EU FP 6 Project
GOCE 037063 with DG Environment

GEO-BENE

Global Earth Observation
-Benefit Estimation: Now, Next and Emerging

STREP
PRIORITY [1.1.6.3]
[Global Change and Ecosystems]

DELIVERABLE D10 (T30)
DRAFT GEO-BENE SYNTHESIS REPORT

Due date of deliverable: T30

Start date of project: 1 July 2006 Duration: 36 Months

Organization name of lead contractor for this deliverable:
International Institute for Applied Systems Analysis (IIASA)

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Purpose of the Deliverable D10

It is the purpose of this report to respond to the GEO-BENE tasks described in WP 7000. According to WP7220 of the DoW of GEO-BENE **"WP 7220 Synthesis**: The main results of GEO-BENE assessment runs will be synthesized in a main report, destined for publication. …." And "**WP 7230 Review and Feedback Integration:** This WP will be implemented in two separate stages, an internal review of the synthesis report by the GEO-BENE consortium and subsequent feedback integration and a wider review process involving a selected pool of experts for external review and comments. It is proposed that the list of experts to involve in this external review be set up jointly by the European Commission, as the contractor, and GEO-BENE." Thus, the <u>draft</u> GEO-BENE Synthesis report serves the purpose of presenting the methodology of synthesis as well as the describing the baseline model structure allowing for synthesis. In essence we are describing the numerical model, calibrated for all SBAs, which will be used to carry out the integrated ex ante assessment of GEOSS. This document or even better the model per se will be used to carry out the work related to WP 7230. The review process shall be finalized for presentation at the ISRSE conference in Stresa.

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Table of Contents

Draft GEO-BENE Synthesis Report D9

1. GEO-BENE Project Goal

Global Earth Observations (GEO) may be instrumental to achieve sustainable development, but to date there have been no integrated assessments of their economic, social and environmental benefits.

The objective of the EC sponsored project "Global Earth Observation – Benefit Estimation: Now, Next and Emerging" (GEOBENE) is to develop methodologies and analytical tools to assess societal benefits of GEO in the domains of: Disasters, Health, Energy, Climate, Water, Weather, Ecosystems, Agriculture and Biodiversity.

2. Overview of GEOBENE integration methodology

According to the D3 Benefit Assessment Framework Report shot-gun as well as rifle results (Public GEOSS Benefit Assessment Data Base / GEO-BENE Benefit Assessment Data Base, see Deliverable D9) shall be integrated in the synthesis report. The methodology applied in the GEOBENE project assumes use of various quantitative and qualitative methods and data. This includes a number of computer models (shot-gun analysis) focusing on issues in particular Social Benefit Areas and a collection of region specific or global data (also historical) as well as results from other sources such as published literature or even anecdotal evidence. GEOBENE has decided to develop and apply a specialized tool to carry out such type of integrated assessment.

The data as well as the outcome of the computer models – be it simulation scenarios, results of optimization experiments – are used as an input to FeliX (**F**ull of **E**conomic-Environment **L**inkage and **I**ntegration d**X**/dt) system dynamics model. While the particular, detailed model and data focus usually on one specific Social Benefit Area, or specific countries or regions, the main purpose of the FeliX model is to integrate all these information into a global model. FeliX attempts to bring system perspective, where various issues are interconnected and constitute a complex system. A change in one area results in some changes also in other areas – for instance depletion of natural resources being a source of energy may constrain population growth but also put a pressure on agriculture sector in order to produce more energy crops as a substitute of such natural resources as oil or gas. The FeliX model is a dynamic model showing development of certain changes (e.g. depletion of natural resources, carbon dioxide emission) or impact of certain policies (e.g. afforestation, emission reduction) over time allowing for analysis of short and long-term effects. The high level view of the FeliX model main sectors and basic interconnection between the sectors are presented in Figure 1. Some of the model sectors and sectors interconnection are still under development. They should be finished by the end of the project.

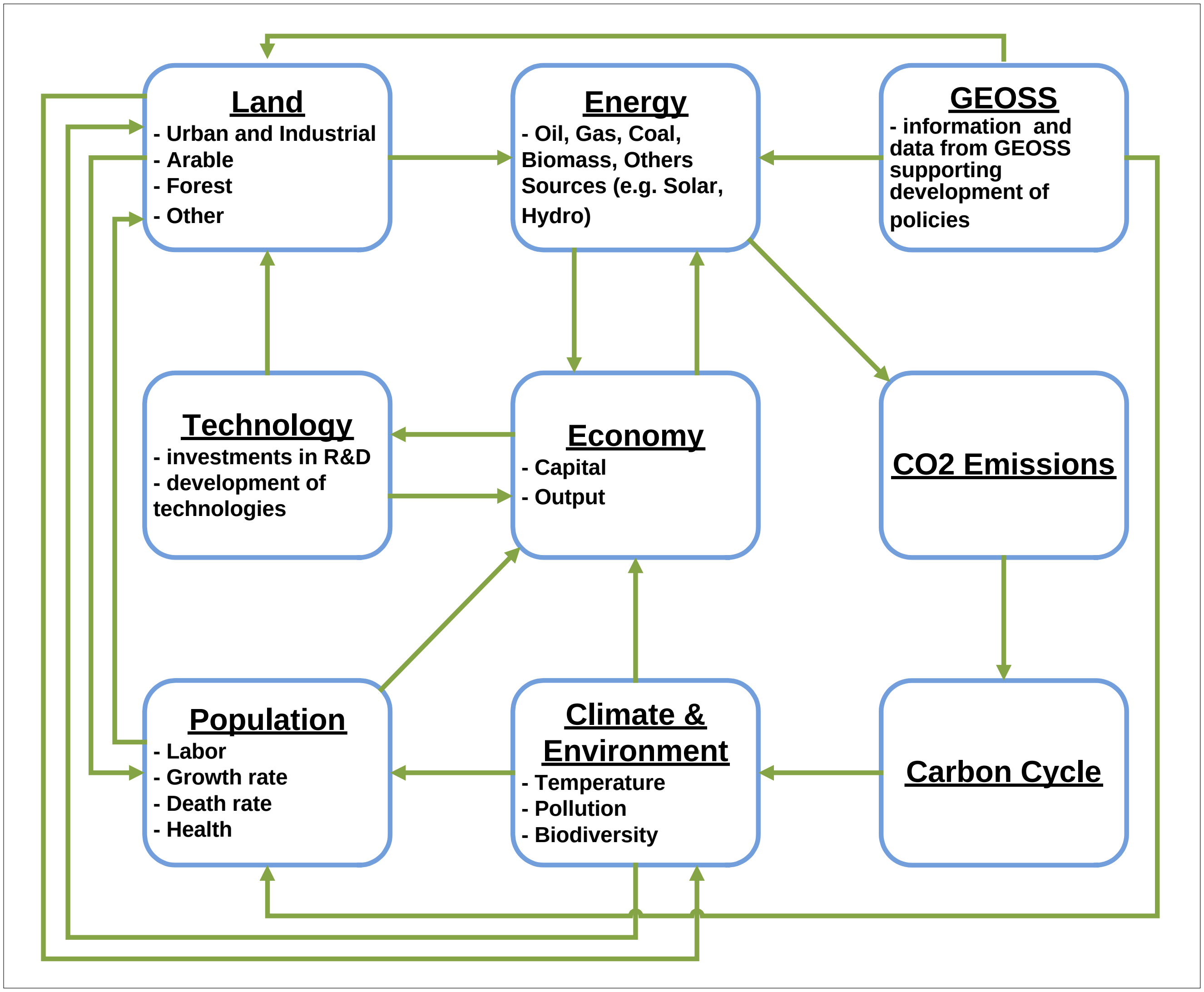

Figure 1 High-level view of the FeliX model

Social Benefits Areas (SBA) - Disasters, Health, Energy, Climate, Water, Weather, Ecosystems, Agriculture and Biodiversity – are inherently embedded into the model structure. Some of them are covered by a specific FeliX model sector, e.g. Population sector covers health issues. Others are addressed in a various FeliX model sectors, e.g. disasters are investigated in Land, Population and Energy sectors. If an SBA is covered by one model sector it does not mean that changes or benefits of GEO in that area are constrained only to this particular model sector, however. All model sectors are interrelated and the changes, outcomes of policies, or impact of GEO can propagate across the whole system as it is happening in the real world.
In order to estimate benefits of GEO there are run dynamic scenarios. There is assumed a direct impact of GEO (e.g. early warning systems) or impact of policies supported by data from GEOSS and the results of computer simulations are compared to the model base run. It follows the guidelines specified in Fritz et al. (2008).

Since the FeliX model is trying to integrate some other models and date, very often build using different techniques, there are places where certain issues had to be simplified or modified. Taking this into account there are also available results of benefits analysis in particular SBA's conducted at the level of particular detailed models. The FeliX model constitutes an overview of many thorough researches.

In order to make it easier for policy makers to deal with the FeliX model, allow them to test various policies and observe GEO benefits across various model sectors over time there will be prepared a user-friendly interface and a simulator.

The GEOBENE integration methodology can be illustrated as in Figure 2.

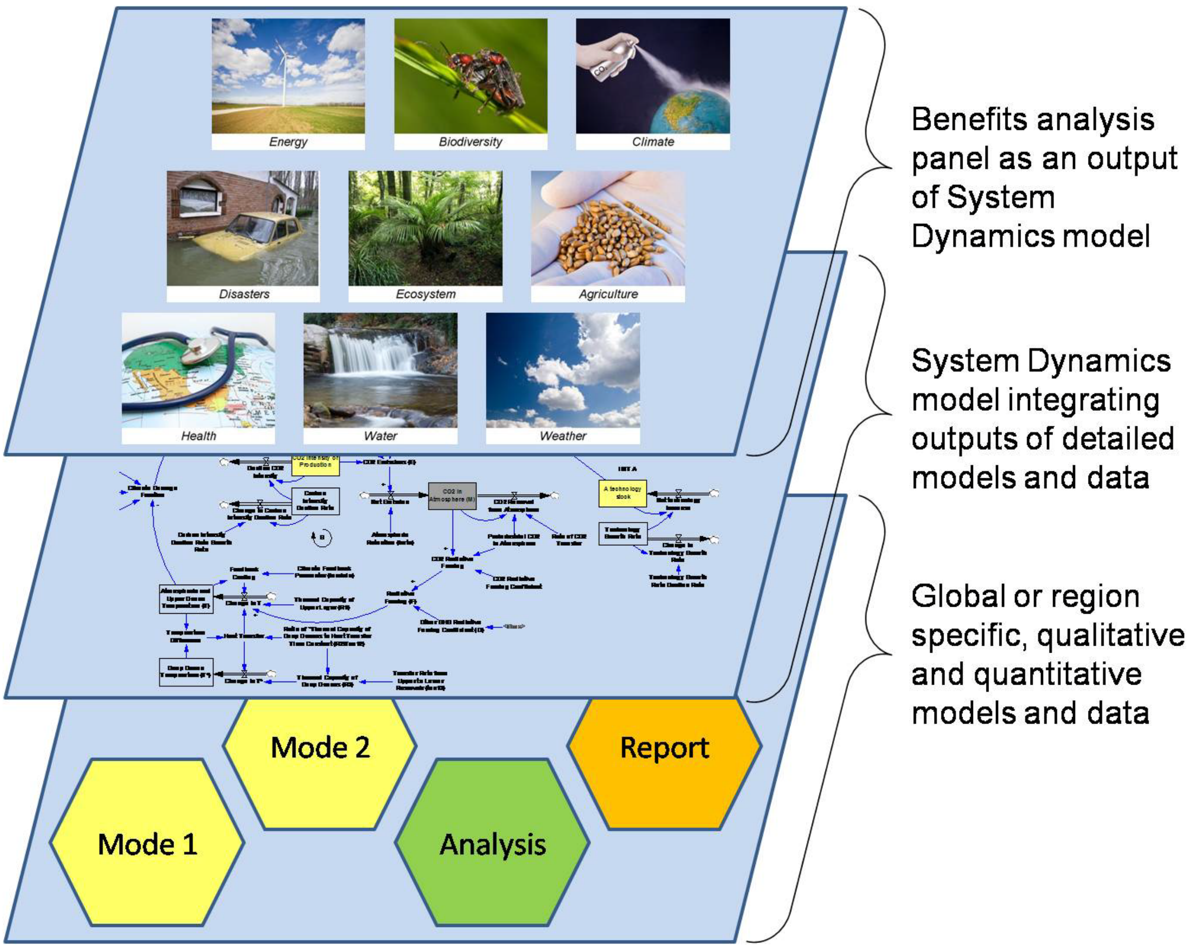

Figure 2 Overview of the GEOBENE integration methodology

3. Description of GEO-BENE models and data

The following list of Models should give and overview on the individual models used in an integrated model cluster for GEO-BENE. The model list indicates the objective of each model of the 15 models and is focusing at the key parameters such as input- and output parameters, scope, resolution, and the general modeling process.

The figure below gives a first glance-overview on the models used within the GEO-BENE approach and indicates their interactions.

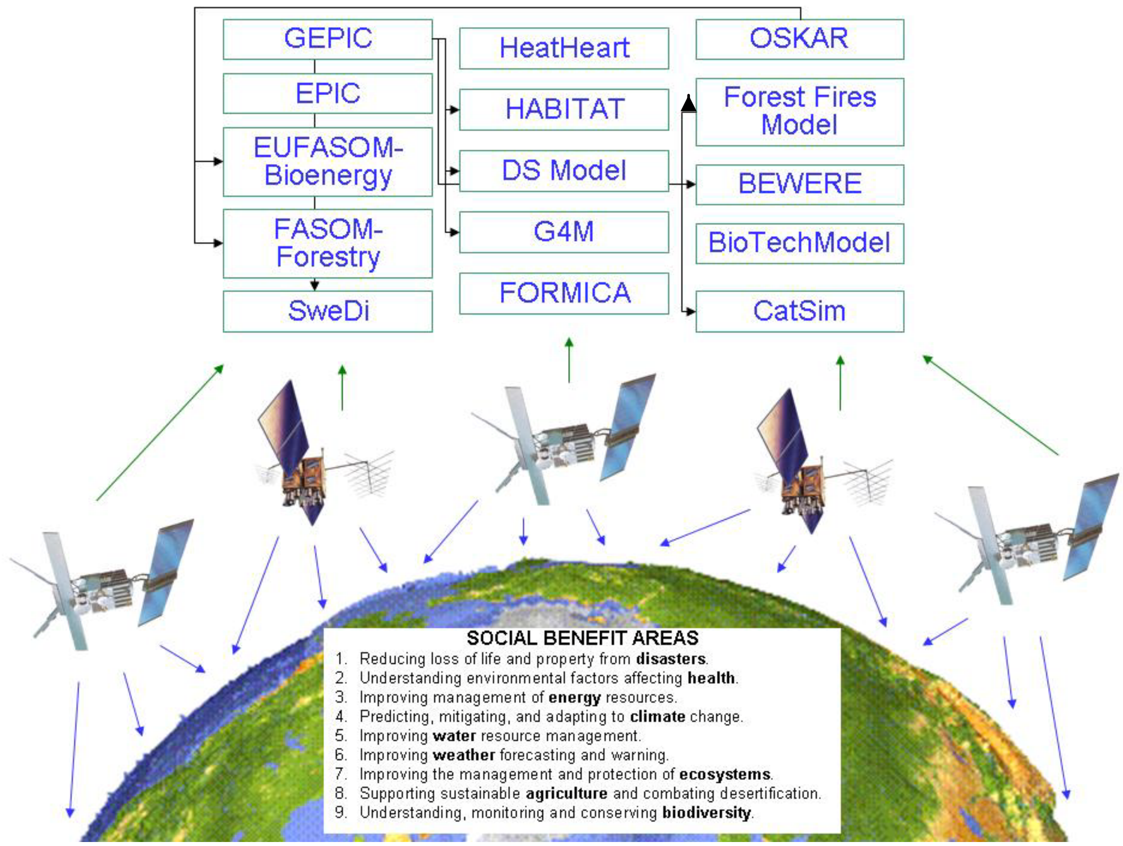

Figure: GEO-BENE Model Cluster and Interactions between the individual models

GEO-BENE Modeling							
	EPIC (Erwin Schmid, BOKU)	GEPIC (Junguo Liu, EAWAG)	EUFASOM-Bioenergy (Ivie Ramos, UHH)	FASOM-Forestry (Petr Havlik, IIASA)	SWeDi Model (Christine Schleupner, UHH)	HABITAT (Kerstin Janrke, UHH)	DS Model (Petr Havlik, IIASA)
	General focus	General focus				General focus	
scope	simulation of spatially and temporally explicit bio-physical impacts (e.g. crop yields, nutrient fate, carbon sequestration, sediment transport) of observed and alternative land use and management systems at regional and global scale.	Simulation of the spatial and temporal dynamics of the major processes of the soil-crop-atmosphere-management system	Long term assessment of the economic, technical and environmental potentials of energy crops in Europe under different market and environmental conditions and policies.	Evaluation of welfare and market impacts • of alternative policies for carbon sequestration • by forestry and agricultural land use in a long-term prospective.	Location of potential existing wetland distribution and spatial modeling of most suitable potential sites for wetland (re-)creation.	Estimation of habitat requirements for viable populations of European animal species under cost or area minimization objectives	Commercial biomass production (forestry, agriculture, bioenergy) and trade equilibrium in terms of prices, quantities and cultivated areas
resolution	spatial: Homogeneous Response Units (HRU) and Individual Simulation Units (ISU) that delineate representative weather-soil-topography-management systems at regional and global scales. temporal: daily time steps over hundreds of years if necessary.	Spatial: user-defined spatial resolution (flexible) Time: up to hundreds of years	Spatial: nuts 0 (EU-FASOM), Regional Time: 5-year periods, 150 years or even more	Spatial: nuts 0 (EU-FASOM), Continental regions (GLOBAL FASOM) Time: 5 years periods, 150 years or even more	Spatial, geographically explicit: EU-25, 1 ha / 1 km²	Spatial: EU 25; 50 km x 50 km grid cells Time: static, 1 period	Spatial: 11 GGI regions Time: Static model – 1 period

GEO-BENE Modeling							
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processes included	• crop growth • hydrology • weather simulation • nutrient cycling (NPKC) • pesticide fate • erosion	• Crop growth • Hydrology • Weather • Climate change • Nutrient cycling • Erosion	• Different uses of a given biomass options are investigated to indicate the optimal way of utilizing the biomass resource and determine the impacts of bioenergy production. • Social welfare, bioenergy and emission offsets maximization	Social welfare maximization by region: consumers maximize their utility and producers maximize their profits -> social welfare (discounted sum of consumer and producer surpluses less the transportation costs resulting from trade with the other regions) restricted by resources, capacity, budget and barriers of trade. Land is transferred in the model between sectors/type of land-use according to its marginal profitability in all alternative forest and agricultural uses included in the model, over the time horizon of the model. Harvesting decisions are endogenous Trade is included endogenously in the model, so that (net) export/import takes place whenever it is profitable	GIS-based model relying on geographical data of: • land cover • soil • DEM • potential natural vegetation • biogeoregions • climate	Cost or area minimization for biodiversity conservation. Ecological constraints reflect representation targets, area requirements for viable populations and habitat type requirements for all considered animal species. Independent (individual species, country-wise, taxon-wise) and joint conservation efforts can be addressed. Opportunity costs can be treated endogenously or exogenously.	Social welfare maximization: consumers maximize their utility and producers maximize their profits restricted by resources. Land is transferred in the model between sectors/type of land-use according to its marginal profitability in all alternative forest and agricultural uses included in the model. Trade is included endogenously in the model.
	Input	Input				Input	

GEO-BENE Modeling

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Parameters and initialization	• regional and global weather/climate change data (statistics) • regional and global soil data • regional and global land use data and representative crop rotations • regional and global topography data • regional and global crop management data (e.g. fertilization, irrigation, tillage)	• Historical daily climate data • Monthly statistical climate data • Land use • Soil parameters • Irrigation • Fertilizer application • Elevation • Future climate scenarios • Others	• Resource endowments, initial land use, production and processing technologies • Production data (planting, fertilizing, harvesting, transportation and delivery to the manufacturing plant from the farm gate) • Crop management options (tillage, irrigation, soil type, altitude and slope) and energy use (fuel consumption and mechanization) • Processing data (electricity, heat, biofuels) • Production and processing costs (labour, electricity, fossil fuel, chemicals, etc.) • Input from many models and data bases (EPIC, New Cronos, FAOstat, etc.)	• shape of the economic growth in each region (driving the demand for final forest products) • production costs (labour, electricity, fossil fuel, chemicals, etc.) • foreign exchange rates • future forest growth changes due to climate change • initial land use, production technologies and production structure/capacity for the land-use and forest industries in each region • initial and potential forest structure (land area, growing stock) • input from many models and data bases (OSKAR, EPIC, GTM, New Cronos, FAOstat…and many others)	• land cover: peatland, forests, grassland, agricultural land • wet and peaty soils • elevation • slope • average annual precipitation • mean temperature of coldest month • mean temperature of warmest month	• presence data of animal species for 2016 grid cells covering the European Union • cell areas; spatial arrangement of cells • population densities of species • proxies for minimum viable population sizes • required and optional habitat types • opportunity costs	• Baseline prices and quantities of considered products • Supply and demand elasticities • Ressource requirements (land, water,…) • Production cost • Transformation cost • Transport cost • Conversion coefficients from primary to final products • Initial land use

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	Output	Output				Output	
Variables	• crop yields • hydrology (PET, runoff, percolation) • sediment transport • N-leaching • green house gases • soil carbon sequestrations	• Crop yield • Crop water use • Potential crop yield • Nutrient cycle • Erosion • Hydrological cycle in cropland	• Prices and harvested quantities of energy crops for each period and country • Different land use options (willow, miscanthus, switchgrass, RCG, etc) • Different end product technologies (electricity, heat, biofuels, biomaterials, etc) • GHG emissions • Scenarios for different product, energy and carbon prices	• prices and harvested quantities (for each period and region) for the agricultural products, for timber (wood fibre), for forest products, and for recycled papers • type of land utilization, land transfer between agriculture and forestry, investments in agriculture and forestry primary production, new forest industry production capacities. • transport quantities from/to each region and total use per 5-year period of production inputs (labor, electricity, bio-energy, fossil fuel) for each region • GHG emissions • forest-, agricultural and bio-energy sector are modeled	• spatial explicit location and size of different wetland types → peatland: fens and bogs → wetforests: alluvial and swamp forests → wetgrasslands on non-peaty soil (reeds and sedges) • connectivity between wetland types • quality of the neighborhood of different wetlands	Area requirement • per cell • per country • per habitat type • Yearly opportunity costs per country	• supply and demand quantities • equilibrium prices • volumes traded between the regions • land use change • water consumption
	Current status	Current status	Current status			Current status	

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	delineation of homogeneous response units (HRU) at global scale developing and testing a prototype of the global data-modeling infrastructure for Europe building the global database (weather, soil, topography, crop management) for global EPIC simulations at HRU scale	Modeling of crop yield and crop water productivity for major crops on a global scale Modeling consumptive water use of 17 major crops on a global scale Simulating the role of irrigation in wheat production in China	Projections for the economic, technical and emission offset potentials (present to future) for willow in Sweden included.		Wetland distribution modeling is completed. Suitability Assessment is under construction.	69 animal species and 5 wetland habitat types included Modeling of area and constant cost minimization scenarios for the EU 25	Forestry and crop production including irrigation – near to validation Bioenergy and livestock sectors in progress
	Potential extensions, future plans?	Potential extensions, future plans?	Potential extensions, future plans?			Potential extensions, future plans?	
	linking with Global- FASOM and BEWHERE by providing spatially and temporally explicit bio-physical impact vectors. analyze the bio-physical impacts of alternative agricultural management systems (e.g. tillage systems, precision farming, etc.). simulation of climate change impacts using a statistical approach.	• Study the impacts of climate change on crop production and consumptive water use • Study global nutrient cycle • Produce potential crops yields for BEWHERE	• Incorporate the effect of changing the plant size on the carbon emissions/savings • Include other energy crops • Include other conversion technologies • Can be integrated in higher scope models including multi-sector energy models, and/or earth system models	• calibration (forest) • including of water • bio-energy (including bio-fuels) • data mining for global FASOM • any many more features	• integrate results into EU-FASOM • integrate results into Habitat Model • include Climate Change parameter for bogs • apply spatial model to other biotopes	• Implementation of existing habitat and convertible sites • Interlinkage to EU-FASOM	• Supply curves derived on the basis of biophysical models like G4M and EPIC • Alternative forest, crop, livestock managements • Introduction of environmental parameters like GHG emissions and food security parameters • Improved spatial resolution based on “homogeneous response units”
	Potential contribution to IIASA projects	Potential contribution to IIASA projects				Potential contribution to IIASA projects	

GEO-BENE Modeling							
	EPIC (Erwin Schmid, BOKU)	GEPIC (Junguo Liu, EAWAG)	EUFASOM-Bioenergy (Ivie Ramos, UHH)	FASOM-Forestry (Petr Havlik, IIASA)	SWeDi Model (Christine Schleupner, UHH)	HABITAT (Kerstin Janrke, UHH)	DS Model (Petr Havlik, IIASA)
	linkages to • Global FASOM • BEWHERE • improve, extend and validate the 'global database' • promote integrative analysis (i.e. bio-physical and economic analysis)	• Simulate crop yield and water use of major crops on a global scale (as inputs to other models) • Simulate the impacts of climate change on crop yield and crop water requirement • Produce potential crops yields for BEWHERE			•		• Global evaluation of economic potentials for forestry, agricultural and bioenery sectors production and their mutual competition including the environmental and food security impacts • Input to other models (BEWHERE, G4M) in terms of equilibrium production quantities and prices
	General evaluation	General evaluation				General evaluation	

GEO-BENE Modeling							
	EPIC (Erwin Schmid, BOKU)	GEPIC (Junguo Liu, EAWAG)	EUFASOM-Bioenergy (Ivie Ramos, UHH)	FASOM-Forestry (Petr Havlik, IIASA)	SWeDi Model (Christine Schleupner, UHH)	HABITAT (Kerstin Janrke, UHH)	DS Model (Petr Havlik, IIASA)
strengths	• spatially and temporally explicit bio-physical impact vectors • simulation of a large set of alternative crop management options. • simulation of bio-physical processes • model flexibility and robustness	• Spatial explicit • Scope: global, national or local • Flexible resolution (but may limited to computing expense) • Powerful functions in food-water-environment-climate study • Widely validated	• Different types of land use and product options are included • Competition for land between agriculture, forestry, biodiversity, livestock and bioenergy are endogenously modeled • Biomass and bioenergy trade included • GHG emissions from various land use options and production/ processing activities are calculated	• incorporation of agriculture and forestry so that the competition for land between agriculture and forestry is endogenously modelled • biomass trade, this might prove important in many countries • track of the GHG emissions from the various land-use and production/consumpt ion activities included in the model. • is designed to work on the forest and/or agricultural sector either independently or simultaneously. (study sector issues either independently or across the two sectors)	• geographical explicit • high spatial resolution for existing wetlands • distinction of different wetland types • easily applicable and transformable to other applications	• Adaptable to different areas, habitats, and taxons • Based on ecological principles; not based on existing nature reserve system • Implicitly integrates many ecological constraints via historic occurrence data • Combination/comparison of cost and area minimization objectives • Linkage to land-use models possible (conservation as a further land-use option)	• Global scope • Comprehensive in terms of the principal land use sectors • Simple structure → tractable results

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weaknesses	• insufficient data to rigorously validate model outputs at global scale • large demands (quantitatively and qualitatively) on input data for EPIC • long modeling experiences	• Mainly focused on the natural, physical, and management factors, but insufficient on the economic aspects • Not possible to directly study the effects of food policies and agricultural research investment on crop production	• see FASOM-Forestry entry	• huge set of data input • perfect foresight • FASOM approach is working on 5-years time steps -> misleading agricultural results • FASOM is not fully operational yet. • FASOM is still not tested much in practice and programming bugs may exist (large EUFASOM versions contain 6 millions variables and more than 600 000 equations).	• uncertainties in source data • source data limit scale for potential convertible sites • underrepresentati on of small running waters due to scale reasons	• Not based on existing reserve system • CPU intensive • Validation not done yet	• For the moment: very rough spatial resolution

GEO-BENE Modeling							
	G4M (Georg Kindermann, IIASA)	FORMICA (Hannes Boettcher, IIASA)	OSKAR (Oskar Franklin, IIASA)	Forest Fires Model (Nikolay Khabarov, IIASA)	BEWHERE (Sylvain Leduc, IIASA)	BioTechModel (Barbara Hermann, IIASA)	CatSim (Stefan Hochrainer, Reinhard Mechler, IIASA - RAV)
				General focus		General focus	
scope	• Afforestation/Deforestation • Forest Biomass • Harvestable Wood	C budget model of managed forests and adjacent forestry sector	Estimation of biomass, dead wood, harvests and costs for different forestry scenarios (thinning, species, climate change) .	Evaluation of weather observations accuracy impact on • burned forest area • air patrolled area • fire impact on population based on application of forest patrolling rules.	Calculation of the optimal location of bio-fuel (methanol) power plants, given the biomass distribution	Calculation of techno-economic characteristics and greenhouse gas emissions (and non-renewable energy) of bio-chemicals production	Calculation of financial vulnerability and macroeconomic risk due to natural disaster events
resolution	Spatial: Global 30’×30’ Time: 1 year	Spatial: not geographically explicit, adjustable, plot level to regional scale Time: 1 year	Spatial: not geographically explicit, adjustable, plot level to regional scale. Time: 1 year (flexible)	Spatial: regional, depending on the area covered by the underlying weather dataset Time: 1-5 years (non-predicting) The model uses internally daily resolution, and aggregates it into yearly descriptive statistics.	Spatial: Biomass and demand input 1km2, power plants: variable Time: as many periods as one wants (depending on the forecast data)	Spatial: not geographically explicit, Time: 2 time steps, current and future technology levels	National scale, NUTS3 Time: Usually 5 and 10 year time periods into the future

