FeliX3 – Impact Assessment Model

Systemic view across Societal Benefit Areas beyond Global Earth Observation

Model Report and Technical Documentation

IIASA, Laxenburg, 2013

Report Authors:

Felicjan Rydzak* (rydzak@iiasa.ac.at) – *contact person*
Michael Obersteiner* (oberstei@iiasa.ac.at)
Florian Kraxner* (kraxner@iiasa.ac.at)
Steffen Fritz* (fritz@iiasa.ac.at)
Ian McCallum* (mccallum@iiasa.ac.at)

**International Institute for Applied Systems Analysis*
Ecosystems Services and Management Program
Schlossplatz 1 A-2361 Laxenburg, Austria

Keywords:

Dynamic modeling
Earth observation
Earth system
Global Earth Observation System of Systems
Societal benefit areas
Value of information

Publication date:

May 2013

Acknowledgement:

Support to this work was provided by:
EC FP6 Project GEO-BENE No. 037063
EC FP7 Project EuroGEOSS No. 226487
EC FP7 Project EnerGEO No. 226364

Table of Contents

Abbreviations

AR5 – Fifth Assessment Report of the UN Intergovernmental Panel on Climate Change
BAU – Business as Usual
CCS – Carbon Capture and Storage
GEO – Global Earth Observation
GEOSS – Global Earth Observation System of System
EO – Earth Observation
RF – Radiative Forcing
RCP – Representative Concentration Pathways
SBA – Societal Benefits Area
SD – System Dynamics
UN – United Nations
VoI – Value of Information

Introduction

Managing global change involves managing risk in a complex system undergoing major transitions. The Earth system in the Anthropocene (Crutzen and Stoermer 2000) is defined by its interdependencies between social, economic, and environmental subsystems constituting a complex dynamic system. Appropriate management of such a system can come only from improved monitoring and understanding of the underlying processes and their interdependence. Recent developments in the fields of information technology, data infrastructures, and Earth observation enable knowledge gains and consequently higher predictive performance, which provide the basis for improved decision making across spatial scales. The Global Earth Observation System of Systems (GEOSS), coordinated by the Group on Earth Observations (GEO), aims at connecting the diverse sets of monitoring systems to support decision making of policymakers, resource managers, scientists, and average citizens.

Despite the obvious advantages that Earth observations can bring to decision making, we lack appropriate theoretical and methodological frameworks to assess the economic and wider societal benefits of a GEOSS-like infrastructure (Craglia et al. 2008). There is extensive literature on the benefits of weather forecasting (Adams et al. 1995, Katz and Murphy 1997) but relatively little assessment work in other fields of Earth observation. Furthermore, the available studies are mostly sectoral and focus on particular areas, such as biodiversity (Leyequien 2007, Muchoney 2008). Case studies on the value of improvements in Earth observation systems are usually very specific and not generalizable. For example, Considine et al. (2004) analyzed the benefits of improved hurricane forecasting in oil and gas production in a confined geographic area. Bouma et al. (2009) examined the effect on water quality management in the North Sea of improved in situ observation networks or remote sensing–based observing systems. Wieand (2008) quantified the effects of an integrated ocean observation system on recreational fishing. Despite their thorough, in-depth analysis and high level of sophistication, these studies do not provide a methodological framework, and integrated assessments of the total global consequences within and across all areas remain lacking.

The need for such evaluation led to a European Commission–sponsored project, Global Earth Observation—Benefit Estimation: Now, Next and Emerging (GEOBENE) —the world's first attempt to systematically and comprehensively study the benefits of a global system of system of Earth observations (European Commission 2008). GEOBENE's goal is to develop methodologies and analytical tools to assess the economic, social, and environmental effects of improved quantitative and qualitative information delivered by GEOSS, in and across nine societal benefit areas (SBAs)—disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. The work on impact of Global Earth Observation was further continued in two other projects EuroGEOSS – "A European Approach to GEOSS" and EnerGEO – "Earth Observation for Monitoring and Assessment of the Environmental Impact of Energy Use".

This report documents on work, developed tools and methodologies that enabled systemic view on benefits of GEO across GEOSS Societal Benefit Areas. It mainly focuses on research related to System Dynamics model called FeliX (Full of Economic-Environment Linkages and Integration dX/dt) which evolved to its current comprehensive form driven by various requirements of the three research projects – GEOBENE, EuroGEOSS and EnerGEO.

In the next chapter the methodology used in this study will be presented. The following chapter will be entirely devoted to the FeliX3 model. Challenges related to its development in order to meet the research goal objectives are described. The overview of the model is followed by a thorough description of the dynamic problems covered by the model, system conceptualization, model formulation and model simulation for all model sectors – Population, Economy, Energy, Land Use, Carbon Cycle, Climate, Water and Biodiversity. The next chapter is dedicated to the simulation scenarios – Business as Usual, GEO scenarios and other scenarios that can be run using the FeliX model. The summary chapter recaps the main information covered in the report. Eventually Appendix section contains all equations behind the FeliX model and their description. Literature section captures the sources of information used in the report or in the development of the FeliX model structure.

Methodology

An overview of methodology applied to evaluate an impact of Global Earth Observation across societal benefits areas is illustrated in Figure 1.

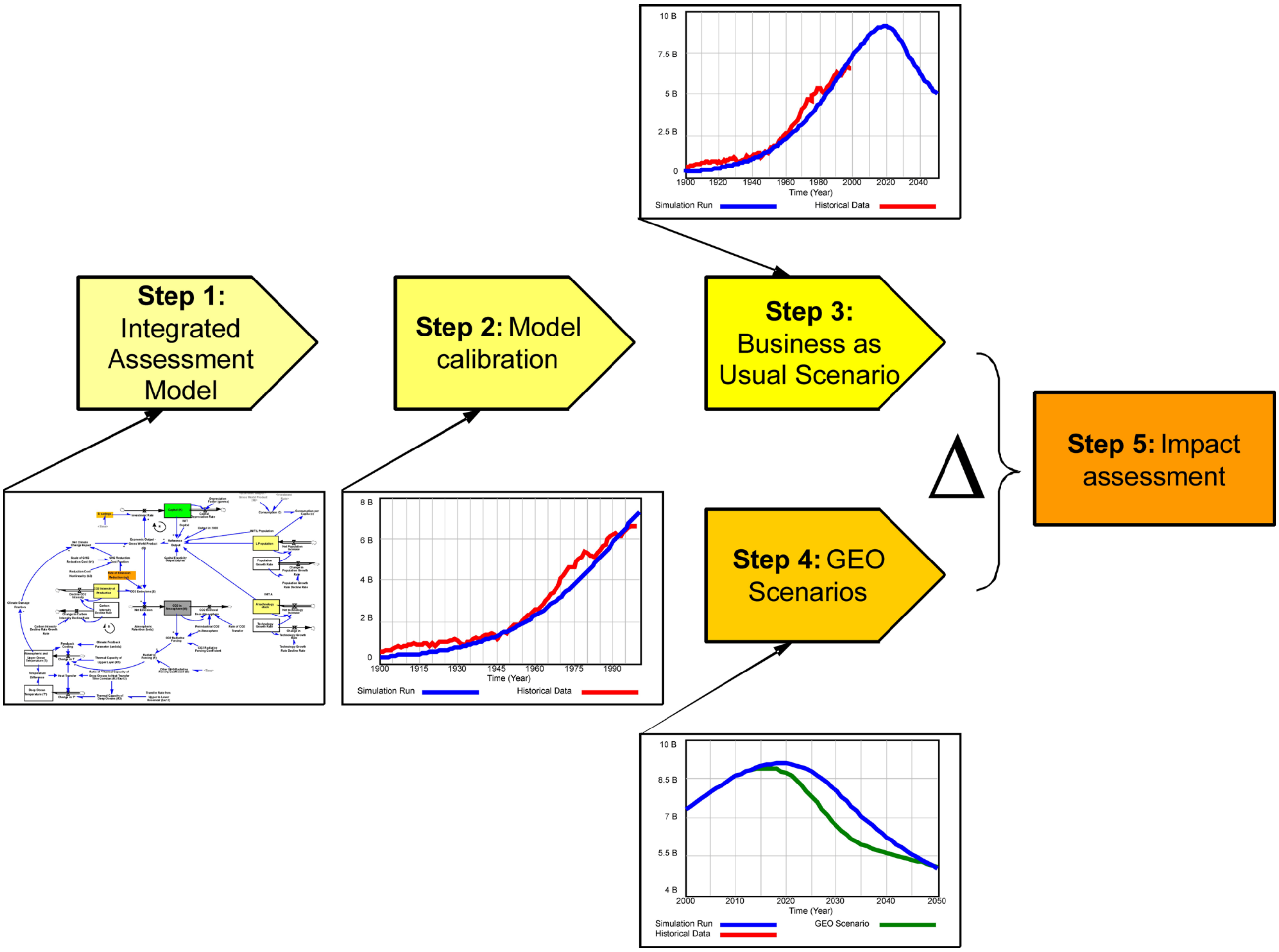


Figure 1 Methodology

The methodology consists of five steps:

1. Global Change Model – development of a System Dynamics model that would constitute a purposefully simplified 'mock-up' of a complex Earth system. The FeliX model had to encompass vital mechanisms and concepts related to the nine societal benefits areas.
2. Model Calibration – as a premise of System Dynamics modeling, the behavior of the constructed model structures needs to replicate behavior over time of the modeled system. Thus the FeliX model was calibrated to historical data using a highly aggregated representation of the Earth system. The calibration was carried out to match multiple observations over the 20th century (subject to data availability).
3. Business as Usual Scenario – saying in another words 'if the things keep going as they are right now, how would the system looks like 50 years from now'. While

‘freezing’ the model parameters the simulation time scale was extended in the model for the next 50 years. The model simulation outcome represents the Business as Usual (BAU) scenario. This scenario constitutes the reference for the impact analysis of GEOSS improvements.

4. GEOSS Scenario – at that step the GEOSS scenarios were constructed within and across the SBAs. This involved working with SBA experts to identify the parameter constellations that would mimic a GEOSS case and choosing the most appropriate parameter values. In case of each research projects a separate set of scenarios was constructed and simulated.
5. Impact Assessment – in the last step, the GEOSS scenarios were compared against the Business As Usual (BAU) scenario. The difference indicates the benefit that GEOSS might have across the SBAs. Multiple indicators are used to measure the impact of GEOSS, including GDP, population, ecosystem value, and the United Nation’s Human Development Index.

The foundation for the approached applied in this study is System Dynamics method and tools. The System Dynamics was originally developed by Jay Forrester at MIT in the 1950s (Forrester 1958, Forrester 1961). Unlike reductionism, breaking the problem into smaller and smaller pieces in order to understand the nature of complex phenomena, System Dynamics is trying to look at the full system. The system is defined here as a collection of elements that interact with each other to form a unified whole and dynamics refers to changes over time following these interactions. Thus, the preliminary notion of System Dynamics is that structure determines performance. System Dynamics views the structure of a system as the primary cause of the problem behaviors it is experiencing, as opposed to seeing these behaviors as being “foist upon” the system by outside agents (Richardson and Pugh 1981). For that reason the System Dynamics models attempt to capture as many as necessary aspects of interactions within a closed system. The variables are therefore “endogenous” or contained within the system represented by a System Dynamics model. In order to describe the system structure System Dynamics focuses on the flow of feedback that occurs throughout the parts of a system (feedback loops) – a change in one variable affects other variables over time, which in turn affects the original variable, and so on. The dynamic behavior than occurs when flows accumulate in stocks. Special dynamic notions are also given by delays and nonlinear relations between the system elements. All these elements produce changes in the way the system has performed in the past and might evolve in the future (Sterman 2000).

In the following sections all methodology steps and associated with them tools and specific results will be described in more details.

Model

The outcome of the first step of the applied methodology – Global Change Model – is a System Dynamics type of model called **FeliX** (Full of Economic-Environment Linkages and Integration dX/dt) consisting of a set of interrelated differential equations allowing for computer simulation that gives quantitative results. Simultaneously with the model development it was calibrated to the historical data (step 2 of the applied methodology) over a period of the last century (subject to data availability).

Challenges

While working on development of the FeliX model, which is supposed to constitute a 'mock-up' of a complex Earth system, a number of decisions, **setting the boundaries** of the model had to be made. It is rather impossible to model the Earth system in all details. Thus it had to be decided what phenomenon will become a part of the model in the sense of physical resources (e.g. population, forest, fossil fuels resources) and flows (e.g. birth rate, deforestation, oil discovery) as well as mechanisms and decisions controlling the change (flows) of resources over time (e.g. fertility, competition for agricultural land, investments in oil discovery and recovery). Some of the phenomenon included in the FeliX model were already well studied and mathematically described. For example, specific model structures on phenomena closely related to climate include atmospheric concentration of CO_2 caused by human activities and the associated carbon cycle. The basic dynamics of the climate system have been intensively researched and described in the literature (Oeschger et al. 1975, Goudriaan and Ketner 1984, Bolin 1986, Rotmans 1990, Nordhaus 1992, Fiddaman 1997), which allowed for adoption of quantitatively expressed relations of the system components in the FeliX model structure. In cases where such relations have not been quantitatively established, group model building sessions (Richardson and Andersen 1995, Vennix 1996, Andersen et al. 1997) or online research was conducted, and subject matter experts defined and quantified the relations of interest and constructed parts of the model. The chosen elements of the FeliX model had to relate to specific societal benefits areas since they were the focus of the studies.

The model boundaries could not be too narrow though. The assumption behind the System Dynamics model is that the model behavior is generated endogenously. That premise forced an internal **integrity** of the model in a sense of extent of the model (how many phenomena to include) but also in a sense of model details. As necessary the reported phenomenon had to be scaled-up to a global level to be consistent with the model perspective.

The next challenge of the modeling work was to assimilate the many heterogeneous sources of information in studies carried out in the area of Earth observation into an integrated global impact study. The primary sources of information were direct results from similar models, impact figures from published articles and sector reports, and information obtained from expert interviews or online research. Generally, Value of Information (VoI) studies are confined to a particular place, time and sector. Impacts are rarely reported on global aggregates or carried out using a wider economic system representation to account for the many potential feedbacks. Therefore, existing information had to be adapted through **aggregation** to mimic effects on a global level and over long time horizons.

Model Overview

The FeliX model was built using Vensim software (http://vensim.com/). Currently the model consists of over 1300 elements including 91 stocks. Its dynamics is determined by many interacting feedback loops. To make navigation through the model easier the model was divided into 8 model sectors – Economy, Energy, Carbon Cycle, Climate, Biodiversity, Water, Population and Land Use (Figure 2).

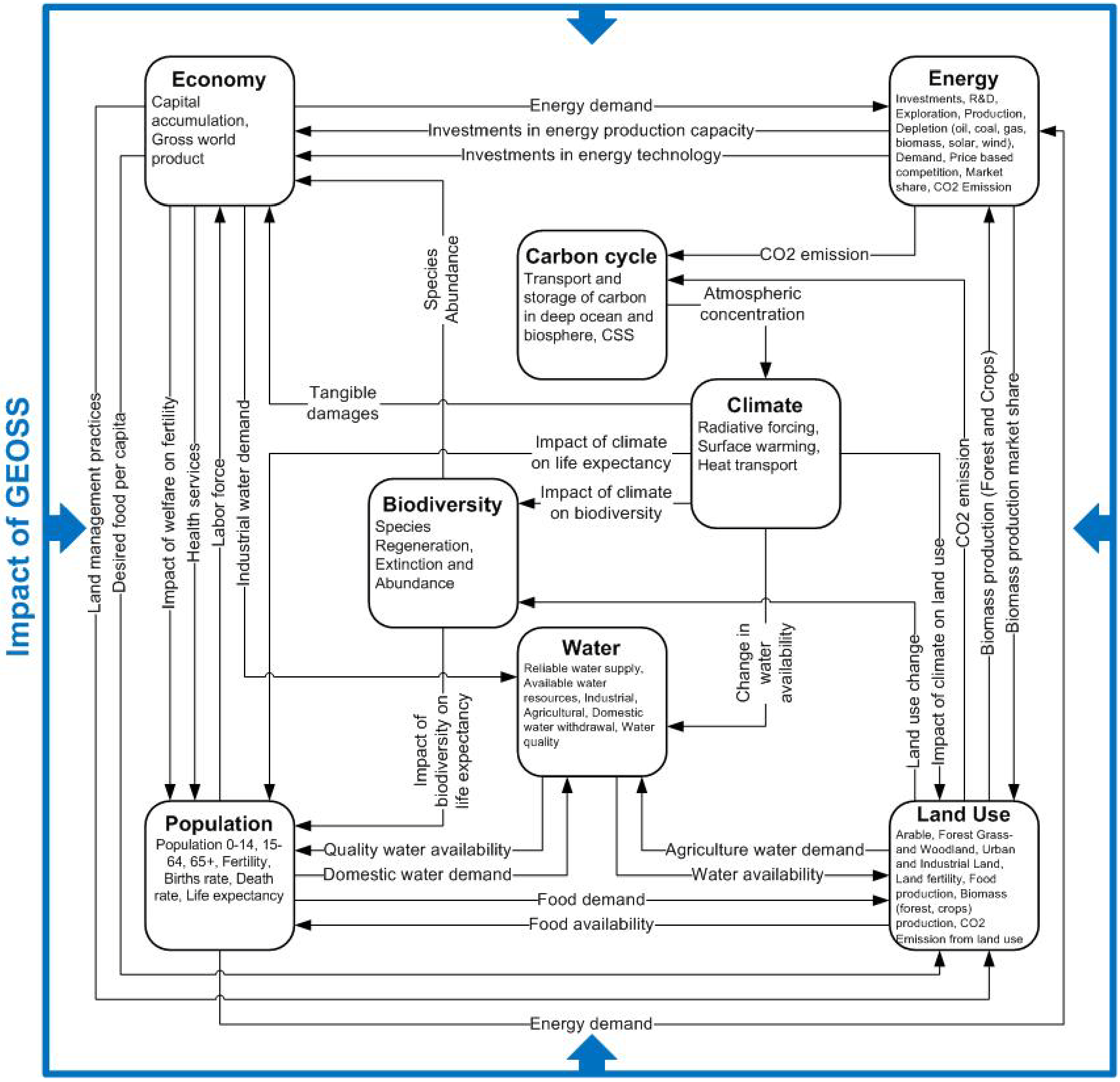


Figure 2 FeliX model sectors and main interrelations

The FeliX model, following the system dynamics approach, attempts a full systems perspective, where the underlying social, economic, and environmental components of the Earth system are interconnected to allow for complex dynamic behavior characterizing the Anthropocene (Schellnhuber 2009). A change in one area often results in changes in other areas. For instance, depletion of oil and gas, a source of energy, may affect population growth but also put pressure on the agriculture sector to produce more energy crops as a substitute. As a dynamic model, FeliX captures important stock changes (e.g., depletion of natural resources, accrual of carbon dioxide in the atmosphere) or consequences of certain policies (e.g., afforestation, emissions reduction) over time.

Economy

At the core of the economy module is a neoclassical growth model. Capital is an accumulation of investments whereby in FeliX, investments in the energy and the GEOSS sector are accounted for separately. Growth in gross world product is driven by increases in the labor force, which is modeled explicitly in the population module, along with capital accumulation and technological change. The economy module contains a representation of the climate system and takes into account the effects of global average temperature change, according to the DICE model (Nordhaus 1992, 1994). In addition to the climate mitigation measures (i.e., reduction in emissions of greenhouse gases, GHGs) in the DICE model, the FeliX model accounts for climate adaptation to more intense storms, forest fires, droughts, floods, and heat waves and also incorporates prevention and adaptation activities. However, the range of effects from climate change is uncertain, the assumed model parameters were revised and some of the damages explicitly modeled. The DICE model is known to potentially underestimate climate impacts (e.g., Stern 2007).

Carbon Cycle

The FeliX model accounts for CO_2 emissions with a detailed representation of emissions in the energy sector and land-use change. Energy production technologies differ in their carbon intensities. The model accounts for CO_2 emissions from oil, gas, coal, biomass, solar, and wind energy technologies for their full life-cycle. Furthermore, the FeliX model uses the carbon cycle model proposed by Fiddaman (1997): CO_2 emissions accumulate in the atmosphere and are reabsorbed through fluxes to the terrestrial biosphere and the ocean. The model also accounts for CO_2 flux between living biomass and humus and also distinguishes between the ocean's mixed layer and the deep ocean.

Climate

The FeliX model takes into account the greenhouse effect and, following Nordhaus (1994) and Fiddaman (2002), captures the additional surface warming from the accumulation of CO_2. Positive forcing increases the atmospheric and upper ocean temperatures. Additionally, heat transfer between the atmosphere and the upper ocean and deep ocean is modeled. This disturbance of the climate system, measured by changes in temperature, leads to climate change, accounted for in various sectors of the model. Thus, the consequences of climate change are spread out across the whole model, affecting land quality, population growth, and biodiversity (explicitly accounted for in a biodiversity model sector).

Energy

Energy demand is driven by population development and the evolution of per capita energy demand. Exploration and production activities, investments in the deployment of energy technologies, R&D activities, and costs of energy carriers are explicitly modeled for each source of primary energy. An economic mechanism of price-based competition between energy sectors determines the market share of primary energy. Technological development is explicitly modeled in the energy and land-use sectors. R&D investments lead to increased growth of either sector- and technology-specific or economy-wide technological change. Technological change is a major driver of economic growth.

Land Use

The FeliX model contains a “competition for land” module. There are distinguished four types of land – Agricultural, Forest, Urban and Industrial, and other (e.g. woodland and grassland). Various social and economic activities as well as natural processes may change the characteristics of a land type and also cause transformation from one land type to another. A growing population and changing food preferences to more protein-rich diets increase the demand for food production and cause agricultural land expansion into forests and grasslands. This phenomenon is even stronger due to increasing demand for animal food. The model accounts for more intensive agriculture due to fertilization, irrigation, and genetic improvement. Furthermore, it accounts for new demands for biomass resources for energy purposes and material use, from both forest biomass and biomass from energy crops. The intensification of competition for land between food and energy crops is explicitly modeled.

Water

Water resources are explicitly accounted for in a water model sector. It accounts on one side for reliable water supply and available water resources and on the other side for water demand due to industrial, agricultural and domestic use. The demand for water is associated with population, its wealth but also with the irrigated versus rainfed agricultural land area. Water scarcity propagates through other model sectors.

