIND-MAgPIE: Inter-temporal (foresight)** ☑ **MAgPIE: recursive-dynamic**
Solution method	☐ Simulation ☑ **Optimization**	☑ **MAgPIE: cost minimization**
Temporal dimension	Base year:2005, time steps:5, horizon: 2005-2100	
Spatial dimension	Number of regions:12	
Time discounting type	☐ Discount rate exogenous	☐ Discount rate endogenous
Policies	☑ **Emission tax** ☑ **Emission pricing** ☑ **Cap and trade** ☑ **Fuel taxes** ☑ **Fuel subsidies** ☐ Feed-in-tariff ☑ **Portfolio standard**	☑ **Capacity targets** ☐ Emission standards ☐ Energy efficiency standards ☐ Agricultural producer subsidies ☐ Agricultural consumer subsidies ☑ **Land protection** ☑ **Pricing carbon stocks**

Socio-economic drivers

Model documentation: Socio-economic drivers - REMIND-MAgPIE

Population	☑ **Yes (exogenous)**	☐ Yes (endogenous)
Population age structure	☐ Yes (exogenous)	☐ Yes (endogenous)
Education level	☐ Yes (exogenous)	☐ Yes (endogenous)
Urbanization rate	☐ Yes (exogenous)	☐ Yes (endogenous)

GDP	☑ **Yes (exogenous)**	☐ Yes (endogenous)
Income distribution	☐ Yes (exogenous)	☐ Yes (endogenous)
Employment rate	☑ **Yes (exogenous)**	☐ Yes (endogenous)
Labor productivity	☑ **Yes (exogenous)**	☐ Yes (endogenous)
Total factor productivity	☑ **Yes (exogenous)**	☐ Yes (endogenous)
Autonomous energy efficiency improvements	☑ **Yes (exogenous)**	☐ Yes (endogenous)

Macro-economy

Model documentation: Macro-economy - REMIND-MAgPIE

Economic sector

Industry	☐ Yes (physical) ☐ Yes (economic)	☐ Yes (physical & economic)
Energy	☑ **Yes (physical)** ☐ Yes (economic)	☐ Yes (physical & economic)
Transportation	☐ Yes (physical) ☐ Yes (economic)	☐ Yes (physical & economic)
Residential and commercial	☐ Yes (physical) ☐ Yes (economic)	☐ Yes (physical & economic)
Agriculture	☑ **Yes (physical)** ☐ Yes (economic)	☐ Yes (physical & economic)
Forestry	☐ Yes (physical) ☐ Yes (economic)	☐ Yes (physical & economic)
Other economic sector		

Note: The macro-economic part contains a single sector representation of the entire economy. A generic final good is produced from capital, labor, and different final energy types.

Macro-economy

Trade

- ☑ **Coal**
- ☑ **Oil**
- ☑ **Gas**
- ☑ **Uranium**
- ☐ Electricity
- ☑ **Bioenergy crops**
- ☑ **Food crops**
- ☑ **Capital**
- ☑ **Emissions permits**
- ☑ **Non-energy goods**
- ☑ **Energy goods**

Cost measures

- ☑ **GDP loss**
- ☑ **Welfare loss**
- ☑ **Consumption loss**
- ☐ Area under MAC
- ☐ Energy system cost mark-up

Categorization by group

- ☐ Income
- ☐ Urban - rural
- ☐ Technology adoption
- ☐ Age
- ☐ Gender
- ☐ Education level
- ☐ Household size

Institutional and political factors

- ☐ Early retirement of capital allowed
- ☐ Interest rates differentiated by country/region
- ☐ Regional risk factors included
- ☐ Technology costs
- differentiated by country/region
- ☐ Technological change differentiated by country/region
- ☐ Behavioural change differentiated by country/region
- ☐ Constraints on cross country financial transfers

Resource use

Coal

- ☐ Yes (fixed)
- ☑ **Yes (supply curve)**
- ☐ Yes (process model)

Conventional Oil

- ☐ Yes (fixed)
- ☑ **Yes (supply curve)**
- ☐ Yes (process model)