GEO-BENE Modeling							
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processes included	Decision of afforestation or deforestation based on Net Present Value of forestry and alternative land use, Increment based on NPP	• Biomass, products, soil (YASSO), substitution • Forest growth species specific, derived from yield tables, transformed to relative growth curves • Standing volume from national forest inventories • Age class information from inventories • Forest Management (FM): different thinning regimes, harvest after prescribed schedule; sustainable forestry (annual allowable cut) • Simple economic model to calculate NPV • Calculation on plot level for different strata (age-class, species type, management), regional aggregation by multiplication with area of each stratum	Predicts growth, density, selfthinning and harvests in response to: • species • initial biomass • initial density (trees per ha) • productivity (from NPP model or inventory) • thinnings and changes in density (assigns an optimal thinning sequence for a specified % removal)	• weather observations • air patrolling • fire occurrence • fire spread Daily weather observations are translated into *Nesterov index* on which, in turn, both, the *fire probability* and the *patrol regime* depend. The fire occurs according to this probability and is detected by the patrol. The spread of the fire depends on the time between the occurrence and the detection, and on the average speed of fire only. The losses are proportional to the fire spread and population density.	• available biomass • demand grid points • transportation cost • power plants set up costs • efficiency of power plants • capacity of power plants • fossil fuel price (for competition)	• chemical plants capital costs • two distinct levels of technology: current and future (ca. 2030) • capacity of power plants • fossil fuel price (for competition) • GHG balance for chemicals production	• Economic growth model • Sollow type • Capital stock as stock losses due to damage • Furthermore indirect losses which translate into macroeconomic losses • Econometric parameter estimates from historical time series
				Input		Input	

GEO-BENE Modeling

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Parameters and initialization	• Net Primary Production • Development of population density • Development of the buildup land • Minimum of agricultural land which is needed for food • production • Agricultural suitability • Price-level of the region • Initial forest biomass • Initial forest area • Discount rate • Protected land area • Current amount of fuel wood production • Corruption of the region • Discount rates • Prices of land, afforestation, carbon and wood	Turnover rate Non-woody litter Fine-woody litter Coarse-woody litter Management mortality Max volume Thinning first year Thinning interval Thinned fraction Harvest age Harvested fraction Fraction to slash Fraction to sawn-wood Fraction to pulp wood Fraction to energy wood Product MRT Recycling rate Energy substitution factor Product substitution factor Costs Revenue Stem volume Soil • soluble • holocellulose • lignin-like • humus1 • humus2 Products sawn-wood • pulp wood • energy wood	Fixed species specific parameters (growth and thinning response) parameterized from yield tables and thinning studies A sub-model estimates initial values for growth rate, density and dead wood from inventory data (done for each cohort)	• daily gridded data - temperature - humidity - precipitation • average fire spread rate • response/extinguishing time • ignition probability (currently based on population density) • fire probability under given weather conditions • number/location of in situ weather stations • satellite/in situ data resolution	• biomass and demand grid points, • amount of biomass, • amount of fuel demand • capacity and efficiency of a methanol plant	• 3 types of biomass input: starch, sugar or lignocellulosics • Fixed output/capacity (100 kt chemical per year) • Exogenous biomass prices • Current or future technology level (static) • production costs (labour, electricity, additives • land-use per type of biomass included • waste management (incineration with or without energy recovery, digestion) •	• Can be distinguished between hazard parameters, resilience and economic parameters • Hazard parameters: return loss periods or loss distribution functions, e.g. extreme value distributions, • Economic parameters: Total capital stock, fixed budget investment of government, growth rates • Resilience parameters: Different financing instruments and mitigation measures the government can set to finance the losses • Portfolio selection of optimal investments possible

GEO-BENE Modeling							
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				Output		Output	
Variables	• forest biomass • forest area • deforested area and carbon from these deforestation • afforested areas • harvestable wood • current rotation time • increment optimum rotation time • age-class distribution of forests	carbon stocks • biomass • soil • products other C services (C substituted) revenues costs NPV age-class distribution	• forest biomass • harvestable wood • harvested wood (thinnings and final harvests) • optimal harvest ages • dead wood carbon • costs of planting , thinning and harvests	• burned area • patrolled area • fire impact on population index (both summary statistics and/or simulated probability distributions)	spatial explicit location and size of methanol power plants	• Price of chemicals • Greenhouse gas balance and non-renewable energy use for chemicals 1) leaving the chemical plant and 2) after waste treatment (incineration with energy recovery) • Scenarios for different oil prices (static, trend to be extrapolated?)	• Return on investment • Discount rates • Depreciation rates • Capital stock rates • Fixed budget • XL pricing (within) • Response variables include probability of financing gap, expected financing gap, Credit buffer drop, • Output uncertainty handled through confidence intervals
				Current status		Current status (August 2007)	Current status

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	G4M (Georg Kindermann, IIASA)	FORMICA (Hannes Boettcher, IIASA)	OSKAR (Oskar Franklin, IIASA)	Forest Fires Model (Nikolay Khabarov, IIASA)	BEWHERE (Sylvain Leduc, IIASA)	BioTechModel (Barbara Hermann, IIASA)	CatSim (Stefan Hochrainer, Reinhard Mechler, IIASA - RAV)
	Model core from DIMA Age/Size dependent increment more or less ready	Parameters and other input currently available for Thuringia, Germany, Europe (not economic part)	Parameterized for all species in Europe. Simulations done for a multitude of scenarios for the EU 25 countries (INSEA). High geographic resolution estimates of productivity for Sweden under way (methanol project)	Weather data (re-modeled) is currently available for Europe (finer resolution is needed), forest patrolling strategy currently implemented is based on Russian rules and for more realistic results needs to be adjusted to local conditions.	Building mill beaver for forest industry (optimal location of the mills with import and export of biomass and forest products)	Modeling of biomass conversion to chemicals is completed.	Based on country case studies the feasibility of general global maps is tested. Under process for Austria.
				Potential extensions, future plans?		Potential extensions, future plans?	Future plans
	• bring it to a stable “user friendly” version • increasing resolution to 30”×30” • include slope • dynamic NPP–Model	Model applications • calculation of plot and regional level mitigation potential of various FM and land-use options (including land-use change) • global technical/biological potential of FM to mitigate Climate Change Technical development • strengthen economic part of the model • include disturbances (like in CBM-CFS, Canada)	• When there is interest: It can be converted from scenario production to real time (ultra fast) productivity response functions (to thinning intensity, species, climate etc.). This could then be integrated with economic optimization models. • A spatially explicit productivity estimation version for Sweden is now being developed.	Introduction of more randomness into the model (response times, fire spread rates); improvement of the fire spread model to account for wind conditions; introduction of heterogeneous forest.	• bio-energy power plants, including side-products • refining the calculation of transport • linking to other models	• link up with BEWHERE model, • extend BEWHERE modeling to link up to EPIC agricultural data • possible to include more ‘real’ materials, e.g. fibres • pre-treatment technologies will have to be aligned with other models (esp. economics)	• Dependent on the case studies a sectorial approach is developed • Possibility to go on more regional scales,
				Potential contribution to IIASA projects		Potential contribution to IIASA projects	

GEO-BENE Modeling							
	G4M (Georg Kindermann, IIASA)	FORMICA (Hannes Boettcher, IIASA)	OSKAR (Oskar Franklin, IIASA)	Forest Fires Model (Nikolay Khabarov, IIASA)	BEWHERE (Sylvain Leduc, IIASA)	BioTechModel (Barbara Hermann, IIASA)	CatSim (Stefan Hochrainer, Reinhard Mechler, IIASA - RAV)
	GeoBene • Downscaled forest biomass map • Slope derived from 3”×3” DEM–Map WWF • Potential biomass production • Existing forest biomass stock • Potential forest biomass stock • Find forests with deforestation pressure		WWF (or wherever European forest development and production is of interest): • Already calculated time series of production, dead wood and carbon potential for all European regions and species. (all forest cohorts included in inventories)	Directly related to GEO-BENE. Hopefully it could be also the basis for the global forest fires model.			
				General evaluation		General evaluation	

GEO-BENE Modeling							
	G4M (Georg Kindermann, IIASA)	FORMICA (Hannes Boettcher, IIASA)	OSKAR (Oskar Franklin, IIASA)	Forest Fires Model (Nikolay Khabarov, IIASA)	BEWHERE (Sylvain Leduc, IIASA)	BioTechModel (Barbara Hermann, IIASA)	CatSim (Stefan Hochrainer, Reinhard Mechler, IIASA - RAV)
strengths	• easy approach • modular • robust	• flexible: adjustable to different scales (stand to regional, probably also global) and crops • optimally used for sector analysis on the regional level • uses data that is often available (inventories)	• predicts biomass AND DENSITY sound modelling of thinning effects (and harvests, costs and dead wood) • based on globally applicable biophysical principles and species characteristics. -easily calibrated and adaptable to different scales and areas • flexible productivity input inventory data or NPP model (e.g.LPJ) • fast	• Clarity (is easy to understand and implement) • Explicitly reflects physical processes • Explicitly connects the increase in quality of observations with benefits • Allows modeling of interaction of satellite and in situ systems • Although involves numerical simulation, is relatively fast to run. (1000 simulations in approx. 30 min)	• very robust model • simple, but powerful • geographical explicit • exogenous prices	• Comparable results for different chemicals • Different types of biomass • Incl. current and future technologies • Any biomass price can be used • CO2 and energy balance including or excluding biomass production and pre-treatment	• Treats probability and flow effects explicitly rather than only looking at stock effects and discrete event scenario analysis • Adaptation is treated as important decision variable for the government financial vulnerability yet and in the future.
weaknesses	• still not finished • validation • slow	• global application is CPU intensive (only possible by region, e.g. US, Europe etc.) • prescribed management only, no optimization • so far no experience on applicability without inventory information • besides C and economy no other impacts of forest management	• no fire and insects • aggregated productivity does not differentiate water and temp effect on different species. • can only be run by oskar	• Relatively rough since it does not account for - different types of trees - fuel load - wind conditions • The rule set is specific to Russia and its adaptation to local conditions may require substantial efforts.	• exogenous prices • no land-use change	• based on Europe (no differentiation between countries) • not yet geographically explicit • standard plant size (though some data on other sizes for sensitivity analysis)	• Economic model has to built very general, however, modulare structure of the model gives the opportunity to test it for specific areas for calibration

	HeatHeart Model (KTL)	Real Options Modeling (Fuss/Szolgayova, IIASA)	Portfolio Optimization (Fuss/Szolgayova/Khabarov, IIASA)	Earthquakes Model (Khabarov, Moltchanova, Bun IIASA/KTL)	Landslide Model (Khabarov,Huggel IIASA/UZH)	Tsunami Model (Khabarov IIASA)	Meningitis-Malaria Vacination Modeling (Chladna, UBR/Moltchanova, THL)
	General focus	General focus	General focus				
scope	Evaluation of the role of weather forecast on the possible prediction of heart attack rate.	Analysis of investment under uncertainty with applications to the timing of satellite missions, transitions between energy regimes and optimal rotations under fire risk. Computation of value of information/observation.	Optimization of energy technology mix under uncertainty (e.g. about emissions regulations due to lack of information on climate sensitivity). (1) Comparison of energy mix (associated return on investment & emissions) in different scenarios. (2) Computation of energy mix robust across all scenarios and associated economic losses.	Measurement of the value of information for rescue operations in the aftermath of an earthquake. Both local and global scales are covered.	Measurement of the value of information for landslide early warning systems on local scale.	Measurement of the value of information for tsunami early warning systems on local scale.	Optimization of vaccination strategy with case study to meningococcal meningitis in Sahel region while taking into account the possible correlation of epidemics with dust storms.
resolution	Spatial: city-specific (other modifications possible) Temporal: 1-day, seasonal components - yearly	Temporal: decisions can be made on a yearly basis. Spatial: plant-specific	Spatial: aggregate energy sector or large energy company within energy sector. Temporal: ad hoc decision.	Temporal: using historical data and projection for a time frame of 30 years. Spatial: input datasets use different resolutions, the average resolution is 0.1 arc-degrees.	Temporal: the assessment is performed for a 10-year timeframe. Basic precipitation dataset has 6 hours temporal resolution. The model is not spatially explicit.	Temporal: the wave arrival time is calculated with a few minutes accuracy. Spatial resolution depends on a particular bathymetry data (e.g. current application uses 20km bathymetry grid)	Temporal: discrete one-week increments. The model is not spatially explicit.
processes included	Daily weather and it's possible effect on the incidence of AMI	Energy applications: price processes (fuel, electricity, CO2 permit price) Satellite missions: Benefit streams estimated from avoided losses Optimal rotation: Poisson-distributed fire occurrence, stochastic biomass price process.	Stochastic price processes (CO2 price of e.g. permits, electricity price)	Observation and damage assessment (related errors), rescue resources distribution, stochastic damage to the building stock.	Observation (modeled errors) of the accumulated rainfall, landslide occurrence, decision making rules for optimal evacuation.	Wave travel from a tsunamigenic source to a settlement using bathymetry data. Detection of tsunami waves for issuance of early warnings. Optimization of the tsunami detectors network configuration.	• Epidemics based on susceptible-infected-recovered mechanism • Annual dust storm events
	Input						

	HeatHeart Model (KTL)	Real Options Modeling (Fuss/Szolgayova, IIASA)	Portfolio Optimization (Fuss/Szolgayova/Khabarov, IIASA)	Earthquakes Model (Khabarov, Moltchanova, Bun IIASA/KTL)	Landslide Model (Khabarov,Huggel IIASA/UZH)	Tsunami Model (Khabarov IIASA)	Meningitis-Malaria Vacination Modeling (Chladna, UBR/Moltchanova, THL)
Parameters and initialization	• weather conditions: temperature, pressure, wind speed, precipitation, etc • disease incidence: number of recorded cases of acute myocardial infarction • population-at-risk • seasonal variation (i.e. purely function of time) The parameters of the model are statistically estimated from the above data.	• Energy applications: price processes (fuel, electricity, CO2 permits), cost data (capital costs, O&M, fuel costs, CO2 costs), rates of technical change. • Satellite mission: benefit streams (in terms of avoided losses), cost data (R&D, deployment, launching, maintaining), hosted payload. • Optimal rotation: fire risk, cost of harvesting/thinning/maintaining, timber price The parameters of the individual models are calibrated from existing data and assumptions based on scenarios and literature review.	• Technology cost parameters (O&M costs, capital costs, fuel costs) • Regulatory parameters (CO2 price, also different scenarios of this) • Other technological parameters (e.g. fuel efficiency, projected rates of technical change, plant life time, …)	• Observation capacity • Probability of a building's collapse, expected number of victims subject to rescue • Available rescue resources • Global population and urban extent data • GDP per capita • Earthquake hazard assessment - the global seismic hazard map (peak ground acceleration)	• Precipitation (ERA-40 reanalysis rainfall data) • Landslide occurrence data • Rainfall parameters intensity (mm/h) and duration (h) have been used to derive landslide triggering thresholds • Observation error parameters • Values of expected damage in case of false positive and false negative landslide prediction	• Configuration of a tsunamigenic zone (e.g. based on historical earthquakes) • Bathymetry data • Settlement locations • Observation capacity in terms of the number of available tsunami detectors/or required lead warning time	• Population size, number of initially susceptible • Number of initially infected • probability of infection, probability of case-fatality, probability of recovery, probability of serious sequelae, number of contacts • costs of vaccination, treatment and disability-adjusted life years The parameters of the model are estimated from the available literature.

	HeatHeart Model (KTL)	Real Options Modeling (Fuss/Szolgayova, IIASA)	Portfolio Optimization (Fuss/Szolgayova/Khabarov, IIASA)	Earthquakes Model (Khabarov, Moltchanova, Bun IIASA/KTL)	Landslide Model (Khabarov,Huggel IIASA/UZH)	Tsunami Model (Khabarov IIASA)	Meningitis-Malaria Vacination Modeling (Chladna, UBR/Moltchanova, THL)
	Output						
Variables	• Predicted AMI incidence. The accuracy of the forecast is assessed using cross-validation techniques. Different models (withi/without seasonal variations and with/without weather information) are compared.	• Energy applications: Investment timing and associated profits and cumulative emissions. The difference between profits and emissions between the case with uncertain and certain parameters (e.g. emissions regulations due to lack of information on climate sensitivity) is computed to be the Earth observation benefit. • Satellite mission: Optimal timing of a launch is computed given uncertain benefits from Earth observation. Avoided losses due to better information from EO are computed to be the Earth observation benefit. • Optimal rotation: Optimal time of harvesting and other managerial decisions is computed, where there is uncertainty about fire incidence. The value of having more information about fire incidence represents the EO benefit.	Amount of investment in specific energy technology clusters/chains. This is determined by minimizing risk (various risk measures tested) subject to a pre-specified constraint on expected return. For the robust portfolios a minimax criterion is used. Portfolios that need to be robust across many scenarios are generally less profitable, thus reducing the amount of scenarios through better EO data, has large, potential socio-economic benefits.	Optimal distribution of available rescue resources over the damaged area. Rescue efficiency calculated for different levels of observation capacity and rescue resource constraints. Quantitative assessment of the extent that better Earth observations may contribute to global reduction of earthquake-induced loss of life.	Expected damage for different levels of observation accuracy and evacuation threshold adjustment. The evacuation threshold adjustment is optimized for each level of precipitation measurement error.	Optimal number of tsunami detectors and their locations given required lead warning times, configuration of a tsunamigenic zone and location of settlements. Dependence of a detector's network density on the required lead warning time and distance between a coastal settlement and tsunamigenic zone.	Susceptible, infected, recovered and dead time series The model is run for different vaccination threshold rules to compare therespective outcomes.
	Current status						

	HeatHeart Model (KTL)	Real Options Modeling (Fuss/Szolgayova, IIASA)	Portfolio Optimization (Fuss/Szolgayova/Khabarov, IIASA)	Earthquakes Model (Khabarov, Moltchanova, Bun IIASA/KTL)	Landslide Model (Khabarov,Huggel IIASA/UZH)	Tsunami Model (Khabarov IIASA)	Meningitis-Malaria Vacination Modeling (Chladna, UBR/Moltchanova, THL)
	Completed for the case of Finland.	All three analyses are completed. Currently, the optimal rotations model is linked up with the Forest Fires Model (N. Khabarov, IIASA) to use this model's output as input. The resulting decision rules will then feed into the G4M (Kindermann, IIASA) model to produce the final result.	Both the more theoretical model with first energy applications and the minimax implementation to value EO benefits more explicitly have been completed.	Both local and global scale models were developed. The validation of the EO benefit assessment methodology was performed in several case studies with the results satisfactory for the present level of aggregation.	The model was applied to the case study in Colombia. The results show that the expected landslide-induced losses depend nearly exponentially on the errors in precipitation measurements.	The mathematical optimality of the suggested detector's placement is proven in an abstract setup. Good agreement is shown with the application to real bathymetry (Okhotsk Sea). The main conclusion for the time of reporting is that there is a hyperbolic dependence of the number of detectors on the lead warning time.	In process. The simulation algorithms for exogenous decision-making mechanisms have been built. The dynamic real options modeling is in process.
	Potential extensions, future plans?						
	Other European countries with more noticeable weather extremes and susceptibility to them.	See previous point about ongoing research.	The analysis will be extended on the temporal scale by allowing for dynamic investment behavior.	The present results should be considered as preliminary. Because of the limitations of the available datasets, there is a space for various improvements of the model. However, it seems to be true, that the current state of the art in this field of science doesn't allow for substantially more reliable and more precise predictive assessments.	Possible directions for improving the model are e.g. making it spatially explicit and applying risk measures in the optimization procedure. Application of the developed model to a global scale or any other approach for making an assessment methodology applicable to a global scale seems to be the major challenge.	Application of the developed model to a global scale or any other approach for making an assessment methodology applicable to a global scale seems to be the major challenge. An assessment taking into account the tsunami-induced inundation is another direction to go next.	• Other diseases of similar nature (contagious, people-to-people, vaccines available)
	Potential contribution to IIASA projects						

	HeatHeart Model (KTL)	Real Options Modeling (Fuss/Szolgayova, IIASA)	Portfolio Optimization (Fuss/Szolgayova/Khabarov, IIASA)	Earthquakes Model (Khabarov, Moltchanova, Bun IIASA/KTL)	Landslide Model (Khabarov,Huggel IIASA/UZH)	Tsunami Model (Khabarov IIASA)	Meningitis-Malaria Vacination Modeling (Chladna, UBR/Moltchanova, THL)
	Part of Geo-BENE work package.	Part of GeoBene work package. Three different SBAs: Weather (satellite mission), Energy (energy applications), Disasters (Forest management/optimal rotations).	Part of GeoBene Energy SBA, but applications in other decision-making areas also possible.	Part of GEO-BENE.	Part of GEO-BENE. The potential for application of the model to LULUC to estimate the soil degradation, needs to be evaluated.	Part of GEO-BENE.	Part of GeoBene (Health + Weather)
	General evaluation						
strengths	• Clear framework, easily applicable to other similar datasets. • Discrimination between the linear trend, the seasonal effect and the daily weather effect.	• Straightforward theoretical tool to incorporate uncertainty in decision-making when irreversibility is involved. • Ideal setting to compute value of information and actually associate numbers with EO benefits (additional profits, CO_2 emissions savings, avoided economic losses, …)	• Solid, theoretical outline, which enables analysis also of other uncertain factors. • Use of modern risk measures allows for use of linear programming. • Value of EO becomes visible in a very straightforward way by comparing results from robust portfolios against results of portfolios optimized under more certainty (i.e. for a more narrow range of scenarios).	• Simple framework for the global assessment of the importance of EO improvements for earthquakes response. • Provides also a tool for global assessment of potential impact of future earthquakes.	• Explicitly deals with observed data and measures the performance of an early warning system against the benchmarking case of using a ‘perfect’ dataset. • Includes optimization procedures pointing out the ways of improving existing early warning systems.	• Presents the optimal placement of tsunami detectors • Discovers the dependency between local conditions and parameters of sensors’ network providing safe warning time.	• Examines vaccination strategies within a dynamic stochastic decision-making framework. • Evaluates the benefits from additional information (dust storm event)

	HeatHeart Model (KTL)	Real Options Modeling (Fuss/Szolgayova, IIASA)	Portfolio Optimization (Fuss/Szolgayova/Khabarov, IIASA)	Earthquakes Model (Khabarov, Moltchanova, Bun IIASA/KTL)	Landslide Model (Khabarov,Huggel IIASA/UZH)	Tsunami Model (Khabarov IIASA)	Meningitis-Malaria Vacination Modeling (Chladna, UBR/Moltchanova, THL)
weaknesses	• Finnish data does not provide enough weather extremes to detect usefulness of weather forecasts. • Ecological fallacy: impossible to report the exact measures people take in case of weather extremes.	• Limited data availability: asks for assumptions. We have tried to minimize this and have conducted multiple scenario and sensitivity analyses in order to gain insight about the robustness of the results. • Computational limitations: Problems have to be reduced to small scale (e.g. looking at one representative power plant or satellite) in order to still be able to extract the full potential from the analysis, while keeping the problems computationally feasible to solve.	• Computational limitations: The technology-specific return distributions used in the portfolio optimization are generated by a real options setting, which means that the focus has to be on specific plant types in order for the problem to remain computationally feasible to solve.	• The lack of the modern scientific understanding of geophysical processes is the major limiting factor which cannot be ignored in this application. • Substantial data gaps were discovered particularly regarding the rescue resources availability information, local building practices, current capacity of rapid earthquake damage assessment systems, etc.	• The current model does not take into account spatial distribution of precipitation. • Due to the data gaps it's impossible to perform any verification of the local landslide triggering thresholds (which are at the model's core) using historical data.	• The model does not take into account such technical parameters as detectability of tsunamis based on their deep sea amplitudes, and the coordination of seismic and hydro early warning subsystems is not formalized. • Social aspects of tsunami warnings are not included into the model.	• Lack of detailed data • Possibly, numerical complexity of the algorithm.

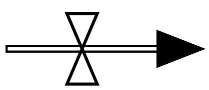
4. Description of integration model

This chapter describes the structure of the whole FeliX model. It starts with a short note on System Dynamics models notation. Each model sector is described separately with indication of interrelations with other model sectors.

4.1. System Dynamics models notation

System Dynamics models consist of a simple notation presented in **Error! Reference source not found.**. The combination of the diagrams, completed with the mathematical equations, constitutes a simulation model.

Table 1. Notation used in System Dynamics models.

Diagram	Name	Description
	Stock	Stocks are accumulators within the system. They are an analogy with a tank of water. They accumulate inflows, reduced by outflows, over time. The level in the tank will vary, depending on the values of inflows and outflows. The accumulations will persist even if all flows will drop to zero. Levels represent system state variables.
	Flow	Flows represent movement of material and information in the system over time. A valve, depicted on the flow, indicates that the flow rate can change.
	Source/Sink	Clouds represent the sources and sinks for the flows. They indicate the boundary of the system. Sources and sinks represent levels from which flows originates or are drained to, respectively. The levels illustrated by the sources and sinks are left beyond the model consideration. Sources and sinks are considered to have infinite capacity.
	Information Arrow	Information arrows connect all model components. They transmit information about an originating variable to the destination variable.
Variable	Constant / Auxiliary Variable	Constants are parameters used by the model; auxiliary variables are used when some mathematical expressions are used.

In formal mathematical terms, System Dynamics models are sets of discrete difference equations. The stock equation performs the process of integration, which can be written as:

$$S_t = S_0 + \int_0^t (IR - OR)dt ,$$

where:

S_t – the value of the stock at any time t,
S_0 – the initial value of the stock at time $t=0$,
IR – the inflow rate,
OR – the outflow rate,
dt – the differential operator representing the infinitesimally small difference time that multiplies the flow rates.

The net flow into the stock is the rate of change of the stock – the derivative of the stock:

$$\frac{dS}{dt} = IR - OR\,.$$

In general, the flow is a function of the stock and other state variables and parameters. The thorough description of the System Dynamics components and technique is presented by Forrester (1961), Lyneis (1980), and Sterman (2000).

4.2. FeliX model sectors – Economy

The Economy sector is based on DICE model by Nordhaus (Nordhaus 1992, 1994) including some changes recognized by Fiddaman (Fiddaman 2002). *Capital* is an accumulation of a percentage of the *Gross World Product* determined by *Savings*. The Capital undergoes depreciation. *Gross World Product* in turn is modeled as a Cobb-Douglas production function taking into account *Labor*, *Capital* and *Technology*. The System Dynamics structure representing these relations is illustrated in Figure 3. All FeliX model equations can be found in Appendix of this report.

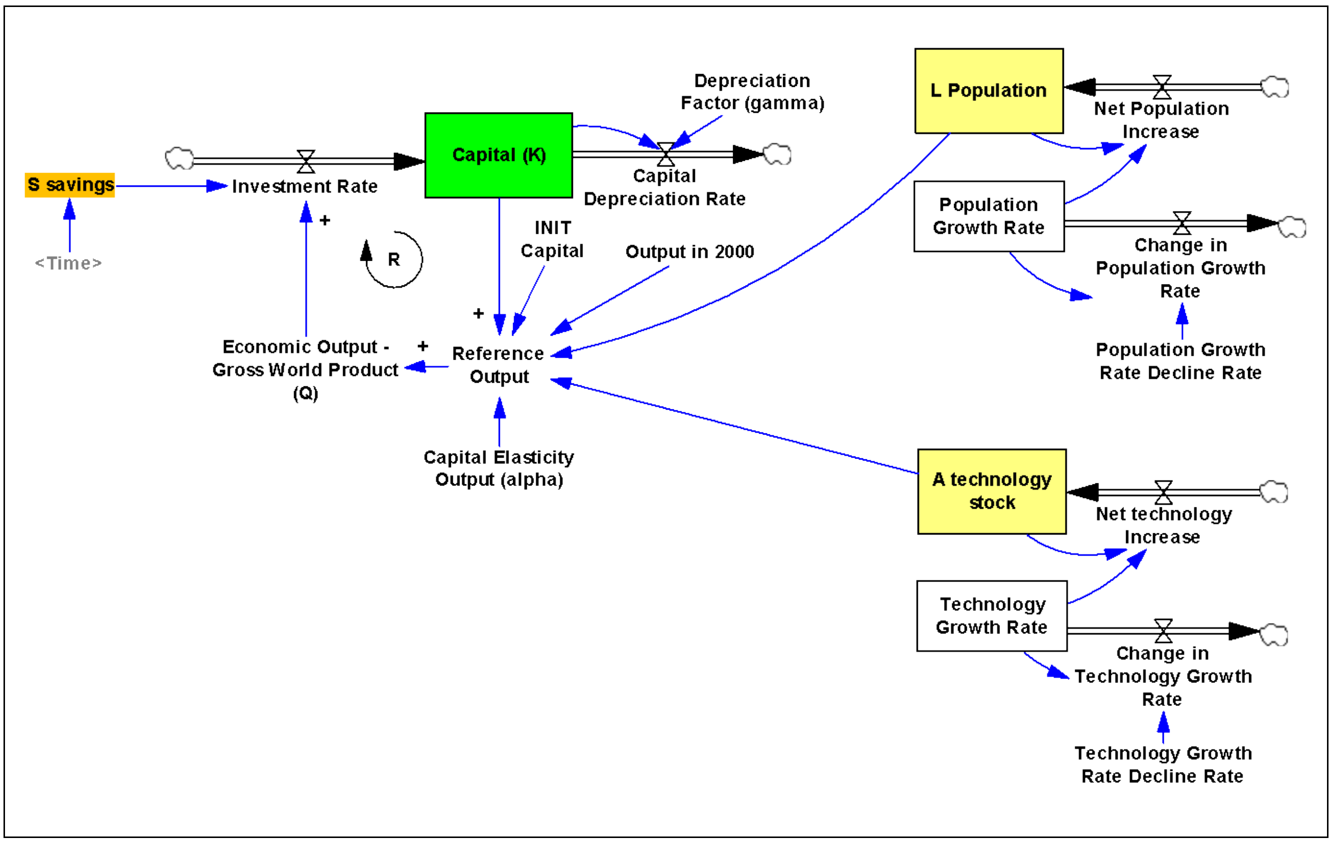


Figure 3 FeliX model - Economy sector structure

As for now the '*L Population*' variable is exogenous. Upon FeliX model completion the dynamics of the Economic model sector will be determined by Population sector.
'*S savings*' variable is determined by the outcome from one of optimization models being in GEOBENE models portfolio.