Biodiversity

Biodiversity calculation in the model is based on global mean species abundance. Degradation or change in forest and agricultural land as well as climate damage impact species carrying capacity which it then reflected in species abundance. The model assumes that change in biodiversity impacts economy, health and land fertility.

Population

At the heart of the FeliX model is population. This model sector drives but also is influenced by other model variables. Thus it strongly determines the dynamics of the model. In the model the world population was divided in three cohorts. Part of the middle age group constitutes labor force which is a variable in the neoclassical growth model equation. The GPD closes the feedback loop as it was modeled to have an impact on the population fertility. Population life expectancy is influenced by issues associated with food availability, climate, and health.

Model Structure

All model sectors will be thoroughly described in the following part of the report. The description structure is consistent among the model sectors and includes four sections:

Dynamic problems definition identifies the main phenomena, tradeoffs, and behaviors over time as observed in the real Earth system and associated with the specific model sector. Each of the identified problems is associated with a graph over time or a description.

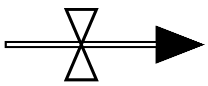
System conceptualization depicts the structure that determines the dynamic problem. In this report the conceptualization takes for of a description, a picture or a System Thinking tool called Casual Loop Diagram.

Model formulation section presents how dynamic problem was translated into the System Dynamics model structure. Stock and flow diagrams presented in this section are directly copied from the FeliX model.

Simulation section provides the results of the model simulation. The main purpose of presenting them at that point is to illustrate FeliX model's fit to the historical data.

Note that detailed equations of the whole model are included in the Appendix. Still it is necessary to be familiar with the System Dynamics models notation in order to follow the information provided in this report. The model components, 'building blocks', from which each System Dynamics model is constructed, are presented in Table 1.

Table 1 Notation used in System Dynamics models.

Diagram	Name	Description
	Stock	Stocks are accumulators within the system. They are an analogy to a tank of water. They accumulate inflows, reduced by outflows, over time. The level in the tank will vary, depending on the rate of inflows and outflows. The accumulations will persist even if all flows will drop to zero.
	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 stocks from which flows originate or are drained to, respectively. The stocks illustrated by the sources and sinks are left beyond the model consideration. Sources and sinks are considered to have an 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 in the model. Also auxiliary variables are used when some mathematical expressions are applied.
+ / –	Polarization	Polarization of a relation,'+' or '–' sign, is placed at the arrowhead of a relation for informative purposes. Sign '+' at arrow head indicates that an increase in the independent variable causes the dependent variable to increase – assuming all other variables stay the same, (in the opposite case – a decrease in the independent variable causes the dependent variable to decrease). Sign '–' at arrow head indicates that an increase in the independent variable causes the dependent variable to decrease – assuming all other variables stay the same, (in the opposite case – a decrease in the independent variable causes the dependent variable to increase).

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:

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

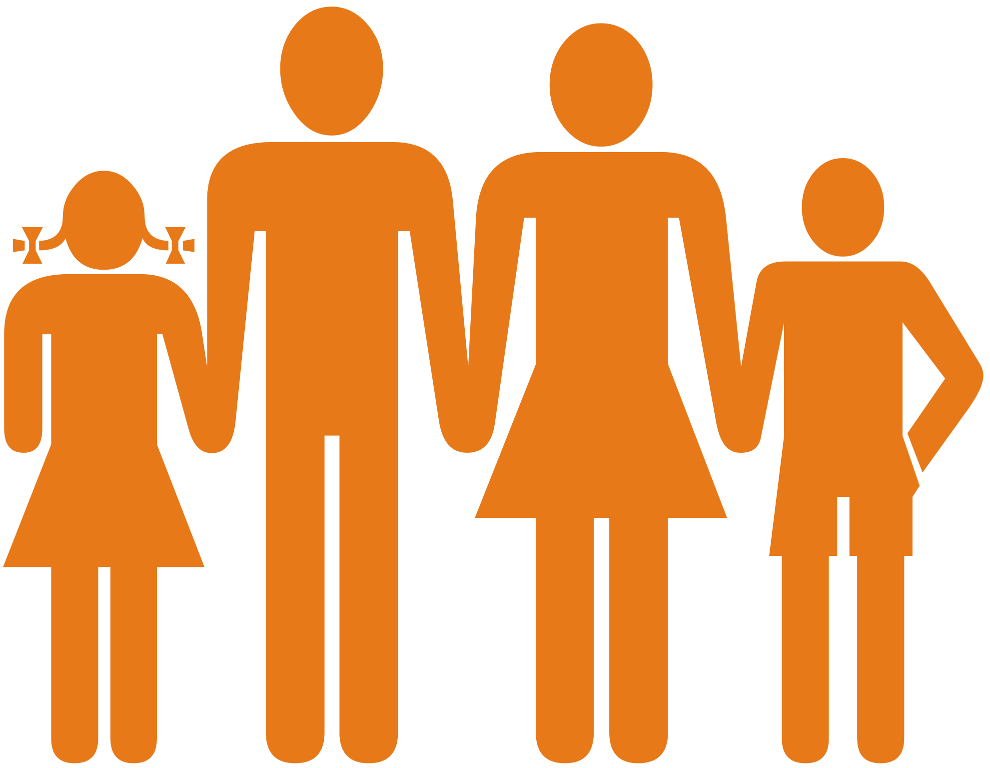
where:

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), Richardson and Pugh (1981) and Sterman(2000).

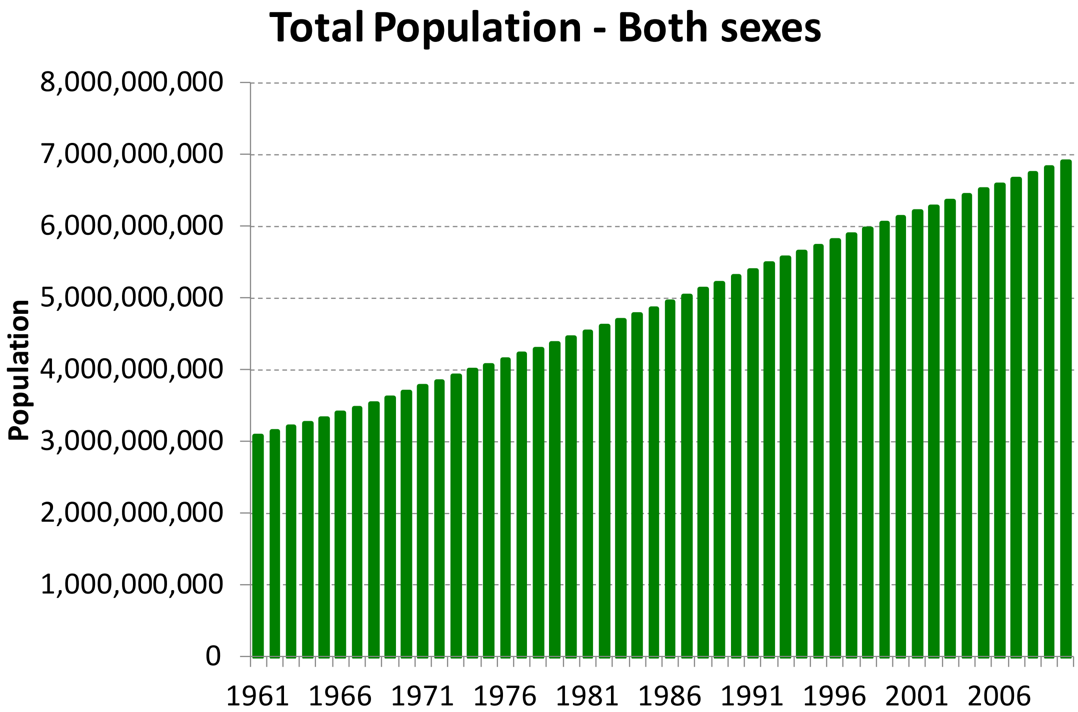


Population

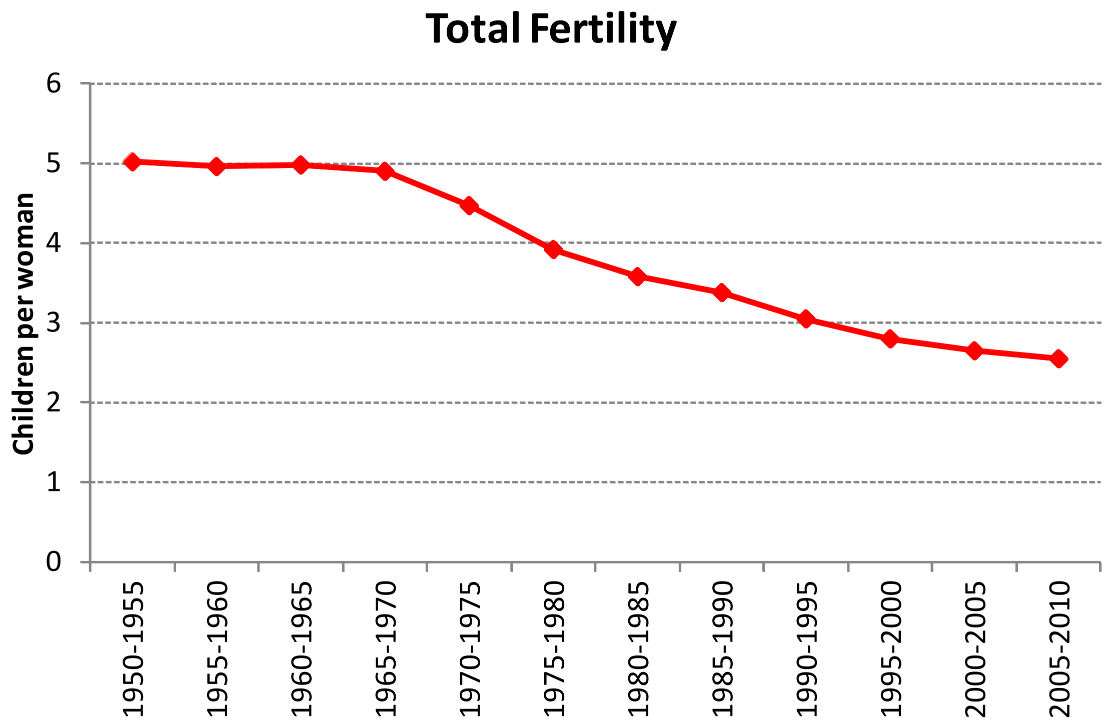
Dynamic problems definition

The Population sector of the model was developed around two main dynamic phenomena – Population Development and Population Ageing.

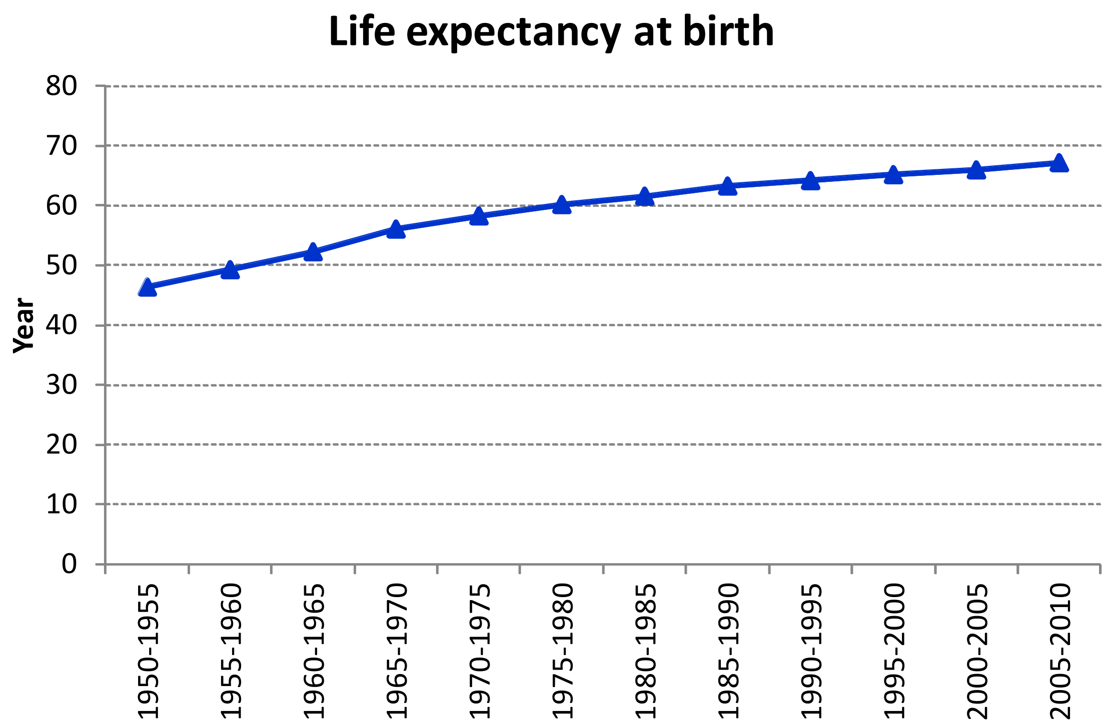
Population Development
Over the last 50 years the World population more than doubled. Even though adoption of "western world life style" of small families is observed and total fertility is declining the Life expectancy is still growing. It is expected that the population growth will continue for at least the next 50 years



Source: FAOSTAT - http://faostat.fao.org (Resource → Population → Annual time series)



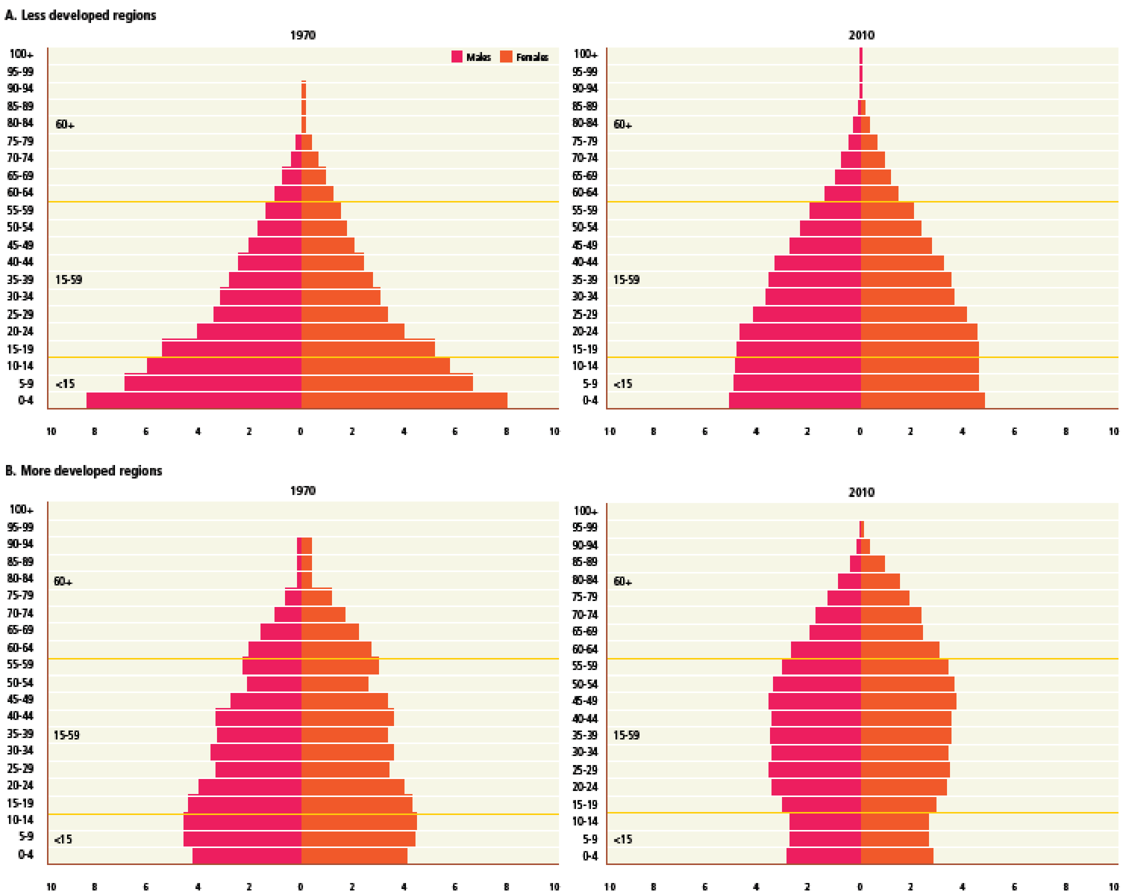
Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects.



Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects.

Population Ageing

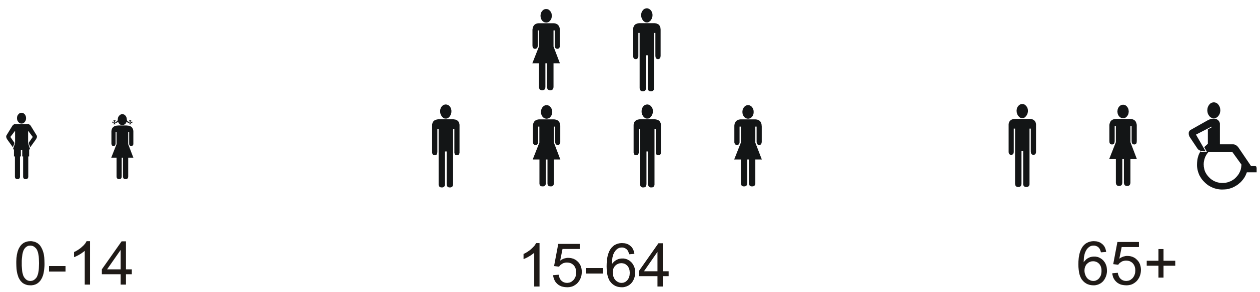
The world has experienced large improvements in longevity. In 1950-1955, life expectancy at birth was 66 years in the more developed regions compared with only 42 years in the less developed regions. By 2010 the life expectancy increased on average by 20 years. This phenomenon is largely responsible for ageing of the population.



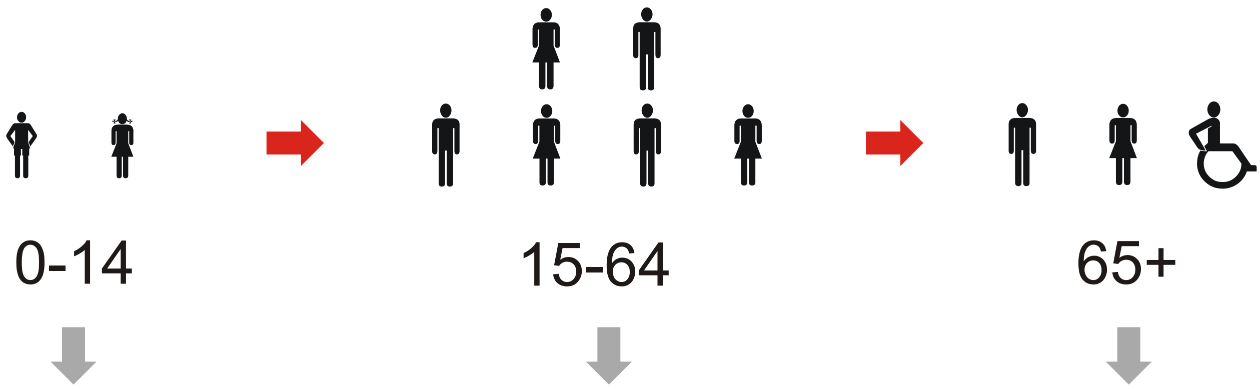
Source: United Nations, Department of Economic and Social Affairs, Population Division - Wall chart on World Population Ageing and Development 2012

System conceptualization

Following a common statistical data structure the world population might be divided into three groups – 0-14 years old, 15-64 years old and older than 65 years.

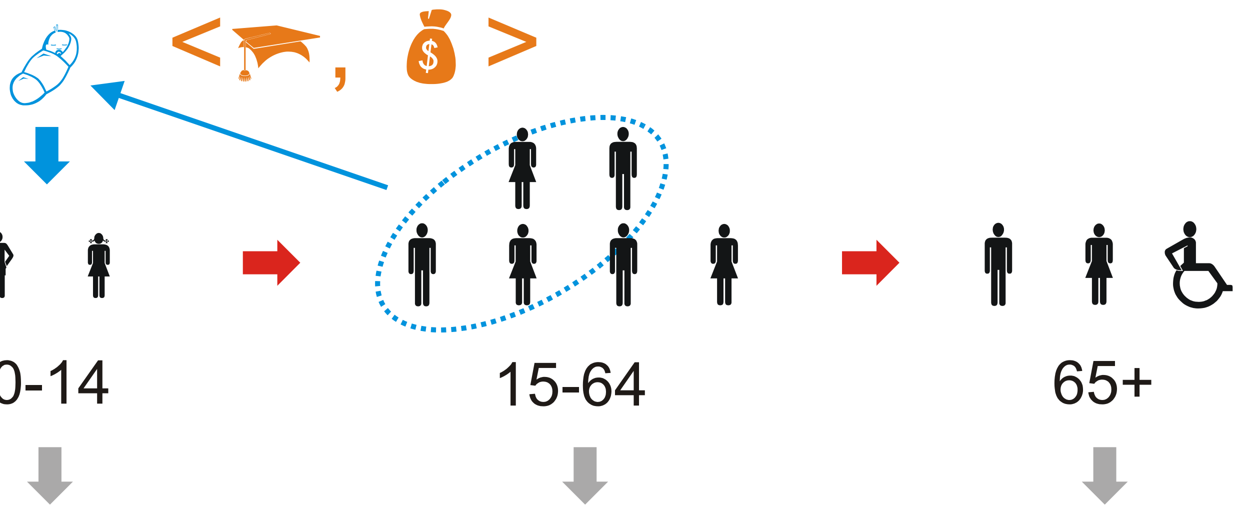


Each of these groups has specific characteristics. With the group that is 0-14 years old there is associated maturity rate to 15-64 years old group (red arrows) but also death rate (grey arrows). With the group that is 15-64 years old there is associated maturity rate to 65+ years old group and death rate that is higher than in case of 0-14 years old group. 65+ years old group is characterized with the highest death rate.

