Model Description

(updated 04 May 2015)

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Introduction

This document provides an overview of the six models which have so far participated in the development of the SSP scenarios. These models are hosted by IAM teams at FEEM, IIASA, PBL, NIES, PIK and PNNL each of which have contributed on a voluntary basis towards this process. Key criterion in order to par6ticipate in this process included the ability to provide detailed reporting on emission as well as on land-use variables. The initial section of this document briefly describes each of the models. These descriptions highlight some of the main model characteristics and describe relevant linkages to other models applied in the modelling process. A file containing further details on models' characteristics can be downloaded here. In addition to the descriptions, for each model, a table mapping the native regions to the harmonized SSP regions has been provided. Details on any deviations from the defined SSP regions on a country level can be found here. Maps have further been included to illustrate the native model regional definitions. The final section provides an overview of the pollution inventories used across the different models.

Summary descriptions of the models

Table 1 below provides an overview of the SSP IAM models followed in turn by a more detailed description of the individual models.

Table 1: Key characteristics of SSP models

Model name (***hosting institution***)	**Model category**	**Solution Algorithm**
AIM/CGE ***(NIES)***	General equilibrium	Recursive dynamic
GCAM ***(PNNL)***	Partial equilibrium	Recursive dynamic
IMAGE/TIMER ***(PBL)***	Partial equilibrium	Recursive dynamic
MESSAGE-GLOBIOM ***(IIASA)***	General equilibrium	Intertemporal optimization
REMIND-MAgPIE ***(PIK)***	General equilibrium	Intertemporal optimization
WITCH-GLOBIOM ***(FEEM)***	General equilibrium	Intertemporal optimization

AIM/CGE (NIES)

The **Asia-Pacific Integrated Assessment/Computable General Equilibrium (AIM/CGE)** [1-5] is a recursive-type dynamic general equilibrium model that covers all regions of the world. The AIM/CGE model includes 17 regions and 42 industrial classifications. Likewise other CGE models, AIM/CGE deals with whole economic production and consumption behaviors with particular emphasis on the representation of energy in order to assess energy related CO2 emissions appropriately. In addition, agriculture and land use classifications have also high resolution in order to deal with the bioenergy and land use competition appropriately. The climate component is represented by the Model for the Assessment of Greenhouse-Gas Induced Climate Change (MAGICC) and the emissions information generated from AIM/CGE is fed into MAGICC.

The production sectors are assumed to maximize profits under multi-nested constant elasticity substitution (CES) functions and each input price. The capital, labor, intermediate inputs and land are the input for each industrial activity. Household expenditures on each commodity are described by a linear expenditure system function. The saving ratio is endogenously determined to balance saving and investment, and capital formation for each good is determined by a fixed coefficient. The international traded goods are substitutable with the domestic production goods.

In addition to energy-related CO2, CO2 from other sources (land use), CH4, N2O, and F-gases are treated as GHGs in the model. Energy-related emissions are associated with fossil fuel consumption and combustion. The non-energy-related CO2 emissions consist of land use change and industrial processes. Land use change emissions are derived from the difference of the forest area from that of the previous year multiplied by the carbon stock density. Non-energy-related emissions other than land use change emissions are assumed to be in proportion to the level of the activities (such as output). CH4 has various sources, but the main sources are the rice production, livestock, fossil fuel mining, and waste management sectors. N2O is emitted as a result of fertilizer application and livestock manure management, and by the chemical industry. Air pollutant gases (BC, CO, NH3, NMVOC, NOX, OC, sulfur) are also associated with fuel combustion and activity levels. Basically, the emissions factors are changed over time according to the implementation of air pollutant removal technologies and relevant legislation.

Table 2: Mapping of AIM/CGE regions to SSP regions

Native Regions	SSP Regions
JPN	OECD90
CHN	ASIA
IND	ASIA
XSE	ASIA
XSA	ASIA
XOC	OECD90
XE25	OECD90
XER	OECD90
CIS	REF
TUR	OECD90
CAN	OECD90
USA	OECD90
BRA	LAM
XLM	LAM

XME	MAF
XNF	MAF
XAF	MAF
Explanations:	
JPN=Japan	TUR=Turkey
CHN=China	CAN=Canada
IND=India	USA=United States
XSE=Southeast Asia	BRA=Brazil
XSA=Rest of Asia	XLM=Rest of South America
XOC=Oceania	XME=Middle East
XE25=EU25	XNF=North Africa
XER=Rest of Europe	XAF=Rest of Africa
CIS=Former Soviet Union	