4.3. FeliX model sectors – CO_2 Emission and Carbon Cycle

The FeliX model accounts for CO_2 emission as the greatest emission among green house gasses (GHG). It is assumed that all sorts of economic activate lead to CO_2 emission. Depending on technologies used the activities may differ with regards to CO_2 Intensity of Production (e.g. there can be used ‘cleaner’ technologies for energy production leading to decrease in CO_2 Intensity of Production). CO_2 accumulates in Atmosphere and flux with biosphere and ocean which is a structure to be still developed. The temporary structure of CO_2 Emission and Carbon Cycle is presented in Figure 4.

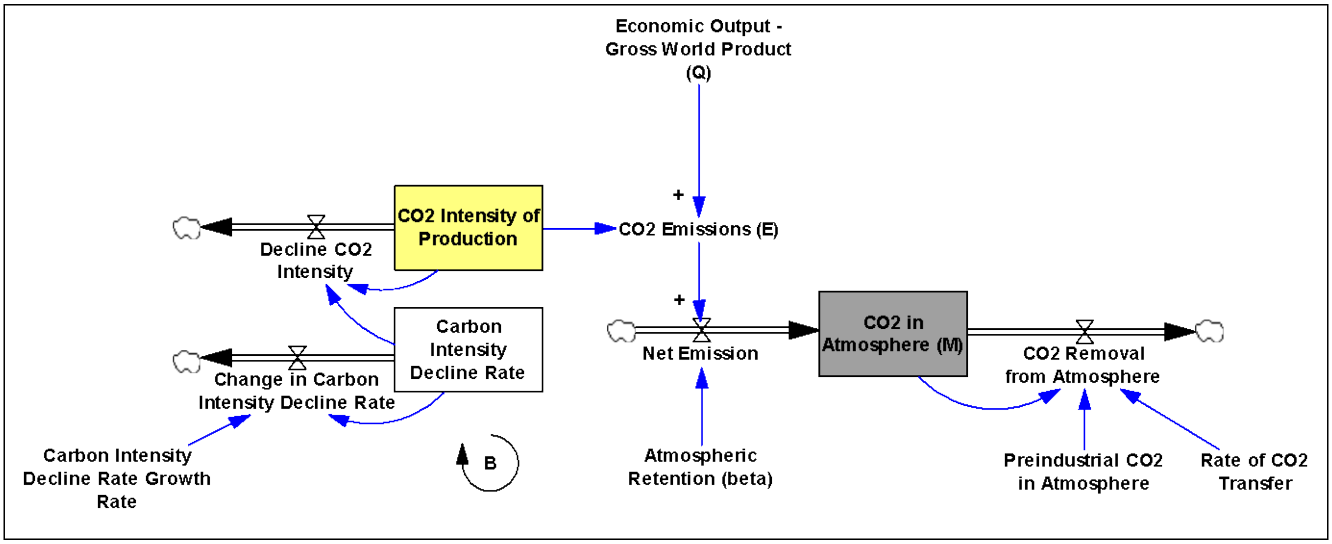


Figure 4 FeliX model - temporary structure of CO_2 Emission and Carbon Cycle sector

As for now the model assumes that the emission is determined by the *Gross World Product* (similarly to DICE model by Nordhaus (1994)). However, the FeliX model is detailed enough to disaggregate this assumption and account for various actions leading to CO_2 emission, like energy production and use or agriculture, which is still to be developed within confines of model sectors integration, and will be completed by the end of the project.

4.4. FeliX model sectors – Climate and Environment

Increasing the atmospheric concentration of CO_2, or any other greenhouse gas, is forcing the global climate to warm. With more molecules of CO_2 in the atmosphere, a higher proportion of the outgoing longwave radiation is absorbed, reducing the net emission to space. The FeliX model takes into account this effect and following DICE model by Nordhaus (1994) models additional surface warming from accumulation of CO_2. Positive forcing makes the *Atmospheric and Upper Ocean Temperature* increase.
Additionally there is modeled a heat transfer between atmospheric and upper ocean and deep ocean.
The higher temperature of atmosphere and upper ocean leads to climate damage and eventually lower economic output.

The structure representing the whole structure of the Climate and Environment sector is presented in Figure 5.

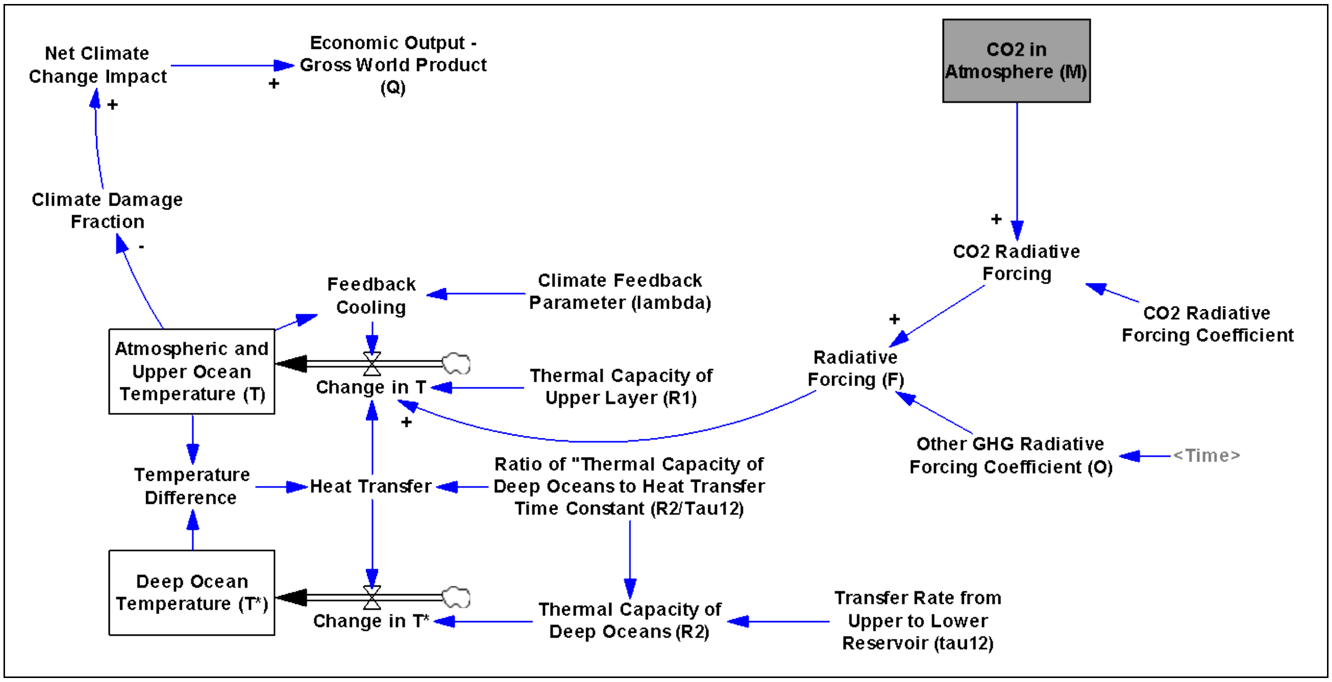


Figure 5 FeliX model - Climate and Environment sector

Once the integration of all FeliX model sectors will be completed the impact of the climate damage will impact some particular model sectors (e.g. Land and Population).

4.5. FeliX model sectors – Population

World population is models as an aging chain (Sterman 2000) in order to account for potential labor and non-labor population. The model sector structure is presented in Figure 6.

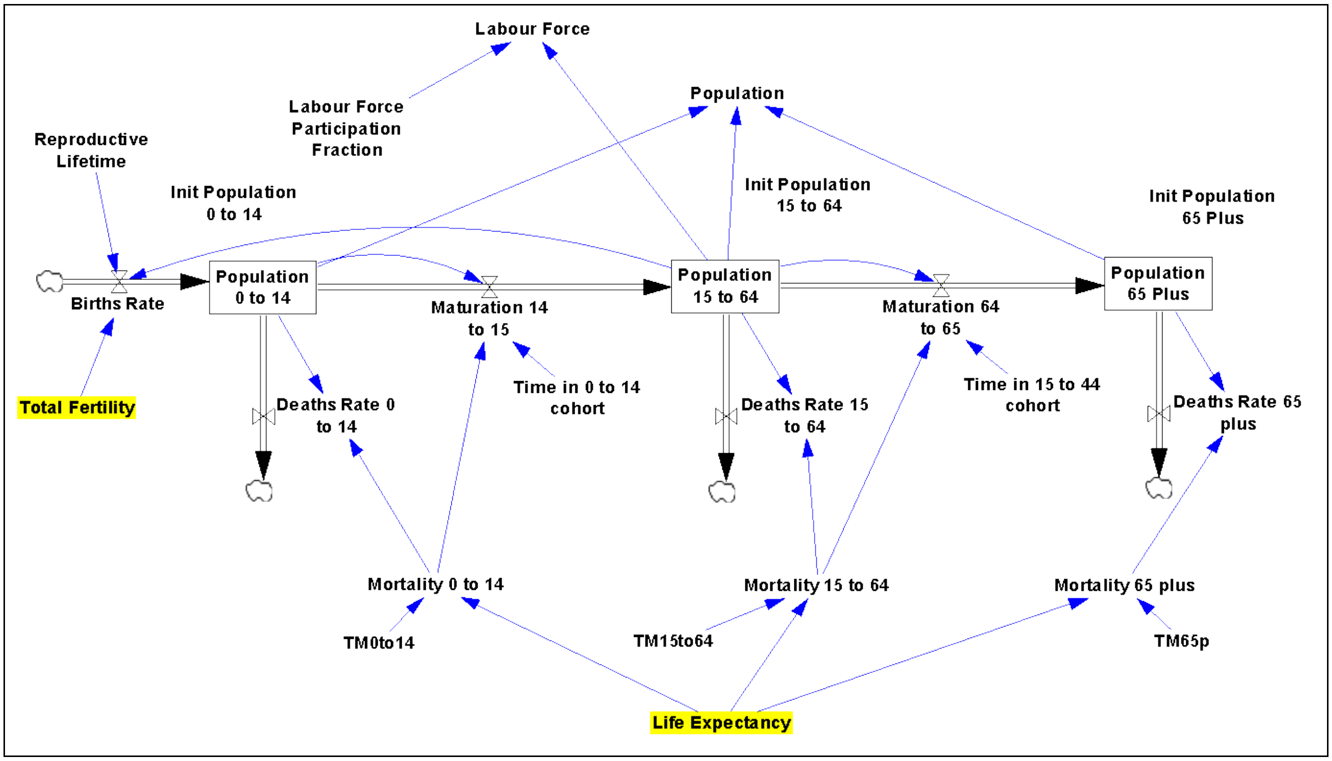


Figure 6 FeliX model - Population sector

Such parameters as *Fertility* and *Life Expectancy* are influenced by economic and social changes. Upon integration of FeliX model structure these parameters will be influenced by such issues as food and energy availability, and health.
Furthermore, upon model sectors integration the variable Labour Force is to determine the economic output.

4.6. FeliX model sectors – Energy

FeliX model structure encompasses various sources of energy – Oil, Gas, Coal, Solar, Wind and Biomass. There is also modeled an economic mechanism of price based competition between these sources of energy influencing the energy market share.
Since Oil, Gas and Coal energy sources have quite similar nature the model structures are also similar. They differ mainly by the values of parameters. For that reason only Oil structure will be described in details. The model equations for all structures can be found in Appnedix.
Similarly there will be described only Solar energy model structure since it has the same feature as Wind energy structure.
Biomass energy model structure will be described as a part of Land sector.

Oil model structure

The basic assumption behind the of Oil energy structure (and also other natural resources) is the life cycle theory of oil and gas discovery and production put forth by Hubbert.

According to Hubbert, the cumulative production of oil and gas must be less than or equal to the ultimately recoverable amount of oil and gas. The rate of petroleum production tends to follow a bell-shaped curve. Early in the curve, the production rate increases due to the discovery rate and the addition of infrastructure. Late in the curve, production declines due to resource depletion. The core of the FeliX model structure illustrating this dynamics is presented in Figure 7.

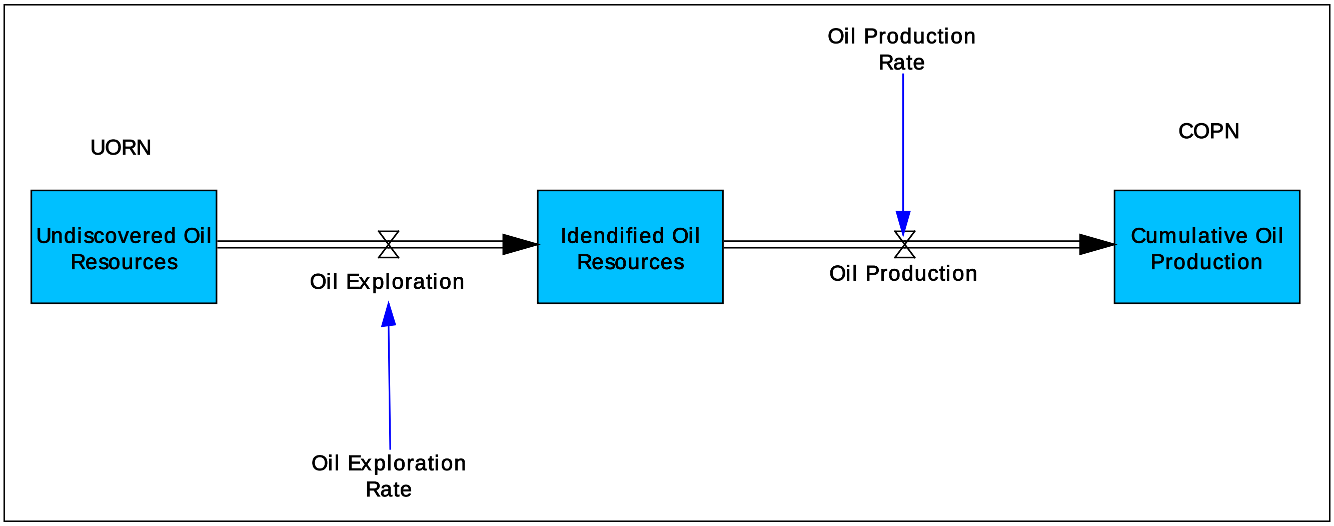


Figure 7 FeliX model – core structure of Oil exploration and production

Stock *Undiscovered Oil Resources* constitutes total oil resources that can be still explored. Stock *Discovered Oil Resources* represent oil resources that are known to exist. Stock *Cumulative Oil Production* represents total oil resources that have been already produced.

Oil Exploration and *Oil Production* are subjects to existing exploration and production technologies (Figure 8) and investments into exploration (Figure 9) and production infrastructure (Figure 10).

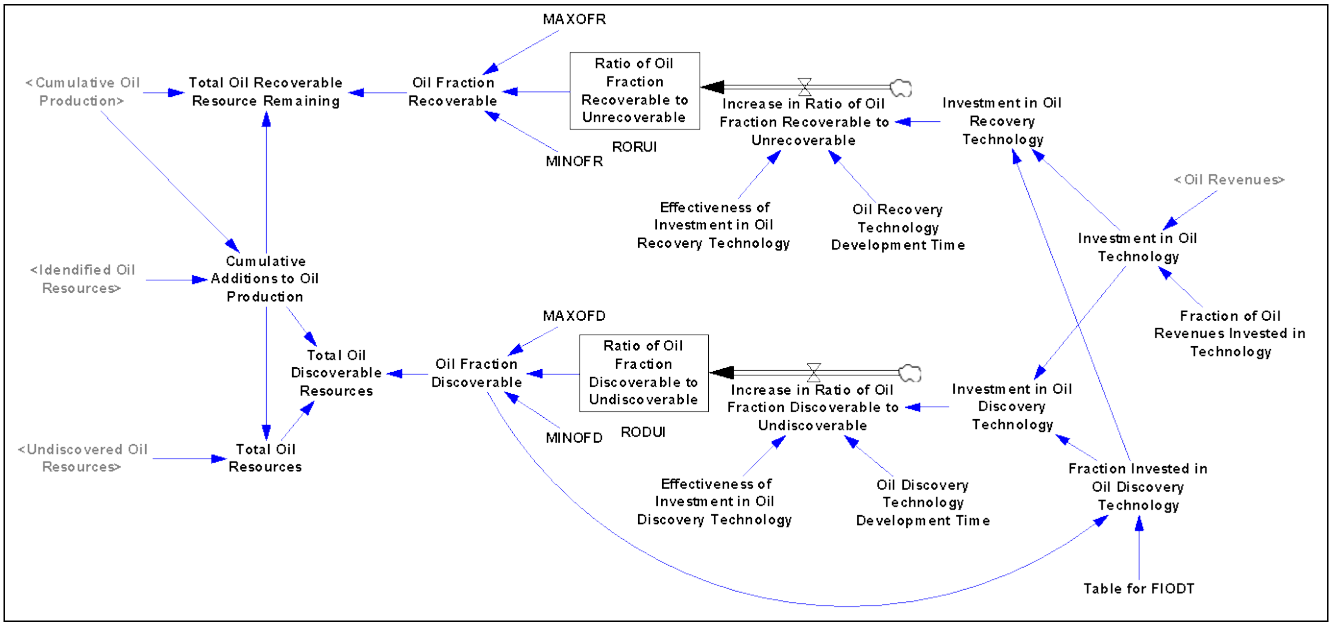


Figure 8 FeliX model – Oil Energy structure – investments in oil exploration and production technologies

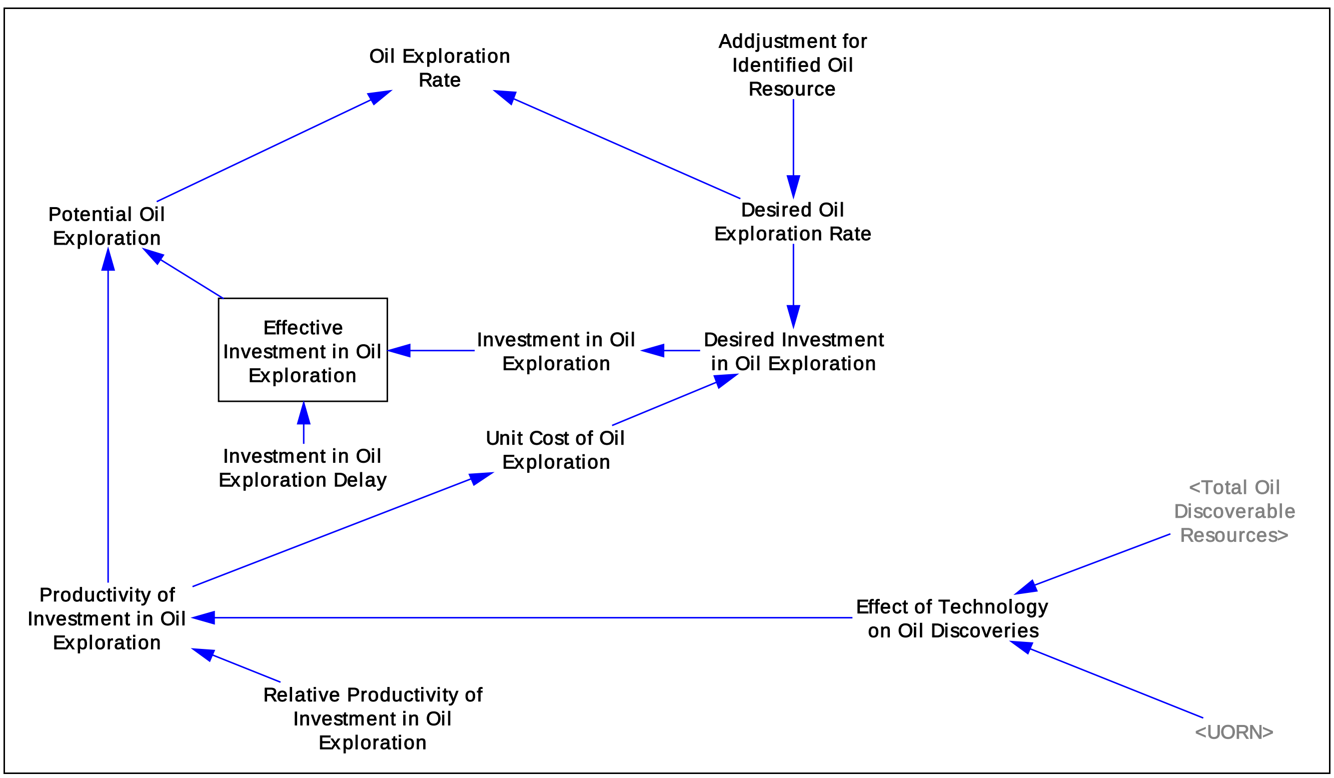


Figure 9 FeliX model – Oil Energy structure – investments in oil exploration infrastructure

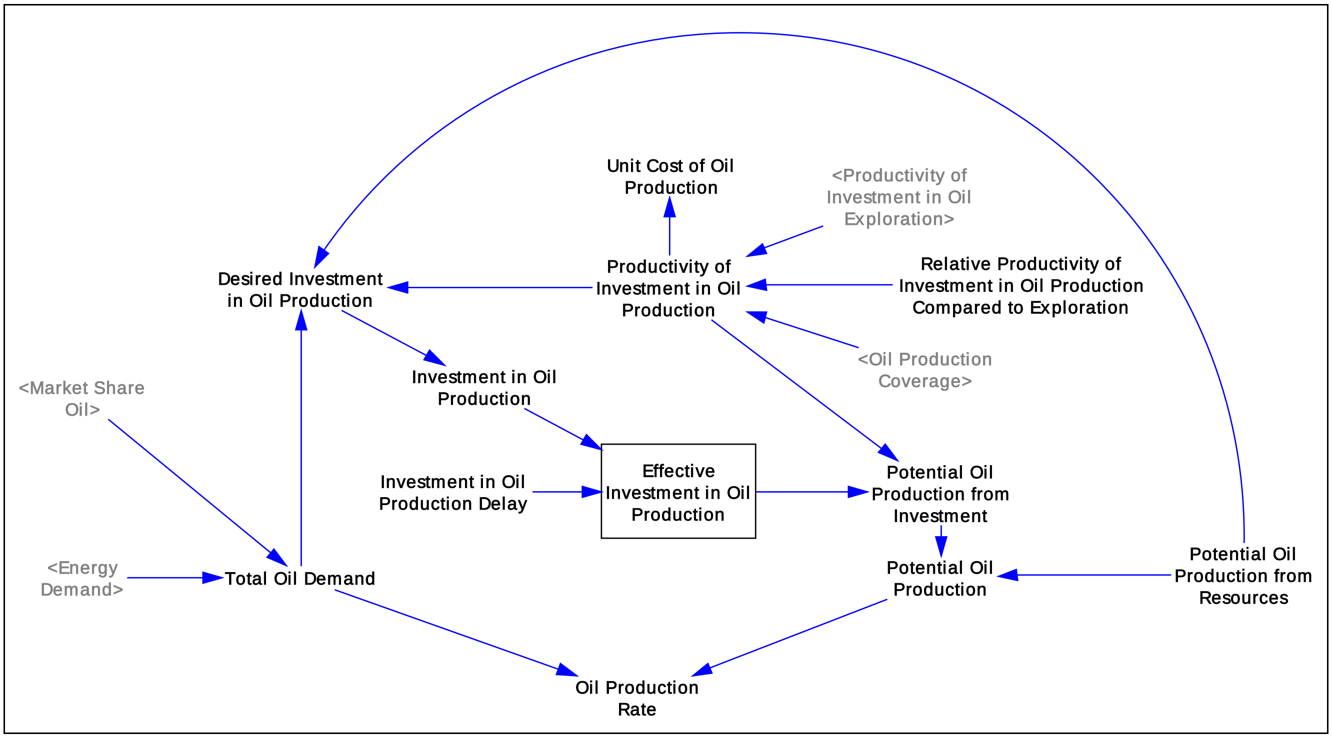


Figure 10 FeliX model – Oil Energy structure – investments in oil production infrastructure

Oil production and exploration is associated with cost of exploration and cost of production. These costs, together with desired *Gross Margin* and taking into account *Sensitivity of Oil Price to Supply and Demand*, determine the market *Oil Price* (Figure 11). A fraction of Oil Revenue is invested in exploration and production technology development (initially with greater focus on exploration and over time while the *Oil Fraction Discoverable* is reaching its maximum more investments are directed into production technologies).

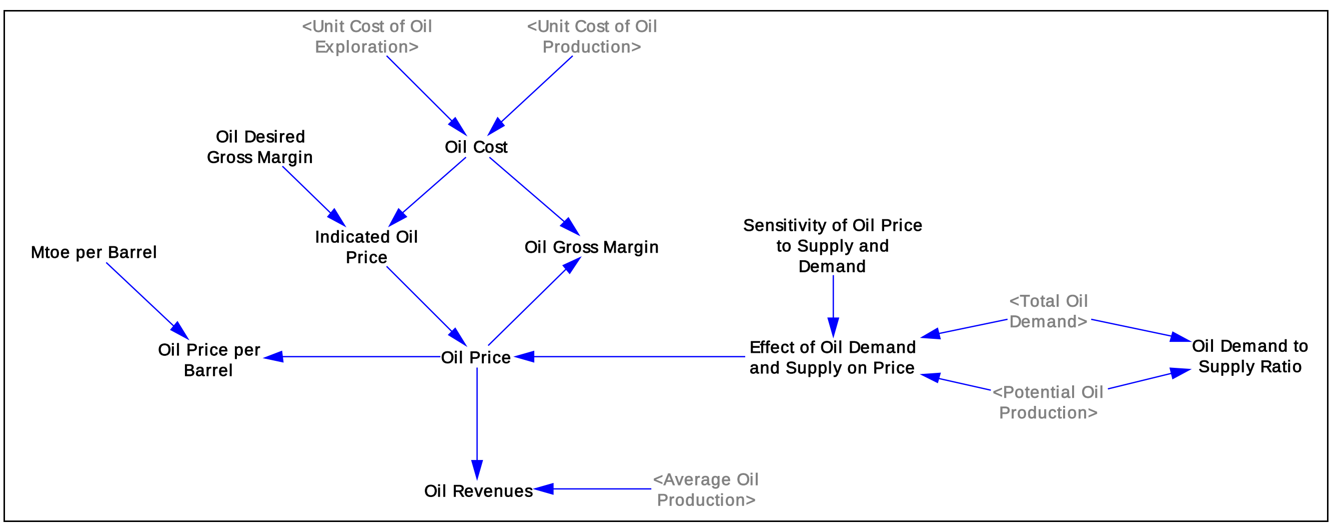


Figure 11 FeliX model – Oil Energy structure – oil price

The production of oil is driven by *Total Oil Demand* (accounting for total *Energy Demand* and *Oil Market Share*) – see Figure 10. The mechanism of market share is described after the Solar model structure.

Solar model structure

Solar energy production is demand driven and constrained by Solar Installed Capacity, Weather conditions (availability of sun or wind in case of similar structure for Wind energy) and Solar Energy Technology. The FeliX model structure indicating these dependencies is presented in Figure 12.