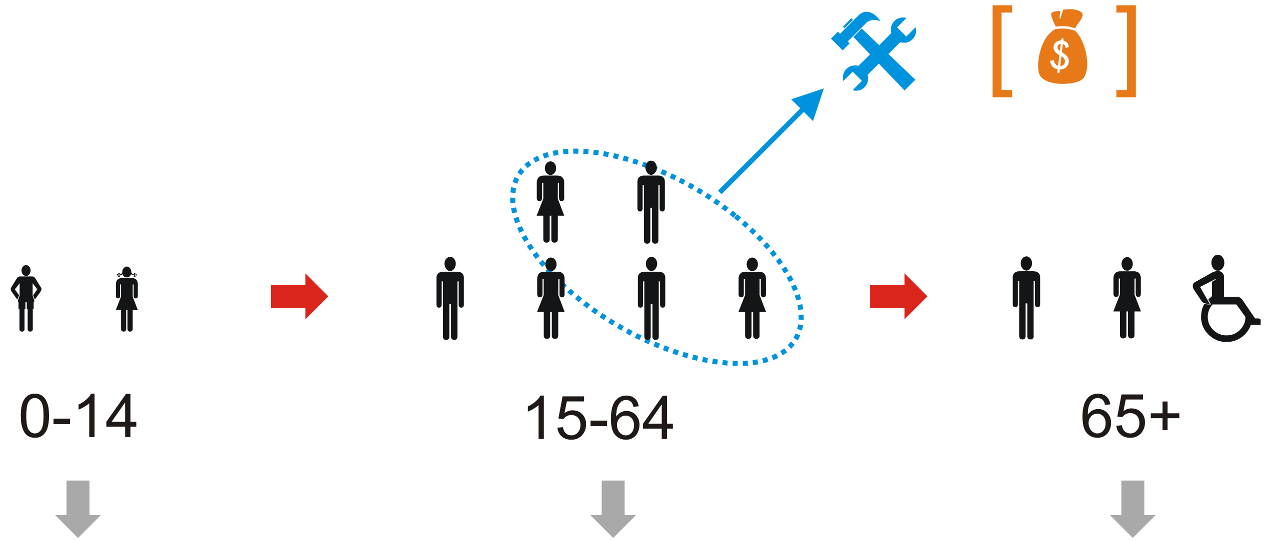


There are also two specific characteristics related to 15-64 years old group. One is fertility and population regeneration. Reproductive ratio of the 15-64 years old group in a limited period of its life decides to have children. The fertility – number of children per women – is a function of educational attainment and population wealth.

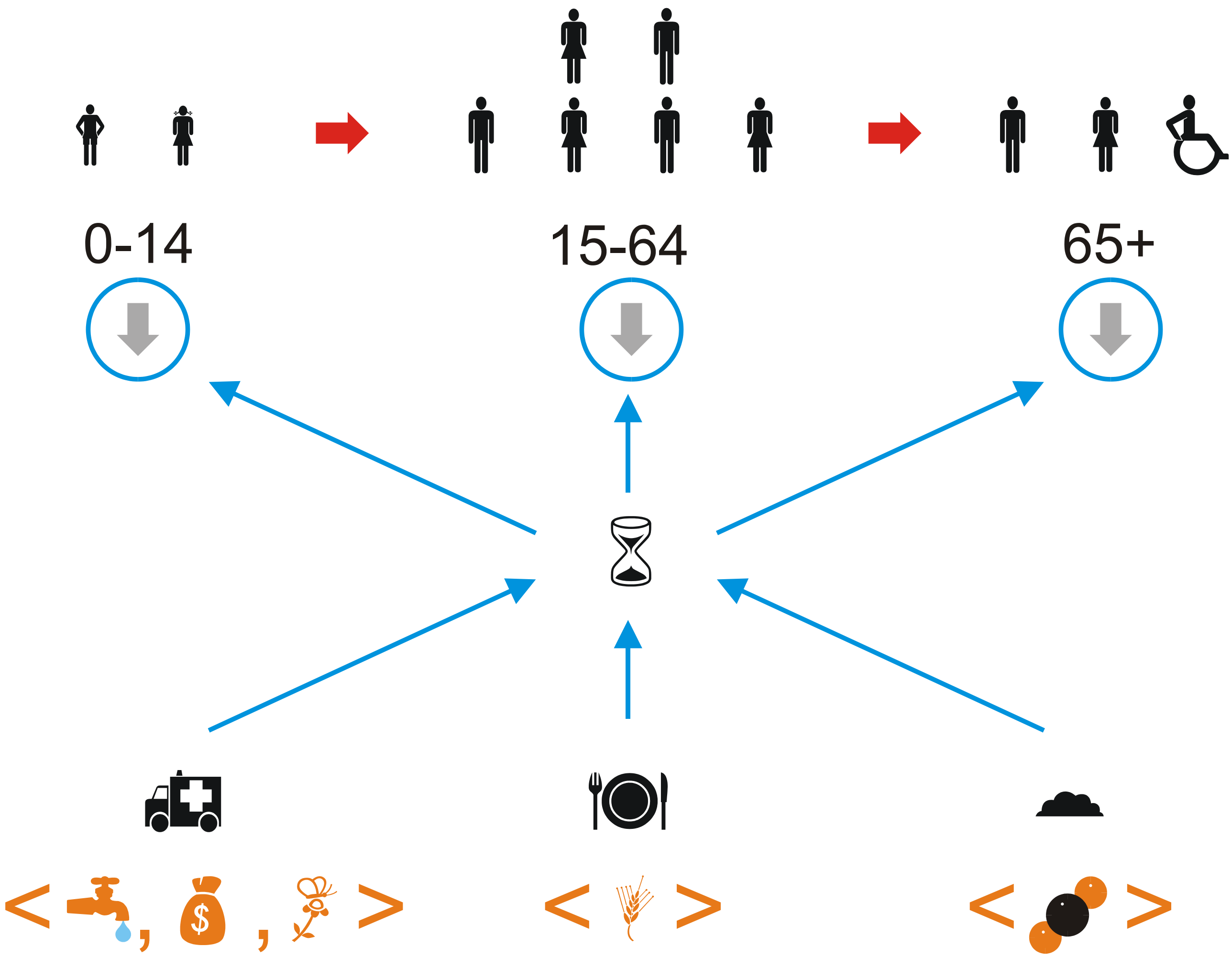
Note: For consistency reasons a unique nomenclature was adopted:
< > brakets indicate a collection of independent variables, or sectors they belong to, influencing a given phenomenon.
[ ] brakets indicate a collection of dependent variables, or sectors they belong to, being influenced by a given phenomenon.
Blue icons indicate variables associated with the given sector.
Orange icons indicate variables or sectors other that the given one.



The other specific characteristic related to 15-64 years old group is that a significant fraction of this group constitutes labor force that impacts Economy sector of the model.



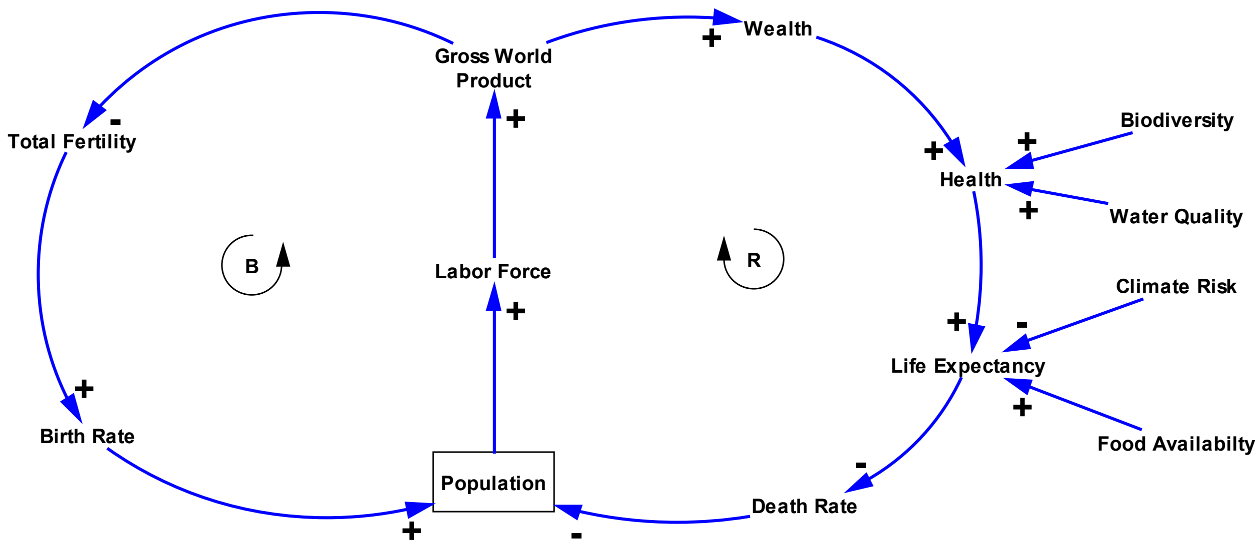
Death rate for each population group differs but all of them depend on life expectation, which is a function of health services quality, availability of food and climate risk. Health services quality depends on population wealth, water quality and biodiversity. Food availability is covered in Land Use sector. Climate risk relates to CO2 concentration.



The dynamics of the population is driven by two feedback loops. The balancing loop captures a phenomenon of lower fertility among more developed societies. While Gross World Product increases, the Total Fertility decreases leading to lower Birth Rate. Since Population is a stock even with the lower Birth Rate the Population level grows but slower. Decline in Population growth translates into slower increase of Labor Force which in turn impacts economic outcome. In a consequence the fertility increases.

The second feedback loop exhibits a reinforcing behavior. While the economic outcome increases the health services quality becomes better. That in turn causes life expectancy to extend and reduces the death rate. Smaller death rate allows for accumulation of the Population.

The combination of both loops dynamics captures the dynamic problems associated with the Population model sector – population development and ageing.



Model formulation

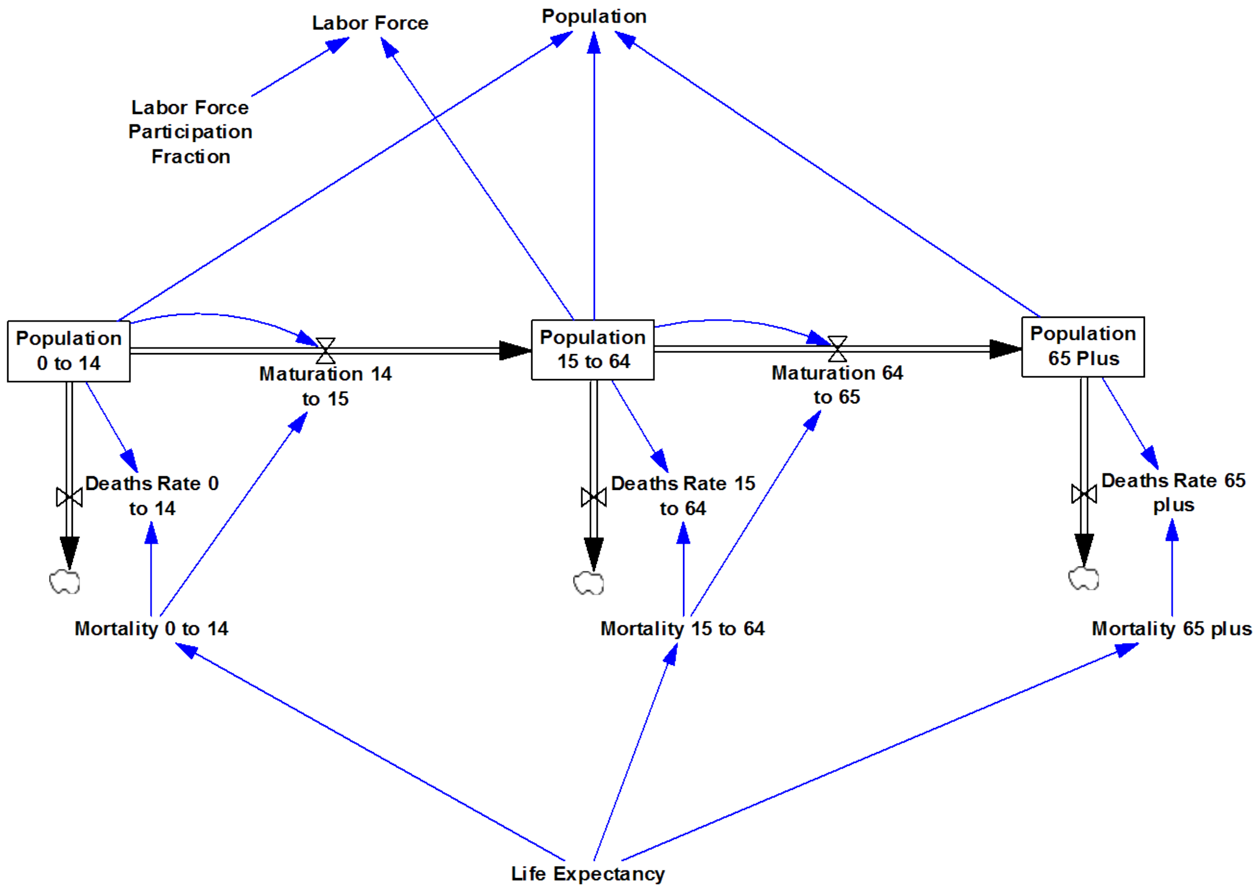
Following the concept of the Population module structure the population was modeled as a specific System Dynamics model structure called 'ageing chain'. At the heart of the Population model sector, there are three population age groups.

Each age group was modeled as stock accumulating inflows and depleted by outflows. What perceived as an outflow from perspective of one stock might be an inflow for another. Outflow from *Population 0-14* stock of which the intensity of flow is determined by *Maturation 14 to 15* rate is an inflow for *Population 15 to 64* stock. Similarly *Maturation 64 to 65* is an outflow from *Population 15 to 64* stock and an inflow to *Population 65 Plus* stock.

Each of the Population model sector core stocks is depleted by flows representing Death Rate. The intensity of flows differs between the age groups and depends on mortality factors that in turn are determined by *Life Expectancy*.

Total *Population* is a sum of three population age groups stocks. Whereas the *Labor Force*, a variable used in economic part of the model, is modeled as a fraction of the *Population 15 to 64* stock.

Note: Detailed equations behind each model variable are presented in alphabetic order in the Appendix. The electronic copy of this report allows navigations through the model variables in the Appendix by clicking the independent variables names constituting the equation.

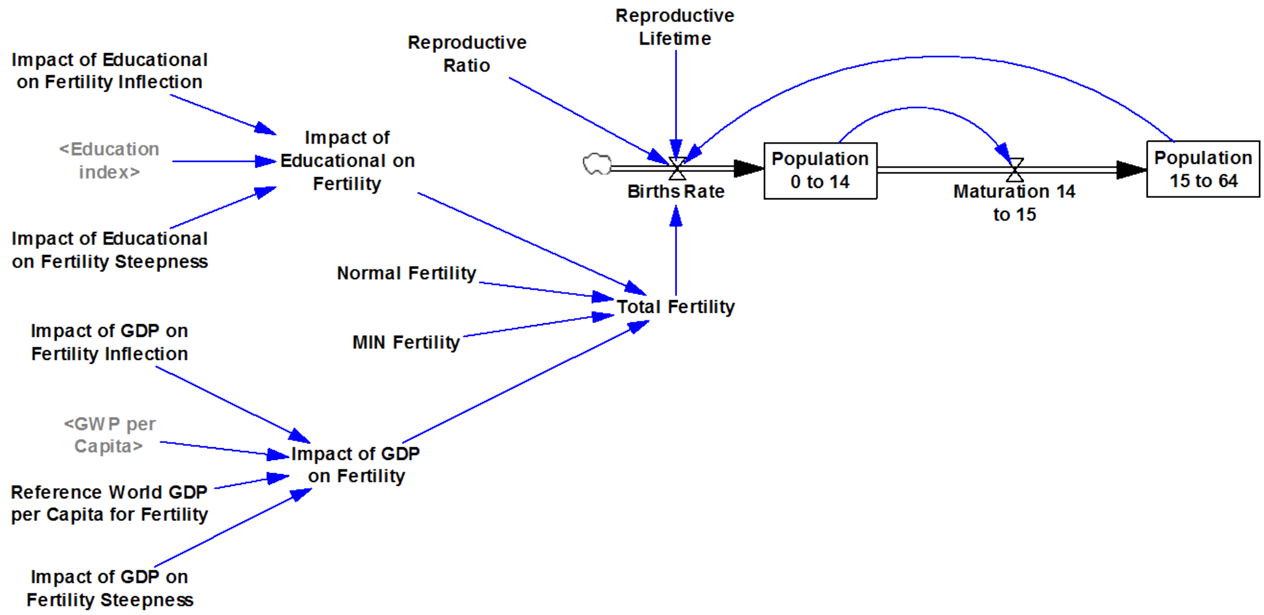


A number of factors impacts rate of the population regeneration. The *Birth Rate* depends on:

- *Population 15 to 64* – age group including population able of reproduction
- *Reproductive Lifetime* – the number of years people can reproduce
- *Reproductive Ratio* – average reproductive percentage of mature population
- *Total Fertility* – average number of children per woman

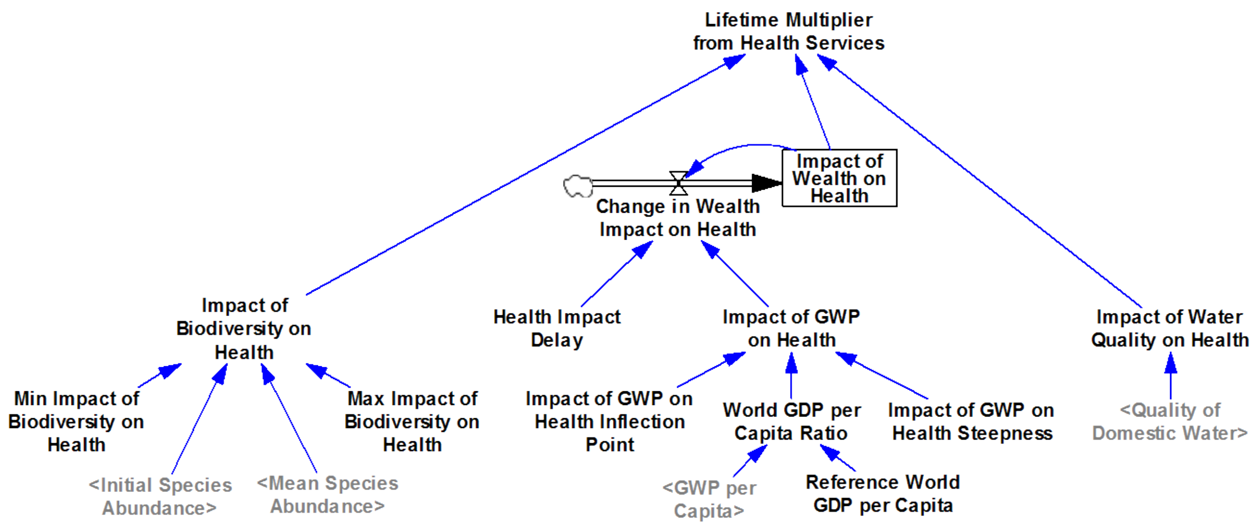
Reproductive Lifetime and *Reproductive Ratio* are parameters. Thus the dynamics of the *Birth Rate* and thus phenomena of population growth and ageing depends on the

Population 15 to 64 stock and *Total Fertility*. The *Total Fertility* is inversely proportional to *GDP* and *Educational index*, a component of Human Development Index.

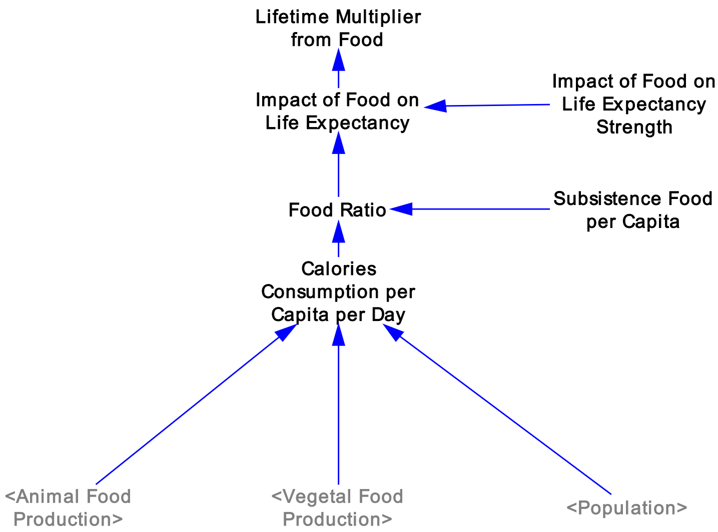


The second element strongly responsible for population development and ageing is *Life Expectancy* variable. The model captures three main elements responsible for its changes over the last century – improvements in health services and food availability as well as increasing climate risk.

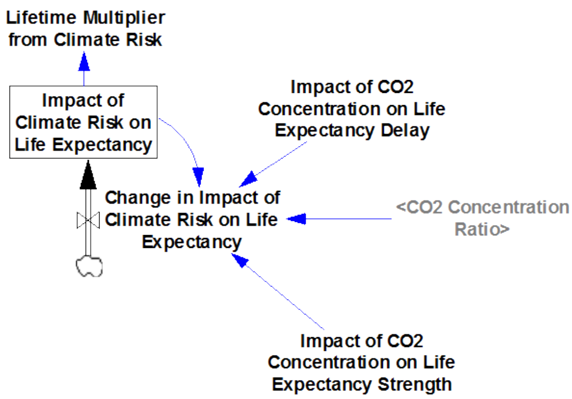
The quality of health services depends mainly on GDP. The wealthier the society the more it can spend on better health services and its availability. Other two factors influencing the society health are Biodiversity and Water Quality.