Unconventional Oil

- ☐ Yes (fixed)
- ☑ **Yes (supply curve)**
- ☐ Yes (process model)

Conventional Gas

- ☐ Yes (fixed)
- ☑ **Yes (supply curve)**

☐ Yes (process model)

Unconventional Gas	☐ Yes (fixed) ☑ **Yes (supply curve)**	☐ Yes (process model)
Uranium	☐ Yes (fixed) ☑ **Yes (supply curve)**	☐ Yes (process model)
Bioenergy	☐ Yes (fixed) ☑ **Yes (supply curve)**	☐ Yes (process model)
Water	☐ Yes (fixed) ☐ Yes (supply curve)	☑ **Yes (process model)**
Raw Materials	☐ Yes (fixed) ☐ Yes (supply curve)	☐ Yes (process model)
Land	☐ Yes (fixed) ☐ Yes (supply curve)	☐ Yes (process model)

Technological change

Energy conversion technologies	☐ No technological change ☐ Exogenous technological	change ☐ Endogenous technological change
Energy End-use	☐ No technological change ☐ Exogenous technological	change ☑ **Endogenous technological change**
Material Use	☐ No technological change ☐ Exogenous technological	change ☐ Endogenous technological change
Agriculture (tc)	☐ No technological change ☐ Exogenous technological	change ☐ Endogenous technological change

Energy

Model documentation: Energy - REMIND-MAgPIE

Energy technology substitution

Energy technology choice

- ☐ No discrete technology choices
- ☐ Logit choice model
- ☐ Production function
- ☐ Linear choice (lowest cost)
- ☐ Lowest cost with adjustment penalties

Energy technology substitutability

- ☑ **Mostly high substitutability**
- ☐ Mostly low substitutability
- ☐ Mixed high and low substitutability

Energy technology deployment

- ☐ Expansion and decline constraints
- ☐ System integration constraints

Energy

Electricity technologies

- ☑ **Coal w/o CCS**
- ☑ **Coal w/ CCS**
- ☑ **Gas w/o CCS**
- ☑ **Gas w/ CCS**
- ☑ **Oil w/o CCS**
- ☐ Oil w/ CCS
- ☑ **Bioenergy w/o CCS**
- ☑ **Bioenergy w/ CCS**
- ☑ **Geothermal power**
- ☑ **Nuclear power**
- ☑ **Solar power**
- ☑ **Solar power-central PV**
- ☐ Solar power-distributed PV
- ☑ **Solar power-CSP**
- ☑ **Wind power**
- ☐ Wind power-onshore
- ☐ Wind power-offshore
- ☑ **Hydroelectric power**
- ☐ Ocean power

Hydrogen production

- ☑ **Coal to hydrogen w/o CCS**
- ☑ **Coal to hydrogen w/ CCS**
- ☑ **Natural gas to hydrogen w/o CCS**
- ☑ **Natural gas to hydrogen w/ CCS**
- ☐ Oil to hydrogen w/o CCS
- ☐ Oil to hydrogen w/ CCS
- ☑ **Biomass to hydrogen w/o CCS**
- ☑ **Biomass to hydrogen w/ CCS**
- ☐ Nuclear thermochemical hydrogen
- ☐ Solar thermochemical hydrogen
- ☑ **Electrolysis**

Refined liquids

- ☑ **Coal to liquids w/o CCS**
- ☑ **Coal to liquids w/ CCS**
- ☐ Gas to liquids w/o CCS
- ☐ Gas to liquids w/ CCS
- ☑ **Bioliquids w/o CCS**
- ☑ **Bioliquids w/ CCS**
- ☑ **Oil refining**

Refined gases

- ☑ **Coal to gas w/o CCS**
- ☐ Coal to gas w/ CCS

☐ Oil to gas w/o CCS	☑ **Biomass to gas w/o CCS**	
☐ Oil to gas w/ CCS	☐ Biomass to gas w/ CCS	
Heat generation	☑ **Coal heat**	☑ **Geothermal heat**
	☑ **Natural gas heat**	☐ Solarthermal heat
	☑ **Oil heat**	☑ **CHP (coupled heat and power)**
	☑ **Biomass heat**	

Grid Infra Structure

Electricity	☐ Yes (aggregate)	☐ Yes (spatially explicit)
Gas	☐ Yes (aggregate)	☐ Yes (spatially explicit)
Heat	☐ Yes (aggregate)	☐ Yes (spatially explicit)
CO2	☐ Yes (aggregate)	☐ Yes (spatially explicit)
Hydrogen	☐ Yes (aggregate)	☐ Yes (spatially explicit)

Other grid and infrastructure

Note: Generalized transmission and distribution costs are included, but not modeled on an explicit spatial level. Regionalized additional grid and storage costs for renewable integration are included.