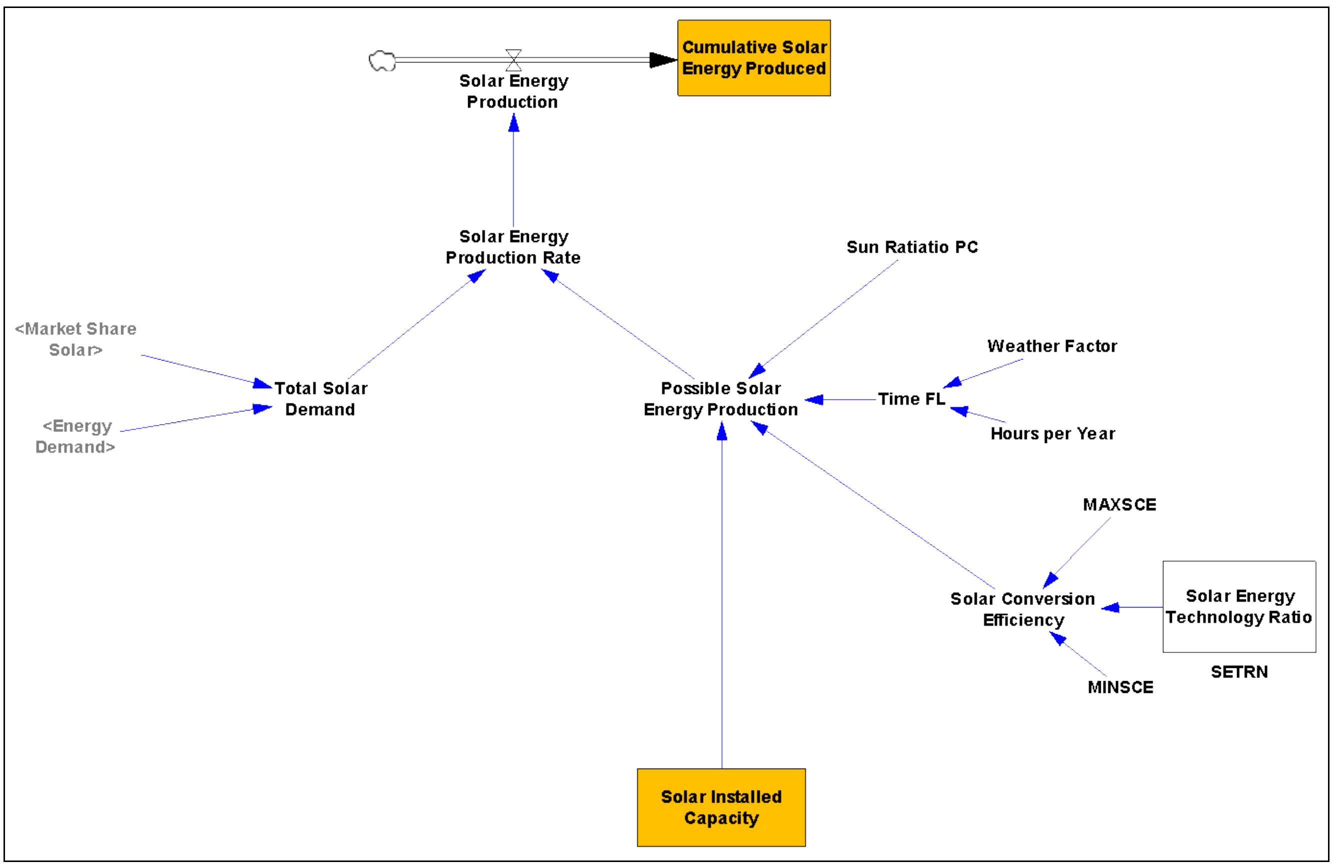


Figure 12 FeliX model – Solar Energy structure – production factors

Investments are increasing whereas aging is decreasing the available stock of *Solar Installed Capacity* (Figure 13). The model takes also into account an available space to place solar energy installations.

Similarly to Oil energy structure, a fraction of revenue from the sale of solar energy is dedicated as an investment into development of solar technology (Figure 14).

The cost of Solar energy is a subject to unit cost of solar Capability installation but also to a learning curve effect (Figure 15). This effect is quite significant in case of relatively new technologies as solar or wind.
The cost of solar energy increased by gross margin and including the sensitivity of price to supply and demand determines the market solar energy price. Production of energy at that price determines revenue (part of which is later invested into technology development).

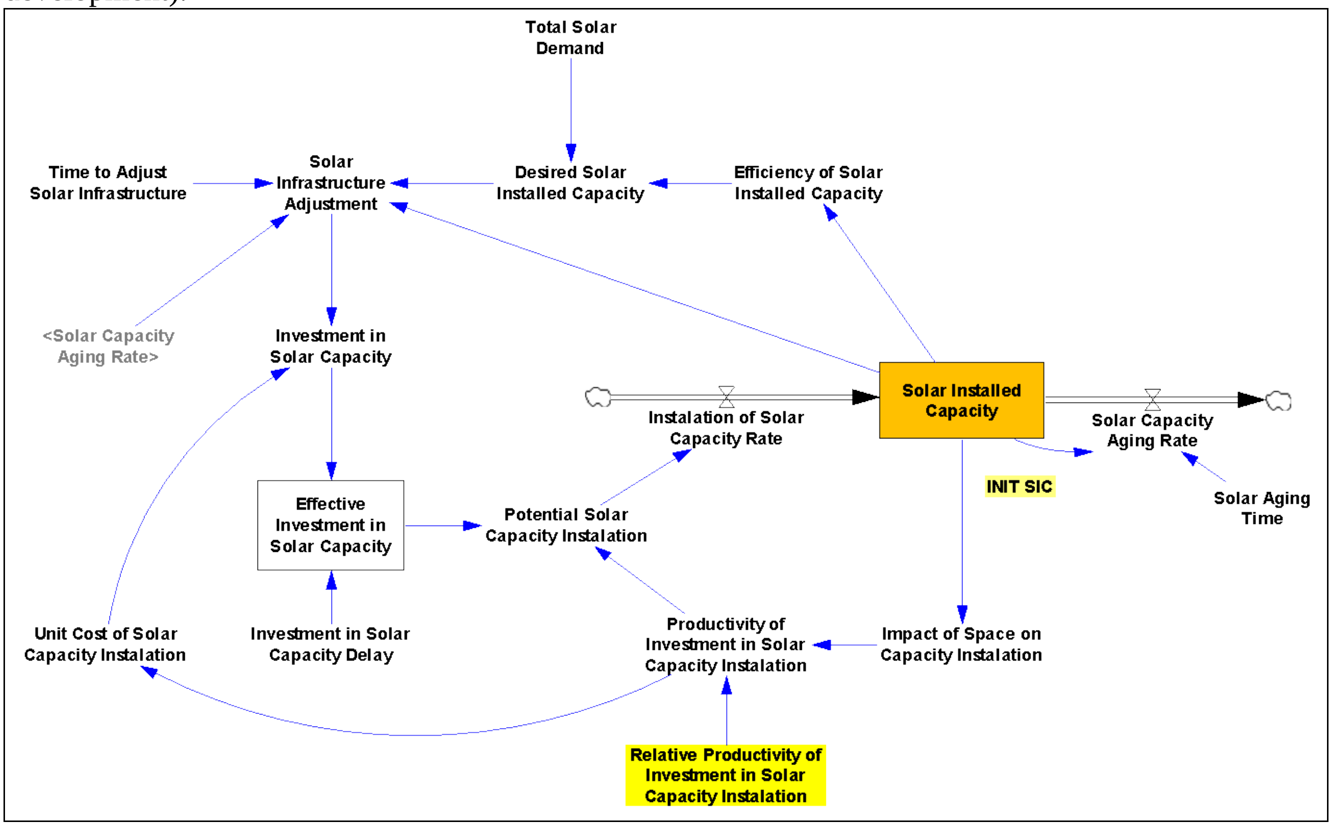


Figure 13 FeliX model – Solar Energy structure – investments in solar installed capability

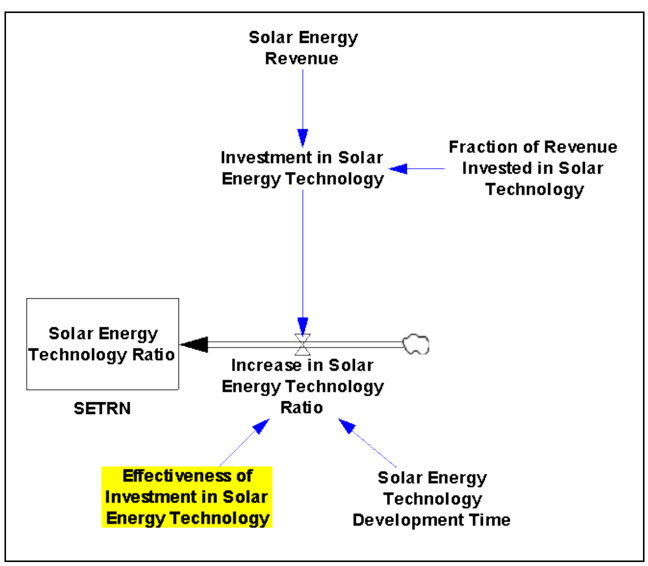


Figure 14 FeliX model – Solar Energy structure – investments in solar technology

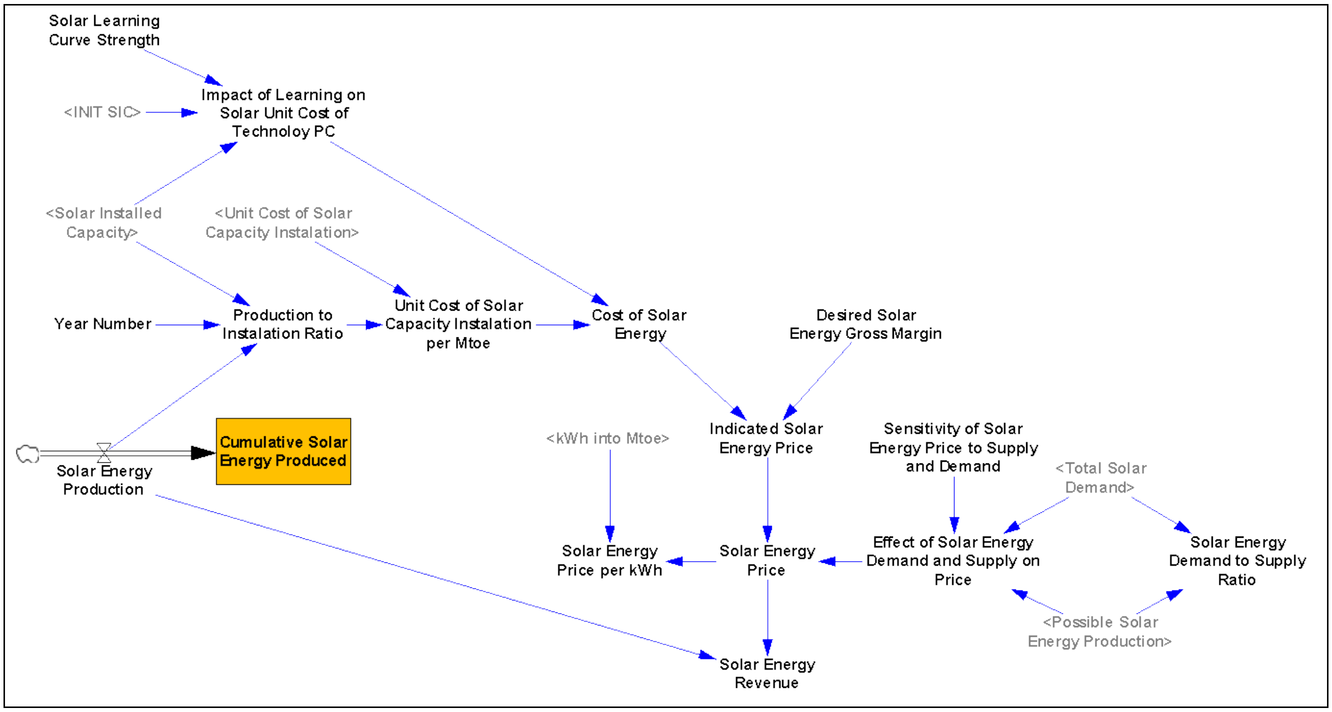


Figure 15 FeliX model – Solar Energy structure – cost, price and revenue

Market Share mechanism

The FeliX model accounts for various sources of energy – Oil, Gas, Coal, Solar, Wind and Biomass. There was build a market share mechanism in order to imitate the completion on energy market. Availability of infrastructure and technology, raw materials in case of Oil, Gas, and Coal and to some extend Biomass, and potential production of Solar and Wind energy due to weather factors, are the main price determiners of each kind of energy. As a simplification of the real market the FeliX model translates prices of all kinds of energy into a common unit, i.e. $/mtoe (dollars per million tons of oil equivalent). Furthermore, the market share mechanism, in order to take into account inherited information delay, averages the energy prices over a year (Figure 16). It also calculates *Average Energy Price* (average price taking into account all kinds of energy).

The yearly average price of each kind of energy is compared to *Average Energy Price* and determines Price Competitiveness Factor for each kind of energy. This in turn dynamically changes the market shares (Figure 17).

So far the market share mechanism still requires integration with solar and wind energy as well as implementation of a competition structure for Biomass energy. These are the model structures that will be completed by the end of the project.

Additionally, the market share includes a savings structure indicating social adaptive behaviors. Increase of *Average Energy Price* initiates savings mechanism – it is assumed that there is more cautious use of energy. Savings are part of market share in order to count for adaptive behaviors.

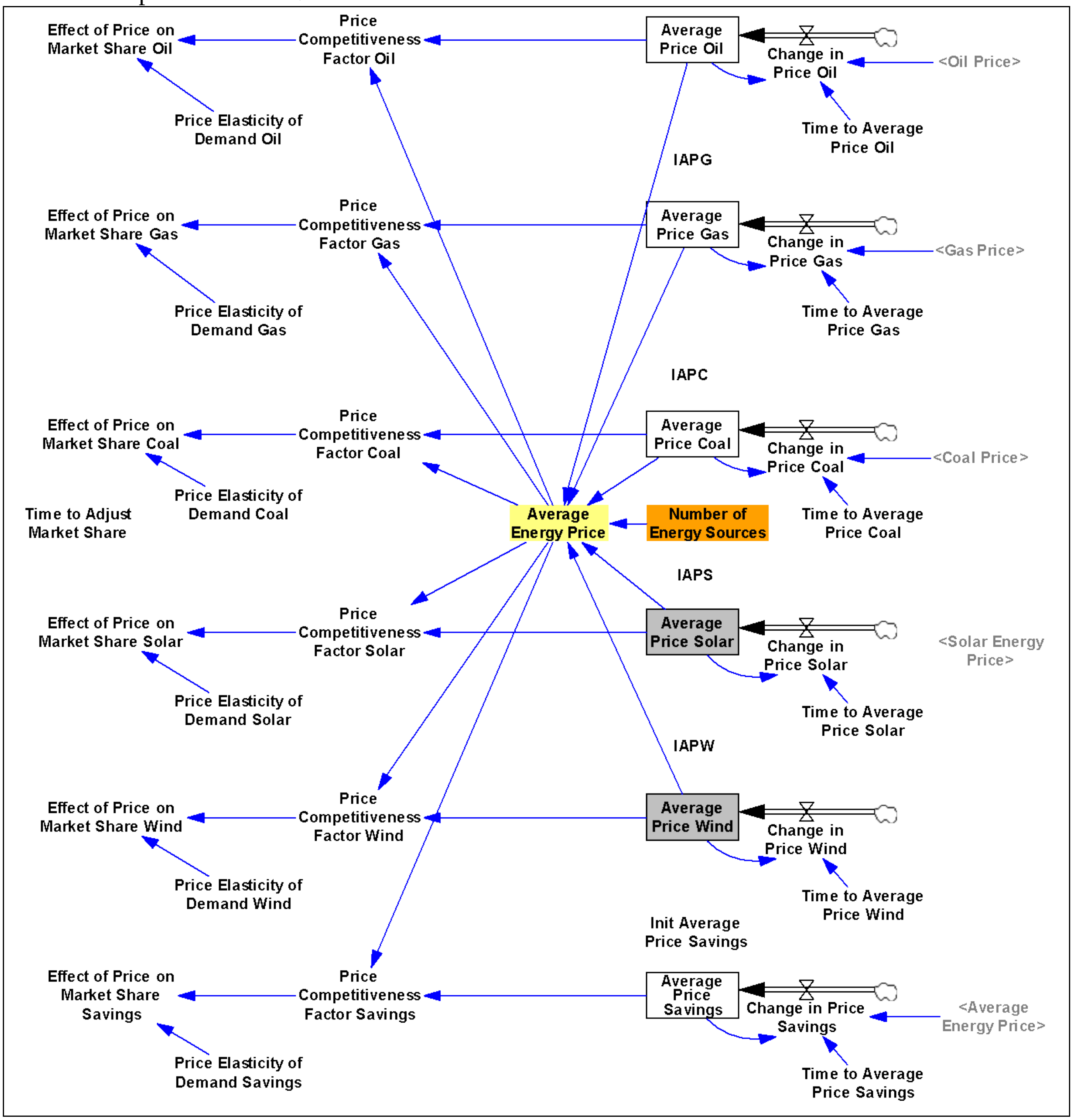


Figure 16 FeliX model – Market Share structure – average prices

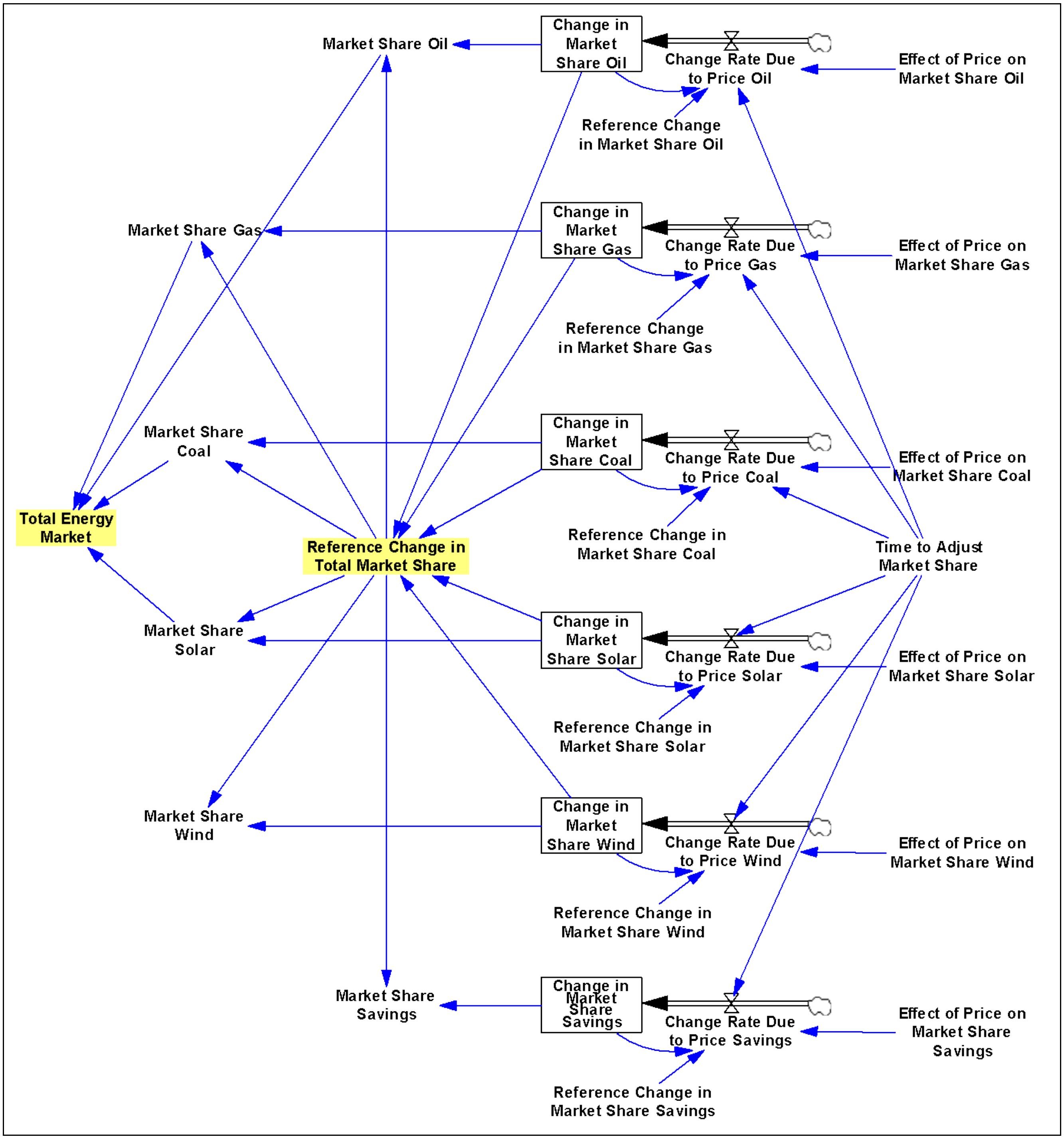


Figure 17 FeliX model – Solar Energy structure – change in energy market share

4.7. FeliX model sectors – Technology

Elements of Technology sector are spread across the whole FeliX model. They were described as a part of Economy and Energy sectors (see Figure 3, Figure 8, Figure 14.

4.8. FeliX model sectors – Land

In the FeliX model the global land was divided into four categories – *Agriculture Land*, *Forest Land*, *Urban and Industrial Land*, and *Other Land* (Figure 18). Various social and economic activities as well as natural processes may impact and change the characteristics of a particular kind of land. Expansion of agriculture has for years been transforming forest land into agriculture land. Deserted farms may become woodland or grassland (named in FeliX model as Other Land) and eventually a forest. Both forest Land and Agriculture Land can be transformed into Urban or Industrial Land.

Time parameters associated with each land transformation flow determined how easy it is to make the transformation happen. There are also other factors influencing the transformations.

Furthermore, there are also assumed certain constrains on the land transformation. It takes into account national park, protected areas and also terrain that cannot be transformed e.g. desert being a part of Other Land.

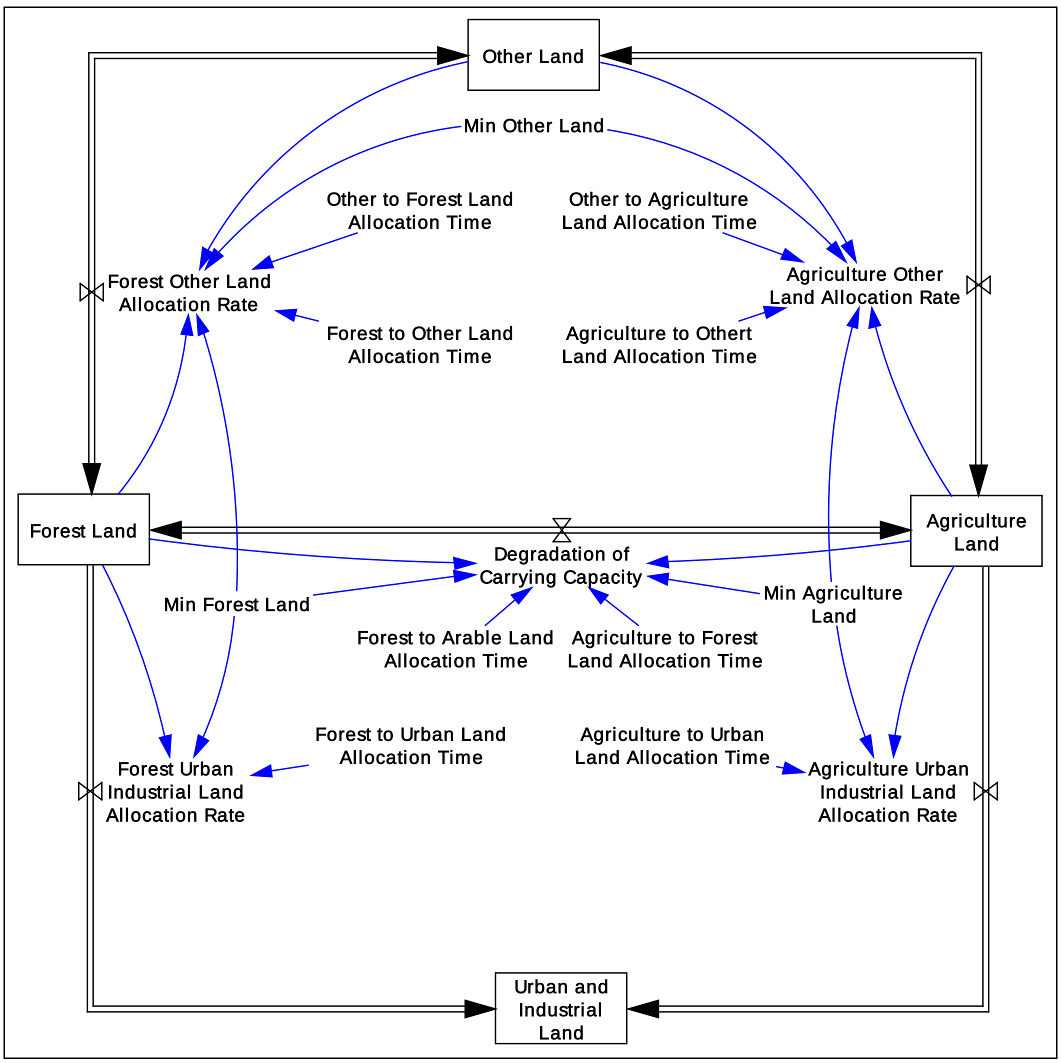


Figure 18 FeliX model – Land sector – kinds of land

Urban and Industrial Land

Growing populations creates a pressure to transform agriculture or forest land into urban or industrial areas. The model structure of this process is illustrated in Figure 19.

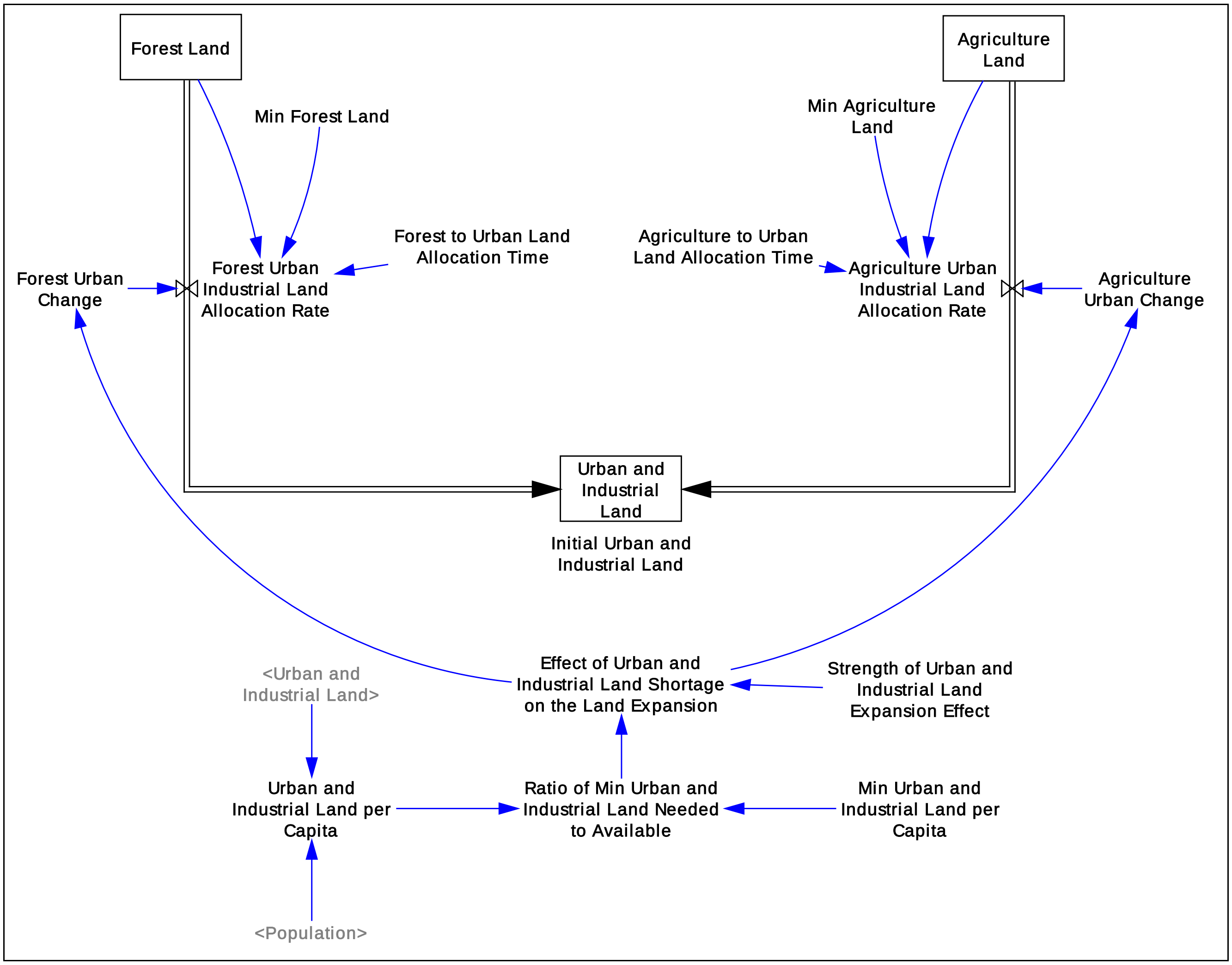


Figure 19 FeliX model – Land sector – Urban and Industrial Land

Agriculture Land

Agriculture Land is a primary source of food. Depending on the *Population* and assuming a *Minimal Annual Food per Capita* there is determined required food production (*Food Production Needed*). This number combined with *Agriculture Land Yield* and average *Food Production Loss* determines the area of *Agricultural Land Needed to be Harvested for Food Production* (Figure 20).

However, there is a competition between producing food and producing energy. *Energy Demand* and biomass energy market share, taking into account *Agriculture Land Yield* and *Energy Crops Processing Loss*, determine *Agricultural Land Needed to be Harvested for Biomass Production* (Figure 20).

Agriculture Land Fertility assumes natural process of regeneration (Figure 21). The fertility can however be degraded due to pollution or impaired biodiversity – the model structures that will be completed by the end of the project.

Any shortage of available agriculture land for food or energy purposes creates a pressure to transform forest and other land areas into agriculture land. However, since there is also a need for Forest Land (e.g. for energy purposes) there exist a competition between the needs for agriculture and forest land. The model structure describing these relations is presented in Figure 22.