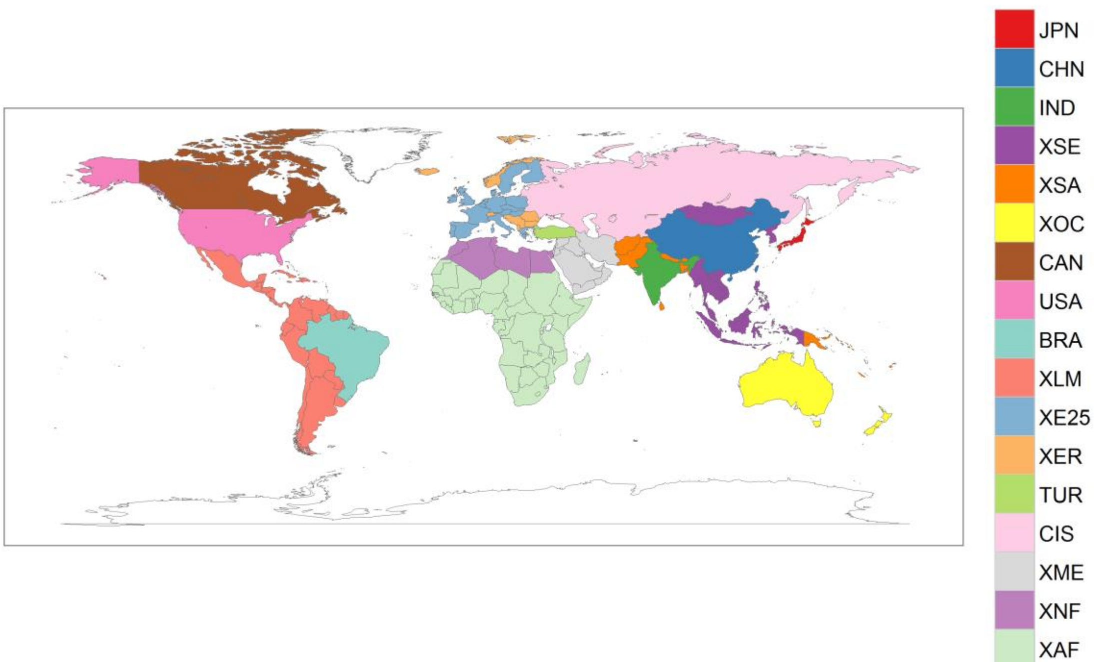

Figure 1: AIM/CGE model regions

GCAM (PNNL)

The **Global Change Assessment Model (GCAM)** [6] is a global integrated assessment model with particular emphasis on the representation of human earth systems including interactions between the global economic, energy, agricultural, land use and technology systems. The GCAM physical atmosphere and climate are represented by Hector, an open source coupled carbon cycle-climate model (Hartin et al., 2015). The GCAM is global in scope and disaggregated into 32 energy and economic regions and 283 agriculture and land use regions. GCAM is a dynamic-recursive market equilibrium model; as such, prices are adjusted to ensure that supplies and demands of all commodities are equilibrated in each model period. The model operates in 5-year timesteps from 1990 to 2100, with 2010 as its last historical year. The energy system model produces and transforms energy for use in three end-use sectors: buildings, industry and transport. Production is limited by resource availability, which varies by region. Fossil fuel and uranium resources are finite and depletable. Wind, solar, hydro, and geothermal resources are renewable. Bioenergy is also renewable but is treated as an explicit product of the agriculture-land-use portion of the model. The agriculture and land use model computes supply, demand, and land use for a variety of crops and other uses, including natural ecosystems. The model operates using an economic paradigm, where landowners allocate land among competing uses based on profitability. GCAM assumes a distribution of profits across each of the 283 regions, and thus, the fraction of each region allocated to each land use is the probability that use has the highest profit. GCAM computes anthropogenic emissions of 24 GHGs, short-lived species, aerosols, and ozone precursors. Emissions are associated with drivers and change in the future due to changes in drivers, income-driven pollution controls, or carbon-price driven abatement efforts. GCAM is open-source and can be downloaded at: http://www.globalchange.umd.edu/models/gcam/download/.

Table 3: Mapping of GCAM regions to SSP regions

Native Regions	**SSP Regions**
Africa	MAF
Australia_NZ	OECD
Canada	OECD
China	ASIA
Eastern Europe	OECD
Former Soviet Union	REF
India	ASIA
Japan	OECD
Korea	ASIA
Latin America	LAM
Middle East	MAF
Southeast Asia	ASIA
USA	OECD
Western Europe	OECD

Explanations:
NZ = New Zealand
Southeast Asia: also including Pakistan
USA = United States of America
Western Europe = Including EU-15, Turkey, EFTA

