Snapshot of - WITCH

Archive of WITCH, version: 5.0

Contents

Reference card - WITCH

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:

☐ <u>not</u> implemented

☑ **implemented**

☑ **implemented (not default option)**

About

Name and version   WITCH 5.0

Model link   https://www.witchmodel.org/; https://github.com/witch-team/witchmodel; https://doc.witchmodel.org

Institution   European Institute on Economics and the Environment (RFF-CMCC EIEE), Italy, http://www.eiee.org.

Documentation   WITCH documentation consists of a referencecard and detailed model documentation

Process state   published

Model scope and methods

Model documentation: Model scope and methods - WITCH

| **Model type** | ☐ Integrated assessment model | ☑ **CGE** |
| | ☐ Energy system model | ☐ CBA-integrated assessment model |

| **Geographical scope** | ☑ **Global** | ☐ Regional |

Objective   WITCH evaluates the impacts of climate policies on global and regional economic systems and provides information on the optimal responses of these economies to climate change. The model considers the positive externalities from leaning-by-doing and learning-by-researching in the technological change.

| **Solution concept** | ☐ Partial equilibrium (price elastic demand) | demand) |
| | ☐ Partial equilibrium (fixed | ☑ **General equilibrium (closed economy)** |

| **Solution horizon** | ☐ Recursive dynamic (myopic) | (foresight) |
| | ☐ Intertemporal optimization | ☑ **inter-temporal (foresight)** |

Solution method	☐ Simulation	☑ **Optimization**

Temporal dimension   Base year:2005, time steps:5, horizon: 2150

Spatial dimension   Number of regions:17

Time discounting type	☐ Discount rate exogenous	☐ Discount rate endogenous

Policies

☑ **Emission tax**	☑ **Capacity targets**
☑ **Emission pricing**	☑ **Emission standards**
☑ **Cap and trade**	☐ Energy efficiency standards
☑ **Fuel taxes**	☐ Agricultural producer subsidies
☑ **Fuel subsidies**	☐ Agricultural consumer subsidies
☐ Feed-in-tariff	
☐ Portfolio standard	☐ Land protection
	☐ Pricing carbon stocks

Socio-economic drivers

Model documentation: Socio-economic drivers - WITCH

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 - WITCH](#)

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	☑ **other**	

Note: A single economy sector is represented. Production inputs are capital, labor and energy services, accounting for the Energy sector split into 8 energy technologies sectors (coal, oil, gas, wind&solar, nuclear, electricity and biofuels).

Macro-economy

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

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

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

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 (process model)
	☑ **Yes (supply curve)**	

Conventional Oil	☐ Yes (fixed)	☑ **Yes (process model)**
	☐ Yes (supply curve)	

Unconventional Oil	☐ Yes (fixed)	☑ **Yes (process model)**
	☐ Yes (supply curve)	

Conventional Gas	☑ **Yes (fixed)**	☐ Yes (process model)
	☐ Yes (supply curve)	

Unconventional Gas	☑ **Yes (fixed)**	☐ Yes (process model)
	☐ Yes (supply curve)	

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

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 - WITCH

Energy technology substitution

Energy technology choice	☑ **No discrete technology choices** ☐ Logit choice model ☐ Production function	☐ Linear choice (lowest cost) ☐ Lowest cost with adjustment penalties
	☑ **Mostly high substitutability**	☐ Mostly low substitutability

Energy technology substitutability

☐ Mixed high and low   substitutability

Energy technology deployment

☑ **Expansion and decline constraints**   ☑ **System integration constraints**

Energy

Electricity technologies

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

Hydrogen production

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

Refined liquids

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

Refined gases

☐ Coal to gas w/o CCS   ☐ Oil to gas w/ CCS
☐ Coal to gas w/ CCS   ☐ Biomass to gas w/o CCS
☐ Oil to gas w/o 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)

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 ☐ 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 - WITCH