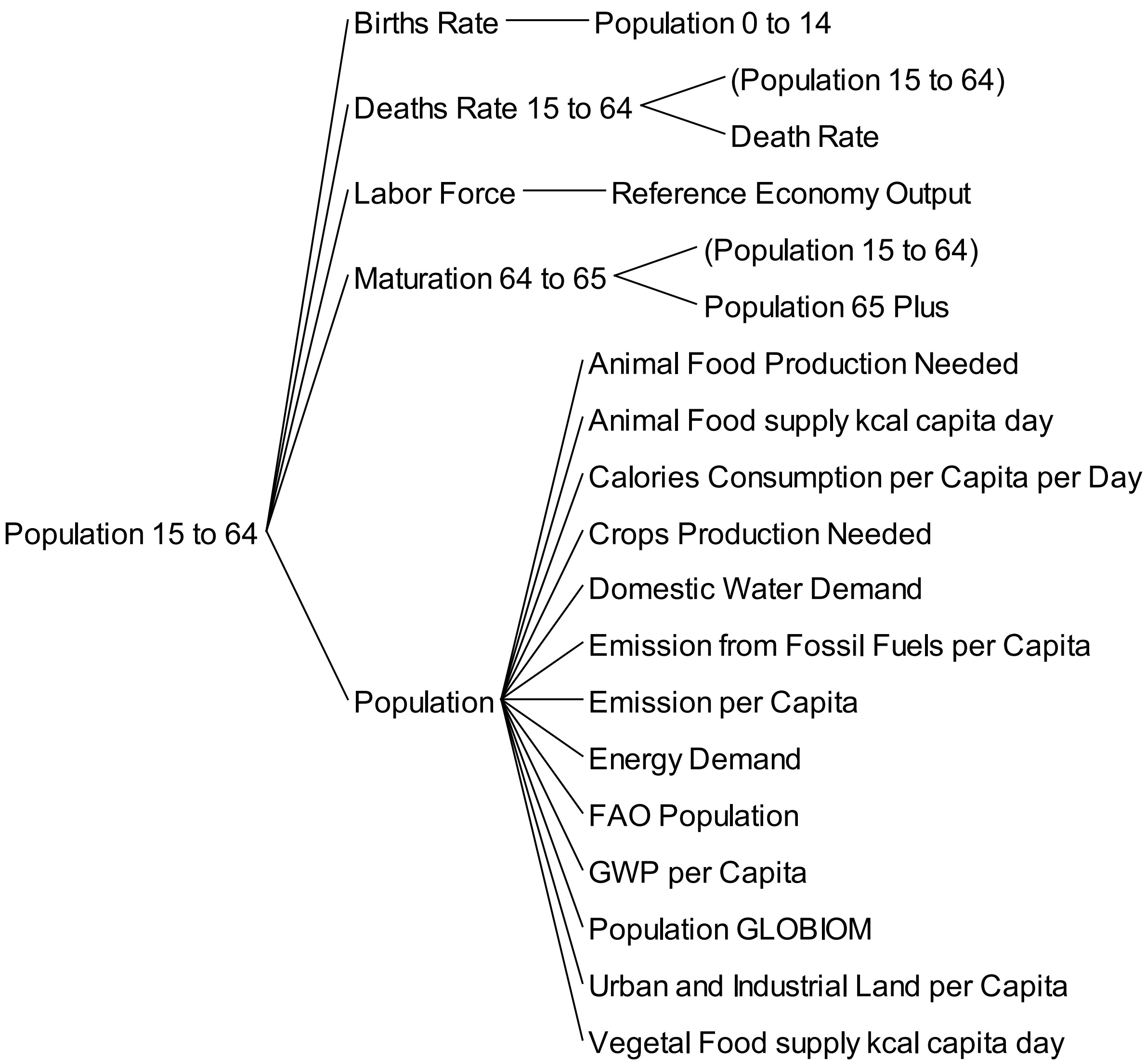
Impact of food on life expectancy is measured by comparing animal and vegetal food production per capita to subsistent food per capita. While food production increases the positive impact on life expectancy increases.



Climate risk as related to life expectancy is proportional to CO2 concentration. The greater the concentration the greater the risk, that impairs the life expectancy.



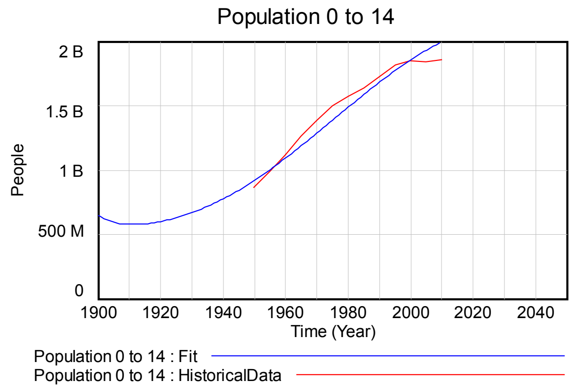
The tree diagram below illustrates variables dependent on Population 15 to 64 and Population across the entire FeliX model. All these relations will be described further in the next sections of this report.



Simulation

The graphs below illustrate the Population model sector variables fit to historical data. The statistical fit parameters were calculated based on Theil inequality statistics (Sterman 1984). The statistical calculations were useful to analyze and diagnose the results of partial model calibrations.

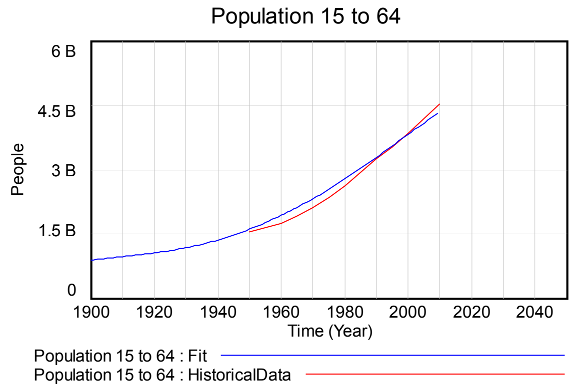
As can be observed the model structure responsible for dynamic behaviors of the variables in the Population sector of the FeliX Model fits well to trends observed over the last 50 years. The proposed here model structure was able to capture population development and ageing phenomena.



Summary Statistics for Historical Fit – Population 0 to 14

n (Count)	12
R^2 (Coefficient of Determination)	0.96725
MAPE (Mean Absolute Percent Error)	0.04138
MSE (Mean Square Error)	4.45E+15
RMSE (Root Mean Square Error)	66676058
UM (Bias component of MSE)	0.20432
US (Variation component of MSE)	0.00038
UC (Covariation component of MSE)	0.79531

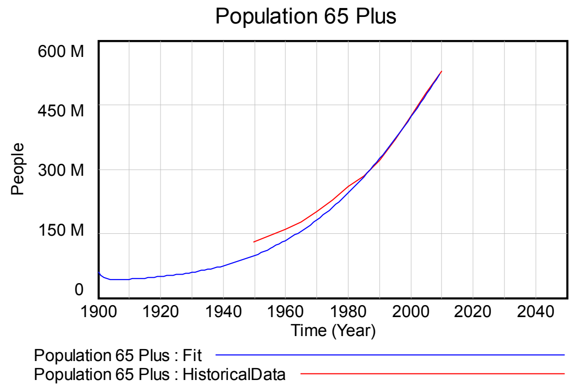
Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp



Summary Statistics for Historical Fit – Population 15 to 64

n (Count)	12
R^2 (Coefficient of Determination)	0.99455
MAPE (Mean Absolute Percent Error)	0.05567
MSE (Mean Square Error)	1.95E+16
RMSE (Root Mean Square Error)	139470498
UM (Bias component of MSE)	0.50113
US (Variation component of MSE)	0.30616
UC (Covariation component of MSE)	0.19271

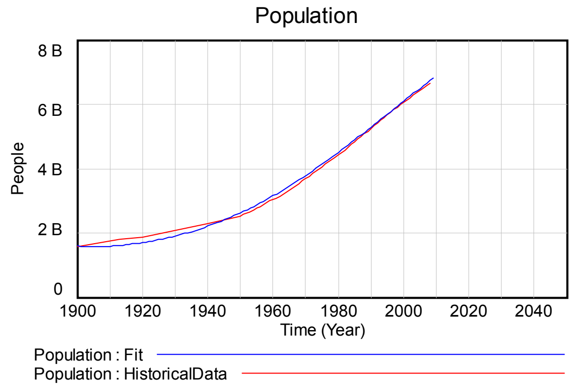
Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp



Summary Statistics for Historical Fit – Population 65 Plus

n (Count)	12
R^2 (Coefficient of Determination)	0.99765
MAPE (Mean Absolute Percent Error)	0.08211
MSE (Mean Square Error)	3.29E+14
RMSE (Root Mean Square Error)	18128427
UM (Bias component of MSE)	0.51969
US (Variation component of MSE)	0.38746
UC (Covariation component of MSE)	0.09285

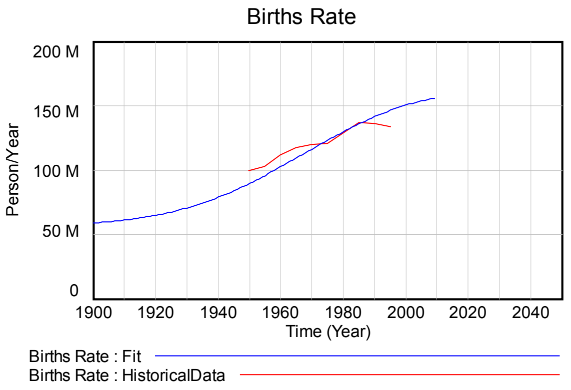
Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp



Summary Statistics for Historical Fit – Population

n (Count)	59
R^2 (Coefficient of Determination)	0.99969
MAPE (Mean Absolute Percent Error)	0.02222
MSE (Mean Square Error)	8.01E+15
RMSE (Root Mean Square Error)	89517572
UM (Bias component of MSE)	0.85558
US (Variation component of MSE)	0.08351
UC (Covariation component of MSE)	0.06091

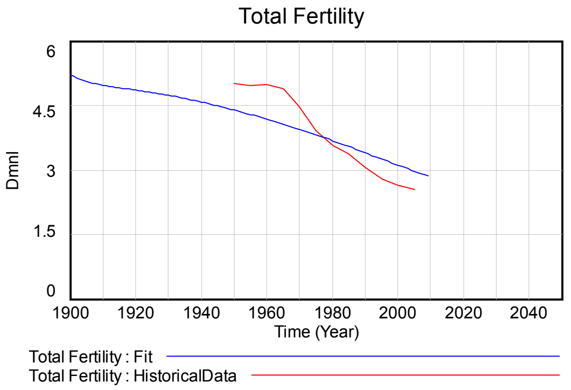
Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp



Summary Statistics for Historical Fit – Births Rate

n (Count)	10
R^2 (Coefficient of Determination)	0.94423
MAPE (Mean Absolute Percent Error)	0.05209
MSE (Mean Square Error)	5.14E+13
RMSE (Root Mean Square Error)	7166051
UM (Bias component of MSE)	0.05490
US (Variation component of MSE)	0.68728
UC (Covariation component of MSE)	0.25782

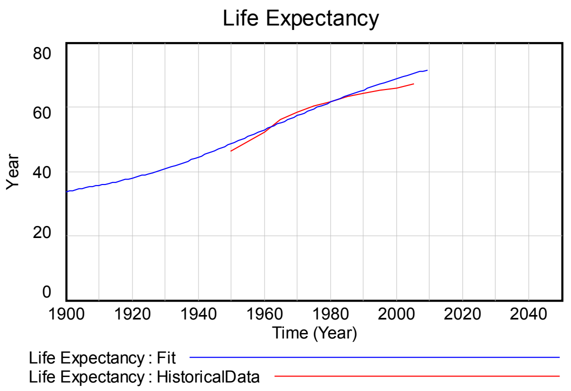
Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp



Summary Statistics for Historical Fit – Total Fertility

n (Count)	12
R^2 (Coefficient of Determination)	0.96477
MAPE (Mean Absolute Percent Error)	0.11871
MSE (Mean Square Error)	2.67E-01
RMSE (Root Mean Square Error)	1
UM (Bias component of MSE)	0.06751
US (Variation component of MSE)	0.87606
UC (Covariation component of MSE)	0.05643

Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp



Summary Statistics for Historical Fit – Life Expectancy

n (Count)	12
R^2 (Coefficient of Determination)	0.96086
MAPE (Mean Absolute Percent Error)	0.02317
MSE (Mean Square Error)	2.73E+00
RMSE (Root Mean Square Error)	2
UM (Bias component of MSE)	0.29717
US (Variation component of MSE)	0.04774
UC (Covariation component of MSE)	0.65509

Source of Historical Data:
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision, http://esa.un.org/unpp

Economy

Dynamic problems definition

The Economy sector of the model was developed around Cobb–Douglas production function:

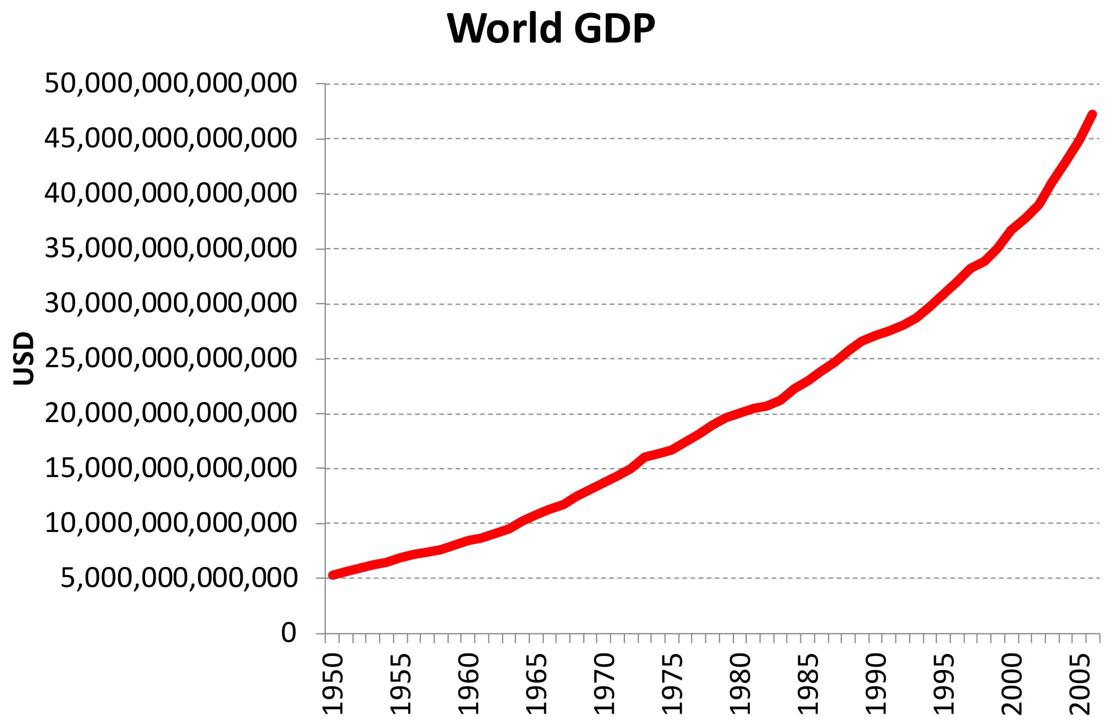
$$Q(t)=A(t)\ K(t)^{\gamma}\ P(t)^{1-\gamma}$$

where:

Q – total production expressed in the monetary value of all goods produced in a year
A – total factor productivity
K – capital input
P – labor input
γ – the elasticity of output with respect to capital

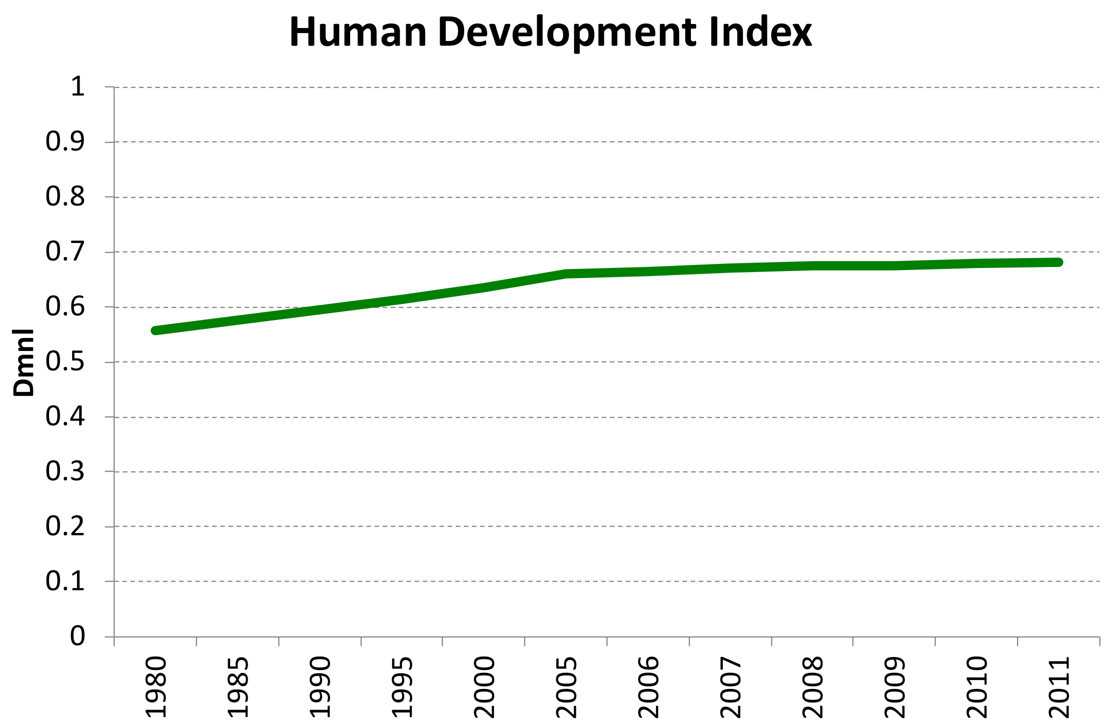
However, the model takes into account two phenomena – changes in ecosystem impacting the growth and also alternative approaches to measures well-being nowadays.

Development jeopardized by ecosystem changes
Although the GDP measure indicates a constant growth the future dynamics is related to changes in ecosystem – mainly climate change and changes in biodiversity. Some models have already taken into account an impact of climate change on GDP (see Nordhaus 1994).



Source: Historical Statistics for the World Economy: 1-2006 AD by Angus Maddison

Alternative measures of development
As argued the human development should not be measured by economic advances but also by improvements in human well-being. Human Development Index is a measure taking into consideration life expectancy, education attainment, and income indices.



Source: United Nations Development Programme, Human Development Report 2011, [*http://hdrstats.undp.org/en/tables/default.html*](http://hdrstats.undp.org/en/tables/default.html)

System conceptualization

In order to take into account the impact of changes in ecosystem on the economic output the Cobb-Douglas function can be further developed:

$$Q(t) = \Omega(t)\ \Phi(t)\ A(t)\ K(t)^{\gamma}\ P(t)^{1-\gamma}$$

where:

Ω – relates to climate impact on the output as proposed by Nordhaus (1994)
Φ – relates to impact of changes in biodiversity on the economic output.

Due to the purpose of the model there is a need to distinguish between the energy related technologies $Ae(t)$ and other technologies $Ao(t)$ where:

$$A(t) = Ae(t) + Ao(t)$$

Also the changes in the capital stock can be distinguished as coming from energy sector and from other sectors.

The economic output can be further used to calculate Human Development Index (HDI) as an alternative measure of human well-being to a single economic perspective. Per Human Development Report (2011)[1] The HDI apart from economy I_{Income} includes also education $I_{Education}$ and health I_{Health} indices.
Each dimention index is calculated as:

$$(actual\ value - minimum\ value) / (maximum\ value - minimum\ value)$$

and the HDI is the geometric mean of the three dimension indices:

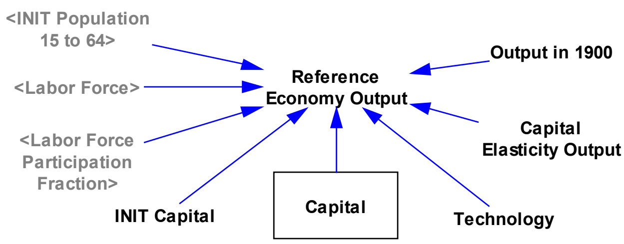
$$HDI = (I_{Life}{}^{1/3}\ \ I_{Education}{}^{1/3}\ \ I_{Income}{}^{1/3})$$

Another index that is taken into consideration is Total Change in Ecosystem Value. The role of this measure is to provide some understanding of human well-being related to natural environment. A simple Total Change in Ecosystem Value index associates a monetary value with a unit change in forest, cropland and other land.