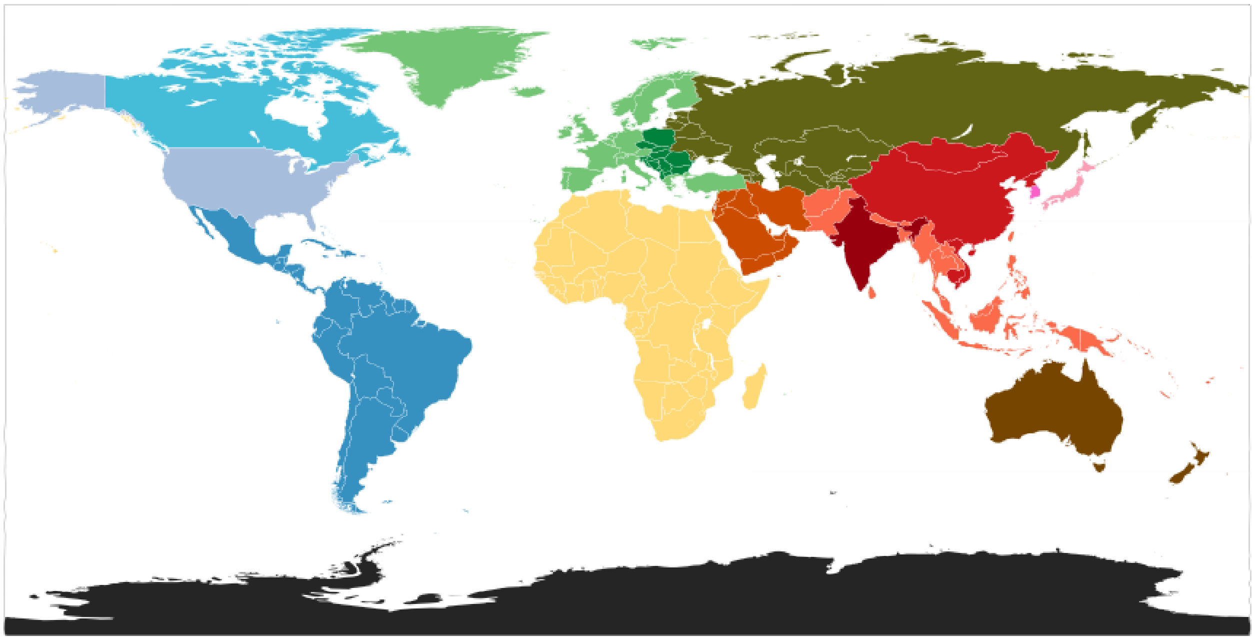

Figure 2: GCAM model regions

IMAGE/TIMER (PBL)

The **IMAGE/TIMER** Integrated Assessment Modelling Framework [7,8] consists of a set of linked and integrated models that together describe important elements of the long-term dynamics of global environmental change, such as air pollution, climate change, and land-use change. The global energy model that forms part of this framework, TIMER, describes the demand and production of primary and secondary energy and the related emissions of GHGs and regional air pollutants. The land and climate modules of IMAGE describe the dynamics of agriculture and natural vegetation, and resulting climate change. For food and agriculture, the IMAGE system uses projections made by the computable-general-equilibrium MAGNET model. This model describes, in interaction with the main IMAGE framework, changes in food production and trade for a broad set of crops and animal products. The Terrestrial Environment System (TES) of IMAGE [7,9] computes land-use changes based on regional production of food, animal feed, fodder, grass, bio-energy and timber, with consideration of local climatic and terrain properties. Climate change affects the productivity of crops and induces changes in natural vegetation with consequences for biodiversity. TES represents the geographically explicit modelling of and use. The potential distribution of natural vegetation and crops is determined on the basis of climate conditions and soil characteristics on a spatial resolution of 0.5 x 0.5 degree. It also estimates potential crop productivity, which is used to determine allocation of cropland to different crops. Emissions from land-use changes, natural ecosystems and agricultural production systems, and the exchange of carbon dioxide between terrestrial ecosystems and the atmosphere are also simulated. The Atmospheric Ocean System (AOS) part of IMAGE calculates changes in atmospheric composition using the emissions from the TIMER model and TES, and by taking oceanic carbon dioxide uptake and atmospheric chemistry into consideration. Subsequently, AOS computes changes in climatic parameters by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport.