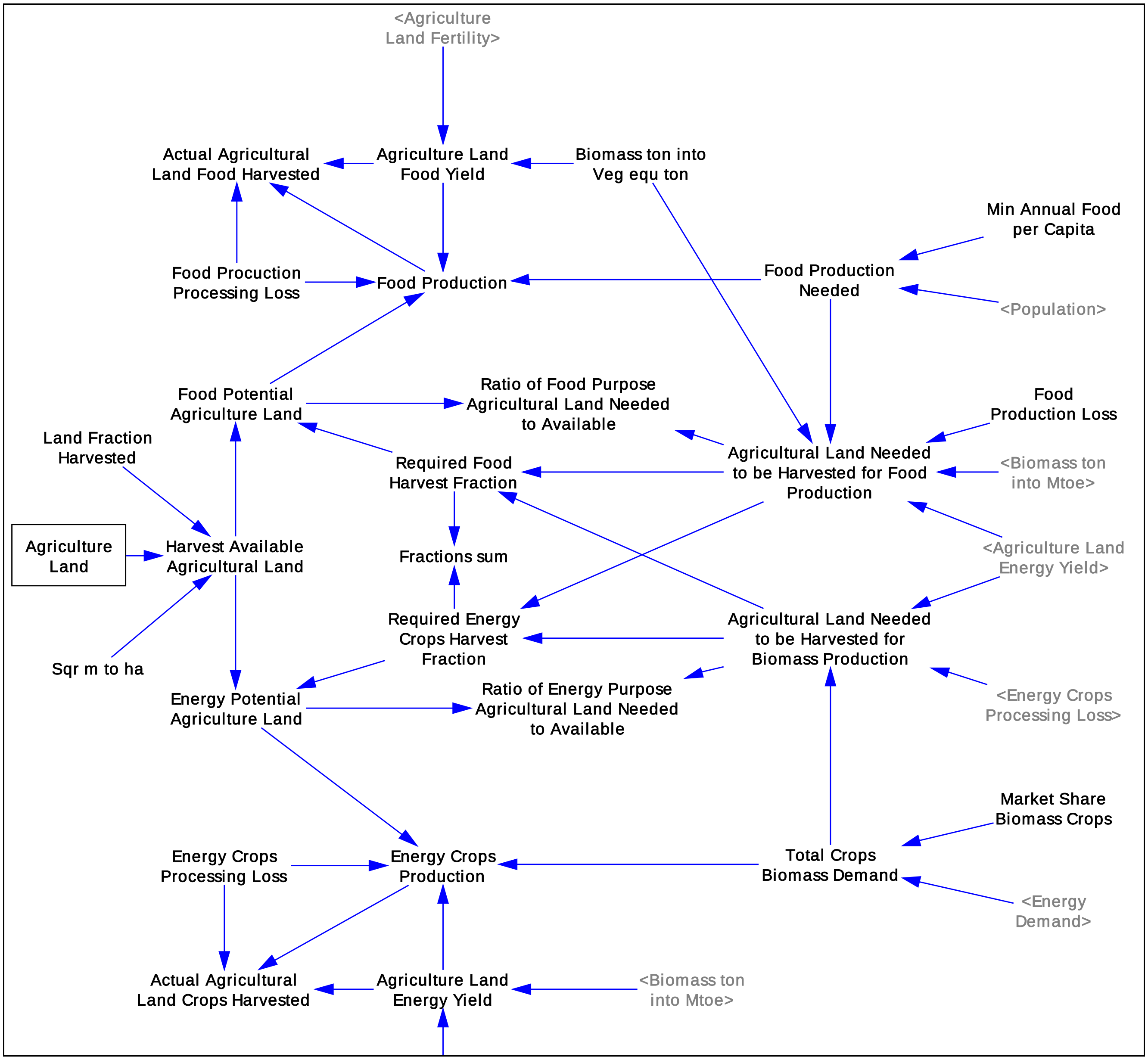


Figure 20 FeliX model – Land sector – Agriculture land for food and energy purposes

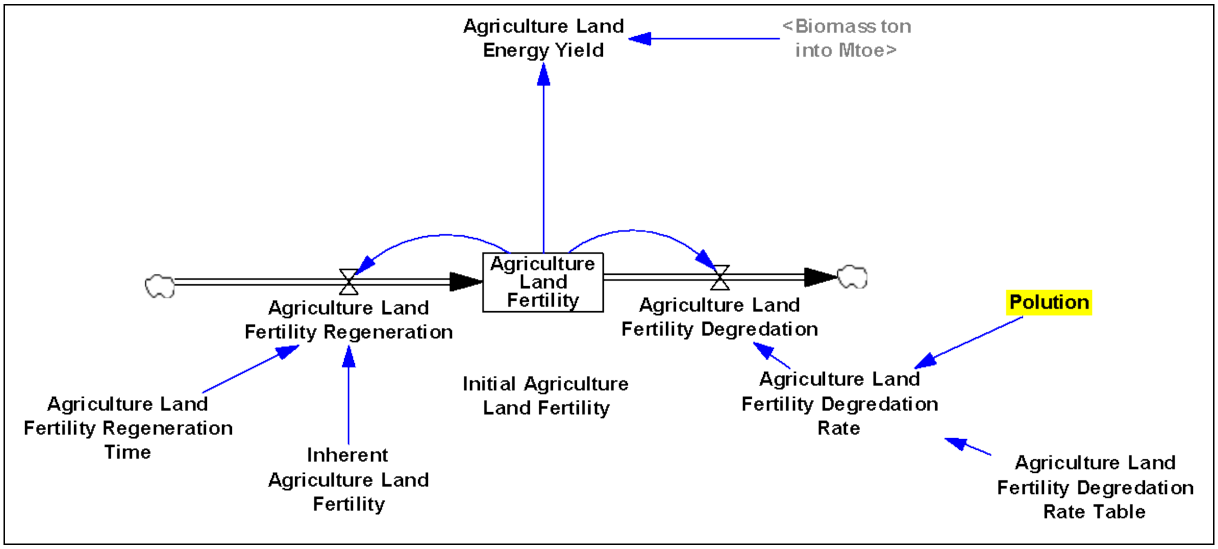


Figure 21 FeliX model – Land sector – agriculture land fertility

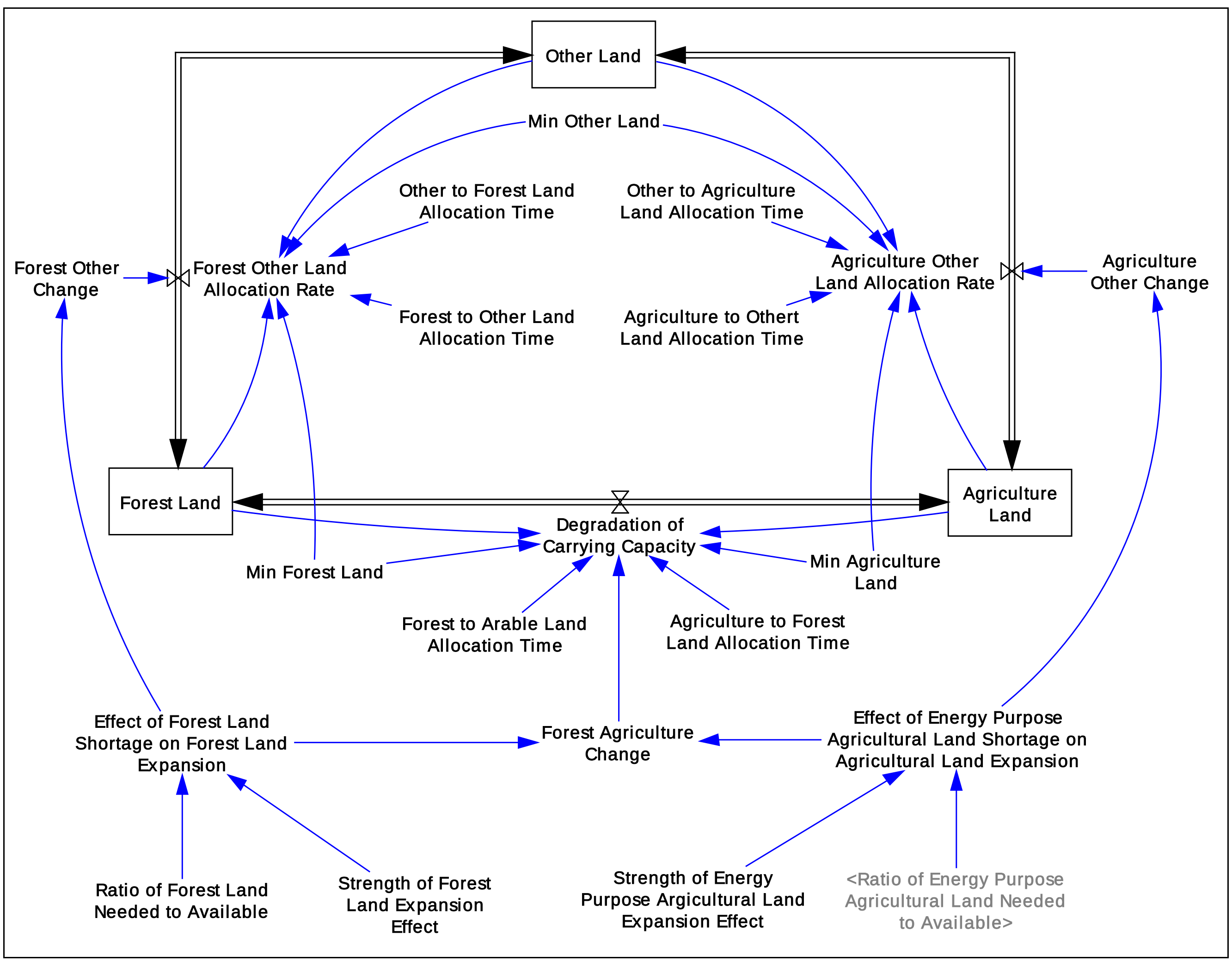


Figure 22 FeliX model – Land sector – need for agriculture and forest land

Forest Land

The structure describing the dynamics of forest land and forest harvesting is quite similar to the energy crops structure. The FeliX model focuses mainly on biomass from forest issues. Energy demand, market share and *Forest Land Fertility* describe how much *Harvest Available Forest Land* shall be harvested for energy purposes (Figure 23). *Ratio of Forest Land Needed to Available* is a basis to calculate a pressure to transform agriculture and other land into forest land.

Similarly to the agriculture land structure, the Forest Land Fertility assumes natural process of regeneration and fertility degradation due to pollution. Additionally the model encompasses the effect of trees age on yield.

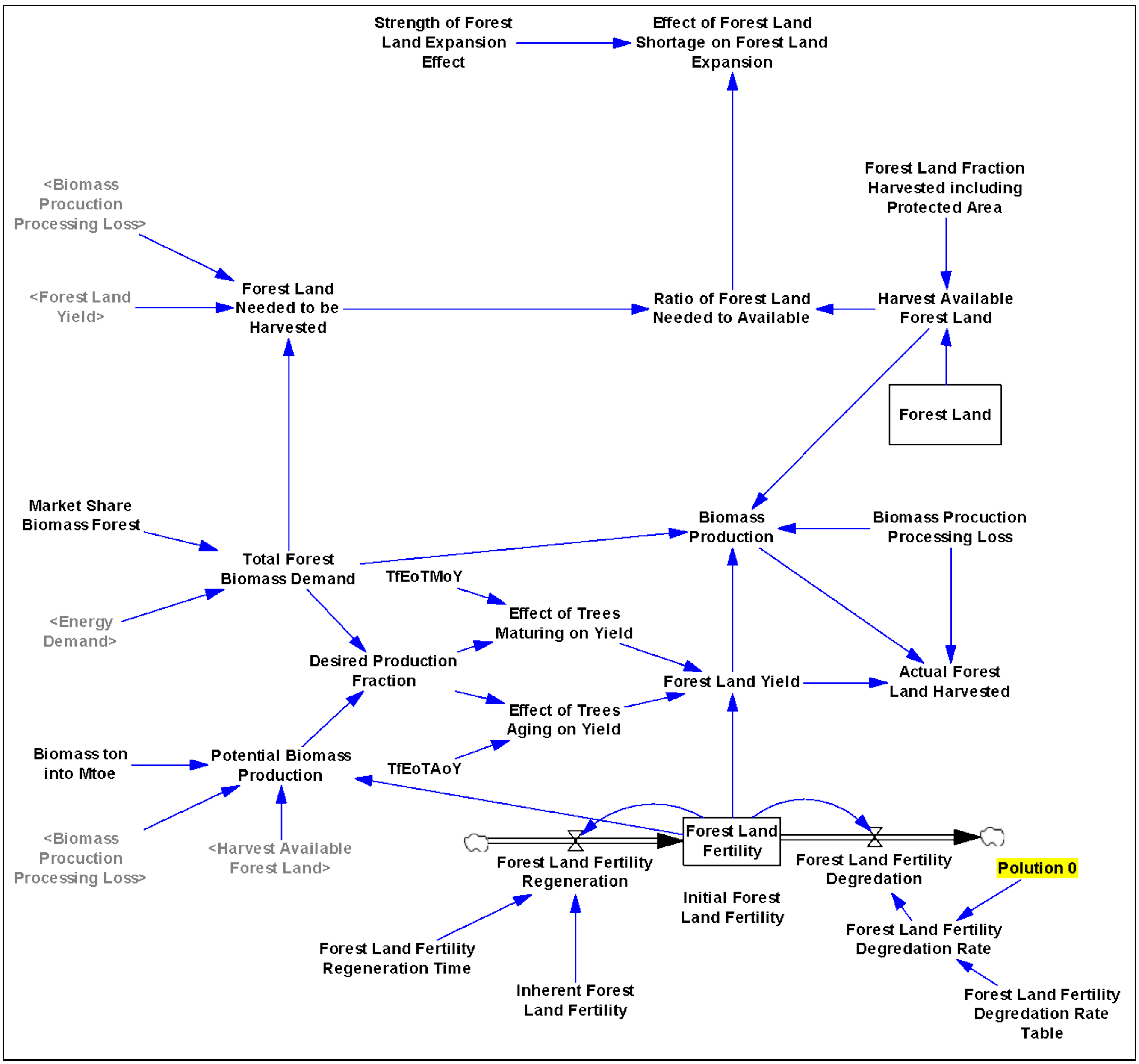


Figure 23 FeliX model – Land sector –forest land

Biomass price

Upon integration of the whole energy sector the biomass will take part in the market share mechanism. For the reason the FeliX model includes calculation of biomass price (both crops and forest biomass). Both prices take into account gross margin and effect of price sensitivity to supply (Figure 24).

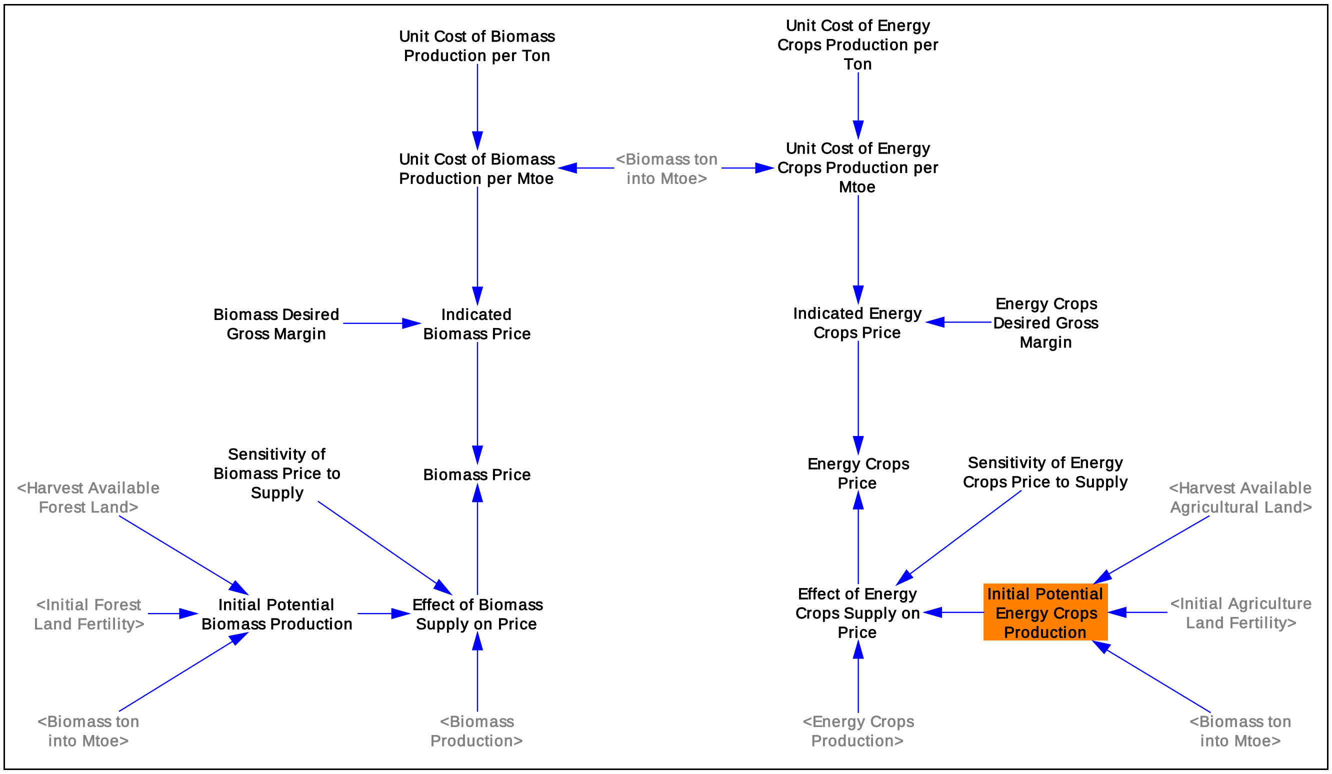


Figure 24 FeliX model – Land sector – biomass price

4.9. FeliX model sectors – GEOSS

GEOSS sector is still under construction. It will be distributed across the whole FeliX model structure as points of interventions – certain policies that are directly supported by available GEO data.

5. Benefits Analysis

This chapter presents an overview of GEO benefits analysis, based on FeliX model. It describes calibration of the model, base run simulation and dynamic simulation scenarios to estimate the benefits of GEO. All simulation runs are conducted using Vensim software.

5.1. Calibration

There are two main stages applied to calibration of the FeliX model.

The first stage is calibration at each sector level. Model inputs, obtained mainly from GEOBENE portfolio – i.e. data, detailed models simulations, are integrated into the structure of FeliX model sectors. Next a simulation is run in order to compare the outcomes of Felix model with historical data. The model is parameterized (in some cases using optimization methods) in order to fit the historical data. As an example Figure 25 presents results of calibration effort in the Energy sector of the FeliX model. Red lines in the presented graphs are historical data regarding global energy demand (IEA 2007), and oil, gas and coal production (BP 2007). Blue lines are the outcomes of the FeliX simulation experiment. The results constitute a good fit to the historical data.

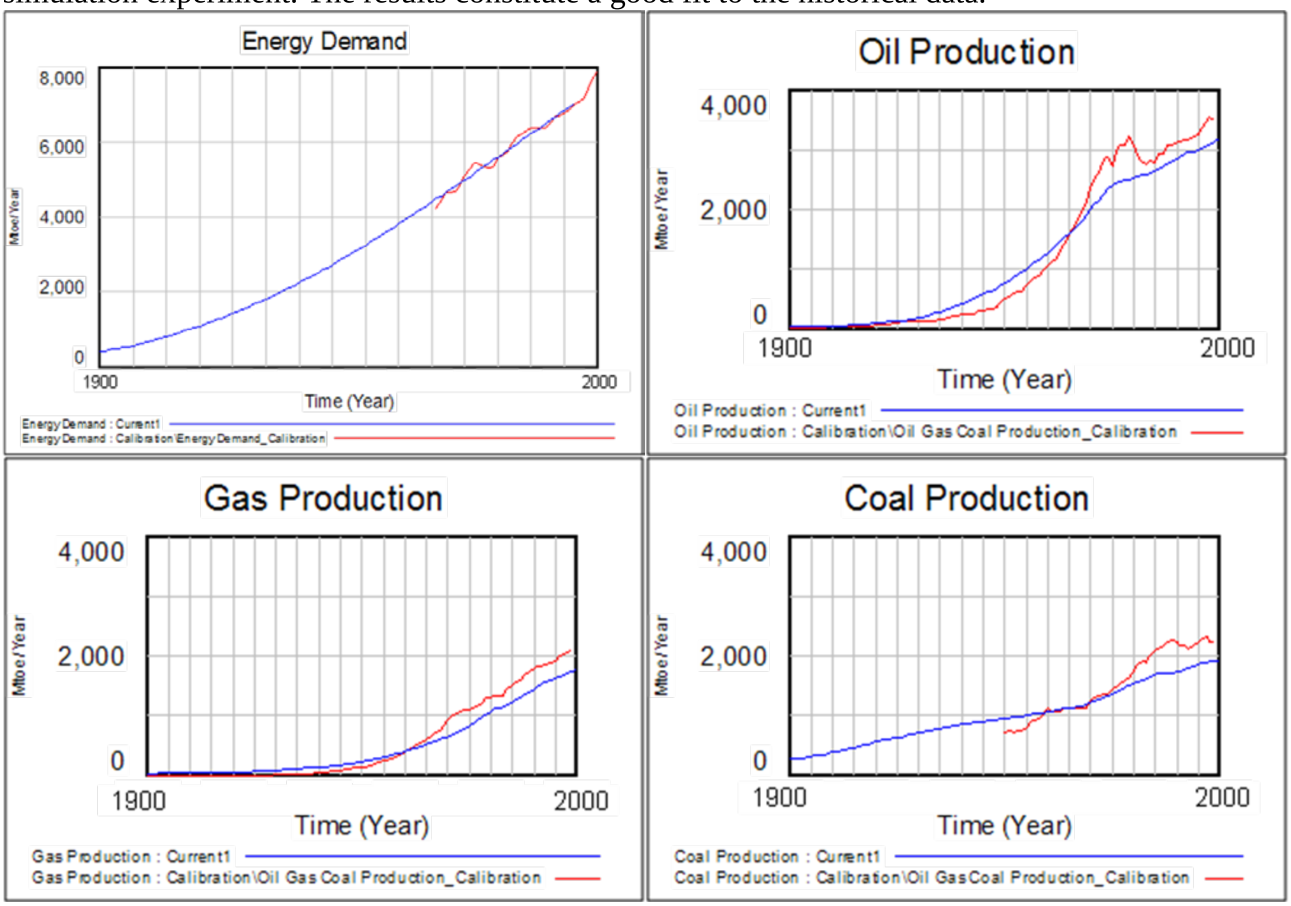


Figure 25 FeliX model – first stage of the model calibration

The second stage of the calibration process will be conducted upon integration of all FeliX model sectors. It will encompass again checking the fit of FeliX model simulation results to historical data.

5.2. Base run

Once the model is calibrated to the historical data there will be changed the time scale of the model. The calibration of the model is conducted on the time scale ranging from year 1900 up to year 2000. For the purposes of the GEO Benefits Analysis the time scale will be extended by the next 100 years, i.e. up to year 2100.
Simulation of the FeliX model, calibrated to the historical data with the extended time scale, is kind of foresight simulation scenario – what would the elements considered in the model look like (e.g. energy production, population, land use) if the economic, social and environmental policies are not changed. The outcome of such simulation scenario will be called *Base Run*.

5.3. GEO benefits estimation

The *Base Run* simulation results will constitute a base line for estimation of GEO benefits across investigated Social Benefits Areas. Upon completion of GEOSS sector including a number of policies supported by GEOSS data it will be possible to test these policies and through comparison to the base run estimate their impact on SBAs.

Only as an example, using the existing, not sector integrated and without extended time scale FeliX model, let's try to investigate how improvement in GEOSS availability and effectiveness influences gas discovery technology. Figure 26 presets the results of such assumption.

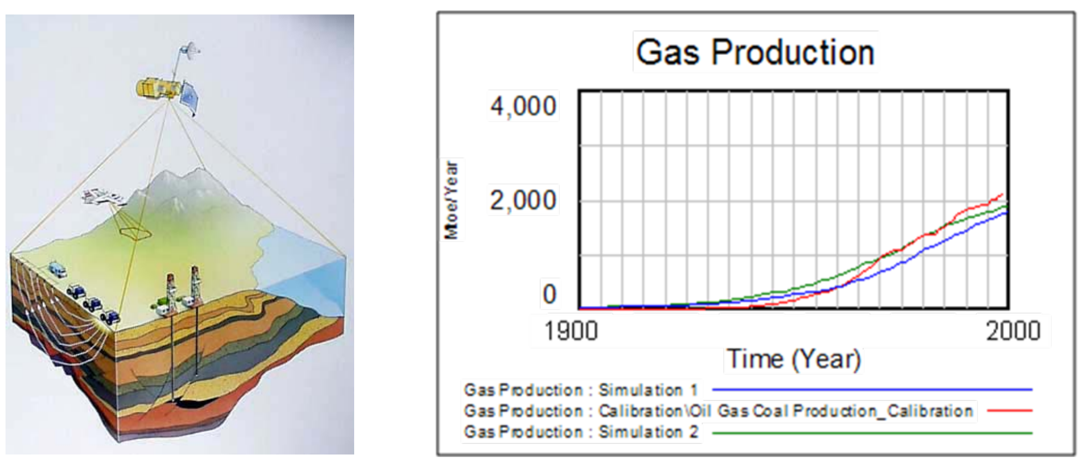


Figure 26 FeliX model – illustrative GEO benefits assessment – gas production

One shall compare a new – green line against the base (blue) line. There is a significant difference between them measured in millions of tons of oil equivalent. The greater effectiveness of gas discovery following involvement of GEOSS enabled greater gas production. However, this is only a part of the outcome.
The more effective gas discovery changes the energy market structure and thus production of energy from other sources. Figure 27 illustrates the lower production of Oil and Coal as a result of such changes. How does it change CO_2 emission? What is than the impact on environment, economy, people's health, and land use? It is rarely that development, implementation and use of GEOSS will result in certain benefits only in

one area of interest. Changes, new policies or practices in one area may lead to quite significant changes in other areas.

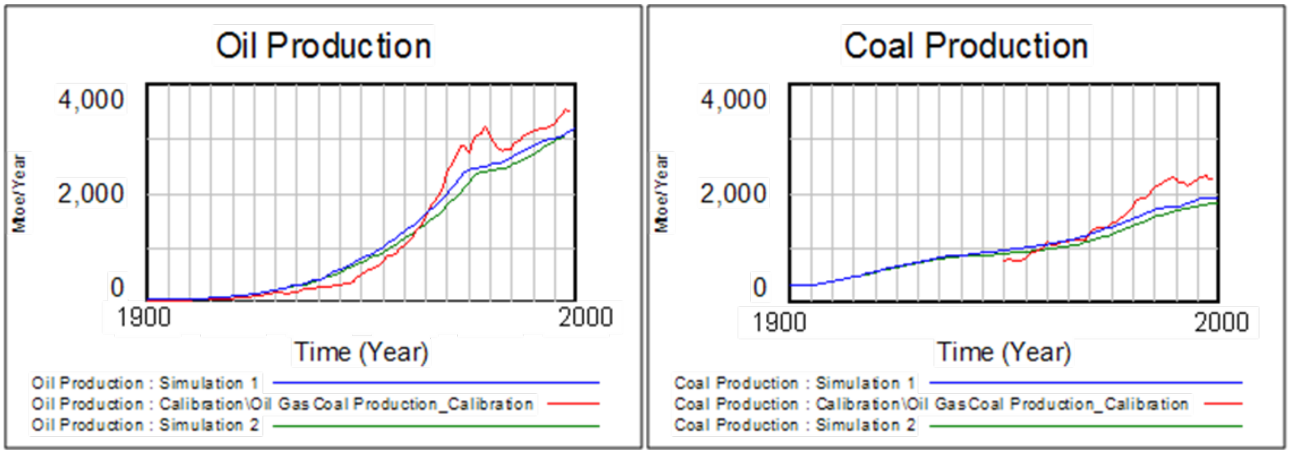


Figure 27 FeliX model – illustrative GEO benefits assessment – energy production from other sources

5.4. Simulator

Once all models sectors are integrated, the FeliX model will allow for cross–sectoral analysis example of which was given in previous section. However, keeping in mind that the policy makers do not need to know all kinds of modeling and simulation techniques there is recognized a need for a tool that would enable use of the FeliX model and tests of various GEO related policies. Under development there is a simulator based on the FeliX model and equipped with a user friendly interface. Policy makers will be able on their own define and run a number of GOE related policies and test the assumptions they had have against results of the FeliX model.

5.5 Detailed models

The purpose of the FeliX model is to integrate various data and detailed models outputs within BEOBENE portfolio. Despite all advantages of the global systems model, which is the FeliX model, one needs to remember that because of the integration process some of the issues investigated as a part of GEO-BENE project were not included into the FeliX model structure. Some issues might have been too detailed or not a part of the sectors considered crucial for the purposes facing the FeliX model. It does not mean that these issues or date are not important, however. On the contrary, they might be of great importance from a perspective of thorough analysis of the GEO benefits. For that reason and as much as possible the FeliX model based simulator will inform and direct the policy makers using the simulator to the detailed models, data and reports from the GEOBENE project portfolio.

6. Conclusion

With FeliX GEO-BENE has produced a unique integrated assessment tool to incorporate both quantitative results from other studies as well other forms of GEO related knowledge. In this way GEO-BENE will be able to quantify the benefits of integration and synthesis. It is envisaged that FeliX will be applied to determine the quantification entering the final GEO-BENE report and will be used for ex ante assessments by other researchers outside the GEO-BENE consortium after the end of the GEO-BENE project – namely for the ex ante evaluation under the GEO Monitoring & Evaluation task force.