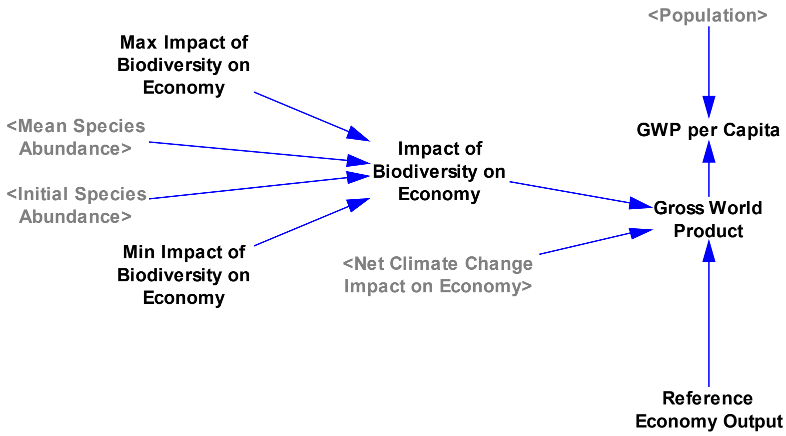
Model formulation

[1] UNDP Human Development Report 2011 – http://hdr.undp.org/en/reports/global/hdr2011/

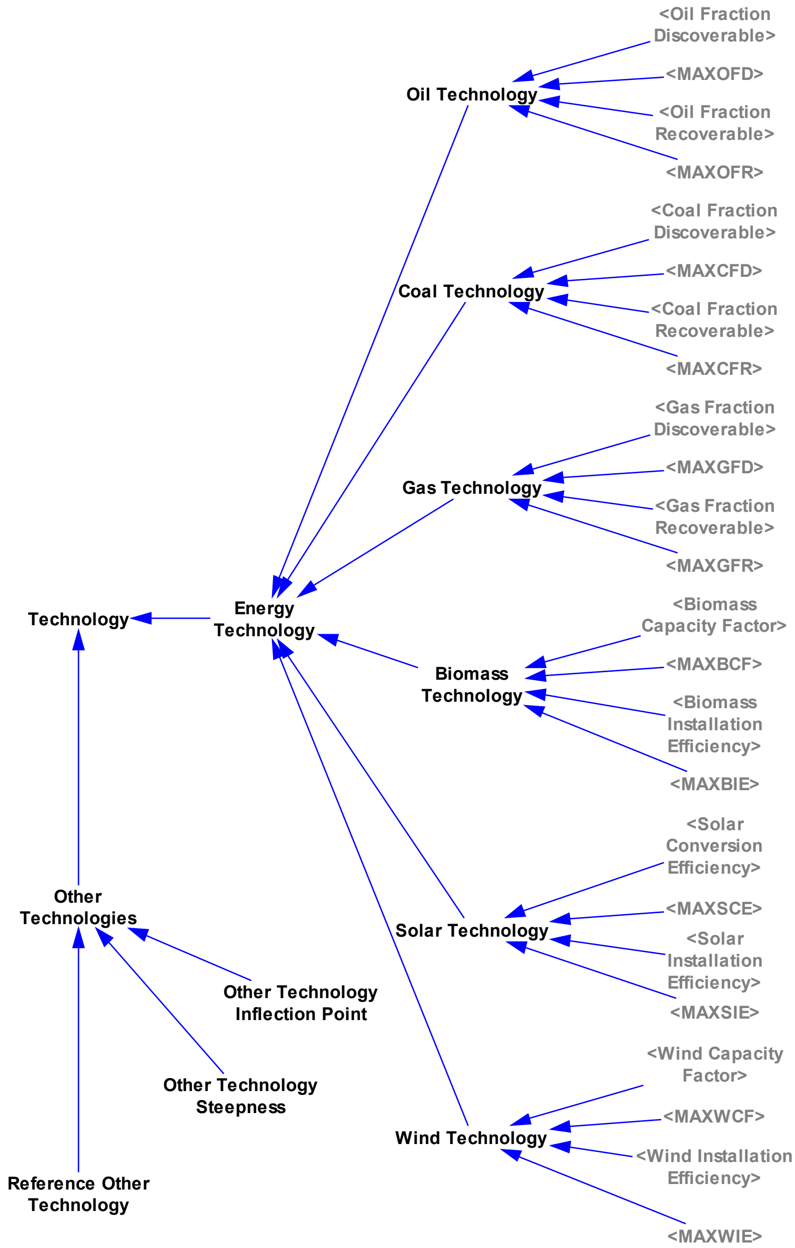
The diagram below represents the representation of the Cobb-Douglas production function in the system dynamics notation. The model was calibrated to the historical data starting from 1900.



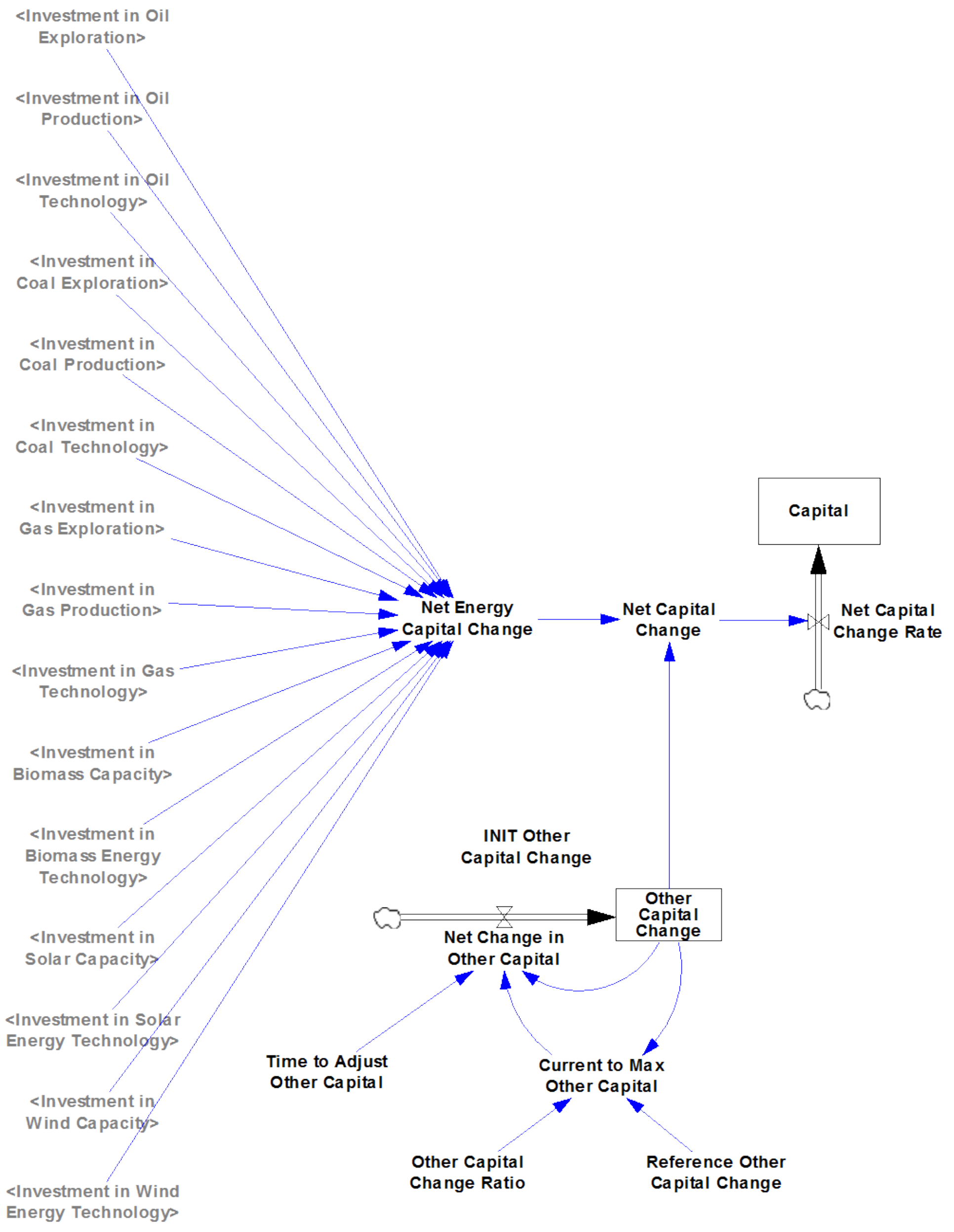
The impact of the climate change and biodiversity was captured as two factors calculated in climate and biodiversity model sector influencing *Gross World Product*.



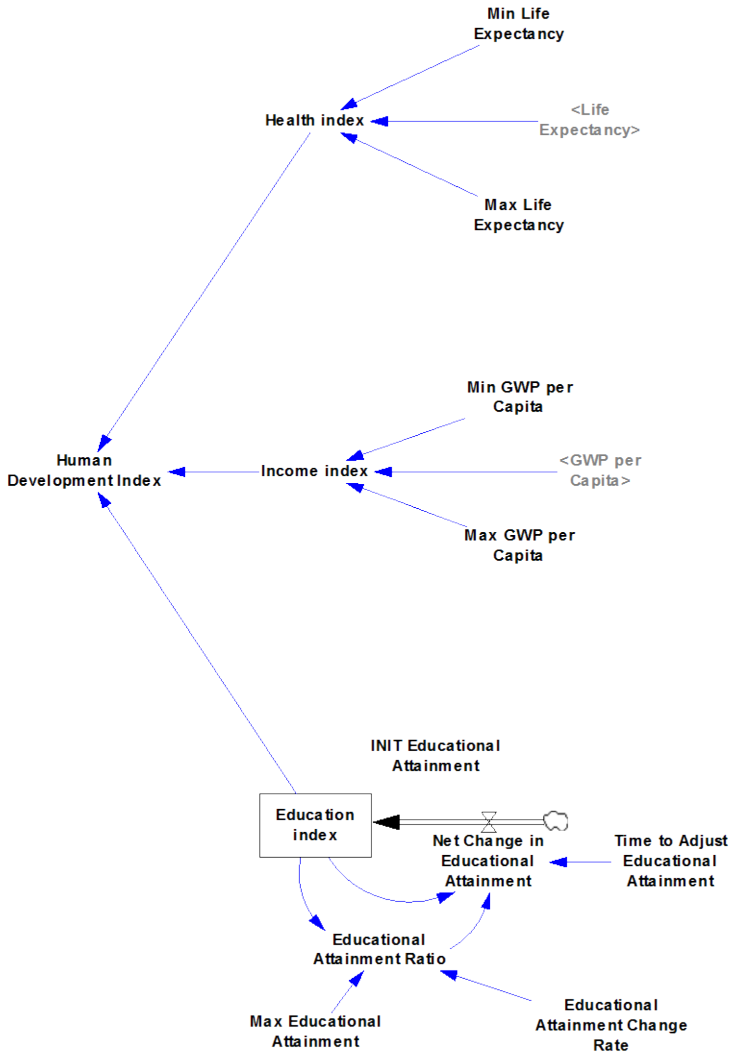
The energy related technologies being developed over years and having an impact on the economic output include technologies related to oil, coal and gas discovery and recovery, as well as biomass, solar and wind conversion and installation efficiency.



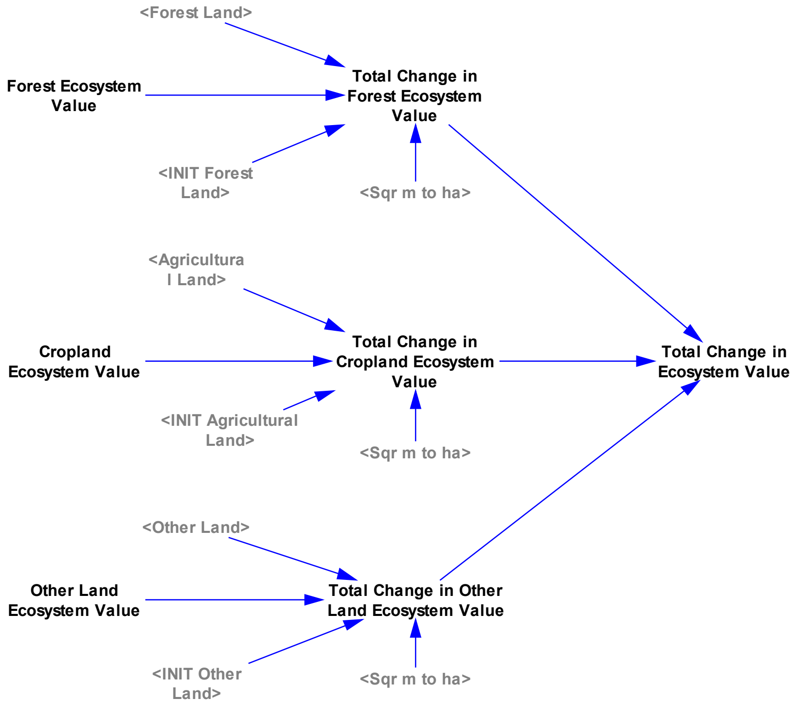
The change in capital, accumulated over time to the capital stock, distinguishes between energy related and other capital. The idea of net change takes into account the capital depreciation.



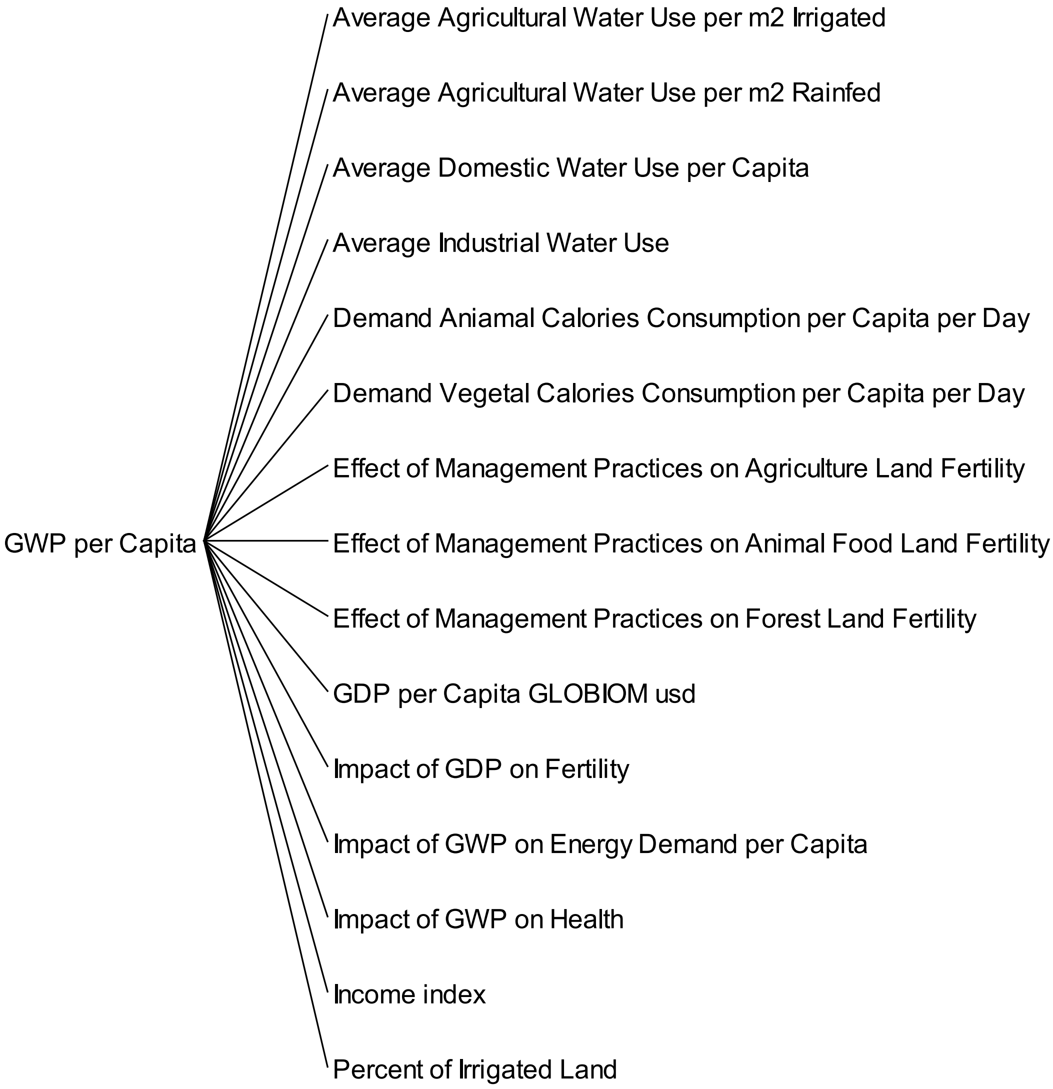
Human Development Index is calculated according to UNDP Human Development Report 2011 including both the formulas and minimal/maximal parameters values. The Income and Health indices are endogenously calculated variables. The *Educations index* is calculated exogenously.



A change in land area compared to initial area is multiplied by a unit cost to obtaine Change in Ecosystem Value. The Total Change in Ecosystem Value includes changes in Forest Cropland and Other Land.



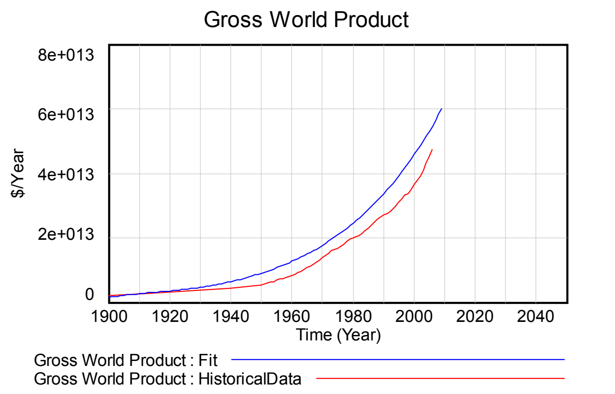
Uses Tree diagram below illustrates variables across the entire FeliX model being influenced by the Global World Product per Capita variable.



Detailed equations of the Economy sector of the model are presented in the Appendix section of this report.

Simulation

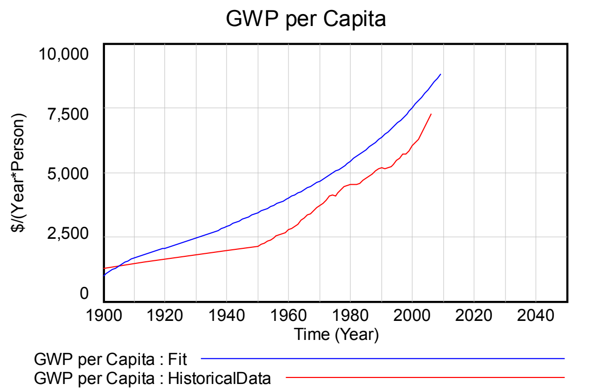
The graphs below illustrate how the structure of the economy sector of FeliX model was able to reproduce the historical behaviors over time.



Summary Statistics for Historical Fit – GWP

n (Count)	57
R^2 (Coefficient of Determination)	0.99586
MAPE (Mean Absolute Percent Error)	0.33800
MSE (Mean Square Error)	3.64E+25
RMSE (Root Mean Square Error)	6.04E+12
UM (Bias component of MSE)	0.88662
US (Variation component of MSE)	0.09607
UC (Covariation component of MSE)	0.01730

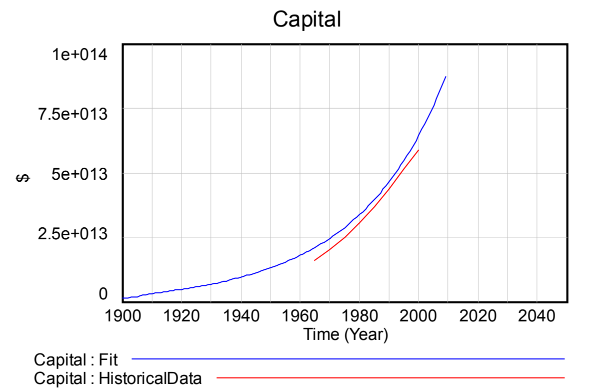
Source of Historical Data:
Historical Statistics for the World Economy: 1-2006 AD by Angus Maddison, http://www.ggdc.net/MADDISON/oriindex.htm



Summary Statistics for Historical Fit – GWP per Capita

n (Count)	57
R^2 (Coefficient of Determination)	0.98023
MAPE (Mean Absolute Percent Error)	0.30725
MSE (Mean Square Error)	1.45E+06
RMSE (Root Mean Square Error)	1204.46
UM (Bias component of MSE)	0.97130
US (Variation component of MSE)	0.00262
UC (Covariation component of MSE)	0.02607

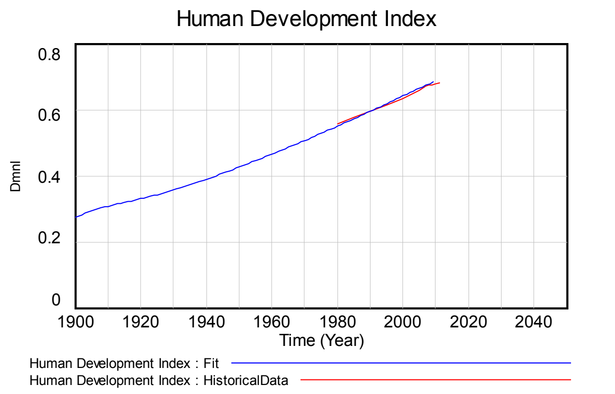
Source of Historical Data:
Historical Statistics for the World Economy: 1-2006 AD by Angus Maddison, http://www.ggdc.net/MADDISON/oriindex.htm



Summary Statistics for Historical Fit – Capital

n (Count)	8
R^2 (Coefficient of Determination)	0.99492
MAPE (Mean Absolute Percent Error)	0.13609
MSE (Mean Square Error)	1.60E+25
RMSE (Root Mean Square Error)	4.00E+12
UM (Bias component of MSE)	0.93571
US (Variation component of MSE)	0.00000
UC (Covariation component of MSE)	0.06428

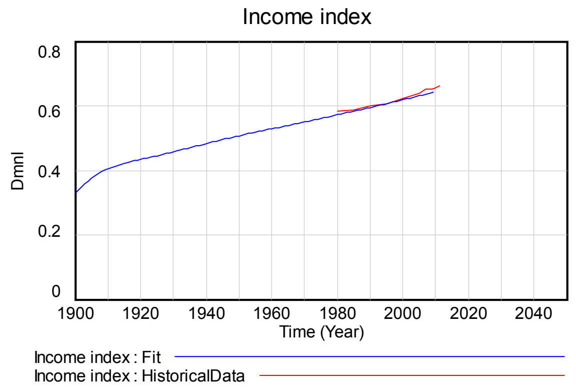
Source of Historical Data:
Historical Statistics for the World Economy: 1-2006 AD by Angus Maddison, http://www.ggdc.net/MADDISON/oriindex.htm



Summary Statistics for Historical Fit – HDI

n (Count)	10
R^2 (Coefficient of Determination)	0.99681
MAPE (Mean Absolute Percent Error)	0.00849
MSE (Mean Square Error)	3.25E-05
RMSE (Root Mean Square Error)	0.00570
UM (Bias component of MSE)	0.30136
US (Variation component of MSE)	0.51125
UC (Covariation component of MSE)	0.18739

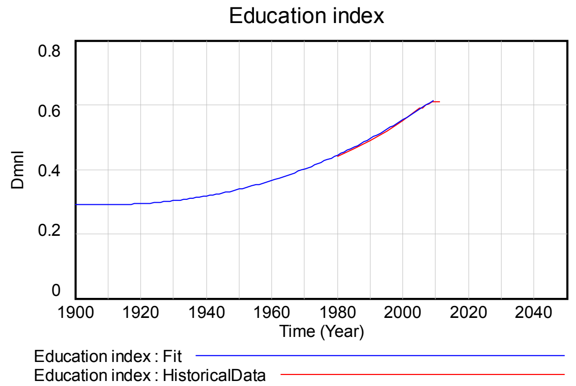
Source of Historical Data:
UNDP Human Development Report 2011
http://hdr.undp.org/en/reports/global/hdr2011/



Summary Statistics for Historical Fit – Income index

n (Count)	10
R^2 (Coefficient of Determination)	0.97433
MAPE (Mean Absolute Percent Error)	0.01383
MSE (Mean Square Error)	9.71E-05
RMSE (Root Mean Square Error)	0.00986
UM (Bias component of MSE)	0.78413
US (Variation component of MSE)	0.05276
UC (Covariation component of MSE)	0.16311

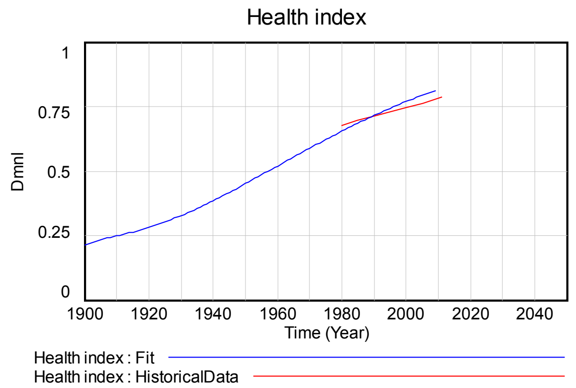
Source of Historical Data:
UNDP Human Development Report 2011
http://hdr.undp.org/en/reports/global/hdr2011/



Summary Statistics for Historical Fit – Education index

n (Count)	10
R^2 (Coefficient of Determination)	0.99867
MAPE (Mean Absolute Percent Error)	0.00777
MSE (Mean Square Error)	1.88E-05
RMSE (Root Mean Square Error)	0.00433
UM (Bias component of MSE)	0.65339
US (Variation component of MSE)	0.09774
UC (Covariation component of MSE)	0.24887

Source of Historical Data:
UNDP Human Development Report 2011
http://hdr.undp.org/en/reports/global/hdr2011/



Summary Statistics for Historical Fit – Health index

n (Count)	10
R^2 (Coefficient of Determination)	0.99464
MAPE (Mean Absolute Percent Error)	0.03202
MSE (Mean Square Error)	6.95E-04
RMSE (Root Mean Square Error)	0.02635
UM (Bias component of MSE)	0.42181
US (Variation component of MSE)	0.56446
UC (Covariation component of MSE)	0.01373

Source of Historical Data:
UNDP Human Development Report 2011
http://hdr.undp.org/en/reports/global/hdr2011/

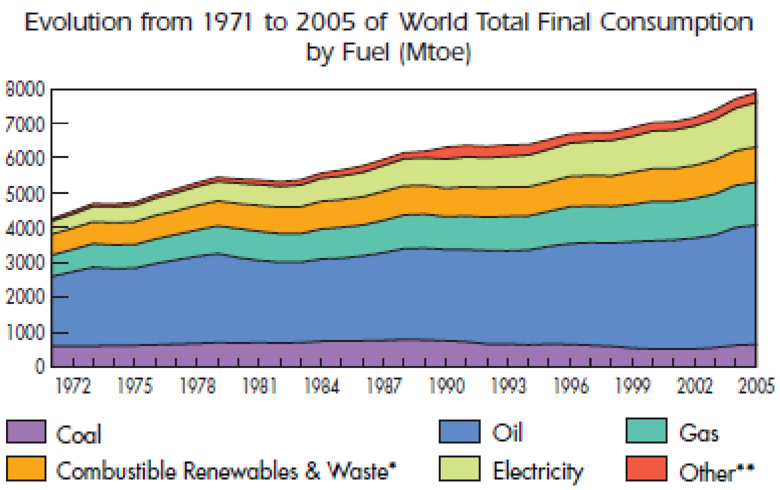
Energy

Dynamic problems definition

Energy has become an essential element of human development but also a stressing issue related to global challenges of the near future.