Land cover

☑ **Cropland** ☐ Cropland feed crops
☑ **Cropland irrigated** ☐ Cropland energy crops
☐ Cropland food crops ☑ **Forest**

☐ Managed forest   ☐ Shrubland

☐ Natural forest   ☐ Built-up area

☑ **Pasture**

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 - WITCH, Climate - WITCH, Non-climate sustainability dimension - WITCH

Greenhouse gases

☑ **CO2 fossil fuels**   ☑ **N2O land use**

☐ CO2 cement   ☑ **N2O other**

☑ **CO2 land use**   ☐ CFCs

☑ **CH4 energy**   ☑ **HFCs**

☑ **CH4 land use**   ☐ SF6

☑ **CH4 other**   ☐ PFCs

☑ **N2O energy**

Pollutants

☑ **CO energy**   ☑ **SO2 other**

☑ **CO land use**   ☑ **BC energy**

☑ **CO other**   ☑ **BC land use**

☑ **NOx energy**   ☑ **BC other**

☑ **NOx land use**   ☑ **OC energy**

☑ **NOx other**   ☑ **OC land use**

☑ **VOC energy**   ☑ **OC other**

☑ **VOC land use**   ☑ **NH3 energy**

☑ **VOC other**   ☑ **NH3 land use**

☑ **SO2 energy**   ☑ **NH3 other**

☑ **SO2 land use**

Climate indicators	☑ **Concentration: CO2**	☑ **Radiative forcing: Kyoto gases**
	☑ **Concentration: CH4**	☑ **Radiative forcing: aerosols**
	☑ **Concentration: N2O**	☑ **Radiative forcing: land albedo**
	☑ **Concentration: Kyoto gases**	
	☑ **Radiative forcing: CO2**	☑ **Radiative forcing: AN3A**
	☑ **Radiative forcing: CH4**	☑ **Radiative forcing: total**
	☑ **Radiative forcing: N2O**	☑ **Temperature change**
	☑ **Radiative forcing: F-gases**	☐ Sea level rise
		☐ Ocean acidification
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**
		☑ **Air pollution & health: Health impacts of air Pollution**
	☐ Energy access: Household energy consumption	☐ Food access
	☑ **Air pollution & health: Source-based aerosol**	☐ Water availability
		☐ Biodiversity

Model Documentation - WITCH

Introduction

WITCH (World Induced Technical Change Hybrid) is an optimal growth model of the world economy that integrates into a unified framework the sources and the consequences of climate change. A climate module links GHG emissions produced by economic activities to their accumulation in the atmosphere and the oceans. The effect of these GHG concentrations on the global mean temperature is derived. A damage function explicitly accounts for the consequences of temperature increases on the economic system.

Regions interact with each other because of the presence of economic (technology, exhaustible natural resources) and global environmental externalities. For each region, a forward-looking agent maximises its inter-temporal social welfare function, strategically and simultaneously to other regions. The inter-temporal equilibrium is calculated as an open-loop Nash equilibrium, or, a cooperative solution can also be solved by aggregating the welfare of each region. More precisely, the

Nash equilibrium is the outcome of a non-cooperative, simultaneous, open membership game with full information. Through the optimisation process, regions choose the optimal dynamic path of a set of control variables, namely investments in the main economic variables.

WITCH is a hard-link hybrid model because the energy sector is fully integrated with the rest of the economy and therefore investments and the quantity of resources for energy generation are chosen optimally, together with the other macroeconomic variables. The model can be defined hybrid because the energy sector features a bottom-up characterization. A broad range of different fuels and technologies can be used in the generation of energy. The energy sector endogenously accounts for technological change, with considerations for the positive externalities stemming from Learning-By-Doing and Learning-By-Researching. Overall, the economy of each region consists of eight sectors: one final good, which can be used for consumption or investments, and seven energy sectors (or technologies): coal, oil, gas, wind & solar, nuclear, electricity, and bio-fuels.

The official model documentation is available at [1] (http://doc.witchmodel.org)

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References

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