7. Appendixes

The FeliX model variables are not documented yet. Upon completion of the project each model variable will be described for its better understanding.

Model Documentation of FeliX (659 variables sorted by group)

Types:	**S** : Stock (58)	**SM** : Smooth (11)	**SI** : Stock Initial (58)	**I** : Initial (0)	**L** : Lookup (10)
	C : Constant (233)	**F** : Flow (65)	**A** : Auxiliary (347)	**Sub**: Subscripts (0)	

Groups:	**Climate** (23)	**Control** (4) Simulation Control Parameters	**Economy** (28)	**Emissions** (29)	**Energy** (100)
	Energy Biomass (37)	**Energy Coal** (76)	**Energy Gas** (77)	**Energy Oil** (74)	**Energy Solar** (55)
	Energy Wind (57)	**Land** (73)	**Population** (26)		

Group (13)	Type (8)	Variable Name and Description (659)
Climate	S	**Atmospheric and Upper Ocean Temperature** (DegreesC) = 0.8923 + ∫(Change in T)
Climate	F,A	**Change in T** (**undefined**) = (Radiative Forcing - Feedback Cooling - Heat Transfer) / Thermal Capacity of Upper Layer
Climate	F,A	**Change in TDO** (DegreesC/Year) = Heat Transfer / Thermal Capacity of Deep Oceans
Climate	A	**Climate Damage Fraction** (Dmnl) = 1 / (1 + Climate Damage Scale * (Atmospheric and Upper Ocean Temperature / Reference Temperature) ^ Climate Damage Nonlinearity)
Climate	C	**Climate Damage Nonlinearity** (Dmnl) = 2
Climate	A	**Climate Damage Rate** (Dmnl) = Climate Damage Scale / (Reference Temperature) ^ Climate Damage Nonlinearity
Climate	C	**Climate Damage Scale** (Dmnl) = 0.013
Climate	C	**Climate Feedback Parameter** (Watt/(Meter*Meter*DegreesC)) = 1.41
Climate	A	**CO2 Radiative Forcing** (Watt/(Meter*Meter)) = CO2 Radiative Forcing Coefficient * LOG (CO2 in Atmosphere / Preindustrial CO2 in Atmosphere , 2)
Climate	C	**CO2 Radiative Forcing Coefficient** (Watt/(Meter*Meter)) = 4.1
Climate	S	**Deep Ocean Temperature** (DegreesC) = 0.13 + ∫(Change in TDO)
Climate	A	**Feedback Cooling** (Watt/(Meter*Meter)) = Climate Feedback Parameter * Atmospheric and Upper Ocean Temperature
Climate	A	**Heat Transfer** (Watt/(Meter*Meter)) = Ratio of Thermal Capacity of Deep Oceans to Heat Transfer Time Constant * Temperature Difference

Climate	A	**Net Climate Change Impact** (Dmnl) = GHG Reduction Cost Fraction * Climate Damage Fraction
Climate	L	**Other GHG Radiative Forcing Coefficient** (Watt/(Meter*Meter)) = WITH LOOKUP(Time , ([(2000,0.6)-(2105,2)],(2000,0.74),(2005,0.78),(2015,0.87),(2025,0.96),(2035,1.05),(2045,1.14),(2055,1.2),(2065,1.25),(2075,1.29),(2085,1.32),(2095,1.35),(2105,1.36)))
Climate	C	**Polution** (Dmln) = 0.2
Climate	A	**Radiative Forcing** (Watt/(Meter*Meter)) = CO2 Radiative Forcing + Other GHG Radiative Forcing Coefficient
Climate	C	**Ratio of Thermal Capacity of Deep Oceans to Heat Transfer Time Constant** (Watt/(Meter*Meter*DegreesC)) = 0.44
Climate	C	**Reference Temperature** (DegreesC) = 3
Climate	A	**Temperature Difference** (DegreesC) = Atmospheric and Upper Ocean Temperature - Deep Ocean Temperature
Climate	A	**Thermal Capacity of Deep Oceans** (Year*Watt/(Meter*Meter*DegreesC)) = Ratio of Thermal Capacity of Deep Oceans to Heat Transfer Time Constant * Transfer Rate from Upper to Lower Reservoir
Climate	C	**Thermal Capacity of Upper Layer** (Year*Watt/(Meter*Meter*DegreesC)) = 44.248
Climate	C	**Transfer Rate from Upper to Lower Reservoir** (Year) = 500
Control	C	**FINAL TIME** (Year) = 2300
Control	C	**INITIAL TIME** (Year) = 2000
Control	C	**SAVEPER** (Year [0,?]) = 1
Control	C	**TIME STEP** (Year [0,?]) = 0.01
Economy	S	**A technology stock** (Dmnl) = INIT A + $\int$(Net technology Increase)

Economy	S	**Capital** ($) = 5.97673e+013 + ∫(Investment Rate - Capital Depreciation Rate)
Economy	F,A	**Capital Depreciation Rate** ($/Year) = Depreciation Factor * Capital
Economy	C	**Capital Elasticity Output** (Dmnl) = 0.25
Economy	F,A	**Change in Economic Output** ($/(Year*Year)) = (Economic Output ie Gross World Product - Previous Economic Output) / EO Adjustment Time
Economy	F,A	**Change in Population Growth Rate** (1/(Year*Year)) = Population Growth Rate * Population Growth Rate Decline Rate
Economy	F,A	**Change in Technology Growth Rate** (1/(Year*Year)) = Technology Growth Rate * Technology Growth Rate Decline Rate
Economy	A	**Consumption** ($/Year) = Economic Output ie Gross World Product - Investment Rate
Economy	A	**Consumption per Capita** ($/(Year*Person)) = Consumption / L Population
Economy	C	**Depreciation Factor** (1/Year) = 0.065
Economy	A	**Economic Output ie Gross World Product** ($/Year) = Net Climate Change Impact * Reference Output
Economy	C	**EO Adjustment Time** (Year) = 1
Economy	A	**EO Current Growth Rate** (1/Year) = Change in Economic Output / Economic Output ie Gross World Product
Economy	SI,C	**INIT A** (Dmnl) = 1.545
Economy	C	**INIT Capital** ($) = 5.97673e+013
Economy	SI,C	**INIT L Population** (Person) = 5.944e+009
Economy	F,A	**Investment Rate** ($/Year) = S savings * Economic Output ie Gross World Product
Economy	S	**L Population** (Person) = INIT L Population + ∫(Net Population Increase)
Economy	F,A	**Net Population Increase** (Person/Year) = L Population * Population Growth Rate
Economy	F,A	**Net technology Increase** (1/Year) = A technology stock * Technology Growth Rate
Economy	C	**Output in 2000** ($/Year) = 1.81136e+013
Economy	S	**Population Growth Rate** (1/Year) = 0.0113 + ∫(- Change in Population Growth Rate)
Economy	C	**Population Growth Rate Decline Rate** (1/Year) = 0.0195
Economy	S	**Previous Economic Output** ($/Year) = 2.7306e+013 + ∫(Change in Economic Output)
Economy	A	**Reference Output** ($/Year) = Output in 2000 * A technology stock * ((Capital / INIT Capital) ^ Capital Elasticity Output) * ((L Population / INIT L Population) ^ (1 - Capital Elasticity Output))

Economy	L	**S savings** (Dmnl) = WITH LOOKUP(Time , ([(2000,0)-(2305,1)],(2000,0.19),(2005,0.18),(2010,0.1775),(2015,0.175),(2020,0.1725),(2025,0.17),(2305,0.17)))
Economy	S	**Technology Growth Rate** (1/Year) = 0.0102 + ∫(- Change in Technology Growth Rate)
Economy	C	**Technology Growth Rate Decline Rate** (1/Year) = 0.011
Emissions	C	**Atmospheric Retention (beta)** (Dmnl) = 0.64
Emissions	S	**Carbon Intensity Decline Rate** (1/Year) = 0.0079 + ∫(- Change in Carbon Intensity Decline Rate)
Emissions	C	**Carbon Intensity Decline Rate Growth Rate** (1/Year) = 0.011
Emissions	F,A	**Change in Carbon Intensity Decline Rate** (1/(Year*Year)) = Carbon Intensity Decline Rate Growth Rate * Carbon Intensity Decline Rate
Emissions	A	**CO2 Emission from Coal Production** (**undefined**) = Coal Production * CO2 Intensity of Production from Coal
Emissions	A	**CO2 Emission from Gas Production** (**undefined**) = Gas Production * CO2 Intensity of Production from Gas
Emissions	A	**CO2 Emission from Oil Production** (**undefined**) = Oil Production * CO2 Intensity of Production from Oil
Emissions	A	**CO2 Emission from Solar Energy Production** (**undefined**) = Solar Energy Production * CO2 Intensity of Production from Solar Energy
Emissions	A	**CO2 Emission from Wind Energy Production** (**undefined**) = Wind Energy Production * CO2 Intensity of Production from Wind Energy
Emissions	A	**CO2 Emissions** (TonC/Year) = (1 - Rate of Emission Reduction) * CO2 Intensity of Production * Economic Output ie Gross World Product
Emissions	S	**CO2 in Atmosphere** (TonC) = 7.9949e+011 + ∫(Net Emission - CO2 Removal from Atmosphere)
Emissions	S	**CO2 Intensity of Production** (TonC/$) = 0.000369743 + ∫(- Decline CO2 Intensity)
Emissions	C	**CO2 Intensity of Production from Coal** (**undefined**) = 1

Emissions	C	**CO2 Intensity of Production from Gas** (**undefined**) = 1
Emissions	C	**CO2 Intensity of Production from Oil** (**undefined**) = 1
Emissions	C	**CO2 Intensity of Production from Solar Energy** (**undefined**) = 1
Emissions	C	**CO2 Intensity of Production from Wind Energy** (**undefined**) = 1
Emissions	F,A	**CO2 Removal from Atmosphere** (TonC/Year) = (CO2 in Atmosphere - Preindustrial CO2 in Atmosphere) * Rate of CO2 Transfer
Emissions	A	**Damage from Greenhouse Warming** (**undefined**) = Reference Output * Climate Damage Rate * Atmospheric and Upper Ocean Temperature ^ Climate Damage Nonlinearity
Emissions	F,A	**Decline CO2 Intensity** (TonC/($*Year)) = Carbon Intensity Decline Rate * CO2 Intensity of Production
Emissions	A	**GHG Reduction Cost Fraction** (Dmnl) = 1 - Scale of GHG Reduction Cost * Rate of Emission Reduction ^ Reduction Cost Nonlinearity
Emissions	F,A	**Net Emission** (TonC/Year) = "Atmospheric Retention (beta)" * CO2 Emissions
Emissions	C	**Preindustrial CO2 in Atmosphere** (TonC) = 5.9e+011
Emissions	C	**Rate of CO2 Transfer** (1/Year) = 0.008333
Emissions	C	**Rate of Emission Reduction** (Dmnl [0,1]) = 0
Emissions	C	**Reduction Cost Nonlinearity** (Dmnl) = 2.887
Emissions	C	**Scale of GHG Reduction Cost** (Dmnl) = 0.0686
Emissions	A	**Total CO2 Emission form Energy Sector** (**undefined**) = CO2 Emission from Oil Production + CO2 Emission from Coal Production + CO2 Emission from Gas Production + CO2 Emission from Solar Energy Production + CO2 Emission from Wind Energy Production
Emissions	A	**Total Cost of Reducing GHG Emissions** ($/Year) = (1 - GHG Reduction Cost Fraction) * Reference Output
Energy	C	**AT** (**undefined**) = 5
Energy	A	**Average Energy Price** ($/Mtoe) = (Average Price Oil + Average Price Gas + Average Price Coal + Average Price Solar + Average Price Wind) / Number of Energy Sources
Energy	S	**Average Price Coal** ($/Mtoe) = IAPC + ∫(Change in Price Coal)
Energy	S	**Average Price Gas** ($/Mtoe) = IAPG + ∫(Change in Price Gas)
Energy	S	**Average Price Oil** ($/Mtoe) = IAPO + ∫(Change in Price Oil)
Energy	S	**Average Price Savings** ($/Mtoe) = Init Average Price Savings + ∫(Change in Price Savings)
Energy	S	**Average Price Solar** ($/Mtoe) = IAPS + ∫(Change in Price Solar)
Energy	S	**Average Price Wind** ($/Mtoe) = IAPW + ∫(Change in Price Wind)
Energy	S	**CC** (**undefined**) = 15000 + ∫(- CCDR)

Energy	C	**CCDF** (**undefined**) = 0
Energy	F,A	**CCDR** (**undefined**) = CC * CCDF
Energy	A	**CCR** (**undefined**) = MR * (1 - ED / CC)
Energy	A	**Change in Energy Demand** (Mtoe/(Year*Year)) = Energy Demand * Energy Demand Growth Rate
Energy	F,A	**Change in Energy Demand Growth Rate** (1/(Year*Year)) = Energy Demand Growth Rate * Energy Demand Growth Rate Decline
Energy	S	**Change in Market Share Coal** (Dmnl) = Reference Change in Market Share Coal * Effect of Price on Market Share Coal + ∫(Change Rate Due to Price Coal)
Energy	S	**Change in Market Share Gas** (Dmnl) = Reference Change in Market Share Gas * Effect of Price on Market Share Gas + ∫(Change Rate Due to Price Gas)
Energy	S	**Change in Market Share Oil** (Dmnl) = Reference Change in Market Share Oil * Effect of Price on Market Share Oil + ∫(Change Rate Due to Price Oil)
Energy	S	**Change in Market Share Savings** (Dmnl) = Reference Change in Market Share Savings * Effect of Price on Market Share Savings + ∫(Change Rate Due to Price Savings)
Energy	S	**Change in Market Share Solar** (Dmnl) = Reference Change in Market Share Solar * Effect of Price on Market Share Solar + ∫(Change Rate Due to Price Solar)
Energy	S	**Change in Market Share Wind** (Dmnl) = Reference Change in Market Share Wind * Effect of Price on Market Share Wind + ∫(Change Rate Due to Price Wind)
Energy	F,A	**Change in Price Coal** ($/(Mtoe*Year)) = ((Coal Price / for price coal) - Average Price Coal) / Time to Average Price Coal
Energy	F,A	**Change in Price Gas** ($/(Mtoe*Year)) = ((Gas Price / for price gas) - Average Price Gas) / Time to Average Price Gas
Energy	F,A	**Change in Price Oil** ($/(Mtoe*Year)) = ((Oil Price / for price oil) - Average Price Oil) / Time to Average Price Oil
Energy	F,A	**Change in Price Savings** ($/(Mtoe*Year)) = (Average Energy Price - Average Price Savings) / Time to Average Price Savings
Energy	F,A	**Change in Price Solar** ($/(Mtoe*Year)) = (Solar Energy Price per kWh - Average Price Solar) / Time to Average Price Solar
Energy	F,A	**Change in Price Wind** ($/(Mtoe*Year)) = (Wind Energy Price per kWh - Average Price Wind) / Time to Average Price Wind
Energy	F,A	**Change Rate Due to Price Coal** (1/Year) = (Reference Change in Market Share Coal * Effect of Price on Market Share Coal - Change in Market Share Coal) / Time to Adjust Market Share
Energy	F,A	**Change Rate Due to Price Gas** (1/Year) = (Reference Change in Market Share Gas * Effect of Price on Market Share Gas - Change in Market Share Gas) / Time to Adjust Market Share
Energy	F,A	**Change Rate Due to Price Oil** (1/Year) = (Reference Change in Market Share Oil * Effect of Price on Market Share Oil - Change in Market Share Oil) / Time to Adjust Market Share
Energy	F,A	**Change Rate Due to Price Savings** (1/Year) = (Reference Change in Market Share Savings * Effect of Price on Market Share Savings - Change in Market Share Savings) / Time to Adjust Market Share

Energy	F,A	**Change Rate Due to Price Solar** (1/Year) = (Reference Change in Market Share Solar * Effect of Price on Market Share Solar - Change in Market Share Solar) / Time to Adjust Market Share
Energy	F,A	**Change Rate Due to Price Wind** (1/Year) = (Reference Change in Market Share Wind * Effect of Price on Market Share Wind - Change in Market Share Wind) / Time to Adjust Market Share
Energy	S	**ED** (**undefined**) = 200 + ∫(EDIR)
Energy	SI,C	**EDGRN** (1/Year) = 0.05535
Energy	F,A	**EDIR** (**undefined**) = DELAY3 (ED * CCR , AT)
Energy	C	**EDN** (Mtoe/Year) = 400
Energy	SI,A	**Effect of Price on Market Share Coal** (Dmnl) = Price Competitiveness Factor Coal ^ (- Price Elasticity of Demand Coal)
Energy	SI,A	**Effect of Price on Market Share Gas** (Dmnl) = Price Competitiveness Factor Gas ^ (- Price Elasticity of Demand Gas)
Energy	SI,A	**Effect of Price on Market Share Oil** (Dmnl) = Price Competitiveness Factor Oil ^ (- Price Elasticity of Demand Oil)
Energy	SI,A	**Effect of Price on Market Share Savings** (Dmnl) = Price Competitiveness Factor Savings ^ (- Price Elasticity of Demand Savings)
Energy	SI,A	**Effect of Price on Market Share Solar** (Dmnl) = Price Competitiveness Factor Solar ^ (- Price Elasticity of Demand Solar)
Energy	SI,A	**Effect of Price on Market Share Wind** (Dmnl) = Price Competitiveness Factor Wind ^ (- Price Elasticity of Demand Wind)
Energy	A	**Energy Demand** (Mtoe/Year) = ED
Energy	S	**Energy Demand Growth Rate** (1/Year) = EDGRN + ∫(- Change in Energy Demand Growth Rate)
Energy	C	**Energy Demand Growth Rate Decline** (1/Year) = 0.0195
Energy	C	**for price coal** (**undefined**) = 2.04082e+006
Energy	C	**for price gas** (**undefined**) = 4e+007
Energy	C	**for price oil** (**undefined**) = 7.33138e+006
Energy	C	**Hours per Year** (Hour/Year) = 8760
Energy	SI,C	**IAPC** ($/Mtoe) = 4
Energy	SI,C	**IAPG** ($/Mtoe) = 450
Energy	SI,C	**IAPO** ($/Mtoe) = 35
Energy	SI,C	**IAPS** ($/Mtoe) = 50000
Energy	SI,C	**IAPW** ($/Mtoe) = 50000
Energy	SI,C	**Init Average Price Savings** ($/Mtoe) = 30
Energy	C	**kW into GW** (kW/GW) = 1e+006

Energy	C	**kW into TW** (kW/TW) = 1e+010
Energy	C	**kWh into Mtoe** (Mtoe/(Hour*kW)) = 8.6e-011
Energy	C	**kWh into Mtoe peak hour** (Mtoe/kW) = 8.6e-011
Energy	C	**Market Share Biomass Crops** (Dmnl) = 0.01
Energy	C	**Market Share Biomass Forest** (1) = 0.01
Energy	A	**Market Share Coal** (Dmnl) = Change in Market Share Coal / Reference Change in Total Market Share
Energy	A	**Market Share Gas** (Dmnl) = Change in Market Share Gas / Reference Change in Total Market Share
Energy	A	**Market Share Oil** (Dmnl) = Change in Market Share Oil / Reference Change in Total Market Share
Energy	A	**Market Share Savings** (Dmnl) = Change in Market Share Savings / Reference Change in Total Market Share
Energy	A	**Market Share Solar** (Dmnl) = Change in Market Share Solar / Reference Change in Total Market Share
Energy	A	**Market Share Wind** (Dmnl) = Change in Market Share Wind / Reference Change in Total Market Share
Energy	C	**MR** (**undefined**) = 0.055
Energy	C	**Mtoe per Ton** (Mtoe/Ton) = 4.9e-007
Energy	C	**Number of Energy Sources** (Dmnl) = 4
Energy	A	**Price Competitiveness Factor Coal** (Dmnl) = (Average Price Coal) / Average Energy Price
Energy	A	**Price Competitiveness Factor Gas** (Dmnl) = (Average Price Gas) / Average Energy Price
Energy	A	**Price Competitiveness Factor Oil** (Dmnl) = (Average Price Oil) / Average Energy Price
Energy	A	**Price Competitiveness Factor Savings** (Dmnl) = (Average Price Savings) / Average Energy Price
Energy	A	**Price Competitiveness Factor Solar** (Dmnl) = (Average Price Solar) / Average Energy Price
Energy	A	**Price Competitiveness Factor Wind** (Dmnl) = (Average Price Wind) / Average Energy Price
Energy	C	**Price Elasticity of Demand Coal** (Dmnl) = 0.8
Energy	C	**Price Elasticity of Demand Oil** (Dmnl) = 0.65
Energy	C	**Price Elasticity of Demand Savings** (Dmnl) = 1
Energy	C	**Price Elasticity of Demand Solar** (Dmnl) = 3
Energy	C	**Price Elasticity of Demand Wind** (Dmnl) = 3
Energy	SI,C	**Reference Change in Market Share Coal** (Dmnl) = 1
Energy	SI,C	**Reference Change in Market Share Gas** (Dmnl) = 1

Energy	SI,C	**Reference Change in Market Share Oil** (Dmnl) = 1
Energy	SI,C	**Reference Change in Market Share Savings** (Dmnl) = 1
Energy	SI,C	**Reference Change in Market Share Solar** (Dmnl) = 1
Energy	SI,C	**Reference Change in Market Share Wind** (Dmnl) = 1
Energy	A	**Reference Change in Total Market Share** (Dmnl) = Change in Market Share Oil + Change in Market Share Gas + Change in Market Share Coal + Change in Market Share Solar + Change in Market Share Wind
Energy	C	**Solar Market Share** (1) = 0.0001
Energy	C	**Time to Adjust Market Share** (Year) = 10
Energy	C	**Time to Average Price Coal** (Year) = 1
Energy	C	**Time to Average Price Gas** (Year) = 1
Energy	C	**Time to Average Price Oil** (Year) = 1
Energy	C	**Time to Average Price Savings** (Year) = 1
Energy	C	**Time to Average Price Solar** (Year) = 50
Energy	C	**Time to Average Price Wind** (Year) = 50
Energy	A	**Total Energy Market** (Dmnl) = Market Share Oil + Market Share Gas + Market Share Coal + Market Share Solar
Energy	C	**W into GW** (W/GW) = 1e+009
Energy	C	**Wind Market Share** (1) = 0.0001
Energy	C	**Year Number** (Year) = 1
Energy Biomass	A	**Actual Agricultural Land Crops Harvested** (ha) = (Energy Crops Production / (1 - Energy Crops Processing Loss)) / Agriculture Land Energy Yield
Energy Biomass	A	**Actual Forest Land Harvested** (ha) = (Biomass Production / (1 - Biomass Procuction Processing Loss)) / Forest Land Yield
Energy Biomass	A	**Agricultural Land Needed to be Harvested for Biomass Production** (ha) = (Total Crops Biomass Demand / (1 - Energy Crops Processing Loss)) / Agriculture Land Energy Yield
Energy Biomass	A	**Agriculture Land Energy Yield** (Mtoe/(Year*ha)) = Agriculture Land Fertility * Biomass ton into Mtoe
Energy Biomass	C	**Biomass Desired Gross Margin** (**undefined**) = 0.2
Energy Biomass	A	**Biomass Price** (**undefined**) = Indicated Biomass Price * Effect of Biomass Supply on Price
Energy Biomass	C	**Biomass Procuction Processing Loss** (1) = 0.1
Energy Biomass	A	**Biomass Production** (Mtoe/Year) = MIN (Total Forest Biomass Demand , Harvest Available Forest Land * Forest Land Yield * (1 - Biomass Procuction Processing Loss))

Energy Biomass	A	**Biomass ton into Mtoe** (Mtoe/Biomass ton) = 1 / 2.4e+006
Energy Biomass	A	**Desired Production Fraction** (Mtoe/Biomass ton) = Total Forest Biomass Demand / Potential Biomass Production
Energy Biomass	A	**Effect of Biomass Supply on Price** (Dmnl) = (Biomass Production / Initial Potential Biomass Production) ^ Sensitivity of Biomass Price to Supply
Energy Biomass	A	**Effect of Energy Crops Supply on Price** (Dmnl) = (Energy Crops Production / Initial Potential Energy Crops Production) ^ Sensitivity of Energy Crops Price to Supply
Energy Biomass	A	**Effect of Trees Aging on Yield** (Dmnl) = TfEoTAoY (Desired Production Fraction)
Energy Biomass	A	**Effect of Trees Maturing on Yield** (Dmnl) = TfEoTMoY (Desired Production Fraction)
Energy Biomass	C	**Energy Crops Desired Gross Margin** (**undefined**) = 0.2
Energy Biomass	A	**Energy Crops Price** (**undefined**) = Indicated Energy Crops Price * Effect of Energy Crops Supply on Price
Energy Biomass	C	**Energy Crops Processing Loss** (Dmnl) = 0.1
Energy Biomass	A	**Energy Crops Production** (Mtoe/Year) = MIN (Total Crops Biomass Demand , Energy Potential Agriculture Land * Agriculture Land Energy Yield * (1 - Energy Crops Processing Loss))
Energy Biomass	A	**Energy Potential Agriculture Land** (ha) = Harvest Available Agricultural Land * Required Energy Crops Harvest Fraction
Energy Biomass	A	**Forest Land Needed to be Harvested** (ha) = (Total Forest Biomass Demand / (1 - Biomass Procuction Processing Loss)) / Forest Land Yield
Energy Biomass	A	**Forest Land Yield** (Mtoe/(Year*ha)) = Forest Land Fertility * Effect of Trees Maturing on Yield * Effect of Trees Aging on Yield * Biomass ton into Mtoe
Energy Biomass	A	**Indicated Biomass Price** (**undefined**) = Unit Cost of Biomass Production per Mtoe * (1 + Biomass Desired Gross Margin)
Energy Biomass	A	**Indicated Energy Crops Price** (**undefined**) = Unit Cost of Energy Crops Production per Mtoe * (1 + Energy Crops Desired Gross Margin)
Energy Biomass	A	**Initial Potential Biomass Production** (Mtoe/Year) = Harvest Available Forest Land * Initial Forest Land Fertility * Biomass ton into Mtoe
Energy Biomass	A	**Initial Potential Energy Crops Production** (Mtoe/Year) = Harvest Available Agricultural Land * Initial Agriculture Land Fertility * Biomass ton into Mtoe
Energy Biomass	A	**Potential Biomass Production** (Mtoe/Year) = Forest Land Fertility * Harvest Available Forest Land * Biomass ton into Mtoe * (1 - Biomass Procuction Processing Loss)
Energy Biomass	A	**Required Energy Crops Harvest Fraction** (Dmnl) = (Agricultural Land Needed to be Harvested for Biomass Production) / (Agricultural Land Needed to be Harvested for Food Production + Agricultural Land Needed to be Harvested for Biomass Production)
Energy Biomass	C	**Sensitivity of Biomass Price to Supply** (Dmnl) = 2
Energy Biomass	C	**Sensitivity of Energy Crops Price to Supply** (Dmnl) = 2

Energy Biomass	L	**TfEoTAoY** (Dmnl) = [(0,0)-(1,1)],(0,1),(0.4,1),(0.5,0.98),(0.6,0.9),(0.7,0.7),(0.8,0.4),(0.9,0.15),(1,0.001)
Energy Biomass	L	**TfEoTMoY** (Dmnl) = [(0,0)-(1,1)],(0,0.15),(0.1,0.45),(0.2,0.75),(0.3,0.95),(0.4,1),(1,1)
Energy Biomass	A	**Total Crops Biomass Demand** (Mtoe/Year) = Energy Demand * Market Share Biomass Crops
Energy Biomass	A	**Total Forest Biomass Demand** (Mtoe/Year) = Energy Demand * Market Share Biomass Forest
Energy Biomass	A	**Unit Cost of Biomass Production per Mtoe** ($/Mtoe) = Unit Cost of Biomass Production per Ton / Biomass ton into Mtoe
Energy Biomass	C	**Unit Cost of Biomass Production per Ton** ($/Biomass ton) = 200
Energy Biomass	A	**Unit Cost of Energy Crops Production per Mtoe** ($/Mtoe) = Unit Cost of Energy Crops Production per Ton / Biomass ton into Mtoe
Energy Biomass	C	**Unit Cost of Energy Crops Production per Ton** ($/Biomass ton) = 200