Energy end-use technologies

Passenger transportation	☑ **Passenger trains**	☐ Hybrid LDVs
	☐ Buses	☑ **Gasoline LDVs**
	☑ **Light Duty Vehicles (LDVs)**	☐ Diesel LDVs
	☑ **Electric LDVs**	☐ Passenger aircrafts
	☑ **Hydrogen LDVs**	
Freight transportation	☐ Freight trains	☐ Freight aircrafts
	☑ **Heavy duty vehicles**	☐ Freight ships
Industry	☐ Steel production	☐ Petrochemical production
	☐ Aluminium production	☐ Paper production
	☐ Cement production	☐ Plastics production

☐ Pulp production

Residential and commercial	☐ Space heating	☐ Refrigeration
	☐ Space cooling	☐ Washing
	☐ Cooking	☐ Lighting

Land-use

Model documentation: Land-use - REMIND-MAgPIE

Land cover	☑ **Cropland**	☑ **Managed forest**
	☑ **Cropland irrigated**	☑ **Natural forest**
	☑ **Cropland food crops**	☑ **Pasture**
	☑ **Cropland feed crops**	☐ Shrubland
	☑ **Cropland energy crops**	☑ **Built-up area**
	☑ **Forest**	
Agriculture and forestry demands	☑ **Agriculture food**	☑ **Agriculture non-food crops**
	☑ **Agriculture food crops**	☑ **Agriculture non-food livestock**
	☑ **Agriculture food livestock**	☑ **Agriculture bioenergy**
	☑ **Agriculture feed**	☑ **Agriculture residues**
	☑ **Agriculture feed crops**	☐ Forest industrial roundwood
	☑ **Agriculture feed livestock**	☐ Forest fuelwood
	☑ **Agriculture non-food**	☐ Forest residues
Agricultural commodities	☑ **Wheat**	☑ **Sugar crops**
	☑ **Rice**	☑ **Ruminant meat**
	☑ **Other coarse grains**	☑ **Non-ruminant meat and eggs**
	☑ **Oilseeds**	☑ **Dairy products**

Emission, climate and impacts

Model documentation: Emissions - REMIND-MAgPIE, Climate - REMIND-MAgPIE, Non-climate sustainability dimension - REMIND-MAgPIE

Greenhouse gases	☑ **CO2 fossil fuels**	☑ **N2O energy**
	☑ **CO2 cement**	☑ **N2O land use**
	☑ **CO2 land use**	☑ **N2O other**
	☑ **CH4 energy**	☑ **CFCs**
	☑ **CH4 land use**	☑ **HFCs**
	☑ **CH4 other**	☑ **SF6**

☐ PFCs

Pollutants

- ☑ **CO energy**
- ☑ **CO land use**
- ☑ **CO other**
- ☑ **NOx energy**
- ☑ **NOx land use**
- ☑ **NOx other**
- ☑ **VOC energy**
- ☑ **VOC land use**
- ☑ **VOC other**
- ☑ **SO2 energy**
- ☑ **SO2 land use**
- ☑ **SO2 other**
- ☑ **BC energy**
- ☑ **BC land use**
- ☑ **BC other**
- ☑ **OC energy**
- ☑ **OC land use**
- ☑ **OC other**
- ☑ **NH3 energy**
- ☑ **NH3 land use**
- ☐ NH3 other

Note: Ozone is not modeled as emission, but is an endogenous result of atmospheric chemistry.

