Snapshot of - GCAM

Archive of GCAM, version: 7.0

Contents

Reference card - GCAM

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	GCAM 7.0
Model link	https://github.com/JGCRI/gcam-core; http://jgcri.github.io/gcam-doc/toc.html
Institution	Pacific Northwest National Laboratory, Joint Global Change Research Institute (PNNL, JGCRI), USA, https://www.pnnl.gov/projects/jgcri.
Documentation	GCAM documentation consists of a referencecard and detailed model documentation
Process state	under review

Model scope and methods

Model documentation: Model scope and methods - GCAM

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

Objective

GCAM is an integrated, multi-sector model that explores both human and Earth system dynamics. The role of models like GCAM is to bring multiple human and physical Earth systems together in one place to shed light on system interactions and provide scientific insights that would not otherwise be available from the pursuit of traditional disciplinary scientific research alone. GCAM is constructed to explore these interactions in a single computational platform with a sufficiently low computational requirement to allow for broad explorations of scenarios and uncertainties. Components of GCAM are designed to capture the behavior of human and physical systems, but they do not necessarily include the most detailed process-scale representations of its constituent components. On the other hand, model components in principle provide a faithful representation of the best current scientific understanding of underlying behavior.

Solution concept	☐ Partial equilibrium (price elastic demand) ☐ Partial equilibrium (fixed demand)	☑ **General equilibrium (closed economy)** ☑ **GCAM solves all energy, water, and land markets simultaneously**
Solution horizon	☑ **Recursive dynamic (myopic)**	

☐ Intertemporal optimization (foresight)

Solution method

☐ Simulation
☐ Optimization
☑ **Recursive dynamic solution method**

Anticipation

GCAM is a dynamic recursive model, meaning that decision-makers do not know the future when making a decision today. After it solves each period, the model then uses the resulting state of the world, including the consequences of decisions made in that period - such as resource depletion, capital stock retirements and installations, and changes to the landscape - and then moves to the next time step and performs the same exercise. For long-lived investments, decision-makers may account for future profit streams, but those estimates would be based on current prices. For some parts of the model, economic agents use prior experience to form expectations based on multi-period experiences.

Temporal dimension

Base year:2015, time steps:5-year (default), minimum time step is 1-year, horizon: 2100

Spatial dimension

Number of regions:32 (default)

1. USA
2. Canada
3. Mexico
4. Australia_NZ
5. Japan
6. South Korea
7. EU-12
8. EU-15
9. European Free Trade Association
10. Europe_Non_EU
11. Europe_Eastern
12. Russia
13. China
14. Taiwan
15. Central Asia
16. South Asia
17. Southeast Asia
18. Indonesia
19. India
20. Pakistan
21. Middle East
22. Africa_Eastern
23. Africa_Northern
24. Africa_Southern
25. Africa_Western
26. South Africa
27. Argentina
28. Brazil
29. Central America and Caribbean
30. Colombia
31. South America_Northern
32. South America_Southern

Note: Dimensionality is flexible and can be expanded by adding additional information about regions. For example, a version of GCAM (GCAM-USA) exists with 82 regions that includes the 50

U.S. states, the District of Columbia and the remaining 31 non-US regions.

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 - GCAM

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 - GCAM

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)**

Macro-economy

Trade	☑ **Coal** ☑ **Oil** ☑ **Gas** ☑ **Uranium** ☑ **Electricity**	☑ **Bioenergy crops** ☑ **Food crops** ☐ Capital ☑ **Emissions permits** ☐ Non-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 ☐ Household size

☐ Education level

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 - GCAM

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

Grid Infra Structure

Electricity	☑ Yes (aggregate)	☐ Yes (spatially explicit)
Gas	☑ Yes (aggregate)	☐ Yes (spatially explicit)
Heat	☑ Yes (aggregate)	☐ Yes (spatially explicit)
CO_2	☑ Yes (aggregate)	☐ Yes (spatially explicit)
Hydrogen	☑ Yes (aggregate)	☐ Yes (spatially explicit)

Energy end-use technologies

Passenger transportation	☑ Passenger trains	☑ Passenger aircrafts
	☑ Buses	☑ CNG Buses
	☑ Light Duty Vehicles (LDVs)	☑ CNG Three-wheelers
	☑ Electric LDVs	☑ Diesel Three-wheelers
	☑ Hydrogen LDVs	☑ Electric Buses
	☑ Hybrid LDVs	☑ Electric Three-wheelers
	☑ Gasoline LDVs	☑ LPG/CNG LDVs
	☑ Diesel LDVs	
Freight transportation	☑ Freight trains	☑ Freight aircrafts
	☑ Heavy duty vehicles	☑ Freight ships
Industry	☑ Steel production	☐ Paper production
	☑ Aluminium production	☐ Plastics production
	☑ Cement production	☐ Pulp production
	☑ Petrochemical production	
Residential and commercial	☑ Space heating	☐ Refrigeration
	☑ Space cooling	☐ Washing
	☐ Cooking	☐ Lighting