Energy Coal	A	**Addjustment for Identified Coal Resource** (Mtoe/Year) = (Required Identified Coal Resources - Idendified Coal Resources) / Identified Coal Resources Adjustment Time
Energy Coal	SM	**Average Coal Production** (Mtoe/Year) = SMOOTH (Coal Production , Time to Average Coal Production)
Energy Coal	SI,C	**CCPN** (Mtoe) = 37630
Energy Coal	A	**Coal Cost** ($/Mtoe) = Unit Cost of Coal Exploration + Unit Cost of Coal Production
Energy Coal	A	**Coal Demand to Supply Ratio** (Dmnl) = Total Coal Demand / Potential Coal Production
Energy Coal	C	**Coal Desired Gross Margin** (Dmnl) = 0.2
Energy Coal	C	**Coal Discovery Technology Development Time** (Year) = 6
Energy Coal	F,A	**Coal Exploration** (Mtoe/Year) = MAX (Coal Exploration Rate , 0)
Energy Coal	A	**Coal Exploration Rate** (Mtoe/Year) = MIN (Desired Coal Exploration Rate , Potential Coal Exploration)
Energy Coal	A	**Coal Fraction Discoverable** (Dmnl) = MINCFD + (MAXCFD - MINCFD) * (Ratio of Coal Fraction Discoverable to Undiscoverable / (Ratio of Coal Fraction Discoverable to Undiscoverable + 1))
Energy Coal	SI,A	**Coal Fraction Recoverable** (Dmnl) = MINCFR + (MAXCFR - MINCFR) * (Ratio of Coal Fraction Recoverable to Unrecoverable / (Ratio of Coal Fraction Recoverable to Unrecoverable + 1))
Energy Coal	A	**Coal Gross Margin** (Dmnl) = (Coal Price - Coal Cost) / Coal Cost
Energy Coal	A	**Coal Price** ($/Mtoe) = Indicated Coal Price * Effect of Coal Demand and Supply on Price
Energy Coal	A	**Coal Price per Ton** ($/Ton) = Coal Price * Mtoe per Ton
Energy Coal	F,A	**Coal Production** (Mtoe/Year) = Coal Production Rate
Energy Coal	A	**Coal Production Coverage** (Year) = Idendified Coal Resources / Average Coal Production
Energy Coal	A	**Coal Production Rate** (Mtoe/Year) = MIN (Total Coal Demand , Potential Coal Production)
Energy Coal	C	**Coal Recovery Technology Development Time** (Year) = 6
Energy Coal	A	**Coal Revenues** ($/Year) = Coal Price * Average Coal Production
Energy Coal	A	**Coal Shortage** (Mtoe/Year) = Total Coal Demand - Coal Production
Energy Coal	A	**Cumulative Additions to Coal Production** (Mtoe) = Idendified Coal Resources + Cumulative Coal Production
Energy Coal	S,SI	**Cumulative Coal Production** (Mtoe) = CCPN + ∫(Coal Production)
Energy Coal	A	**Desired Coal Exploration Rate** (Mtoe/Year) = MAX (0, Addjustment for Identified Coal Resource + Coal Production)
Energy Coal	A	**Desired Investment in Coal Exploration** ($/Year) = Desired Coal Exploration Rate * Unit Cost of Coal Exploration
Energy Coal	A	**Desired Investment in Coal Production** ($/Year) = MIN (Potential Coal Production from Resources , Total Coal Demand) / Productivity of Investment in Coal Production

Energy Coal	A	**Desired Investment in Oil Production** ($/Year) = MIN (Potential Oil Production from Resources , Total Oil Demand) / Productivity of Investment in Oil Production
Energy Coal	A	**Effect of Coal Demand and Supply on Price** (Dmnl) = (Total Coal Demand / Potential Coal Production) ^ Sensitivity of Coal Price to Supply and Demand
Energy Coal	A	**Effect of Technology on Coal Discoveries** (Dmnl) = Total Coal Discoverable Resources / UCRN
Energy Coal	SM	**Effective Investment in Coal Exploration** ($/Year) = SMOOTH (Investment in Coal Exploration , Investment in Coal Exploration Delay)
Energy Coal	SM	**Effective Investment in Coal Production** ($/Year) = SMOOTH (Investment in Coal Production , Investment in Coal Production Delay)
Energy Coal	C	**Effectiveness of Investment in Coal Discovery Technology** (1/($*Year)) = 3.24955e-011
Energy Coal	C	**Effectiveness of Investment in Coal Recovery Technology** (1/($*Year)) = 2.60635e-012
Energy Coal	A	**Fraction Invested in Coal Discovery Technology** (Dmnl) = Table for FICDT (Coal Fraction Discoverable)
Energy Coal	C	**Fraction of Coal Revenues Invested in Technology** (Dmnl) = 0.04
Energy Coal	S	**Idendified Coal Resources** (Mtoe) = (Total Coal Demand * Normal Coal Production Ratio + Cumulative Coal Production * (1 - Coal Fraction Recoverable)) / Coal Fraction Recoverable + ∫(Coal Exploration - Coal Production)
Energy Coal	C	**Identified Coal Resources Adjustment Time** (Year) = 15
Energy Coal	F,A	**Increase in Ratio of Coal Fraction Discoverable to Undiscoverable** (1/Year) = DELAY3 (Investment in Coal Discovery Technology * Effectiveness of Investment in Coal Discovery Technology , Coal Discovery Technology Development Time)
Energy Coal	F,A	**Increase in Ratio of Coal Fraction Recoverable to Unrecoverable** (1/Year) = DELAY3 (Investment in Coal Recovery Technology * Effectiveness of Investment in Coal Recovery Technology , Coal Recovery Technology Development Time)
Energy Coal	A	**Indicated Coal Price** ($/Mtoe) = Coal Cost * (1 + Coal Desired Gross Margin)
Energy Coal	A	**Investment in Coal Discovery Technology** ($/Year) = Investment in Coal Technology * Fraction Invested in Coal Discovery Technology
Energy Coal	A	**Investment in Coal Exploration** ($/Year) = Desired Investment in Coal Exploration
Energy Coal	C	**Investment in Coal Exploration Delay** (Year) = 5
Energy Coal	A	**Investment in Coal Production** ($/Year) = Desired Investment in Coal Production
Energy Coal	C	**Investment in Coal Production Delay** (Year) = 1
Energy Coal	A	**Investment in Coal Recovery Technology** ($/Year) = Investment in Coal Technology * (1 - Fraction Invested in Coal Discovery Technology)
Energy Coal	A	**Investment in Coal Technology** ($/Year) = Fraction of Coal Revenues Invested in Technology * Coal Revenues
Energy Coal	C	**MAXCFD** (Dmnl) = 1
Energy Coal	C	**MAXCFR** (Dmnl) = 1
Energy Coal	C	**MINCFD** (Dmnl) = 0.415886

Energy Coal	C	**MINCFR** (Dmnl) = 0.14653
Energy Coal	SI,C	**Normal Coal Production Ratio** (Year) = 20
Energy Coal	A	**Potential Coal Exploration** (Mtoe/Year) = Effective Investment in Coal Exploration * Productivity of Investment in Coal Exploration
Energy Coal	A	**Potential Coal Production** (Mtoe/Year) = MIN (Potential Coal Production from Investment , Potential Coal Production from Resources)
Energy Coal	A	**Potential Coal Production from Investment** (Mtoe/Year) = Productivity of Investment in Coal Production * Effective Investment in Coal Production
Energy Coal	A	**Potential Coal Production from Resources** (Mtoe/Year) = Total Coal Recoverable Resource Remaining / Normal Coal Production Ratio
Energy Coal	C	**Price Elasticity of Demand Gas** (Dmnl) = 0.6
Energy Coal	A	**Productivity of Investment in Coal Exploration** (Mtoe/$) = MAX (0, Relative Productivity of Investment in Coal Exploration * Effect of Technology on Coal Discoveries)
Energy Coal	A	**Productivity of Investment in Coal Production** (Mtoe/$) = Relative Productivity of Investment in Coal Production Compared to Exploration * SMOOTH (Productivity of Investment in Coal Exploration , Coal Production Coverage)
Energy Coal	S	**Ratio of Coal Fraction Discoverable to Undiscoverable** (Dmnl) = RCDUI + ∫(Increase in Ratio of Coal Fraction Discoverable to Undiscoverable)
Energy Coal	S	**Ratio of Coal Fraction Recoverable to Unrecoverable** (Dmnl) = RCRUI + ∫(Increase in Ratio of Coal Fraction Recoverable to Unrecoverable)
Energy Coal	SI,C	**RCDUI** (Dmnl) = 0
Energy Coal	SI,C	**RCRUI** (Dmnl) = 0
Energy Coal	C	**Relative Productivity of Investment in Coal Exploration** (Mtoe/$) = 4.9e-007
Energy Coal	C	**Relative Productivity of Investment in Coal Production Compared to Exploration** (Dmnl) = 10
Energy Coal	A	**Required Identified Coal Resources** (Mtoe) = (Idendified Coal Resources / Total Coal Recoverable Resource Remaining) * (Normal Coal Production Ratio * Total Coal Demand)
Energy Coal	C	**Sensitivity of Coal Price to Supply and Demand** (Dmnl) = 4

Energy Coal	L	**Table for FICDT** (Dmnl) = [(0,0)-(1,1)],(0,0.8),(0.2,0.8),(0.4,0.7),(0.6,0.5),(0.8,0.2),(1,0)
Energy Coal	C	**Time to Average Coal Production** (Year) = 1
Energy Coal	SI,A	**Total Coal Demand** (Mtoe/Year) = Energy Demand * Market Share Coal
Energy Coal	A	**Total Coal Discoverable Resources** (Mtoe) = Total Coal Resources * Coal Fraction Discoverable - Cumulative Additions to Coal Production
Energy Coal	A	**Total Coal Recoverable Resource Remaining** (Mtoe) = Cumulative Additions to Coal Production * Coal Fraction Recoverable - Cumulative Coal Production
Energy Coal	A	**Total Coal Resources** (Mtoe) = Undiscovered Coal Resources + Cumulative Additions to Coal Production
Energy Coal	SI,C	**UCRN** (Mtoe) = 400000
Energy Coal	S	**Undiscovered Coal Resources** (Mtoe) = UCRN + ∫(- Coal Exploration)
Energy Coal	A	**Unit Cost of Coal Exploration** ($/Mtoe) = IF THEN ELSE (Productivity of Investment in Coal Exploration = 0, 0, 1 / Productivity of Investment in Coal Exploration)
Energy Coal	A	**Unit Cost of Coal Production** ($/Mtoe) = ZIDZ (1, Productivity of Investment in Coal Production)
Energy Gas	C	**ad** (**undefined**) = 1
Energy Gas	C	**ad3** (**undefined**) = 1
Energy Gas	A	**Addjustment for Identified Gas Resource** (Mtoe/Year) = (Required Identified Gas Resources - Idendified Gas Resources) / Identified Gas Resources Adjustment Time
Energy Gas	SM	**Average Gas Production** (Mtoe/Year) = SMOOTH (Gas Production , Time to Average Gas Production)
Energy Gas	SI,C	**CGPN** (Mtoe) = 0
Energy Gas	A	**Cumulative Additions to Gas Production** (Mtoe) = Idendified Gas Resources + Cumulative Gas Production

Energy Gas	S,SI	**Cumulative Gas Production** (Mtoe) = CGPN + ∫(Gas Production)
Energy Gas	A	**Desired Gas Exploration Rate** (Mtoe/Year) = MAX (0, Addjustment for Identified Gas Resource + Gas Production)
Energy Gas	C	**Desired Gas Gross Margin** (Dmnl) = 0.2
Energy Gas	A	**Desired Investment in Gas Exploration** ($/Year) = Desired Gas Exploration Rate * Unit Cost of Gas Exploration
Energy Gas	A	**Desired Investment in Gas Production** ($/Year) = MIN (Potential Gas Production from Resources , Total Gas Demand) / Productivity of Investment in Gas Production
Energy Gas	A	**Effect of Gas Demand and Supply on Price** (Dmnl) = (Total Gas Demand / Potential Gas Production) ^ Sensitivity of Gas Price to Supply and Demand
Energy Gas	A	**Effect of Technology on Gas Discoveries** (Dmnl) = Total Gas Discoverable Resources / UGRN
Energy Gas	SM	**Effective Investment in Gas Exploration** ($/Year) = SMOOTH (Investment in Gas Exploration , Investment in Gas Exploration Delay)
Energy Gas	SM	**Effective Investment in Gas Production** ($/Year) = SMOOTH (Investment in Gas Production , Investment in Gas Production Delay)
Energy Gas	A	**Effectiveness of Investment in Gas Discovery Technology** (1/($*Year)) = ad3 * 3.7144e-011
Energy Gas	A	**Effectiveness of Investment in Gas Recovery Technology** (1/($*Year)) = ad3 * 3.57752e-013
Energy Gas	A	**Fraction Invested in Gas Discovery Technology** (Dmnl) = Table for FIGDT (Gas Fraction Discoverable)
Energy Gas	C	**Fraction of Gas Revenues Invested in Technology** (Dmnl) = 0.04
Energy Gas	A	**Gas Cost** ($/Mtoe) = Unit Cost of Gas Exploration + Unit Cost of Gas Production
Energy Gas	A	**Gas Demand to Supply Ratio** (Dmnl) = Total Gas Demand / Potential Gas Production
Energy Gas	C	**Gas Discovery Technology Development Time** (Year) = 6
Energy Gas	F,A	**Gas Exploration** (Mtoe/Year) = MAX (0, Gas Exploration Rate)
Energy Gas	A	**Gas Exploration Rate** (Mtoe/Year) = MIN (Desired Gas Exploration Rate , Potential Gas Exploration)
Energy Gas	A	**Gas Fraction Discoverable** (Dmnl) = MINGFD + (MAXGFD - MINGFD) * (Ratio of Gas Fraction Discoverable to Undiscoverable / (Ratio of Gas Fraction Discoverable to Undiscoverable + 1))
Energy Gas	SI,A	**Gas Fraction Recoverable** (Dmnl) = MINGFR + (MAXGFR - MINGFR) * (Ratio of Gas Fraction Recoverable to Unrecoverable / (Ratio of Gas Fraction Recoverable to Unrecoverable + 1))
Energy Gas	A	**Gas Gross Margin** (Dmnl) = (Gas Price - Gas Cost) / Gas Cost
Energy Gas	A	**Gas Price** ($/Mtoe) = Indicated Gas Price * Effect of Gas Demand and Supply on Price
Energy Gas	A	**Gas Price per MBtu** ($/MBtu) = Gas Price * Mtoe per Btu
Energy Gas	F,A	**Gas Production** (Mtoe/Year) = Gas Production Rate
Energy Gas	A	**Gas Production Coverage** (Year) = Idendified Gas Resources / Average Gas Production

Energy Gas	A	**Gas Production Rate** (Mtoe/Year) = MIN (Total Gas Demand , Potential Gas Production)
Energy Gas	C	**Gas Recovery Technology Development Time** (Year) = 6
Energy Gas	A	**Gas Revenues** ($/Year) = Gas Price * Average Gas Production
Energy Gas	A	**Gas Shortage** (Mtoe/Year) = Total Gas Demand - Gas Production
Energy Gas	S	**Idendified Gas Resources** (Mtoe) = (Total Gas Demand * Normal Gas Production Ratio + Cumulative Gas Production * (1 - Gas Fraction Recoverable)) / Gas Fraction Recoverable + ∫(Gas Exploration - Gas Production)
Energy Gas	C	**Identified Gas Resources Adjustment Time** (Year) = 15
Energy Gas	F,A	**Increase in Ratio of Gas Fraction Discoverable to Undiscoverable** (1/Year) = DELAY3 (Investment in Gas Discovery Technology * Effectiveness of Investment in Gas Discovery Technology , Gas Discovery Technology Development Time)
Energy Gas	F,A	**Increase in Ratio of Gas Fraction Recoverable to Unrecoverable** (1/Year) = DELAY3 (Investment in Gas Recovery Technology * Effectiveness of Investment in Gas Recovery Technology , Gas Recovery Technology Development Time)
Energy Gas	A	**Indicated Gas Price** ($/Mtoe) = Gas Cost * (1 + Desired Gas Gross Margin)
Energy Gas	A	**Investment in Gas Discovery Technology** ($/Year) = Investment in Gas Technology * Fraction Invested in Gas Discovery Technology
Energy Gas	A	**Investment in Gas Exploration** ($/Year) = Desired Investment in Gas Exploration
Energy Gas	C	**Investment in Gas Exploration Delay** (Year) = 1
Energy Gas	A	**Investment in Gas Production** ($/Year) = Desired Investment in Gas Production
Energy Gas	C	**Investment in Gas Production Delay** (Year) = 1
Energy Gas	A	**Investment in Gas Recovery Technology** ($/Year) = Investment in Gas Technology * (1 - Fraction Invested in Gas Discovery Technology)
Energy Gas	A	**Investment in Gas Technology** ($/Year) = Fraction of Gas Revenues Invested in Technology * Gas Revenues
Energy Gas	C	**MAXGFD** (Dmnl) = 1
Energy Gas	C	**MAXGFR** (Dmnl) = 1
Energy Gas	C	**MINGFD** (Dmnl) = 0.0192098
Energy Gas	C	**MINGFR** (Dmnl) = 0.00812097
Energy Gas	C	**Mtoe per Btu** (Mtoe/MBtu) = 2.5e-008
Energy Gas	SI,C	**Normal Gas Production Ratio** (Year) = 20
Energy Gas	A	**Potential Gas Exploration** (Mtoe/Year) = Effective Investment in Gas Exploration * Productivity of Investment in Gas Exploration
Energy Gas	A	**Potential Gas Production** (Mtoe/Year) = MIN (Potential Gas Production from Investment , Potential Gas Production from Resources)
Energy Gas	A	**Potential Gas Production from Investment** (Mtoe/Year) = Productivity of Investment in Gas Production * Effective Investment in Gas Production

Energy Gas	A	**Potential Gas Production from Resources** (Mtoe/Year) = Total Gas Recoverable Resource Remaining / Normal Gas Production Ratio
Energy Gas	A	**Productivity of Investment in Gas Exploration** (Mtoe/$) = MAX (0, Relative Productivity of Investment in Gas Exploration * Effect of Technology on Gas Discoveries * ad)
Energy Gas	A	**Productivity of Investment in Gas Production** (Mtoe/$) = Relative Productivity of Investment in Gas Production to Exploration * SMOOTH (Productivity of Investment in Gas Exploration , Gas Production Coverage)
Energy Gas	S	**Ratio of Gas Fraction Discoverable to Undiscoverable** (Dmnl) = RCDUI 0 + ∫(Increase in Ratio of Gas Fraction Discoverable to Undiscoverable)
Energy Gas	S	**Ratio of Gas Fraction Recoverable to Unrecoverable** (Dmnl) = RGRUI + ∫(Increase in Ratio of Gas Fraction Recoverable to Unrecoverable)
Energy Gas	SI,C	**RCDUI 0** (Dmnl) = 0
Energy Gas	C	**Relative Productivity of Investment in Gas Exploration** (Mtoe/$) = 2.5e-008
Energy Gas	C	**Relative Productivity of Investment in Gas Production to Exploration** (Dmnl) = 10
Energy Gas	A	**Required Identified Gas Resources** (Mtoe) = (Idendified Gas Resources / Total Gas Recoverable Resource Remaining) * (Normal Gas Production Ratio * Total Gas Demand)
Energy Gas	SI,C	**RGRUI** (Dmnl) = 0
Energy Gas	C	**Sensitivity of Gas Price to Supply and Demand** (Dmnl) = 2
Energy Gas	L	**Table for FIGDT** (Dmnl) = [(0,0)-(1,1)],(0,0.8),(0.2,0.8),(0.4,0.7),(0.6,0.5),(0.8,0.2),(1,0)
Energy Gas	C	**Time to Average Gas Production** (Year) = 1
Energy Gas	SI,A	**Total Gas Demand** (Mtoe/Year) = Energy Demand * Market Share Gas
Energy Gas	A	**Total Gas Discoverable Resources** (Mtoe) = Total Gas Resources * Gas Fraction Discoverable - Cumulative Additions to Gas Production

Energy Gas	A	**Total Gas Recoverable Resource Remaining** (Mtoe) = Cumulative Additions to Gas Production * Gas Fraction Recoverable - Cumulative Gas Production
Energy Gas	A	**Total Gas Resources** (Mtoe) = Undiscovered Gas Resources + Cumulative Additions to Gas Production
Energy Gas	SI,C	**UGRN** (Mtoe) = 325000
Energy Gas	S	**Undiscovered Gas Resources** (Mtoe) = UGRN + ∫(- Gas Exploration)
Energy Gas	A	**Unit Cost of Gas Exploration** ($/Mtoe) = IF THEN ELSE (Productivity of Investment in Gas Exploration = 0, 0, 1 / Productivity of Investment in Gas Exploration)
Energy Gas	A	**Unit Cost of Gas Production** ($/Mtoe) = 1 / Productivity of Investment in Gas Production
Energy Oil	A	**Addjustment for Identified Oil Resource** (Mtoe/Year) = (Required Identified Oil Resources - Idendified Oil Resources) / Identified Oil Resources Adjustment Time
Energy Oil	SM	**Average Oil Production** (Mtoe/Year) = SMOOTH (Oil Production , Time to Average Oil Production)
Energy Oil	SI,C	**COPN** (Mtoe) = 0
Energy Oil	A	**Cumulative Additions to Oil Production** (Mtoe) = Idendified Oil Resources + Cumulative Oil Production
Energy Oil	S,SI	**Cumulative Oil Production** (Mtoe) = COPN + ∫(Oil Production)
Energy Oil	A	**Desired Investment in Oil Exploration** ($/Year) = Desired Oil Exploration Rate * Unit Cost of Oil Exploration
Energy Oil	A	**Desired Oil Exploration Rate** (Mtoe/Year) = MAX (0, Addjustment for Identified Oil Resource + Oil Production)
Energy Oil	A	**Effect of Oil Demand and Supply on Price** (Dmnl) = (Total Oil Demand / Potential Oil Production) ^ Sensitivity of Oil Price to Supply and Demand
Energy Oil	A	**Effect of Technology on Oil Discoveries** (Dmnl) = Total Oil Discoverable Resources / UORN
Energy Oil	SM	**Effective Investment in Oil Exploration** ($/Year) = SMOOTH (Investment in Oil Exploration , Investment in Oil Exploration Delay)
Energy Oil	SM	**Effective Investment in Oil Production** ($/Year) = SMOOTH (Investment in Oil Production , Investment in Oil Production Delay)
Energy Oil	C	**Effectiveness of Investment in Oil Discovery Technology** (1/($*Year)) = 5.6011e-010
Energy Oil	C	**Effectiveness of Investment in Oil Recovery Technology** (1/($*Year)) = 3.4997e-012
Energy Oil	A	**Fraction Invested in Oil Discovery Technology** (Dmnl) = Table for FIODT (Oil Fraction Discoverable)
Energy Oil	C	**Fraction of Oil Revenues Invested in Technology** (Dmnl) = 0.04
Energy Oil	S	**Idendified Oil Resources** (Mtoe) = (Total Oil Demand * Normal Oil Production Ratio + Cumulative Oil Production * (1 - Oil Fraction Recoverable)) / Oil Fraction Recoverable + ∫(Oil Exploration - Oil Production)
Energy Oil	C	**Identified Oil Resources Adjustment Time** (Year) = 5
Energy Oil	F,A	**Increase in Ratio of Oil Fraction Discoverable to Undiscoverable** (1/Year) = DELAY3 (Investment in Oil Discovery Technology * Effectiveness of Investment in Oil Discovery Technology , Oil Discovery Technology Development Time)

Energy Oil	F,A	**Increase in Ratio of Oil Fraction Recoverable to Unrecoverable** (1/Year) = DELAY3 (Investment in Oil Recovery Technology * Effectiveness of Investment in Oil Recovery Technology , Oil Recovery Technology Development Time)
Energy Oil	A	**Indicated Oil Price** ($/Mtoe) = Oil Cost * (1 + Oil Desired Gross Margin)
Energy Oil	A	**Investment in Oil Discovery Technology** ($/Year) = Investment in Oil Technology * Fraction Invested in Oil Discovery Technology
Energy Oil	A	**Investment in Oil Exploration** ($/Year) = Desired Investment in Oil Exploration
Energy Oil	C	**Investment in Oil Exploration Delay** (Year) = 1
Energy Oil	A	**Investment in Oil Production** ($/Year) = Desired Investment in Oil Production
Energy Oil	C	**Investment in Oil Production Delay** (Year) = 1
Energy Oil	A	**Investment in Oil Recovery Technology** ($/Year) = Investment in Oil Technology * (1 - Fraction Invested in Oil Discovery Technology)
Energy Oil	A	**Investment in Oil Technology** ($/Year) = Fraction of Oil Revenues Invested in Technology * Oil Revenues
Energy Oil	C	**MAXOFD** (Dmnl) = 1
Energy Oil	C	**MAXOFR** (Dmnl) = 1
Energy Oil	C	**MINOFD** (Dmnl) = 0.0226041
Energy Oil	C	**MINOFR** (Dmnl) = 0.112106
Energy Oil	C	**Mtoe per Barrel** (Mtoe/Barrel) = 1.364e-007
Energy Oil	SI,C	**Normal Oil Production Ratio** (Year) = 20
Energy Oil	A	**Oil Cost** ($/Mtoe) = Unit Cost of Oil Exploration + Unit Cost of Oil Production
Energy Oil	A	**Oil Demand to Supply Ratio** (Dmnl) = Total Oil Demand / Potential Oil Production
Energy Oil	C	**Oil Desired Gross Margin** (Dmnl) = 0.2
Energy Oil	C	**Oil Discovery Technology Development Time** (Year) = 6
Energy Oil	F,A	**Oil Exploration** (Mtoe/Year) = MAX (0, Oil Exploration Rate)
Energy Oil	A	**Oil Exploration Rate** (Mtoe/Year) = MIN (Desired Oil Exploration Rate , Potential Oil Exploration)
Energy Oil	A	**Oil Fraction Discoverable** (Dmnl) = MINOFD + (MAXOFD - MINOFD) * (Ratio of Oil Fraction Discoverable to Undiscoverable / (Ratio of Oil Fraction Discoverable to Undiscoverable + 1))
Energy Oil	SI,A	**Oil Fraction Recoverable** (Dmnl) = MINOFR + (MAXOFR - MINOFR) * (Ratio of Oil Fraction Recoverable to Unrecoverable / (Ratio of Oil Fraction Recoverable to Unrecoverable + 1))
Energy Oil	A	**Oil Gross Margin** (Dmnl) = (Oil Price - Oil Cost) / Oil Cost
Energy Oil	A	**Oil Price** ($/Mtoe) = Indicated Oil Price * Effect of Oil Demand and Supply on Price

Energy Oil	A	**Oil Price per Barrel** ($/Barrel) = Oil Price * Mtoe per Barrel
Energy Oil	F,A	**Oil Production** (Mtoe/Year) = Oil Production Rate
Energy Oil	A	**Oil Production Coverage** (Year) = Idendified Oil Resources / Average Oil Production
Energy Oil	A	**Oil Production Rate** (Mtoe/Year) = MIN (Total Oil Demand , Potential Oil Production)
Energy Oil	C	**Oil Recovery Technology Development Time** (Year) = 6
Energy Oil	A	**Oil Revenues** ($/Year) = Oil Price * Average Oil Production
Energy Oil	A	**Oil Shortage** (Mtoe/Year) = Total Oil Demand - Oil Production
Energy Oil	A	**Potential Oil Exploration** (Mtoe/Year) = Effective Investment in Oil Exploration * Productivity of Investment in Oil Exploration
Energy Oil	A	**Potential Oil Production** (Mtoe/Year) = MIN (Potential Oil Production from Investment , Potential Oil Production from Resources)
Energy Oil	A	**Potential Oil Production from Investment** (Mtoe/Year) = Productivity of Investment in Oil Production * Effective Investment in Oil Production
Energy Oil	A	**Potential Oil Production from Resources** (Mtoe/Year) = Total Oil Recoverable Resource Remaining / Normal Oil Production Ratio
Energy Oil	A	**Productivity of Investment in Oil Exploration** (Mtoe/$) = MAX (0, Relative Productivity of Investment in Oil Exploration * Effect of Technology on Oil Discoveries)
Energy Oil	A	**Productivity of Investment in Oil Production** (Mtoe/$) = Relative Productivity of Investment in Oil Production Compared to Exploration * SMOOTH (Productivity of Investment in Oil Exploration , Oil Production Coverage)
Energy Oil	S	**Ratio of Oil Fraction Discoverable to Undiscoverable** (Dmnl) = RODUI + ∫(Increase in Ratio of Oil Fraction Discoverable to Undiscoverable)
Energy Oil	S	**Ratio of Oil Fraction Recoverable to Unrecoverable** (Dmnl) = RORUI + ∫(Increase in Ratio of Oil Fraction Recoverable to Unrecoverable)
Energy Oil	C	**Relative Productivity of Investment in Oil Exploration** (Mtoe/$) = 1.364e-007
Energy Oil	C	**Relative Productivity of Investment in Oil Production Compared to Exploration** (Dmnl) = 10
Energy Oil	A	**Required Identified Oil Resources** (Mtoe) = (Idendified Oil Resources / Total Oil Recoverable Resource Remaining) * (Normal Oil Production Ratio * Total Oil Demand)
Energy Oil	SI,C	**RODUI** (Dmnl) = 0
Energy Oil	SI,C	**RORUI** (Dmnl) = 0
Energy Oil	C	**Sensitivity of Oil Price to Supply and Demand** (Dmnl) = 2