Table 4: Mapping of IMAGE regions to SSP regions

Native Regions	SSP Regions
BRA	LAM
CAN	OECD
CEU	OECD
CHN	ASIA
EAF	MAF
INDIA	ASIA
INDO	ASIA
JAP	OECD
KOR	ASIA
ME	MAF
MEX	LAM
NAF	MAF
OCE	OECD
RCAM	LAM
RSAF	MAF
RSAM	LAM
RSAS	ASIA
RUS	REF
SAF	MAF

SEAS	ASIA
STAN	REF
TUR	OECD
UKR	REF
USA	OECD
WAF	MAF
WEU	OECD

Explanations:

BRA = Brazil
CAN = Canada
CEU = Central Europe
CHN = China
EAF = East Africa
INDIA = India
INDO = Indonesia
JAP = Japan
KOR = Korea
ME = Middle East
MEX = Mexico
NAF = North Africa
OCE = Oceania
RCAM = Rest of Central America
RSAF = Rest of Sub-Saharan Africa
RSAM = Rest of South America
RSAS = Rest of South Asia
RUS = Russia
SAF = South Africa
SEAS = Southeast Asia
STAN = Kazakhstan region
TUR = Turkey
UKR = Ukraine, Belarus, Moldova
USA = United States of America
WAF = West Africa
WEU = Western Europe

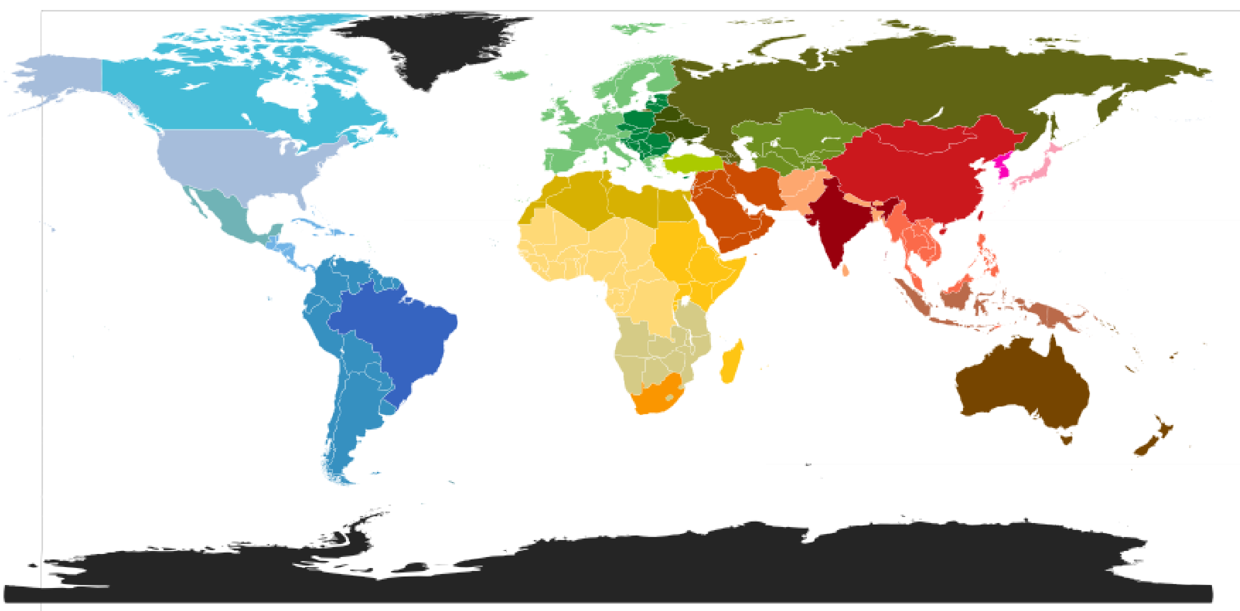

Figure 3: IMAGE model regions

MESSAGE-GLOBIOM (IIASA)

Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) is an energy engineering model based on a linear programming (LP) optimization approach which is used for medium- to long-term energy system planning and policy analysis [10,11]. The model minimizes total discounted energy system costs, and provides information on the utilization of domestic resources, energy imports and exports and trade-related monetary flows, investment requirements, the types of production or conversion technologies selected (technology substitution), pollutant emissions, and inter-fuel substitution processes, as well as temporal trajectories for primary, secondary, final, and useful energy. In addition to the energy system, the model also includes generic representations of agriculture and forestry, which allows incorporation of emissions and mitigation options for the full basket of greenhouse gases and other radiatively active substances [12]. MESSAGE is linked to a macro-economic model - MACRO [13]. In MACRO, capital stock, available labor, and energy inputs determine the total output of the economy according to a nested constant elasticity of substitution (CES) production function. Through the linkage to MESSAGE, internally consistent projections of GDP and energy demand are calculated in an iterative fashion that takes price-induced changes of demand and GDP into account. MESSAGE is in addition coupled to agricultural model GLOBIOM for consistent projections of land-use. MESSAGE has also been linked to the GAINS model [14,15] to provide estimates of air pollution [16,17,18]. Additional extensive model documentation can be found at https://wiki.ucl.ac.uk/display/ADVIAM/MESSAGE.