Climate indicators

- ☑ **Concentration: CO2**
- ☑ **Concentration: CH4**
- ☑ **Concentration: N2O**
- ☑ **Concentration: Kyoto gases**
- ☑ **Radiative forcing: CO2**
- ☑ **Radiative forcing: CH4**
- ☑ **Radiative forcing: N2O**
- ☑ **Radiative forcing: F-gases**
- ☑ **Radiative forcing: Kyoto gases**
- ☑ **Radiative forcing: aerosols**
- ☐ Radiative forcing: land albedo
- ☑ **Radiative forcing: AN3A**
- ☑ **Radiative forcing: total**
- ☑ **Temperature change**
- ☐ Sea level rise
- ☐ Ocean acidification
- ☑ **Radiative Forcing (Land Albedo) - Yes (exogenous)**

Carbon dioxide removal

- ☑ **Bioenergy with CCS**
- ☐ Reforestation
- ☑ **Afforestation**
- ☐ Soil carbon enhancement
- ☑ **Direct air capture**
- ☑ **Enhanced weathering**

Climate change impacts

- ☐ Agriculture
- ☐ Energy supply
- ☐ Energy demand
- ☐ Economic output
- ☐ Built capital
- ☐ Inequality

Co-Linkages

- ☑ **Energy security: Fossil fuel imports & exports (region)**
- ☐ Energy access: Household energy consumption
- ☐ Air pollution & health: Source-based aerosol emissions
- ☐ Air pollution & health: Health impacts of air Pollution
- ☐ Food access
- ☑ **Water availability**
- ☐ Biodiversity

Model Documentation - REMIND-MAgPIE

Introduction

This documentation describes the **REMIND-MAgPIE** framework coupling the energy-economy model **REMIND** and the agricultural production model **MAgPIE**.

REMIND

The Integrated Assessment Model **REMIND** (REgional Model of Investment and Development) represents the future evolution of the world economies with a special focus on the development of the energy sector and the implications for our world climate. Given a set of population, technology, policy and climate constraints, the goal of REMIND is to find the welfare-optimal mix of investments in the economy and the energy sectors of each model region. It also accounts for regional trade characteristics on goods, energy fuels, and emissions allowances. All greenhouse gas emissions due to human activities are represented in the model.

REMIND is an energy-economy general equilibrium model linking a macro-economic growth model with a bottom-up engineering-based energy system model. It covers twelve world regions, differentiates various energy carriers and technologies and represents the dynamics of economic growth and international trade.

A Ramsey-type growth model with perfect foresight serves as a macro-economic core projecting growth, savings and investments, factor incomes, energy and material demand. The macro-economic production factors are capital, labor, and final energy. A nested production function with constant elasticity of substitution determines the final energy demand. REMIND uses economic output for investments in the macro-economic capital stock as well as for consumption, trade, and energy system expenditures.

The energy system representation differentiates between a variety of fossil, biogenic, nuclear and renewable energy resources. More than 50 technologies are available for the conversion of primary energy into secondary energy carriers as well as for the distribution of secondary energy carriers into final energy. The macro-economic core and the energy system part are hard-linked via the final energy demand and the costs incurred by the energy system. Economic activity results in demand for final energy in different sectors (transport, industry, buildings..) and of different type (electric and non-electric).

The model accounts for crucial drivers of energy system inertia and path dependencies by representing full capacity vintage structure, technological learning of emergent new technologies, as well as adjustment costs for rapid upscaling of new technologies. The emissions of greenhouse gases (GHGs) and air pollutants are largely represented by source and linked to activities in the energy-economic system. Several energy sector policies are represented explicitly, including energy-sector fuel taxes and consumer subsidies.

Further reading:

- REMIND code on GitHub: https://github.com/remindmodel/remind

- REMIND documentation (version 2.1.3): https://rse.pik-potsdam.de/doc/remind/2.1.3
- REMIND2.1 paper: https://doi.org/10.5194/gmd-14-6571-2021

MAgPIE

The Model of Agricultural Production and its Impact on the Environment (**MAgPIE**) is a global land use allocation model, which is connected to the grid-based dynamic vegetation model LPJmL, with a spatial resolution of 0.5°x0.5°. It takes regional economic conditions such as demand for agricultural commodities, technological development and production costs as well as spatially explicit data on potential crop yields, land and water constraints (from LPJmL) into account. Based on these, the model derives specific land use patterns, yields and total costs of agricultural production for each grid cell. The objective function of the land use model is to minimize total cost of production for a given amount of regional food and bioenergy demand. Regional food energy demand is defined for an exogenously given population in 10 food energy categories, based on regional diets. Future trends in food demand are derived from a cross-country regression analysis, based on future scenarios on GDP and population growth.