Increasing energy demand

Energy demand is growing rapidly. On one hand the demand rises due to the population growth. However, the use of energy per capita is also increasing, driven by lifestyle and economic prosperity.

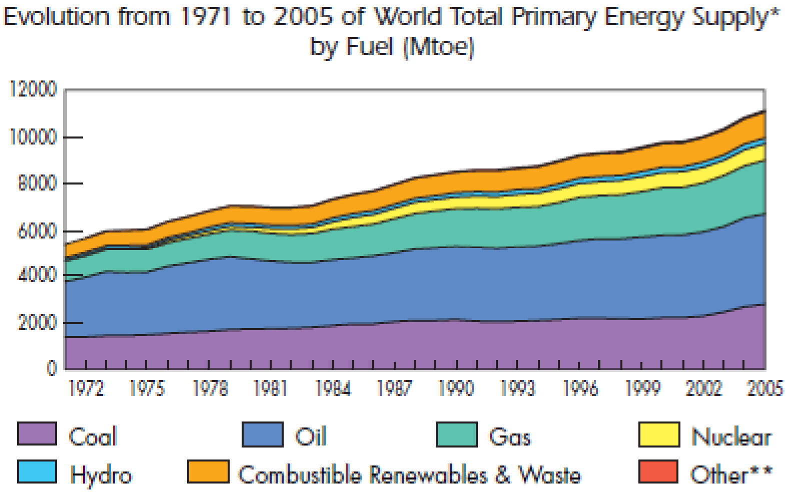


*** Other includes geothermal, solar, wind, heat*

Source: International Energy Agency – Key World Energy Statistics 2007

Investment in energy technology and production capacity to meet demand

There is an ongoing effort to explore new world areas in order to find the resources of fossil fuels that would secure the demand for energy. However, most of the resources have been already proven. In case of oil resources it seems that the maximum rate of extraction has been reached (Hubbert peak theory, also known as peak oil). Thus in recent years very prominent became activities that focus on optimization of production and energy delivery. There is also ongoing development of new technologies that would improve the known resources recovery (e.g. projects on viscous and heavy oil production).

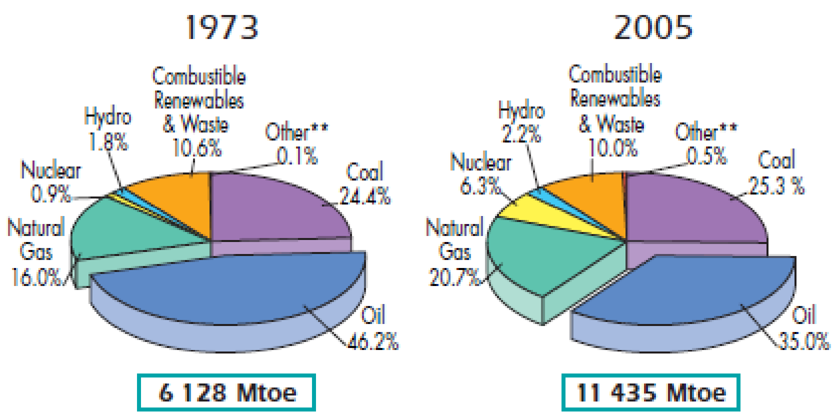


*** Other includes geothermal, solar, wind, heat*

Source: International Energy Agency – Key World Energy Statistics 2007

Fossil fuels securing most of the needs for energy

More than 80% of total primary energy production constitutes fossil fuels – oil, coal and gas. Even though historically 100% of the demand was covered by biofuels, nowadays the renewable sources of energy in separation are not sufficient to secure the fulfillment of the demand.

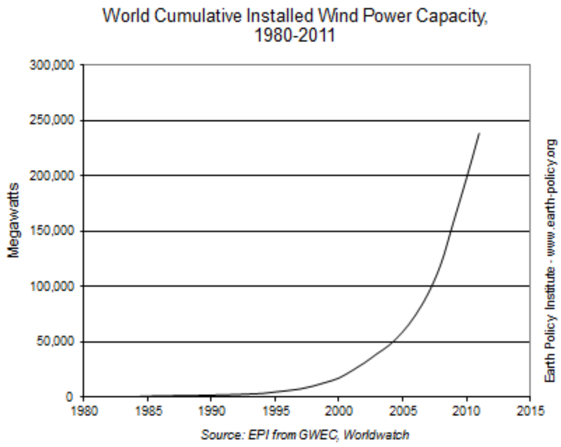


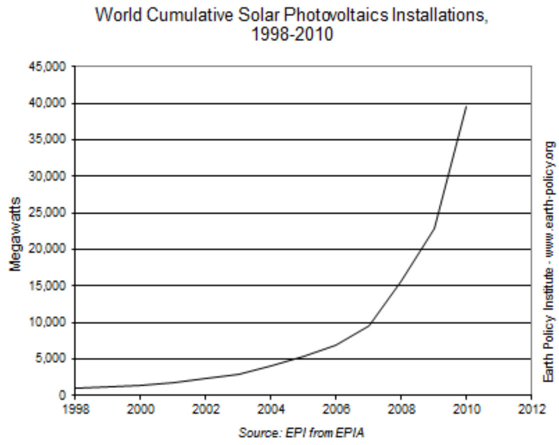
*** Other includes geothermal, solar, wind, heat*

Source: International Energy Agency – Key World Energy Statistics 2007

Alternative sources of energy competing for market share

There is observable a strong trend to develop and improve the efficiency of alternative sources of energy such as wind and solar. The demand for those sources of energy is significantly policy driven with conviction of economic demand taking over in the near future.



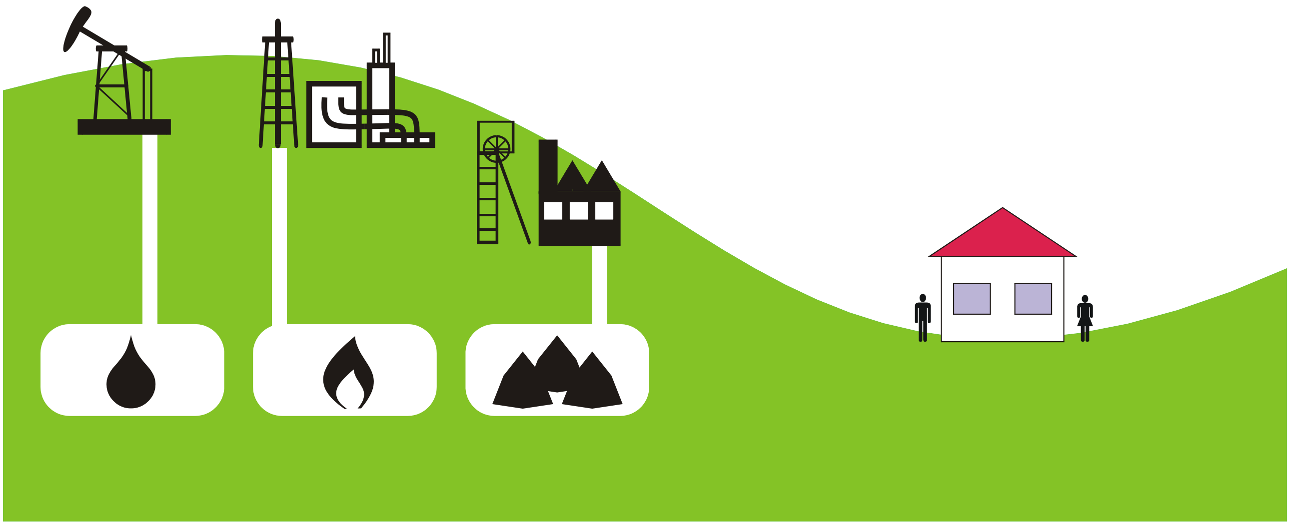


System conceptualization

Total energy demand is driven by population and energy demand per capita, which in turn is determined by wealth of the population, captured by gross world product.

Before energy is produced and delivered the sources of energy need to be explored. Various technologies have been developed over time that enabled discovery and identification of oil, gas and coal resources. With the current technologies it seems that all existing reserves have been proven.

Identified reserves can be produced. A significant capital investment has been made to establish production capacities. However, only a fraction of the reserves are recoverable with a given technology. There is an ongoing effort and investment into development of better and more efficient production technologies. The volume of production is on one hand determined by production capacity and on the other by price based market share of a given source of energy.



The difference between the fossil fuels and relatively new wind and solar energy as well as returning to use bioenergy is availability of energy sources. There are no constrains on wind and the sun availability. The biomass also regenerates. Thus the model structure needs to be different in order to capture that structure. Also the Hubbert peak theory is not applicable for renewable sources of energy. Still, similarly to fossil fuel energy, the investments need to be made in energy production capacity as well as production technology and its efficiency in order to improve conversion efficiency.

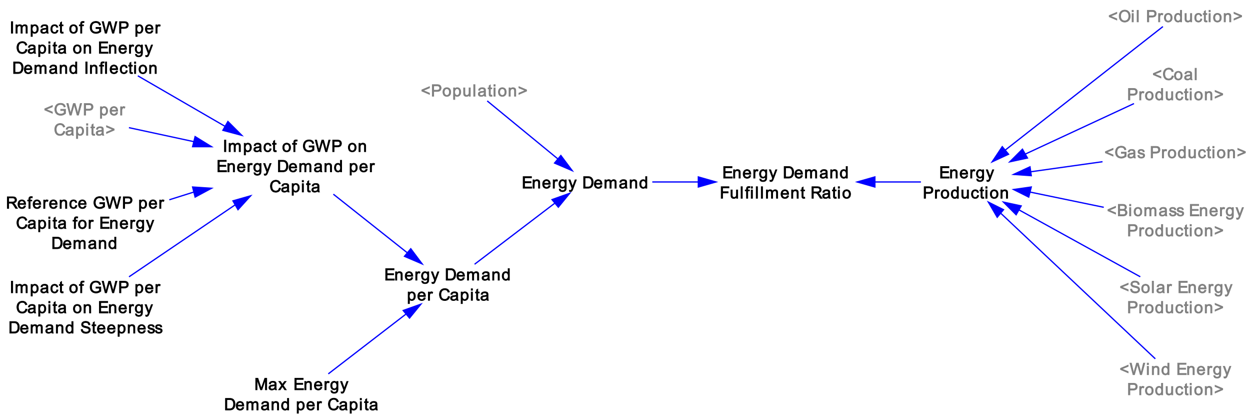
Depending on cost of a given energy the market share changes dynamically and determines demand for energy from a specific energy source. The production volume adjusts to the demand.

Capital investments in production capacity for all different kinds of energy contribute to global capital stock increase. Energy technology development contributes to global technology increase. Both processes influence Gross World Product.

Model formulation

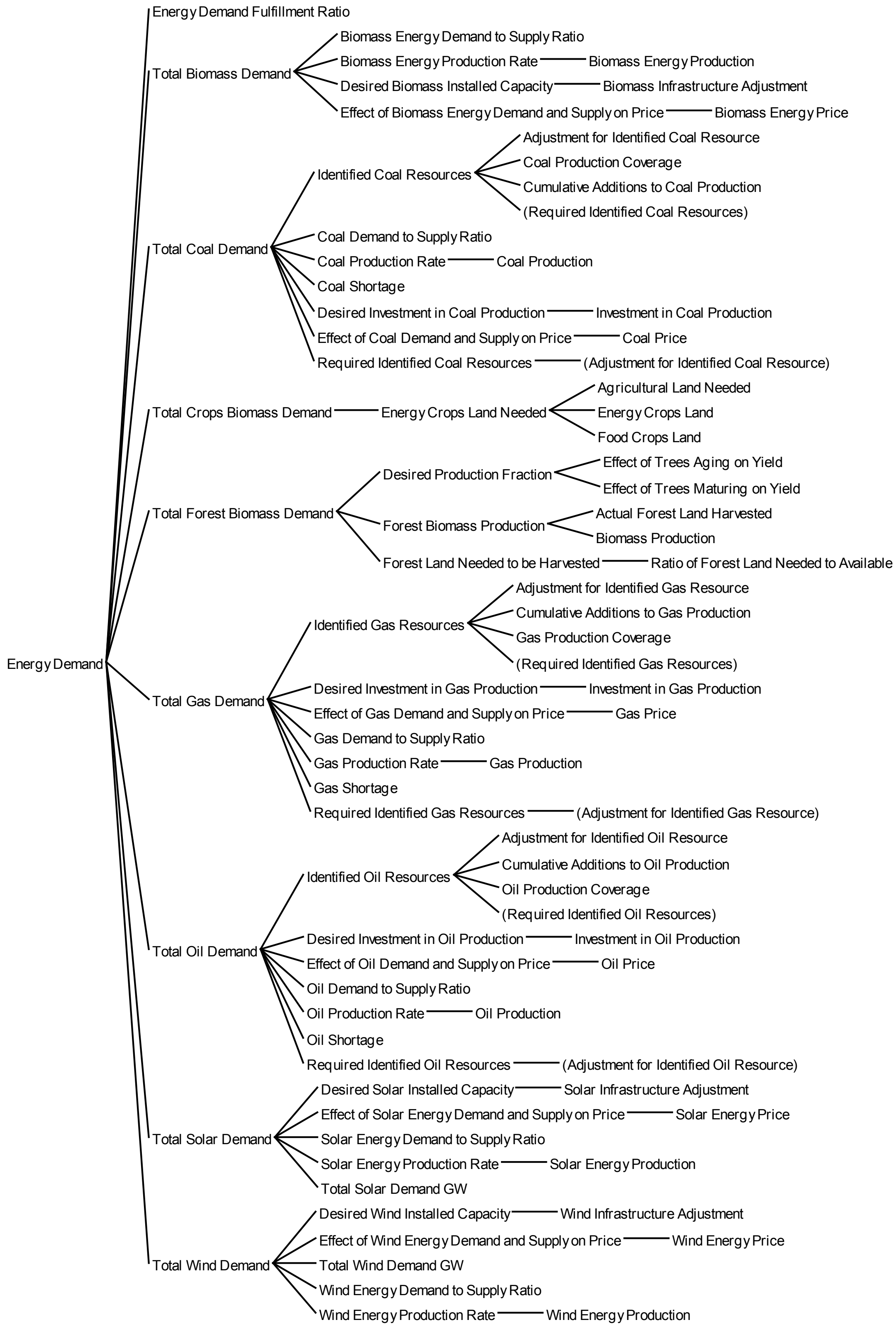
Energy Demand

The structure of the FeliX model depicts the causality between the wealth of the society and the energy demand. Energy Demand per Capita is an average value and does not distinguishes between development disparities of various world regions. Energy Demand per Capita multiplied by the number of Population constitutes the total Energy Demand.



The Energy Demand compared to Energy Production (sum of production from all considered in the model energy sources) constitutes Energy Demand Fulfillment Ratio which is an indicator of how well the investments in energy and production efficiency is able to secure the demand of the energy users.

Uses Tree diagram below illustrates the scope of relations (only 3 depth levels) of Energy Demand and specific energy source demand across the entire FeliX model.

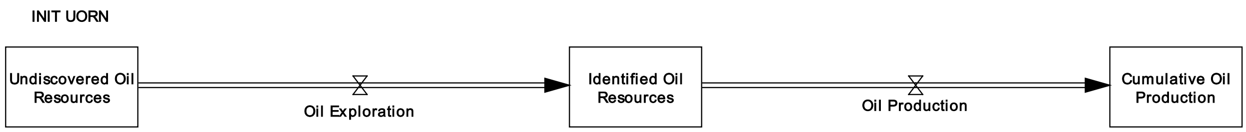


Fossil Fuels
The fossil fuel based energy model sectors is adapted from Sterman and Richardson (1985) and Davidsen, Sterman and Richardson (1990). The basic system dynamics structure behind this sector is called supply chain. The pictures in this sub-section relate to oil model sector. The gas and coal model sectors have the same model structure and the only difference is parameters values. The detailed model equations are presented in the Appendix.

Undiscovered Oil Resources are explored using surface geographical studies like aerial photographs and satellite images, landsat, radars and geophysical surveys like magnetic and electromagnetic, gravity or seismic surveys. In the FeliX model the initial value of *Undiscovered Oil Resources* was set to 375000 million tons of oil equivalent (Mtoe).

The proven reserves become *Identified Oil Resources* that can be produced – subject to production infrastructure and technology availability as well as demand for that particular source of energy. The aspects of leasing or law issues are not covered in the model.

Cumulative Oil Production stock tracks the total volume of produced oil resources.

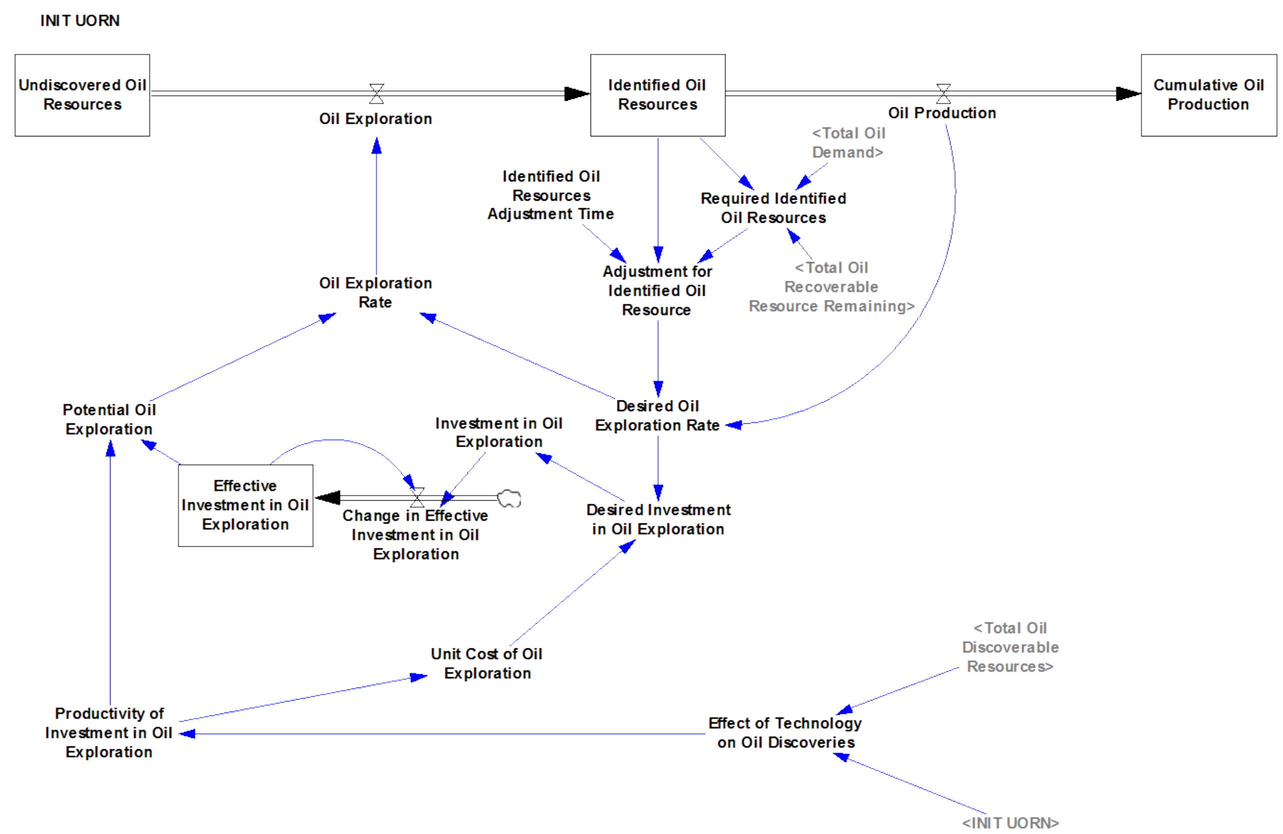


Oil Exploration equals to *Potential Oil Exploration* or *Desired Oil Exploration Rate*, depending on which variable value is lower.