The **Global Biosphere Management Model (GLOBIOM)** has been developed at the International Institute for Applied Systems Analysis (IIASA) since the late 2000s. The partial-equilibrium model represents various land-use based activities, including agriculture, forestry and bioenergy sectors. The model is built following a bottom-up setting based on detailed grid-cell information, providing the biophysical and technical cost information. This detailed structure allows taking into account a rich set of environmental parameters. Its spatial equilibrium modelling approach represents bilateral trade based on cost competitiveness. The model was initially developed mostly for integrated assessment of climate change mitigation policies in land based sectors, including biofuels, and is increasingly being implemented also for agricultural and timber markets foresight, and economic impacts analysis of climate change and adaptation. More details on GLOBIOM can be found in [19,20].

Table 5: Mapping of MESSAGE-GLOBIOM regions to SSP regions[1]

Native Regions	SSP Regions
AFR	MAF
CPA	ASIA
EEU	OECD
FSU	REF
LAM	LAM
MEA	MAF
NAM	OECD
PAO	OECD
PAS	ASIA
SAS	ASIA
WEU	OECD
Explanations:	
AFR = Africa	MEA = Middle East and North Africa
CPA = Centrally-planned Asia, including China, Vietnam and others	NAM = North America PAO = Pacific OECD (Australia, Japan, New Zealand)
EEU = Eastern Europe	PAS = Other Pacific Asia
FSU = Former Soviet Union	SAS = South Asia
LAM = Latin America and Carribean	WEU = Western Europe

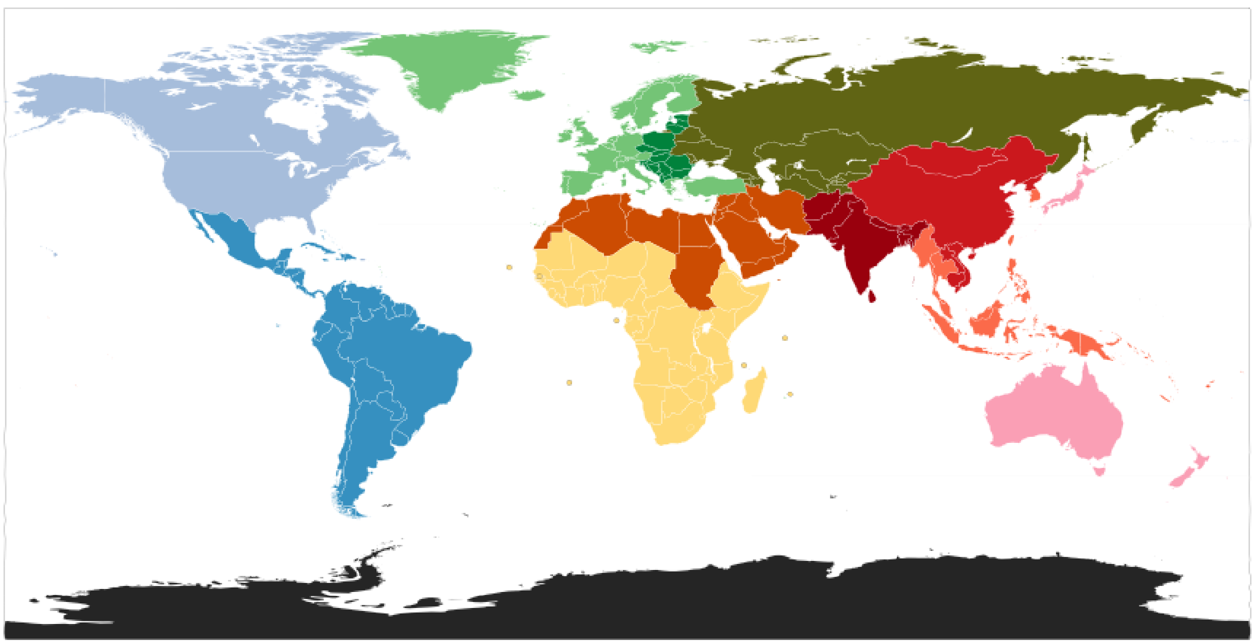

Figure 4: MESSAGE-GLOBIOM model regions

[1] Note that GLOBIOM model can also be applied as a stand-alone tool, in which case it comprises a number of additional regions.