Energy Oil	L	**Table for FIODT** (Dmnl) = [(0,0)-(1,1)],(0,0.8),(0.2,0.8),(0.4,0.7),(0.6,0.5),(0.8,0.2),(1,0)
Energy Oil	C	**Time to Average Oil Production** (Year) = 1
Energy Oil	SI,A	**Total Oil Demand** (Mtoe/Year) = Energy Demand * Market Share Oil
Energy Oil	A	**Total Oil Discoverable Resources** (Mtoe) = Total Oil Resources * Oil Fraction Discoverable - Cumulative Additions to Oil Production
Energy Oil	A	**Total Oil Recoverable Resource Remaining** (Mtoe) = Cumulative Additions to Oil Production * Oil Fraction Recoverable - Cumulative Oil Production
Energy Oil	A	**Total Oil Resources** (Mtoe) = Undiscovered Oil Resources + Cumulative Additions to Oil Production
Energy Oil	S	**Undiscovered Oil Resources** (Mtoe) = UORN + ∫(- Oil Exploration)
Energy Oil	A	**Unit Cost of Oil Exploration** ($/Mtoe) = IF THEN ELSE (Productivity of Investment in Oil Exploration = 0, 0, 1 / Productivity of Investment in Oil Exploration)
Energy Oil	A	**Unit Cost of Oil Production** ($/Mtoe) = 1 / Productivity of Investment in Oil Production
Energy Oil	SI,C	**UORN** (Mtoe) = 375000
Energy Solar	A	**Cost of Solar Energy** ($/Mtoe) = Unit Cost of Solar Capacity Instalation per Mtoe * Impact of Learning on Solar Unit Cost of Technoloy PC
Energy Solar	S	**Cumulative Solar Energy Produced** (Mtoe) = 0 + ∫(Solar Energy Production)
Energy Solar	C	**Desired Solar Energy Gross Margin** (Dmnl) = 0.2
Energy Solar	A	**Desired Solar Installed Capacity** (m*m) = Total Solar Demand / Efficiency of Solar Installed Capacity
Energy Solar	A	**Effect of Solar Energy Demand and Supply on Price** (Dmnl) = (Total Solar Demand / Possible Solar Energy Production) ^ Sensitivity of Solar Energy Price to Supply and Demand

Energy Solar	SM	**Effective Investment in Solar Capacity** ($/Year) = SMOOTH (Investment in Solar Capacity , Investment in Solar Capacity Delay)
Energy Solar	C	**Effectiveness of Investment in Solar Energy Technology** (1/($*Year)) = 0
Energy Solar	A	**Efficiency of Solar Installed Capacity** (Mtoe/(m*m*Year)) = ZIDZ (Possible Solar Energy Production , Solar Installed Capacity)
Energy Solar	C	**Fraction for Solar Learning Curve Strength** (1) = 0.2
Energy Solar	C	**Fraction of Revenue Invested in Solar Technology** (Dmnl) = 0.03
Energy Solar	A	**g** (**undefined**) = Possible Solar Energy Production - Total Solar Demand
Energy Solar	A	**Impact of Learning on Solar Unit Cost of Technoloy PC** (1) = (Solar Installed Capacity / INIT SIC) ^ Solar Learning Curve Strength
Energy Solar	A	**Impact of Space on Capacity Instalation** (1) = 1 - Solar Installed Capacity / Solar Available Area
Energy Solar	F,A	**Increase in Solar Energy Technology Ratio** (1/Year) = DELAY3 (Investment in Solar Energy Technology * Effectiveness of Investment in Solar Energy Technology , Solar Energy Technology Development Time)
Energy Solar	A	**Indicated Solar Energy Price** ($/Mtoe) = Cost of Solar Energy * (1 + Desired Solar Energy Gross Margin)
Energy Solar	SI,C	**INIT SIC** (m*m) = 400000
Energy Solar	F,A	**Instalation of Solar Capacity Rate** (**undefined**) = MAX (0, Potential Solar Capacity Instalation)
Energy Solar	A	**Investment in Solar Capacity** ($/Year) = Solar Infrastructure Adjustment * Unit Cost of Solar Capacity Instalation
Energy Solar	C	**Investment in Solar Capacity Delay** (Year) = 1
Energy Solar	A	**Investment in Solar Energy Technology** ($/Year) = Fraction of Revenue Invested in Solar Technology * Solar Energy Revenue
Energy Solar	A	**Max Power Point** (W) = Solar Conversion Efficiency * Standard Test Conditions * Solar Installed Capacity
Energy Solar	A	**Max Power Point GW** (GW) = Max Power Point / W into GW
Energy Solar	C	**MAXSCE** (Dmnl) = 0.4
Energy Solar	C	**MINSCE** (Dmnl) = 0.13
Energy Solar	A	**Possible Solar Energy Production** (Mtoe/Year) = Sun Ratiatio PC * Solar Installed Capacity * Time FL * Solar Conversion Efficiency * kWh into Mtoe
Energy Solar	A	**Production to Instalation Ratio** (Mtoe/(m*m)) = Solar Energy Production * Year Number / Solar Installed Capacity
Energy Solar	A	**Productivity of Investment in Solar Capacity Instalation** (m*m/$) = MAX (0, Relative Productivity of Investment in Solar Capacity Instalation * Impact of Space on Capacity Instalation)
Energy Solar	C	**Relative Productivity of Investment in Solar Capacity Instalation** (m*m/$) = 0.005
Energy Solar	C	**SAADF** (1/Year) = 0
Energy Solar	F,A	**SAADR** (m*m/Year) = Solar Available Area * SAADF

Energy Solar	C	**Sensitivity of Solar Energy Price to Supply and Demand** (Dmnl) = 2
Energy Solar	SI,C	**SETRN** (Dmnl) = 0
Energy Solar	S	**Solar Available Area** (m*m) = 5e+011 + ∫(- SAADR)
Energy Solar	F,A	**Solar Capacity Aging Rate** (m*m/Year) = Solar Installed Capacity / Solar Aging Time
Energy Solar	A	**Solar Conversion Efficiency** (1) = MINSCE + (MAXSCE - MINSCE) * (Solar Energy Technology Ratio / (Solar Energy Technology Ratio + 1))
Energy Solar	A	**Solar Energy Demand to Supply Ratio** (Dmnl) = Total Solar Demand / Possible Solar Energy Production
Energy Solar	A	**Solar Energy Price** ($/Mtoe) = Indicated Solar Energy Price * Effect of Solar Energy Demand and Supply on Price
Energy Solar	A	**Solar Energy Price per kWh** ($/(Hour*kW)) = Solar Energy Price * kWh into Mtoe
Energy Solar	F,A	**Solar Energy Production** (Mtoe/Year) = Solar Energy Production Rate
Energy Solar	A	**Solar Energy Production Rate** (Mtoe/Year) = MIN (Possible Solar Energy Production , Total Solar Demand)
Energy Solar	A	**Solar Energy Revenue** ($/Year) = Solar Energy Production * Solar Energy Price
Energy Solar	C	**Solar Energy Technology Development Time** (Year) = 6
Energy Solar	S	**Solar Energy Technology Ratio** (Dmnl) = SETRN + ∫(Increase in Solar Energy Technology Ratio)
Energy Solar	A	**Solar Infrastructure Adjustment** (m*m/Year) = Solar Capacity Aging Rate + (Desired Solar Installed Capacity - Solar Installed Capacity) / Time to Adjust Solar Infrastructure
Energy Solar	S	**Solar Installed Capacity** (m*m) = INIT SIC + ∫(Instalation of Solar Capacity Rate - Solar Capacity Aging Rate)
Energy Solar	A	**Solar Learning Curve Strength** (1) = LN (1 - Fraction for Solar Learning Curve Strength) / LN (2)
Energy Solar	C	**Standard Test Conditions** (W/(m*m)) = 1000
Energy Solar	C	**Sun Ratiatio PC** (kW/(m*m)) = 0.5
Energy Solar	A	**Time FL** (Hour/Year) = Weather Factor * Hours per Year
Energy Solar	C	**Time to Adjust Solar Infrastructure** (Year) = 1
Energy Solar	A	**Total Solar Demand** (Mtoe/Year) = Energy Demand * Market Share Solar
Energy Solar	A	**Total Solar Demand GW** (GW/Year) = Total Solar Demand / kWh into Mtoe peak hour / kW into GW
Energy Solar	A	**Unit Cost of Solar Capacity Instalation** ($/(m*m)) = ZIDZ (1, Productivity of Investment in Solar Capacity Instalation)
Energy Solar	A	**Unit Cost of Solar Capacity Instalation per Mtoe** ($/Mtoe) = Unit Cost of Solar Capacity Instalation / Production to Instalation Ratio
Energy Solar	C	**Weather Factor** (Dmln) = 0.1
Energy Wind	C	**Average Capacity per SqMeter** (kW/(m*m)) = 0.009

Energy Wind	A	**Cost of Wind Energy** ($/Mtoe) = Unit Cost of Wind Capacity Instalation per Mtoe * Impact of Learning on Wind Unit Cost of Technoloy
Energy Wind	S	**Cumulative Wind Energy Produced** (Mtoe) = 0 + ∫(Wind Energy Production)
Energy Wind	C	**Desired Wind Energy Gross Margin** (Dmnl) = 0.2
Energy Wind	A	**Desired Wind Installed Capacity** (m*m) = Total Wind Demand / Efficiency of Wind Installed Capacity
Energy Wind	A	**Effect of Wind Energy Demand and Supply on Price** (Dmnl) = (Total Wind Demand / Possible Wind Energy Production) ^ Sensitivity of Wind Energy Price to Supply and Demand
Energy Wind	SM	**Effective Investment in Wind Capacity** ($/Year) = SMOOTH (Investment in Wind Capacity , Investment in Wind Capacity Delay)
Energy Wind	C	**Effectiveness of Investment in Wind nergy Technology** (1/($*Year)) = 0
Energy Wind	A	**Efficiency of Wind Installed Capacity** (Mtoe/(m*m*Year)) = ZIDZ (Possible Wind Energy Production , Wind Installed Capacity)
Energy Wind	C	**Fraction for Wind Learning Curve Strength** (1) = 0.2
Energy Wind	C	**Fraction of Revenue Invested in Wind Technology** (Dmnl) = 0.03
Energy Wind	A	**gw** (**undefined**) = Possible Wind Energy Production - Total Wind Demand
Energy Wind	A	**Impact of Learning on Wind Unit Cost of Technoloy** (1) = (Wind Installed Capacity / INIT WIC) ^ Wind Learning Curve Strength
Energy Wind	A	**Impact of Space on Wind Capacity Instalation** (1) = 1 - Wind Installed Capacity / Wind Available Area
Energy Wind	F,A	**Increase in Wind Energy Technology Ratio** (1/Year) = DELAY3 (Investment in Wind Energy Technology * Effectiveness of Investment in Wind nergy Technology , Wind Energy Technology Development Time)
Energy Wind	A	**Indicated Wind Energy Price** ($/Mtoe) = Cost of Wind Energy * (1 + Desired Wind Energy Gross Margin)
Energy Wind	SI,C	**INIT WIC** (m*m) = 400000
Energy Wind	F,A	**Instalation of Wind Capacity Rate** (**undefined**) = MAX (0, Potential Wind Capacity Instalation)
Energy Wind	A	**Investment in Wind Capacity** ($/Year) = Wind Infrastructure Adjustment * Unit Cost of Wind Capacity Instalation
Energy Wind	C	**Investment in Wind Capacity Delay** (Year) = 1
Energy Wind	A	**Investment in Wind Energy Technology** ($/Year) = Fraction of Revenue Invested in Wind Technology * Wind Energy Revenue
Energy Wind	A	**Max Wind Power Point** (kW) = Wind Installed Capacity * Average Capacity per SqMeter * Wind Capacity Factor
Energy Wind	A	**Max Wind Power Point GW** (GW) = Max Wind Power Point / kW into GW
Energy Wind	A	**Max Wind Power Point TW** (TW) = Max Wind Power Point / kW into TW
Energy Wind	C	**MAXWCF** (Dmnl) = 0.5
Energy Wind	C	**MINWCF** (Dmnl) = 0.2

Energy Wind	A	**Possible Wind Energy Production** (Mtoe/Year) = Wind Installed Capacity * Average Capacity per SqMeter * Wind Capacity Factor * Hours per Year * kWh into Mtoe
Energy Wind	A	**Potential Solar Capacity Instalation** (m*m/Year) = Effective Investment in Solar Capacity * Productivity of Investment in Solar Capacity Instalation
Energy Wind	A	**Potential Wind Capacity Instalation** (m*m/Year) = Effective Investment in Wind Capacity * Productivity of Investment in Wind Capacity Instalation
Energy Wind	A	**Productivity of Investment in Wind Capacity Instalation** (m*m/$) = MAX (0, Relative Productivity of Investment in Wind Capacity Instalation * Impact of Space on Wind Capacity Instalation)
Energy Wind	C	**Relative Productivity of Investment in Wind Capacity Instalation** (m*m/$) = 0.005
Energy Wind	C	**Sensitivity of Wind Energy Price to Supply and Demand** (Dmnl) = 2
Energy Wind	C	**Solar Aging Time** (Year) = 20
Energy Wind	C	**Time to Adjust Wind Infrastructure** (Year) = 1
Energy Wind	A	**Total Wind Demand** (Mtoe/Year) = Energy Demand * Market Share Wind
Energy Wind	A	**Total Wind Demand GW** (GW/Year) = Total Wind Demand / kWh into Mtoe peak hour / kW into GW
Energy Wind	A	**Unit Cost of Wind Capacity Instalation** ($/(m*m)) = ZIDZ (1, Productivity of Investment in Wind Capacity Instalation)
Energy Wind	A	**Unit Cost of Wind Capacity Instalation per Mtoe** ($/Mtoe) = Unit Cost of Wind Capacity Instalation / Wind Production to Instalation Ratio
Energy Wind	C	**WAADF** (1/Year) = 0
Energy Wind	F,A	**WAADR** (m*m/Year) = Wind Available Area * WAADF
Energy Wind	SI,C	**WETRN** (Dmnl) = 0
Energy Wind	C	**Wind Aging Time** (Year) = 20
Energy Wind	S	**Wind Available Area** (m*m) = 8e+012 + ∫(- WAADR)
Energy Wind	F,A	**Wind Capacity Aging Rate** (m*m/Year) = Wind Installed Capacity / Wind Aging Time
Energy Wind	A	**Wind Capacity Factor** (1) = MINWCF + (MAXWCF - MINWCF) * (Wind Energy Technology Ratio / (Wind Energy Technology Ratio + 1))
Energy Wind	A	**Wind Energy Demand to Supply Ratio** (Dmnl) = Total Wind Demand / Possible Wind Energy Production
Energy Wind	A	**Wind Energy Price** ($/Mtoe) = Indicated Wind Energy Price * Effect of Wind Energy Demand and Supply on Price
Energy Wind	A	**Wind Energy Price per kWh** ($/(Hour*kW)) = Wind Energy Price * kWh into Mtoe
Energy Wind	F,A	**Wind Energy Production** (Mtoe/Year) = Wind Energy Production Rate
Energy Wind	A	**Wind Energy Production Rate** (Mtoe/Year) = MIN (Possible Wind Energy Production , Total Wind Demand)

Energy Wind	A	**Wind Energy Revenue** ($/Year) = Wind Energy Production * Wind Energy Price
Energy Wind	C	**Wind Energy Technology Development Time** (Year) = 6
Energy Wind	S	**Wind Energy Technology Ratio** (Dmnl) = WETRN + ∫(Increase in Wind Energy Technology Ratio)
Energy Wind	A	**Wind Infrastructure Adjustment** (m*m/Year) = Wind Capacity Aging Rate + (Desired Wind Installed Capacity - Wind Installed Capacity) / Time to Adjust Wind Infrastructure
Energy Wind	S	**Wind Installed Capacity** (m*m) = INIT WIC + ∫(Instalation of Wind Capacity Rate - Wind Capacity Aging Rate)
Energy Wind	A	**Wind Learning Curve Strength** (1) = LN (1 - Fraction for Wind Learning Curve Strength) / LN (2)
Energy Wind	A	**Wind Production to Instalation Ratio** (Mtoe/(m*m)) = Wind Energy Production * Year Number / Wind Installed Capacity
Land	A	**Actual Agricultural Land Food Harvested** (ha) = (Food Production / (1 - Food Procuction Processing Loss)) / Agriculture Land Food Yield
Land	A	**Agricultural Land Needed to be Harvested for Food Production** (ha) = (((Food Production Needed / Biomass ton into Veg equ ton) / (1 - Food Production Loss)) / Agriculture Land Energy Yield) * Biomass ton into Mtoe
Land	S	**Agriculture Land** (m*m) = Initial Agriculture Land + ∫(Degradation of Carrying Capacity - Agriculture Other Land Allocation Rate - Agriculture Urban Industrial Land Allocation Rate)
Land	S	**Agriculture Land Fertility** (Biomass ton/(Year*ha)) = Initial Agriculture Land Fertility + ∫(Agriculture Land Fertility Regeneration - Agriculture Land Fertility Degredation)
Land	F,A	**Agriculture Land Fertility Degredation** (Biomass ton/(Year*ha)) = Agriculture Land Fertility * Agriculture Land Fertility Degredation Rate
Land	A	**Agriculture Land Fertility Degredation Rate** (1) = Agriculture Land Fertility Degredation Rate Table (Polution)
Land	F,A	**Agriculture Land Fertility Regeneration** (Biomass ton/(Year*Year*ha)) = (Inherent Agriculture Land Fertility - Agriculture Land Fertility) / Agriculture Land Fertility Regeneration Time
Land	C	**Agriculture Land Fertility Regeneration Time** (Year) = 20
Land	A	**Agriculture Land Food Yield** (Veg equiv ton/(Year*ha)) = Agriculture Land Fertility * Biomass ton into Veg equ ton
Land	A	**Agriculture Other Change** (**undefined**) = - Effect of Energy Purpose Agricultural Land Shortage on Agricultural Land Expansion
Land	F,A	**Agriculture Other Land Allocation Rate** (**undefined**) = MAX (0, Agriculture Other Change * (Agriculture Land - Min Agriculture Land) / Agriculture to Othert Land Allocation Time) + MIN (0, Agriculture Other Change * (Other Land - Min Other Land) / Other to Agriculture Land Allocation Time)
Land	C	**Agriculture to Forest Land Allocation Time** (Year) = 20
Land	C	**Agriculture to Othert Land Allocation Time** (**undefined**) = 20
Land	C	**Agriculture to Urban Land Allocation Time** (**undefined**) = 5
Land	A	**Agriculture Urban Change** (Dmnl) = Effect of Urban and Industrial Land Shortage on the Land Expansion
Land	F,A	**Agriculture Urban Industrial Land Allocation Rate** (**undefined**) = MAX (0, Agriculture Urban Change * (Agriculture Land - Min Agriculture Land) / Agriculture to Urban Land Allocation Time)

Land	C	**Biomass ton into Veg equ ton** (Veg equiv ton/Biomass ton) = 0.006
Land	F,A	**Degradation of Carrying Capacity** (Person/Year) = MAX (0, Forest Agriculture Change * (Forest Land - Min Forest Land) / Forest to Arable Land Allocation Time) + MIN (0, Forest Agriculture Change * (Agriculture Land - Min Agriculture Land) / Agriculture to Forest Land Allocation Time)
Land	A	**Effect of Energy Purpose Agricultural Land Shortage on Agricultural Land Expansion** (Dmnl) = 2 / (1 + EXP (- Strength of Energy Purpose Agricultural Land Expansion Effect * (MAX (0, Ratio of Energy Purpose Agricultural Land Needed to Available - 1)))) - 1
Land	A	**Effect of Forest Land Shortage on Forest Land Expansion** (Dmln) = 2 / (1 + EXP (- Strength of Forest Land Expansion Effect * (MAX (0, Ratio of Forest Land Needed to Available - 1)))) - 1
Land	A	**Effect of Urban and Industrial Land Shortage on the Land Expansion** (Dmnl) = 2 / (1 + EXP (- Strength of Urban and Industrial Land Expansion Effect * (MAX (0, Ratio of Min Urban and Industrial Land Needed to Available - 1)))) - 1
Land	A	**Food Potential Agriculture Land** (ha) = Harvest Available Agricultural Land * Required Food Harvest Fraction
Land	C	**Food Procution Processing Loss** (Dmnl) = 0.1
Land	A	**Food Production** (Veg equiv ton/Year) = MIN (Food Production Needed , Food Potential Agriculture Land * Agriculture Land Food Yield * (1 - Food Procution Processing Loss))
Land	C	**Food Production Loss** (Dmnl) = 0.1
Land	A	**Food Production Needed** (Veg equiv ton/Year) = Population * Min Annual Food per Capita
Land	A	**Forest Agriculture Change** (**undefined**) = Effect of Energy Purpose Agricultural Land Shortage on Agricultural Land Expansion - Effect of Forest Land Shortage on Forest Land Expansion
Land	S	**Forest Land** (m*m) = Initial Forest Land + ∫(- Degradation of Carrying Capacity - Forest Other Land Allocation Rate - Forest Urban Industrial Land Allocation Rate)
Land	S	**Forest Land Fertility** (Biomass ton/(Year*ha)) = Initial Forest Land Fertility + ∫(Forest Land Fertility Regeneration - Forest Land Fertility Degredation)
Land	F,A	**Forest Land Fertility Degredation** (Biomass ton/(Year*ha)) = Forest Land Fertility * Forest Land Fertility Degredation Rate
Land	A	**Forest Land Fertility Degredation Rate** (1) = Forest Land Fertility Degredation Rate Table (Polution 0)
Land	F,A	**Forest Land Fertility Regeneration** (Biomass ton/(Year*Year*ha)) = (Inherent Forest Land Fertility - Forest Land Fertility) / Forest Land Fertility Regeneration Time
Land	C	**Forest Land Fertility Regeneration Time** (Year) = 20
Land	C	**Forest Land Fraction Harvested including Protected Area** (1) = 0.5
Land	A	**Forest Other Change** (**undefined**) = - Effect of Forest Land Shortage on Forest Land Expansion
Land	F,A	**Forest Other Land Allocation Rate** (**undefined**) = MAX (0, Forest Other Change * (Forest Land - Min Forest Land) / Forest to Other Land Allocation Time) + MIN (0, Forest Other Change * (Other Land - Min Other Land) / Other to Forest Land Allocation Time)

Land	C	**Forest to Arable Land Allocation Time** (Year) = 5
Land	C	**Forest to Other Land Allocation Time** (**undefined**) = 50
Land	C	**Forest to Urban Land Allocation Time** (**undefined**) = 10
Land	A	**Forest Urban Change** (Dmnl) = Effect of Urban and Industrial Land Shortage on the Land Expansion
Land	F,A	**Forest Urban Industrial Land Allocation Rate** (**undefined**) = MAX (0, Forest Urban Change * (Forest Land - Min Forest Land) / Forest to Urban Land Allocation Time)
Land	A	**Fractions sum** (**undefined**) = Required Food Harvest Fraction + Required Energy Crops Harvest Fraction
Land	A	**Harvest Available Agricultural Land** (ha) = Agriculture Land * Land Fraction Harvested * Sqr m to ha
Land	A	**Harvest Available Forest Land** (ha) = Forest Land Fraction Harvested including Protected Area * (Forest Land - Min Forest Land) * Sqr m to ha
Land	C	**Inherent Agriculture Land Fertility** (Biomass ton/(Year*ha)) = 100
Land	C	**Inherent Forest Land Fertility** (Biomass ton/(Year*ha)) = 100
Land	SI,C	**Initial Agriculture Land** (m*m) = 1.5335e+013
Land	SI,C	**Initial Agriculture Land Fertility** (Biomass ton/(Year*ha)) = 100
Land	SI,C	**Initial Forest Land** (m*m) = 3.9886e+013
Land	SI,C	**Initial Forest Land Fertility** (Biomass ton/(Year*ha)) = 100
Land	SI,C	**Initial Other Land** (m*m) = 3.4421e+013
Land	SI,C	**Initial Urban and Industrial Land** (m*m) = 4e+011
Land	C	**Land Fraction Harvested** (Dmnl) = 0.7
Land	C	**Min Agriculture Land** (m*m) = 1.46683e+013
Land	C	**Min Annual Food per Capita** (Veg equiv ton/(Year*Person)) = 0.5
Land	C	**Min Forest Land** (m*m) = 4.78632e+012
Land	C	**Min Other Land** (m*m) = 2.00901e+013
Land	C	**Min Urban and Industrial Land per Capita** (m*m/Person) = 10
Land	S	**Other Land** (m*m) = Initial Other Land + ∫(Agriculture Other Land Allocation Rate + Forest Other Land Allocation Rate)
Land	C	**Other to Agriculture Land Allocation Time** (**undefined**) = 100
Land	C	**Other to Forest Land Allocation Time** (**undefined**) = 100

Land	C	**Polution 0** (Dmln) = 0.2
Land	A	**Ratio of Energy Purpose Agricultural Land Needed to Available** (Dmnl) = Agricultural Land Needed to be Harvested for Biomass Production / Energy Potential Agriculture Land
Land	A	**Ratio of Food Purpose Agricultural Land Needed to Available** (Dmnl) = Agricultural Land Needed to be Harvested for Food Production / Food Potential Agriculture Land
Land	A	**Ratio of Forest Land Needed to Available** (Dmnl) = Forest Land Needed to be Harvested / Harvest Available Forest Land
Land	A	**Ratio of Min Urban and Industrial Land Needed to Available** (Dmnl) = Min Urban and Industrial Land per Capita / Urban and Industrial Land per Capita
Land	A	**Required Food Harvest Fraction** (Dmnl) = (Agricultural Land Needed to be Harvested for Food Production) / (Agricultural Land Needed to be Harvested for Food Production + Agricultural Land Needed to be Harvested for Biomass Production)
Land	C	**Sqr m to ha** (ha/(m*m)) = 0.0001
Land	C	**Strength of Energy Purpose Argicultural Land Expansion Effect** (Dmnl) = 0.5
Land	C	**Strength of Forest Land Expansion Effect** (Dmnl) = 0.5
Land	C	**Strength of Urban and Industrial Land Expansion Effect** (Dmnl) = 0.5
Land	S	**Urban and Industrial Land** (m*m) = Initial Urban and Industrial Land + ∫(Agriculture Urban Industrial Land Allocation Rate + Forest Urban Industrial Land Allocation Rate)
Land	A	**Urban and Industrial Land per Capita** (m*m/Person) = Urban and Industrial Land / Population
Population	F,A	**Births Rate** (**undefined**) = Total Fertility * Population 15 to 64 * 0.5 / Reproductive Lifetime
Population	F,A	**Deaths Rate 0 to 14** (People/Year) = Population 0 to 14 * Mortality 0 to 14
Population	F,A	**Deaths Rate 15 to 64** (People/Year) = Population 15 to 64 * Mortality 15 to 64
Population	F,A	**Deaths Rate 65 plus** (People/Year) = Population 65 Plus * Mortality 65 plus
Population	SI,C	**Init Population 0 to 14** (People) = 1.85025e+009
Population	SI,C	**Init Population 15 to 64** (People) = 3.85292e+009
Population	SI,C	**Init Population 65 Plus** (People) = 4.20952e+008
Population	A	**Labour Force** (People) = Population 15 to 64 * Labour Force Participation Fraction
Population	C	**Labour Force Participation Fraction** (Dmnl) = 0.75
Population	C	**Life Expectancy** (Year) = 65
Population	F,A	**Maturation 14 to 15** (People/(Year*Year)) = Population 0 to 14 * (1 - Mortality 0 to 14) / Time in 0 to 14 cohort
Population	F,A	**Maturation 64 to 65** (**undefined**) = Population 15 to 64 * (1 - Mortality 15 to 64) / Time in 15 to 44 cohort

Population	A	**Mortality 0 to 14** (1/Year) = TM0to14 (Life Expectancy)
Population	A	**Mortality 15 to 64** (1/Year) = TM15to64 (Life Expectancy)
Population	A	**Mortality 65 plus** (1/Year) = TM65p (Life Expectancy)
Population	A	**Population** (People) = Population 0 to 14 + Population 15 to 64 + Population 65 Plus
Population	S	**Population 0 to 14** (People) = Init Population 0 to 14 + ∫(Births Rate - Deaths Rate 0 to 14 - Maturation 14 to 15)
Population	S	**Population 15 to 64** (People) = Init Population 15 to 64 + ∫(Maturation 14 to 15 - Deaths Rate 15 to 64 - Maturation 64 to 65)
Population	S	**Population 65 Plus** (People) = Init Population 65 Plus + ∫(Maturation 64 to 65 - Deaths Rate 65 plus)
Population	C	**Reproductive Lifetime** (Year) = 30
Population	C	**Time in 0 to 14 cohort** (Year) = 15
Population	C	**Time in 15 to 44 cohort** (Year) = 50
Population	L	**TM0to14** (1/Year) = [(0,0)-(80,0.06)],(20,0.0567),(30,0.0366),(40,0.0243),(50,0.0155),(60,0.0082),(70,0.0023),(80,0.001)

Population	L	**TM15to64** (1/Year) = [(0,0)-(80,0.04)],(20,0.0266),(30,0.0171),(40,0.011),(50,0.0065),(60,0.004),(70,0.0016),(80,0.0008)
Population	L	**TM65p** (Dmnl) = [(0,0)-(80,0.2)],(20,0.13),(30,0.11),(40,0.09),(50,0.07),(60,0.06),(70,0.05),(80,0.04)
Population	C	**Total Fertility** (**undefined**) = 2.8

Literature

BP. 2007. Statistical Review of World Energy 2007: BP.

Fiddaman, Thomas S. 2002. Exploring policy options with a behavioral climate-economy model. *System Dynamics Review* 18 (2):243-267.

Forrester, Jay W. 1961. *Industrial Dynamics*. Cambridge MA: Productivity Press.

Fritz S., Scholes R. J., Obersteiner M., Bouma J., Reyers B. 2008: A conceptual framework for assessing the benefits of a Global Earth Observation System of Systems.Systems Journal, IEEE, 2(3):338-348.

IEA. 2007. Key World Energy Statistics 2007: International Energy Agency.

Lyneis, James M. 1980. *Corporate Planning and Policy Design: A System Dynamics Approach*. Boston MA: MIT Press.

Nordhaus, William D. 1992. The "DICE" Model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming Discussion. Paper No. 1009: Cowles Foundation for Research in Economics at Yale University.

———. 1994. *Managing the Global Commons*. Cambridge, MA: MIT Press.

Sterman, John D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: Irwin/McGraw-Hill.