Desired Oil Exploration Rate takes into account current *Oil Production* adjusted by safety coverage – the amount of identified oil resources that would secure undisrupted oil production at the current rate.

Potential Oil Exploration is an exploration possible due to effective volume of investments in oil resources exploration as well as availability of exploration technology.

Here also the *Unit Cost of Oil Exploration* is calculated – a component of oil energy price.



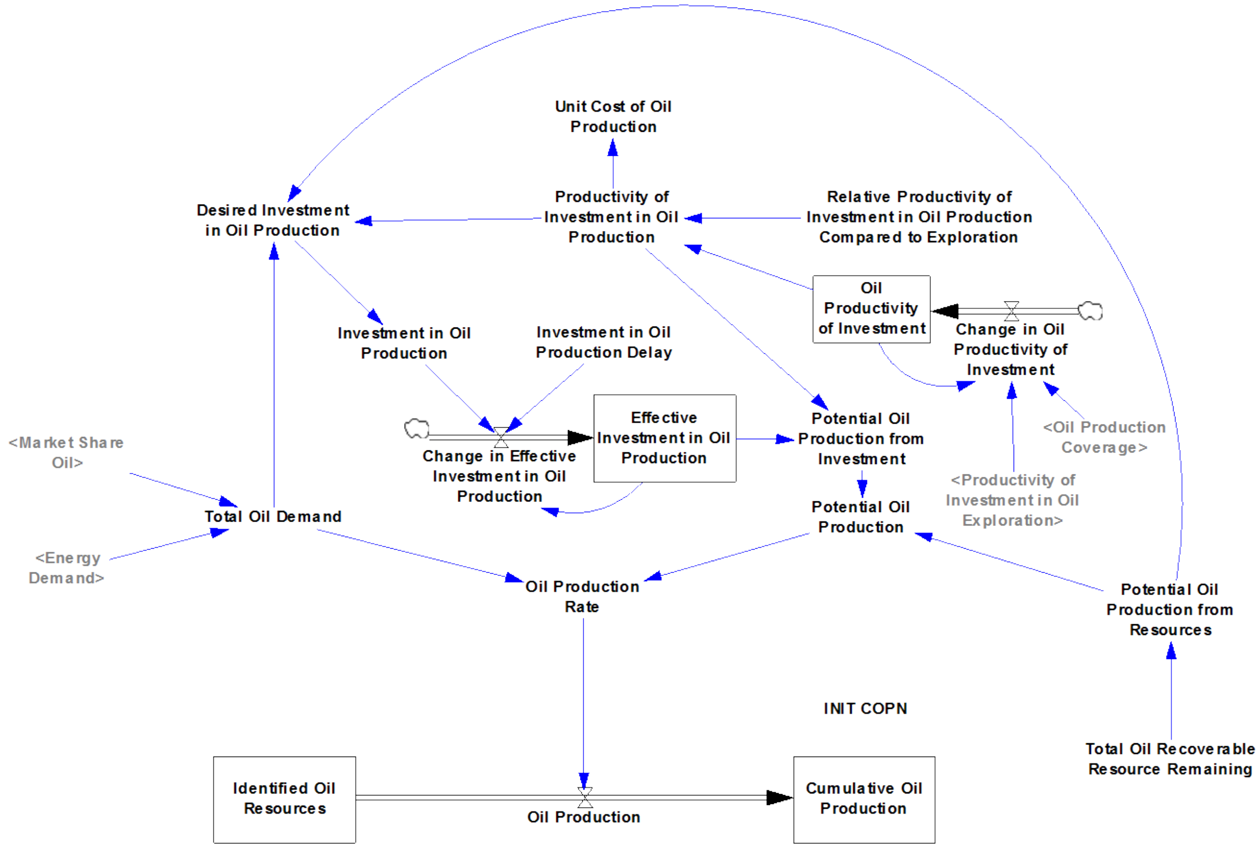
Oil Production equals to *Potential Oil Production* or *Total Oil Demand*, depending on which variable value is lower.

Total Oil Demand represents price-dependent fraction (*Market Share Oil*) of total *Energy Demand*.

Not all resources are recoverable. Thus *Total Oil Demand* adjusted by *Potential Oil Production from Resources* determines the level of *Desired Investment in Oil Production*. Over time potential investment becomes *Effective Investment in Oil Production*. This is an investment in production capital.

Effective Investment in Oil Production and *Productivity of Investment in Oil Production* adjusted by *Potential Oil Production from Resources* constitute *Potential Oil Production*.

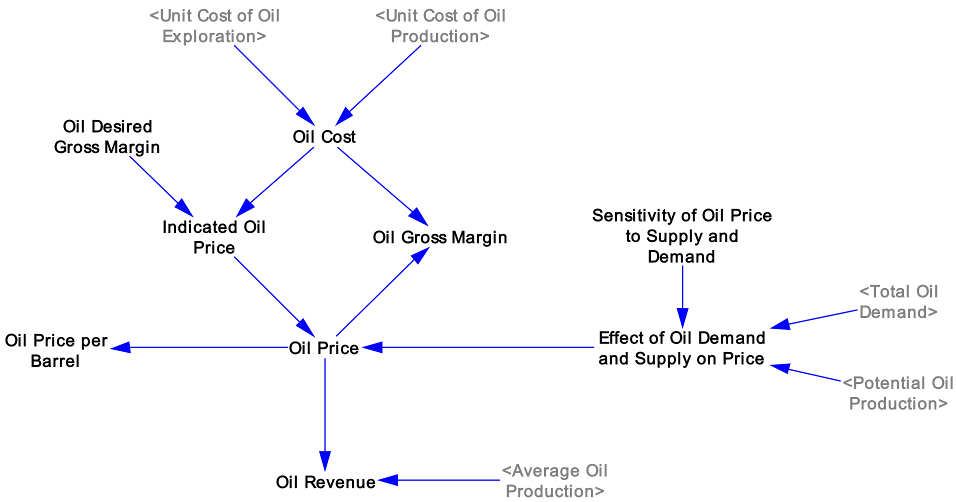
Productivity of Investment in Oil Production parameter indicates the amount of oil resources possible to be recovered per unit investment spent. It is a basis to calculate a *Unit Cost of Oil Production*.



Unit Cost of Oil Exploration and *Unit Cost of Oil Production* constitute a real *Oil Cost*. *Oil Cost* adjusted by *Oil Desired Gross Margin* and *Sensitivity of Oil Price to Supply and Demand* constitute market *Oil Price*.

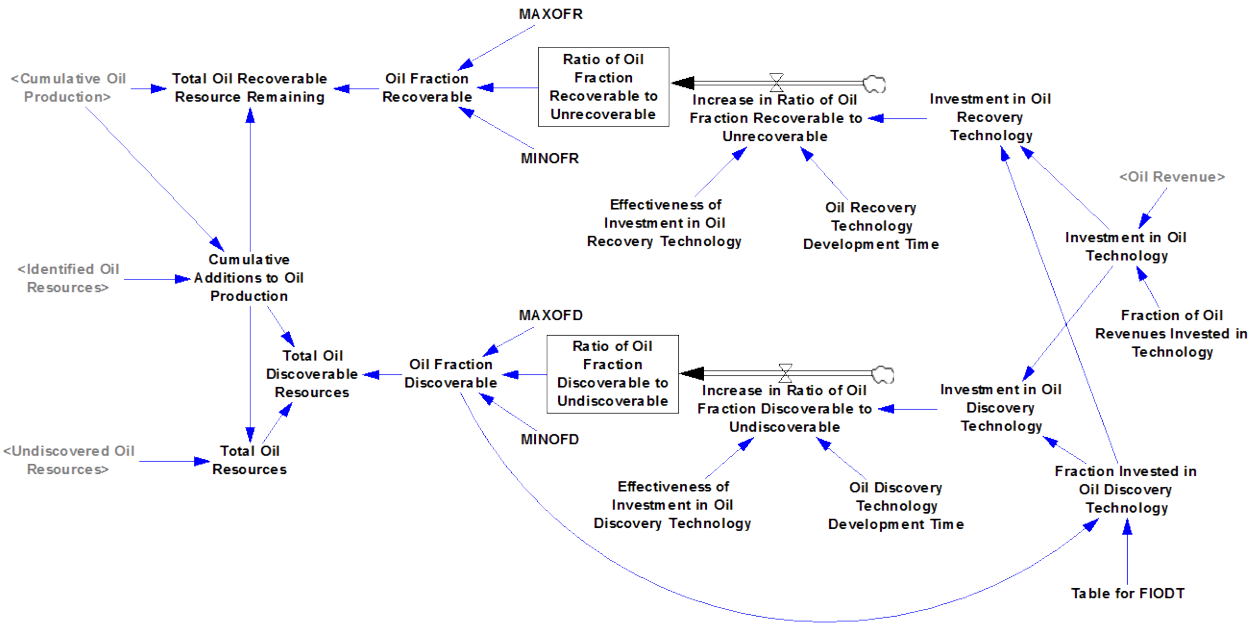
The market *Oil Price* is being considered while competing with other energy sources for energy demand.

Oil Price and the *Average Oil Production* constitute *Oil Revenue*.



A fraction of *Oil Revenue* is being reinvested. Initially the most of the investments go into development of discovery technology.

Oil Fraction Discoverable changes on the scale between 0 and 1 where 1 would indicate that all existing oil resources are identified.
Oil Fraction Recoverable changes on the scale between 0 and 1 where 1 would indicate that all identified oil resources can be produced.



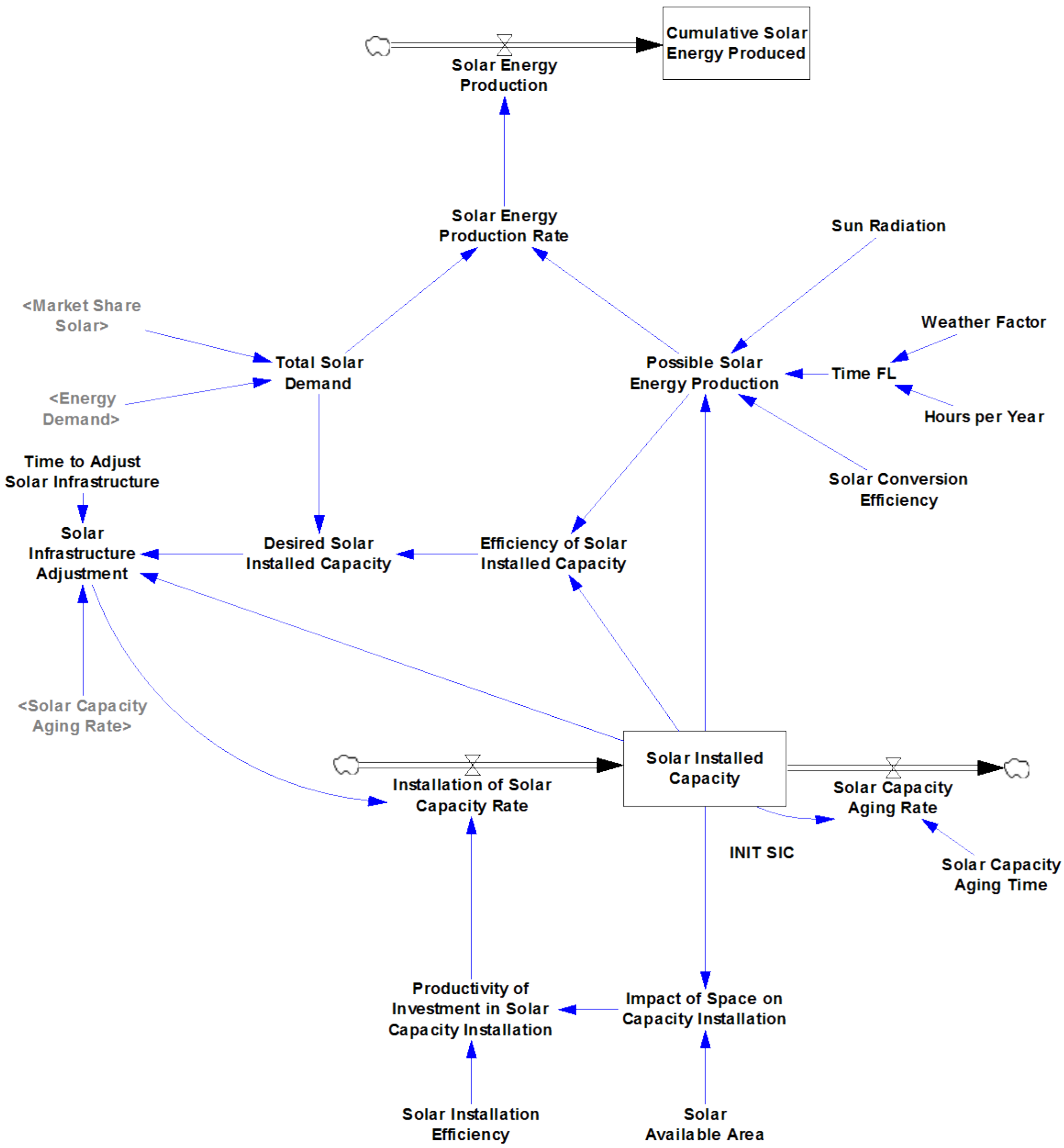
Renewable Energy

The basic model structure for all renewable energy model sectors – solar, wind and biomass – is very similar and differs only due to specifics of the energy source. The diagrams in this subsection will reflect the model structure of solar energy and only the elements of wind and bioenergy model sectors, which are different than solar energy structure, will brought to attention.

Total Solar Demand is determined by market share of solar energy (*Market Share Solar*) and total *Energy Demand*. The demand drives the solar energy production. However, *Solar Energy Production Rate* is constrained by *Possible Solar Energy Production*.

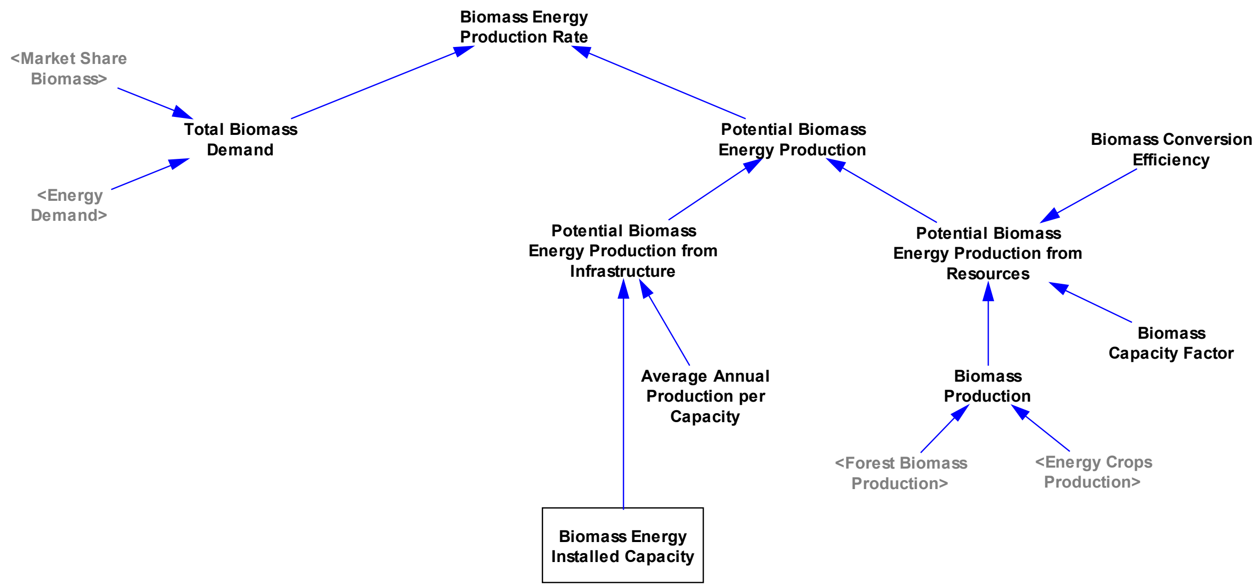
Possible Solar Energy Production is determined by four factors – average Sun Radiation, average time of sun availability, Solar Conversion Efficiency and Solar Installed Capacity.

Solar Installed Capacity is a stock representing total solar installations. The installation ages over time and needs to be replaced. The *Installation of Solar Capacity Rate* includes the installation replacement as well as the difference between desired and currently available capacity. The *Desired Solar Installed Capacity* is adjusted by a factor of *Efficiency of Solar Installed Capacity* due to technology advancement in conversion efficiency.
The *Installation of Solar Capacity Rate* is additionally determined by *Solar Installation Efficiency*, whereas the total amount of solar installation – *Solar Installation Capacity* – is constrained by available area that can be dedicated to place solar installation.
Investment in solar capacity adds to world capital stock.



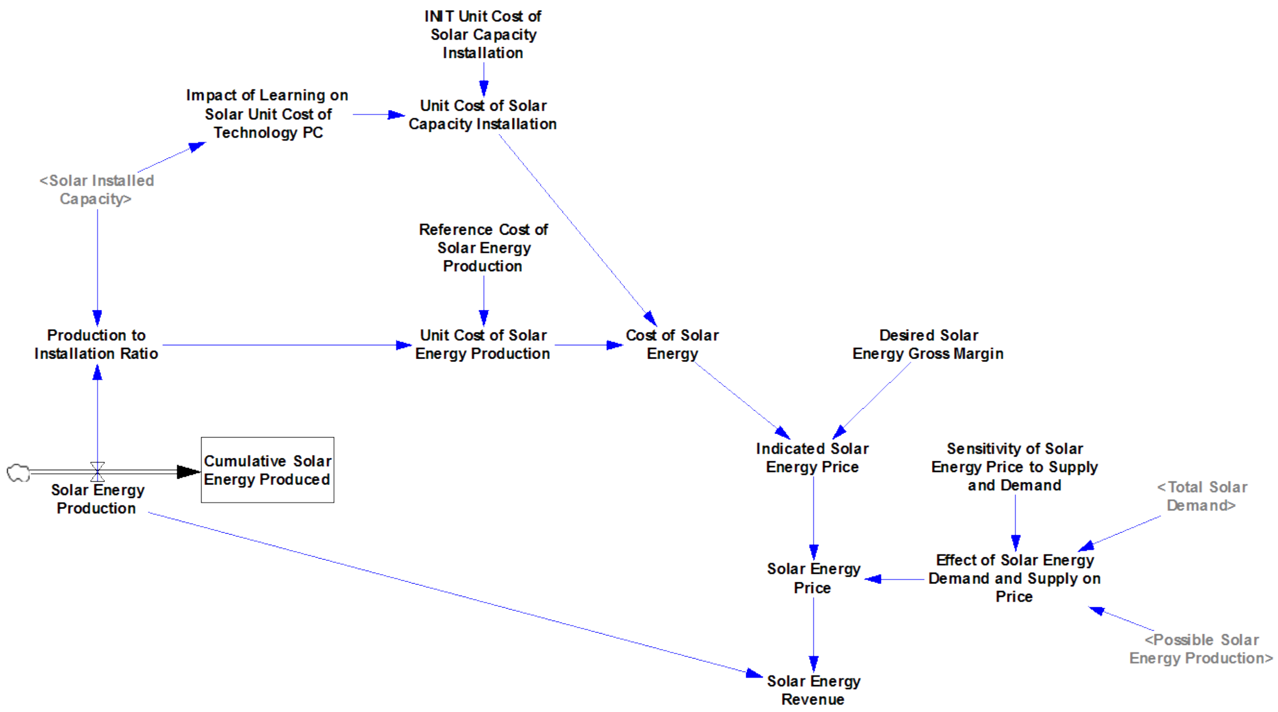
Note: In case of wind energy model sector the *Potential Wind Energy Production* is determined by the volume of installed capacity to transform wind into energy, wind energy production from one sqr meter of wind installed capacity and a parameter indicating what fraction of average wind capacity per sqr meter it is possible to realize with the current state of technical developments.

The *Potential Biomass Energy Production* depends on *Potential Biomass Energy Production from Infrastructure* and *Potential Biomass Energy Production from Resources*. *Potential Biomass Energy Production from Infrastructure* includes the volume of *Biomass Energy Installed Capacity* and *Average Annual Production per Capacity* unit. *Potential Biomass Energy Production from Resources* is determined by the volume of forest and crops related resources as well as conversion efficiency – the target level described by *Biomass Conversion Efficiency* variable and *Biomass Capacity Factor* referring to the technological advancement.