REMIND-MAgPIE (PIK)

The **Regionalized Model of Investment and Technological Development (REMIND)** [21 (Model description),22,23,24,25,26][2] is a global multi-regional integrated assessment model that couples a top-down macroeconomic growth model with a detailed bottom-up energy system model and a simple climate model. By embedding technological change in the energy sector into a representation of the macroeconomic environment, REMIND combines the major strengths of bottom-up and top-down models. To obtain a detailed evaluation of the climate implications of the scenarios, the model is further coupled with the climate module MAGICC6 [27]. Economic dynamics are calculated through inter-temporal optimization, assuming perfect foresight by economic actors. This implies that technological options requiring large up-front investments that have long pay-back times (e.g. via technological learning) are taken into account in determining the optimal solution. REMIND incorporates a detailed description of energy carriers and conversion technologies, including a wide range of carbon free energy sources as well as fossil and biomass conversion technologies in combination with carbon capture and storage. REMIND also represents trade relations and capital movements between eleven world regions, and also has a detailed representation of global markets for energy resources such as crude oil, coal and gas. Mitigation cost estimates thus take into account technological opportunities and constraints as well as macro-economic feedbacks and trade effects.

Table 6: Mapping of REMIND regions to SSP regions

Native Regions	**SSP Regions**
AFR	MAF
CHN	ASIA
EUR	OECD
IND	ASIA
JPN	OECD
LAM	LAM
MEA	MAF
OAS	ASIA
ROW	OECD
RUS	REF
USA	OECD
Abbreviations: AFR = Sub-saharan Africa excluding South Africa CHN = China EUR = EU27 IND = India JPN = Japan LAM = Latin America, also including Mexico	MEA = Middle East and North Africa, also including Central Asia OAS = Other Asia, also including Pakistan ROW = Rest of the world RUS = Russia USA = United States of America

[2] Relevant further resources, including a documentation of the equations, can be found on the REMIND webpage at https://www.pik-potsdam.de/research/sustainable-solutions/models/remind/

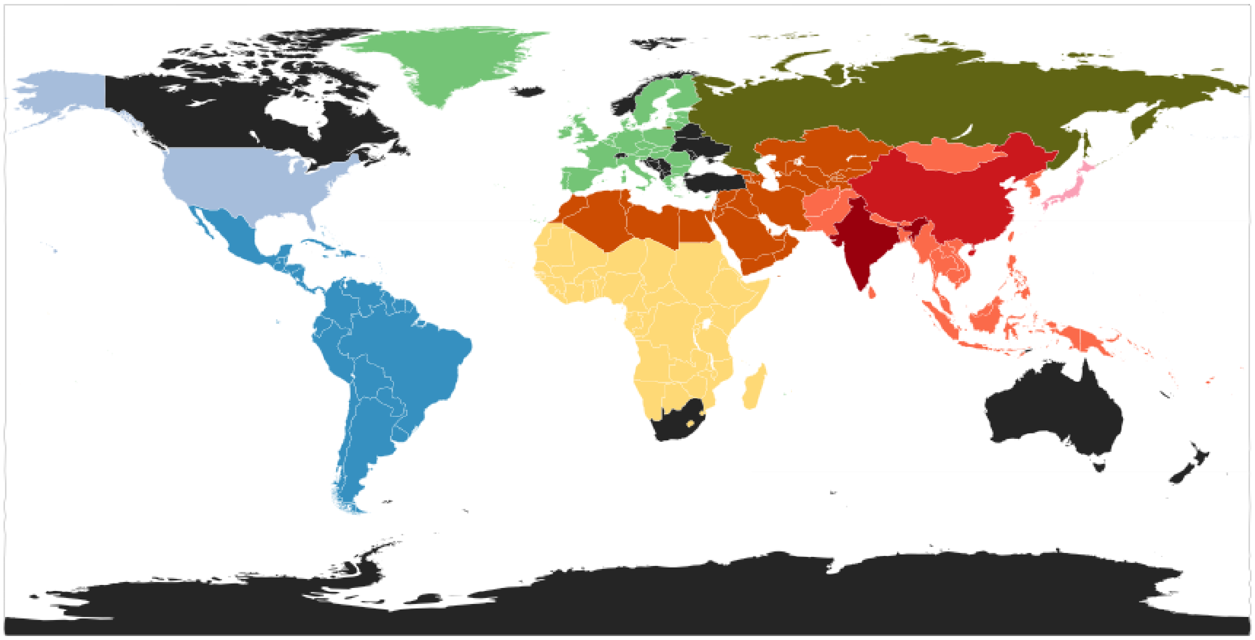

Figure 5: REMIND model regions

The **Model of Agricultural Production and its Impacts on the Environment (MAgPIE)** is a global multi regional partial equilibrium model of the agricultural sector [28-33]. MAgPIE links demand for 10 economic world regions with spatially explicit biophysical inputs such as land, agricultural yields and water availability. The objective function of MAgPIE is the fulfillment of regional demand at minimum global production costs (cost minimization). Costs accrue for labor, capital, transport, land conversion and R&D investments. For meeting the demand, MAgPIE endogenously decides, based on cost-effectiveness, about the level of intensification (yield-increasing technological change), extensification (land-use change) and production relocation (international trade). In climate policy scenarios, GHG emissions from land-use and land-use change are priced. The resulting cost term enters the objective function of MAgPIE, which provides an incentive for endogenous abatement of land-related GHG emissions. MAgPIE is solved in a recursive dynamic mode with a variable time step length of five or ten years on a timescale from 1995 to 2100.