Food and feed energy for the demand categories can be produced by 20 cropping activities and 3 livestock activities. Feed for livestock is produced as a mixture of crops, crop residuals, processing byproducts, green fodder produced on crop land, and pasture. Variable inputs of production are labour, chemicals, and other capital (all measured in US$). Costs of production are derived from the Global Trade Analysis Project (GTAP) Database. The model can endogenously decide to acquire yield-increasing technological change at additional costs. The costs for technological change for each economic region are based on its level of agricultural development, measured as agricultural land-use intensity. These costs grow with further investment in technological change. The use of technological change is either triggered by a better cost-effectiveness compared to other investments or as a response to resource constraints, such as land scarcity.

For future projections the model works on 5-10 year a time steps of 10 years in a recursive dynamic mode. The link between two consecutive periods is established through the land-use pattern. The optimized land-use pattern from one period is taken as the initial land constraint in the next. If necessary, additional land from non-agricultural areas can be converted into cropland at additional costs. Potential crop yields for MAgPIE are originally computed with LPJmL at a 0.5° resolution, as weighted average of irrigated and non-irrigated production, if part of the grid cell is equipped for irrigation according to the global map of irrigated areas. In case of purely rain-fed production, no additional water is required, but yields are generally lower than under irrigation. If a certain area share is irrigated, additional water for agriculture is taken from available water discharge in the grid cell. Each cell of the geographic grid is assigned to 1 of 120 economic world regions: CAZ (Canada, Australia and New Zealand; CHA (China); EUR (European Union); IND (India); JPN (Japan); LAM (Latin America); MEA (Middle East and north Africa); NEU (non-EU member states); OAS (other Asia); REF (reforming countries); SSA (Sub-Saharan Africa); USA (United States) The regions are initially characterized by data for the year 1995 on population, gross domestic product (GDP), food energy demand, average production costs for different production activities, and current self-sufficiency ratios for food. Land-conversion activities provide for potential expansion and shifts of agricultural land in specific locations. For the base year 1995, total agricultural land is constrained to the area currently used within each grid cell, according to the dataset of as extended by. Cropland can be converted into rangeland, and vice versa. If additional land is required for fulfilling demand, this can be taken from the pool of non-agricultural land at additional costs. These land-conversion costs

force the model to utilize available cropland and rangeland first, and land conversion will become relevant only if land becomes scarce in a certain location or if the marginal cost reductions by producing crops on converted land outweigh the costs of conversion.

Further reading:

- MAgPIE code on GitHub: https://github.com/magpiemodel/magpie
- MAgPIE documentation (Version 4.3.0): https://rse.pik-potsdam.de/doc/magpie/4.3/
- MAgPIE 4 paper: https://doi.org/10.5194/gmd-12-1299-2019

REMIND-MAgPIE

For some questions, **REMIND** and **MAgPIE** are soft coupled to provide a detailed answer. From a climate protection perspective, two aspects of the land-use sector are of particular interest: the supply of biomass that can be used for energy production (possibly with carbon capture and storage – CCS) and the total emissions of the land-use sector. Changing crucial parameters in REMIND (such as the climate target or the availability of technologies or resources) can have significant impact on GHG prices and bioenergy demand. Thus, REMIND and MAgPIE can be run in an iterative soft-coupled mode, where REMIND updates MAgPIE's assumptions regarding bioenergy demand and GHG prices, and MAgPIE, in turn, updates REMIND's assumptions regarding bioenergy prices and land-use emissions and agricultural production costs. The iteration is continued until changes between iterations become negligible. The resulting scenarios are consistent regarding the price and quantity of bioenergy and GHG emissions.

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