Land-use

Model documentation: Land-use - GCAM

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
	☑ Agriculture food crops	☑ Agriculture non-food crops
	☑ Agriculture food livestock	☑ Agriculture non-food livestock
	☑ Agriculture feed	☑ Agriculture bioenergy
	☑ Agriculture feed crops	☑ Agriculture residues
	☑ Agriculture feed livestock	

- ☑ Forest industrial roundwood
- ☑ Forest residues
- ☑ Forest fuelwood

Agricultural commodities

- ☑ Wheat
- ☑ Rice
- ☑ Other coarse grains
- ☑ Oilseeds
- ☑ Sugar crops
- ☑ Ruminant meat
- ☑ Non-ruminant meat and eggs
- ☑ Dairy products

Emission, climate and impacts

Model documentation: Emissions - GCAM, Climate - GCAM, Non-climate sustainability dimension - GCAM

Greenhouse gases

- ☑ CO2 fossil fuels
- ☑ CO2 cement
- ☑ CO2 land use
- ☑ CH4 energy
- ☑ CH4 land use
- ☑ CH4 other
- ☑ N2O energy
- ☑ N2O land use
- ☑ N2O other
- ☑ CFCs
- ☑ HFCs
- ☑ 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

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	☐ Soil carbon enhancement
	☑ Reforestation	☐ Direct air capture
	☑ Afforestation	☐ Enhanced weathering
Climate change impacts	☑ Agriculture	☐ Economic output
	☐ Energy supply	☐ Built capital
	☑ Energy demand	☐ Inequality
Co-Linkages	☑ Energy security: Fossil fuel imports & exports (region)	**emissions**
	☑ Energy access: Household energy consumption	☐ Air pollution & health: Health impacts of air Pollution
	☑ Air pollution & health: Source-based aerosol	☑ Food access
		☑ Water availability
		☐ Biodiversity

Model Documentation - GCAM

GCAM is a global model that represents the behavior of, and interactions between five systems: the energy system, water, agriculture and land use, the economy, and the climate. GCAM has been under development for over 30 years. Work began in 1980 with the work first documented in 1982 in working papers (Edmonds and Reilly, 1982a,b,c)[1] [2] [3] and the first peer-reviewed publications in 1983 (Edmonds and Reilly, 1983a,b,c)[4][5][6]. At this point, the model was known as the Edmonds-Reilly (and subsequently the Edmonds-Reilly-Barnes) model. The model was renamed MiniCAM in the mid-1990s, the model code was re-written in object-oriented C++ (Kim et al. 2006)[7] and renamed to GCAM in the mid-2000s. The first coupling to a carbon cycle model was published in Edmonds et al. (1984)[8]. The first use of GCAM (MiniCAM at the time) in conjunction with a Monte Carlo uncertainty analysis was published in Reilly et al. (1987)[9].

Throughout its lifetime, GCAM has evolved in response to the need to address an expanding set of science and assessment questions. The original question that the model was developed to address was the magnitude of mid-21st-century global emissions of fossil fuel CO2. Over time GCAM has expanded its scope to include a wider set of energy producing, transforming, and using technologies, emissions of non-CO2 greenhouse gases, agriculture and land use, water supplies and demands, and physical Earth systems. GCAM has been used to produce scenarios for national and international assessments ranging from the very first IPCC scenarios (Response Strategies Working Group, 1990)[9] through the present Shared Socioeconomic Pathways (Calvin et al., 2017)[10]. GCAM is increasingly being used in multi-model, multi-scale analysis, in which it is either soft- or hard-coupled to other models with different focuses and often greater resolution in key sectors. For example, a range of downscaling tools have been developed for use with GCAM to be able to land and water outputs at a grid resolution. Similarly, it has been coupled to a state of the art Earth system model (Collins, et al.,

2015)[11]. Hundreds of papers have been published in peer-reviewed journals using GCAM over its lifetime and the GCAM system continues to be an important international tool for scientific inquiry. GCAM is also a community model being used by researchers across the globe, creating a shared global research enterprise. GCAM can be run on Windows, Linux, Mac, and high-performance computing systems.

The official documentation for GCAM can be found here (http://jgcri.github.io/gcam-doc/index.html).

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