REMIND and MAgPIE are coupled by exchanging price and quantity information on bioenergy and GHGs. First, REMIND is initialized with bioenergy supply curves and a GHG emission baseline derived from MAgPIE. Starting from this initialization, REMIND derives bioenergy demand and GHG prices consistent with a predefined climate target. MAgPIE takes bioenergy demand and GHG prices from REMIND as input and derives bioenergy prices and GHG emissions, which in turn serve as input for the next iteration of REMIND. REMIND and MAgPIE run iteratively until changes in prices and quantities of bioenergy and GHGs are sufficiently small.

Table 7: Mapping of MAgPIE regions to SSP regions

Native Regions	**SSP Regions**
AFR	MAF
CPA	ASIA
EUR	OECD
FSU	REF
LAM	LAM
MEA	MAF
NAM	OECD
PAO	OECD
PAS	ASIA
SAS	ASIA

Explanations:

AFR = Sub-Saharan Africa
CPA = Centrally planned Asia including China
EUR = Europe including Turkey
FSU = States of the former Soviet Union
LAM = Latin America
MEA = Middle East/North Africa
NAM = North America
PAO = Pacific OECD including Japan, Australia, New Zealand
PAS = Pacific (or Southeast) Asia
SAS = South Asia including India

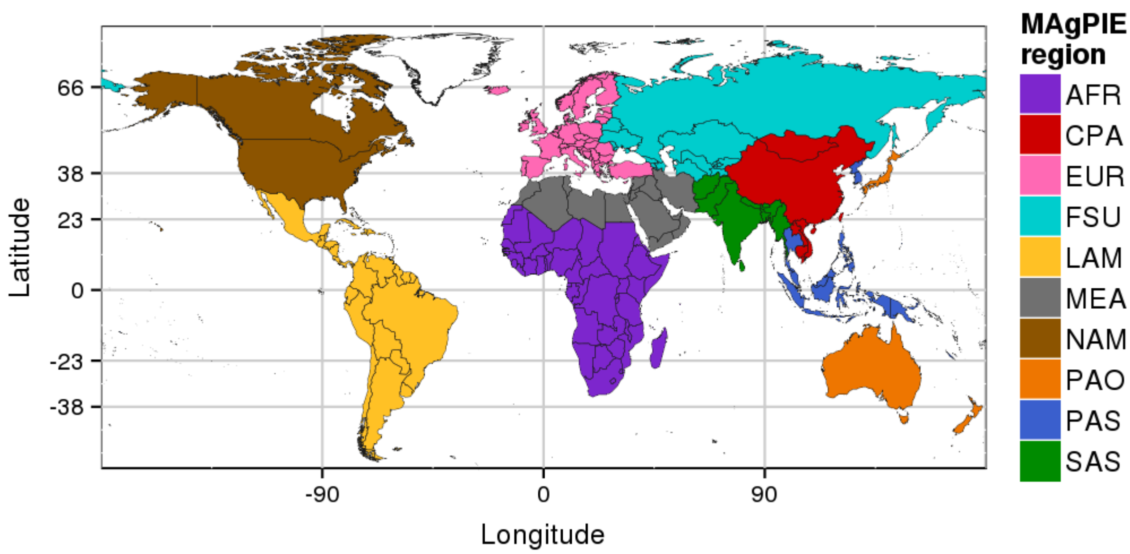

Figure 6: MAgPIE model regions

WITCH-GLOBIOM (FEEM)

The **World Induced Technical Change Hybrid** model **(WITCH)**, developed by the climate change modelling and policy group at FEEM [34,35] is a hybrid top-down economic model with a representation of the energy sector of medium complexity. Two distinguishing features of the WITCH model are the game-theoretic set-up, which is particularly useful for analyzing fragmented international policy settings, and the representation of endogenous technological change. World countries are grouped into thirteen regions. Innovation spills across regions in the form of knowledge, with important repercussions on the optimal R&D investments that major economic actors decide to undertake. WITCH is an inter-temporal optimization model in which perfect foresight prevails over a time horizon covering the whole century. The model includes a wide range of energy technology options with different assumptions on their future development related to the level of innovation effort undertaken by countries. Special emphasis is put on the emergence of carbon-free energy technologies in the electricity and non-electricity sectors as well as on endogenous improvements in energy efficiency triggered by dedicated R&D investments contributing to a stock of energy efficiency knowledge. WITCH is also coupled to the GLOBIOM model for the land-use sector and includes a module on air pollutant emissions. The full description is available at [36].

Table 8: Mapping of WITCH-GLOBIOM regions to SSP regions

Native Regions	**SSP Regions**
CAJAZ	OECD
CHINA	ASIA
EASIA	ASIA
INDIA	ASIA
KOSAU	OECD
LACA	LAM
MENA	MAF
NEWEURO	OECD
OLDEURO	OECD
SASIA	ASIA
SSA	MAF
TE	REF
USA	OECD

Explanations:

CAJAZ = Canada, Japan, New Zealand,
CHINA = China
EASIA = Southeast Asia
INDIA = India
KOSAU = Korea, South Africa, Australia
LACA =Latin America
MENA = Middle East, Northern Africa
NEWEURO = EU New Accession States
OLDEURO = EU 15
SASIA = South Asia, also including Pakistan, excluding India
SSA = Sub-Saharan Africa
TE = Russia, Eastern Europe, Turkey, Central Asia
USA = United States of America

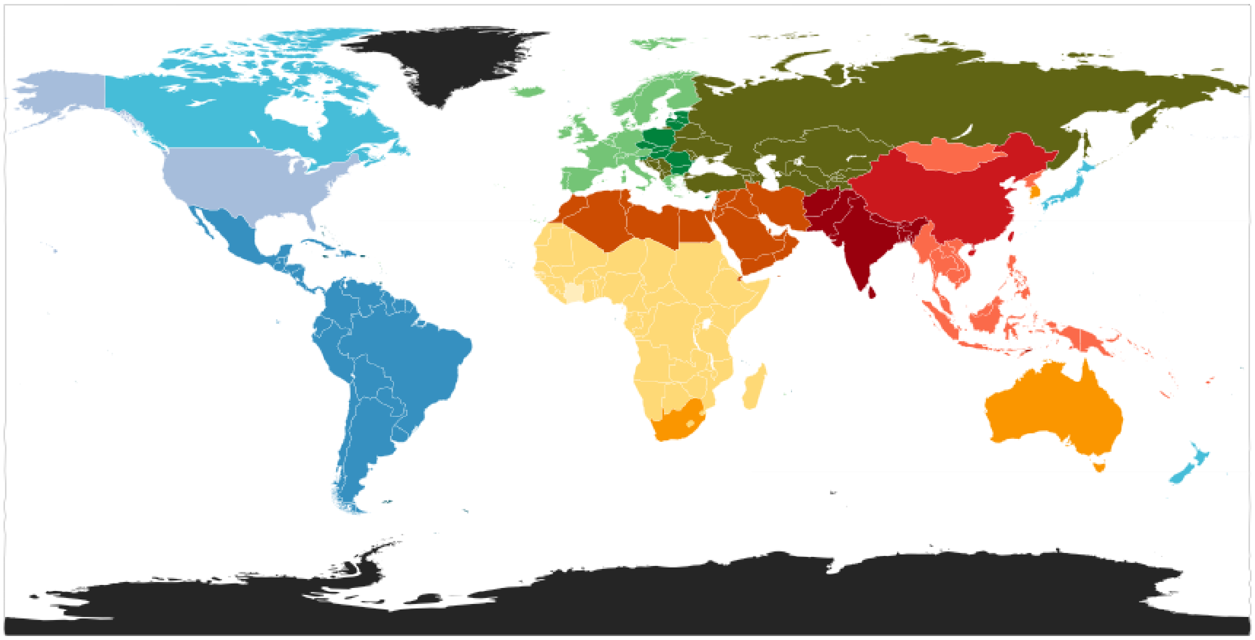

Figure 7: WITCH model regions

Air Pollution Inventories

The models report emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), organic carbon (OC), black carbon (BC), carbon monoxide (CO), and non-methane volatile organic carbons (NMVOC). The models use different inventories for base year calibration (Table 3.3.1) and the reported values are not harmonized to a single source. The SSP pathways represent internally consistent representations of future pollution development across the models and reflect institutional and technological constraints in implementation of pollution controls. They include in particular a catch up of all countries to reference target pollutant concentration levels in current OECD countries and an assumed development of pollution control technologies and aspirations over the century.

Table 9: Inventory Sources for Pollutants

Model	Base Year Inventories
AIM/CGE	EDGAR4.2 [37], RCP [38]
GCAM	EDGAR4.2, RCP
IMAGE	EDGAR4.2
MESSAGE-GLOBIOM	GAINS [39], RCP
REMIND-MAGPIE	GAINS, RCP, IPCC 2006 Guidelines for National greenhouse gas inventories [40], GFED3.1 [41]
WITCH-GLOBIOM	RCP

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