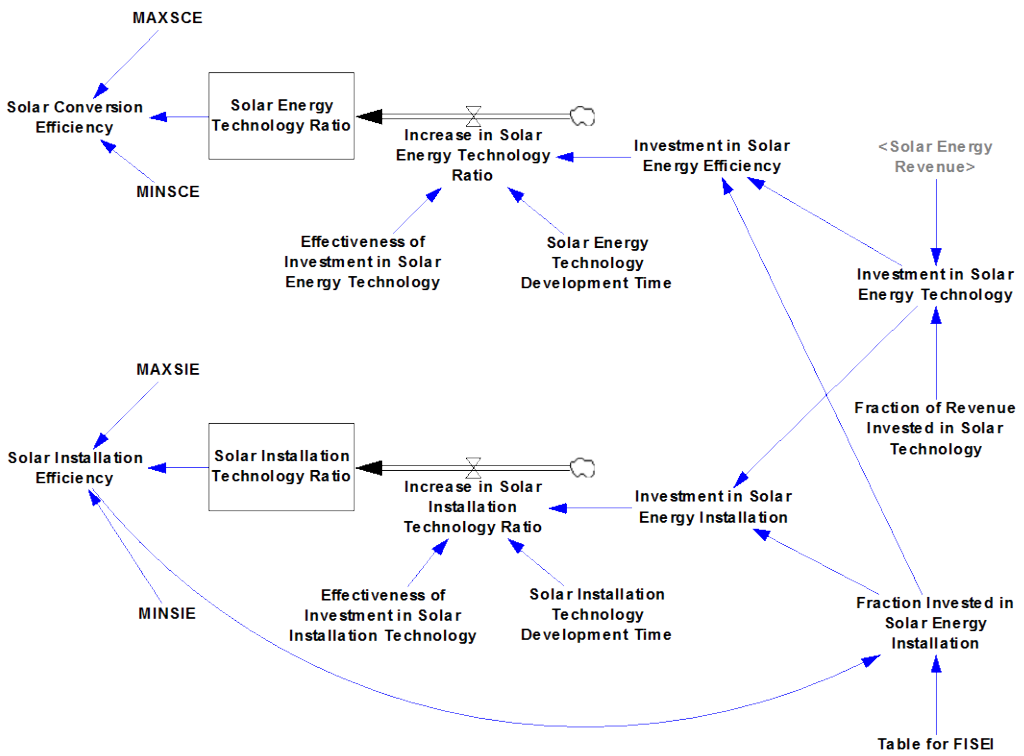


A real Cost of Solar Energy is calculated as a sum of Unit Cost of Energy Production and Unit Cost of Solar Capacity Installation. The Unit Cost of Solar Capacity Installation is a subject to learning curve.
Cost of Solar Energy adjusted by *Desired Solar Energy Gross Margin* as well as *Sensitivity of Solar Energy Price to Supply and Demand* constitutes *Solar Energy Price*.

Solar Energy Price multiplied by *Solar Energy Production* constitutes *Solar Energy Revenue*.



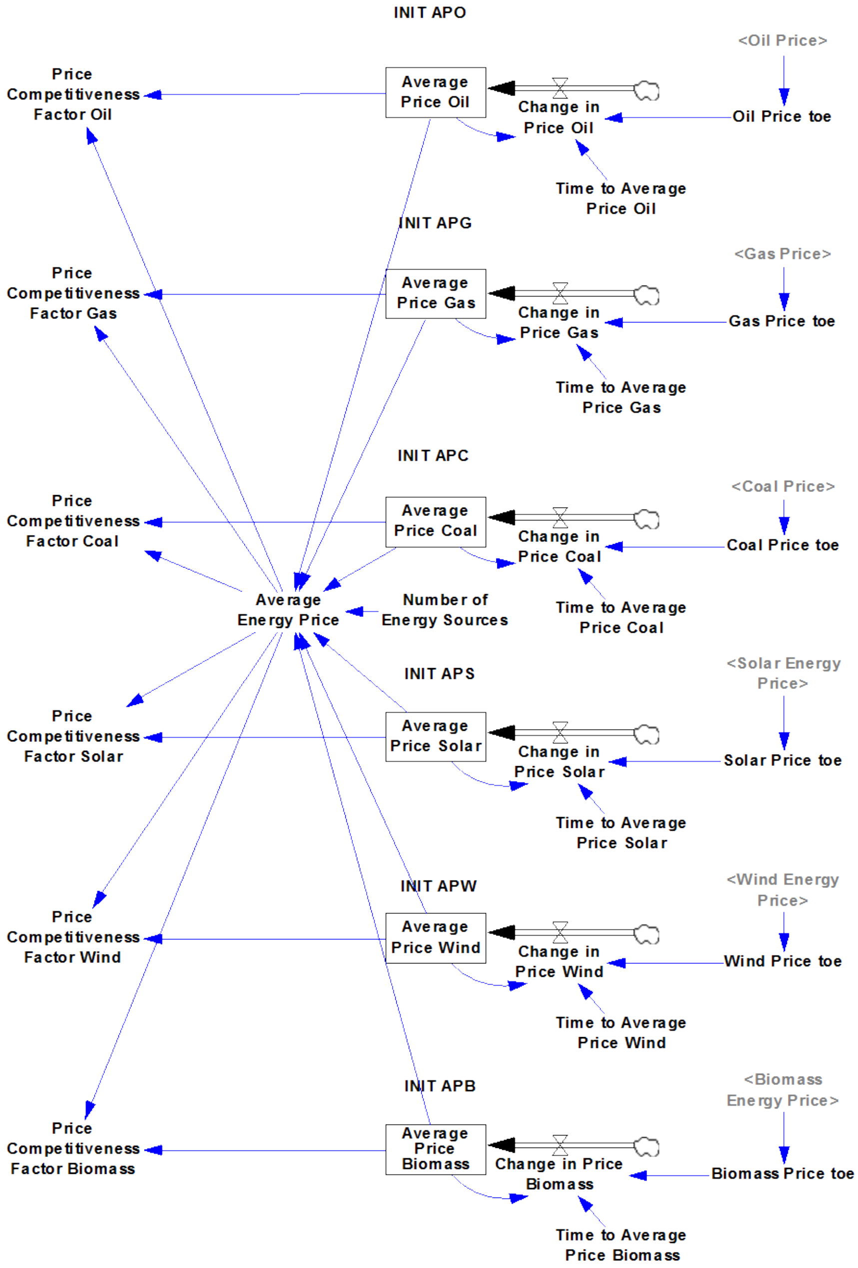
A fraction of *Solar Energy Revenue* can be reinvested in solar technology – *Solar Installation Efficiency* and *Solar Conversion Efficiency*.



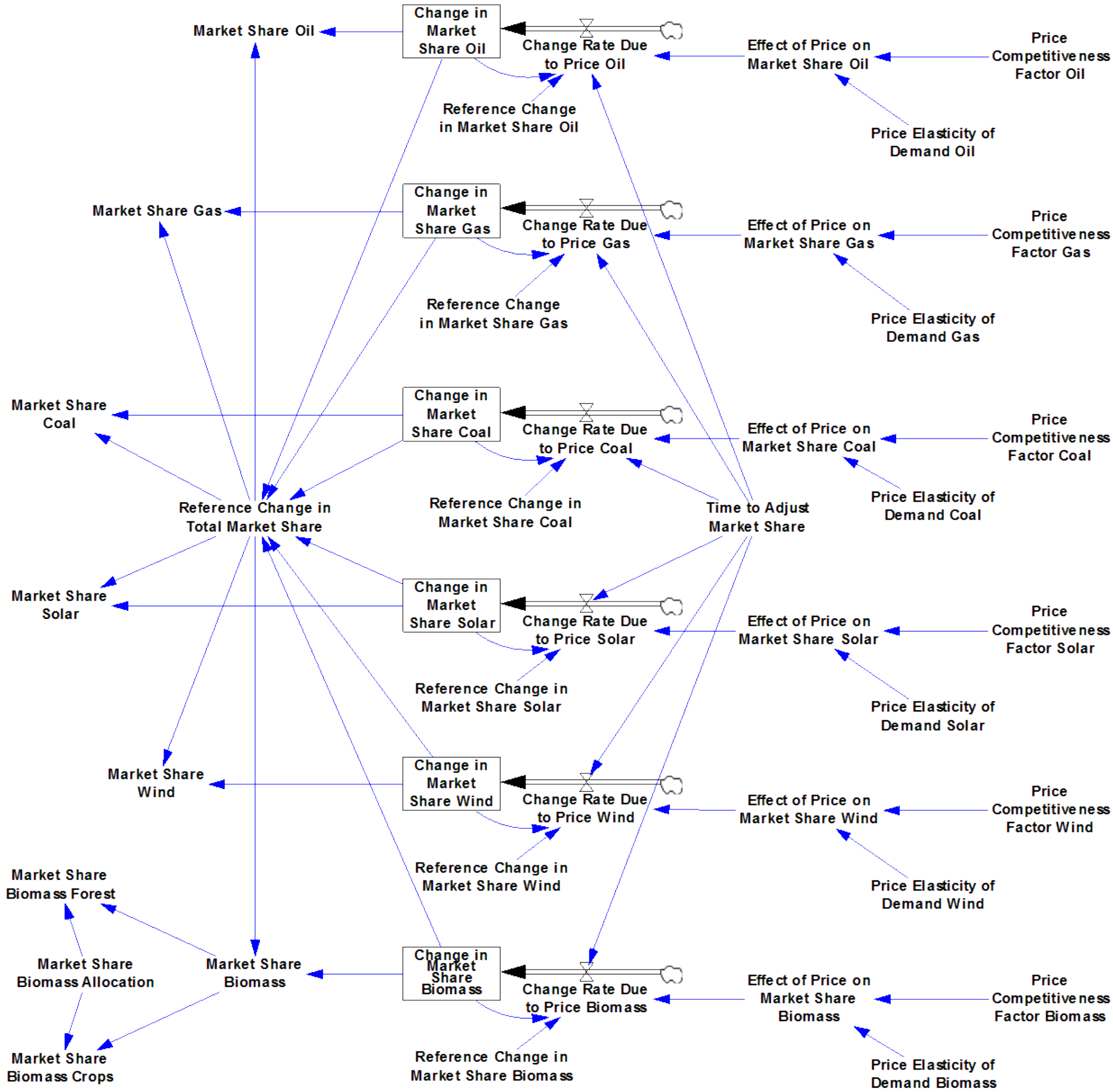
Market Shares

The total Energy Demand is split up between different energy sources due to the actual market share of a given energy source. The market share depends on the specific energy source price and its competitive price elasticity. The FeliX model sector mimics the dynamics of energy market shares in two steps.

In the first step the price of each specific energy source is averaged over a period of time. The *Average Energy Price* is calculated as arithmetic mean of all averaged energy prices. Price competitive factor is calculated for all energy sources as a comparison of the averaged energy source price and *Average Energy Price*.



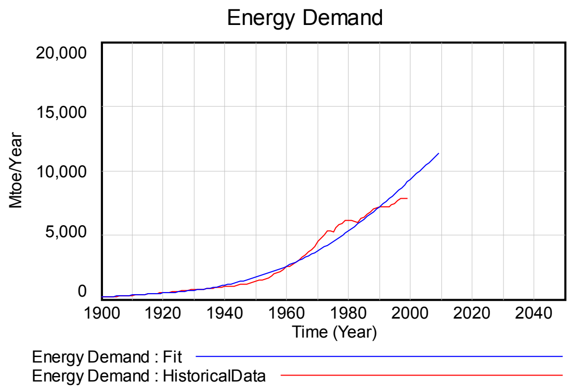
In the second step the Price Competitive Factor for each energy source is adjusted by elasticity of that energy source price to demand. Based on the competitiveness and elasticity the market share of a specific energy source is adjusted. In case of biomass the market share is additionally separated into forest and crops related resources.



Detailed equations of the Energy model sector are presented in the Appendix section of this report.

Simulation

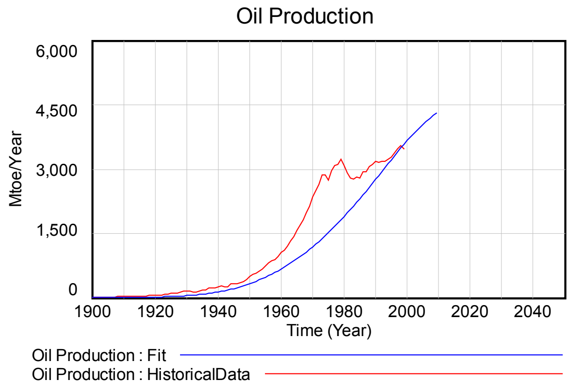
The graphs over time below illustrate the fit of the model structure and its behavior to the historical data from the energy sector. The fit graphs are the subject to the data availability.



Summary Statistics for Historical Fit – Energy Demand

n (Count)	100
R^2 (Coefficient of Determination)	0.97400
MAPE (Mean Absolute Percent Error)	0.09488
MSE (Mean Square Error)	1.77E+05
RMSE (Root Mean Square Error)	420.19835
UM (Bias component of MSE)	0.00111
US (Variation component of MSE)	0.00020
UC (Covariation component of MSE)	0.99869

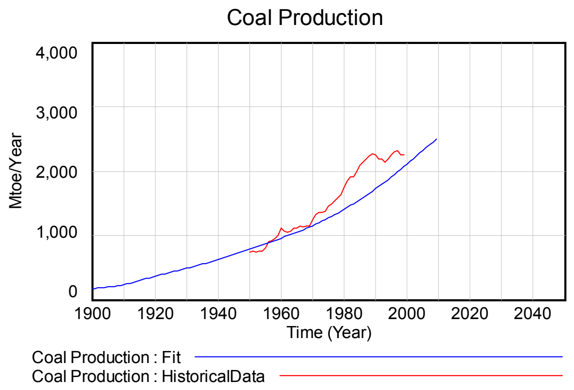
Source of Historical Data:
International Energy Agency – Key World Energy Statistics 2007



Summary Statistics for Historical Fit – Oil Production

n (Count)	100
R^2 (Coefficient of Determination)	0.90938
MAPE (Mean Absolute Percent Error)	0.44985
MSE (Mean Square Error)	2.87E+05
RMSE (Root Mean Square Error)	535.91326
UM (Bias component of MSE)	0.38769
US (Variation component of MSE)	0.17302
UC (Covariation component of MSE)	0.43928

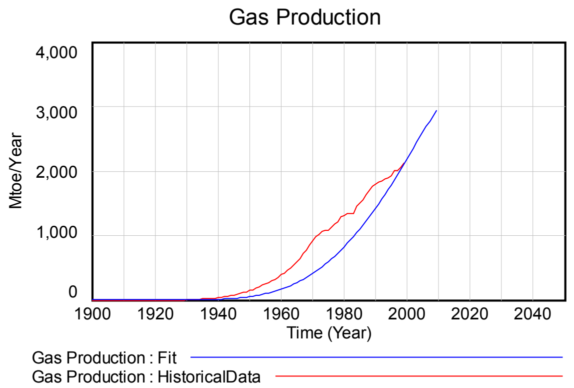
Source of Historical Data:
International Energy Agency – Key World Energy Statistics 2007
BP Statistical Review of World Energy June 2008



Summary Statistics for Historical Fit – Coal Production

n (Count)	50
R^2 (Coefficient of Determination)	0.94821
MAPE (Mean Absolute Percent Error)	0.12836
MSE (Mean Square Error)	8.31E+04
RMSE (Root Mean Square Error)	288.27772
UM (Bias component of MSE)	0.52008
US (Variation component of MSE)	0.35198
UC (Covariation component of MSE)	0.12794

Source of Historical Data:
International Energy Agency – Key World Energy Statistics 2007
BP Statistical Review of World Energy June 2008



Summary Statistics for Historical Fit – Gas Production

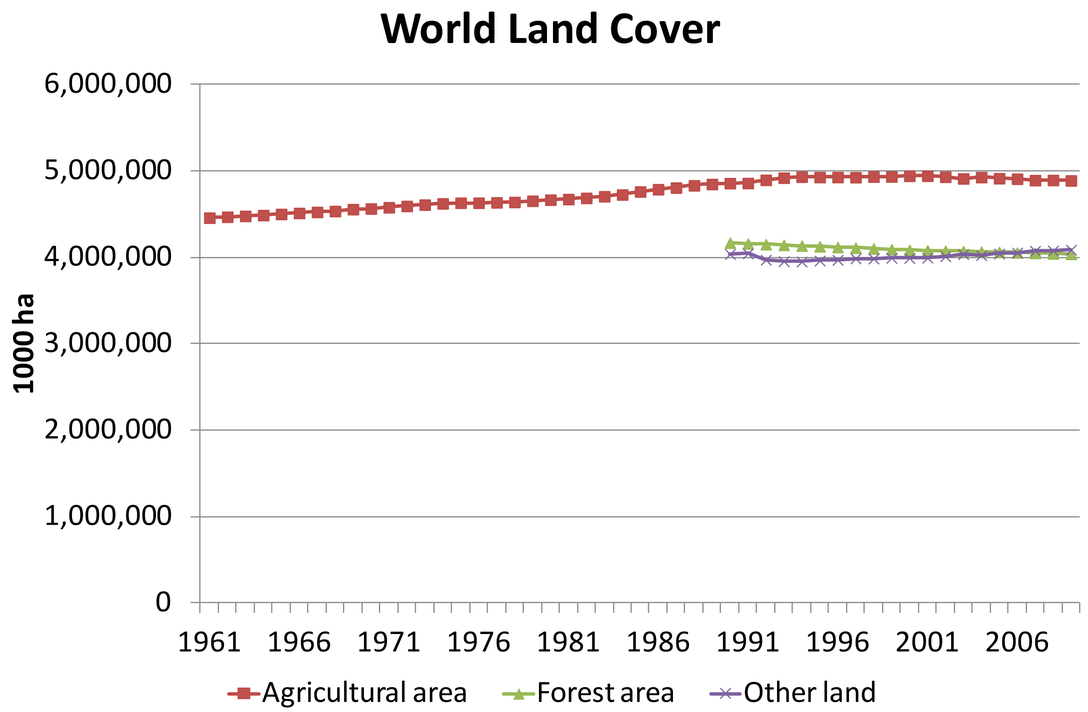
n (Count)	70
R^2 (Coefficient of Determination)	0.93737
MAPE (Mean Absolute Percent Error)	0.46599
MSE (Mean Square Error)	8.90E+04
RMSE (Root Mean Square Error)	298.33652
UM (Bias component of MSE)	0.62015
US (Variation component of MSE)	0.06997
UC (Covariation component of MSE)	0.30988

Source of Historical Data:
International Energy Agency – Key World Energy Statistics 2007
BP Statistical Review of World Energy June 2008

Land Use

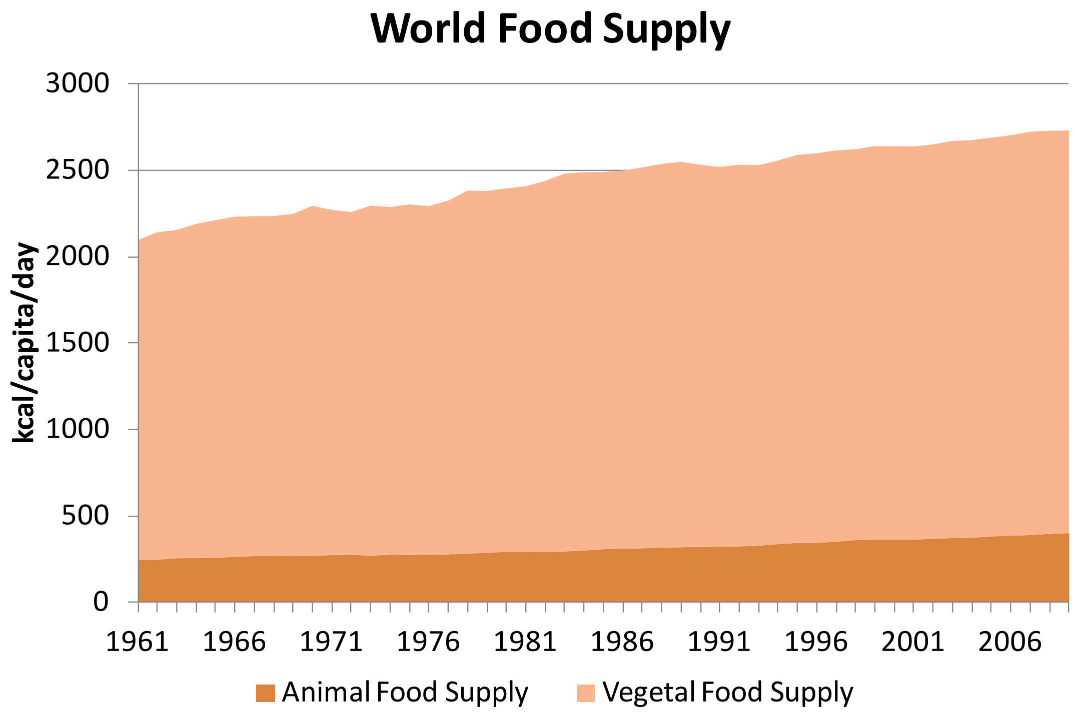
Dynamic problems definition

FAOSTAT distinguishes three main Land Cover groups that are inseparably relater to human activities on the Earth and societal benefits. Total 13 billion of land encompasses agriculture area, forest area and other land area. Among many challenges there are two pressing problems – food security and deforestation, driving the dynamics of land use.

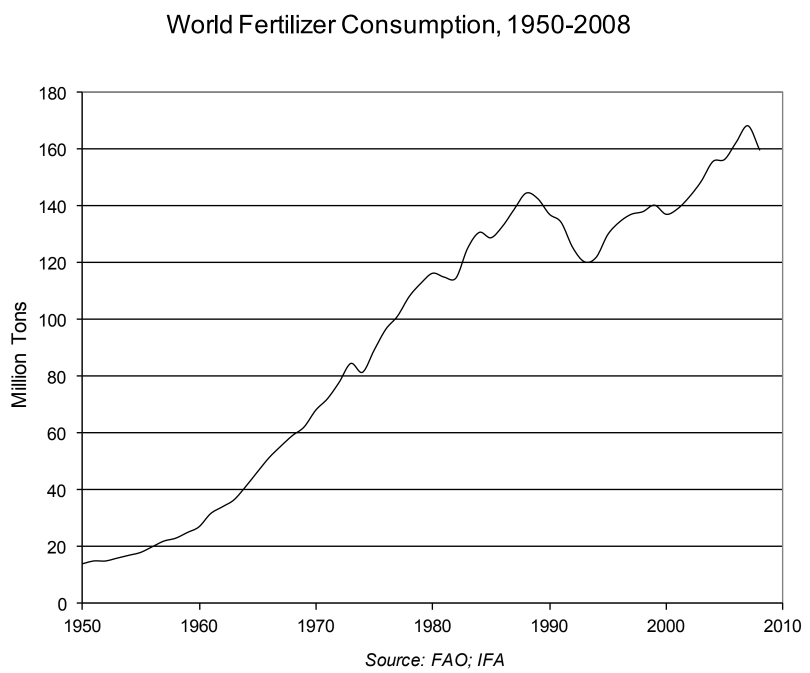


Source: FAOSTAT - http://faostat.fao.org (Resource → Land)

Food security
Growing population requires more food. Furthermore food demand per capita is also growing. The food diet includes more animal calories. Crops are used for energy (biofuels) purposes. Those factors drive the agriculture land expansion as well as investments in and use of management practices increasing the land fertility. The use of nitrogen, phosphate and potash fertilizers increased more than 11 times over the last 50 years.

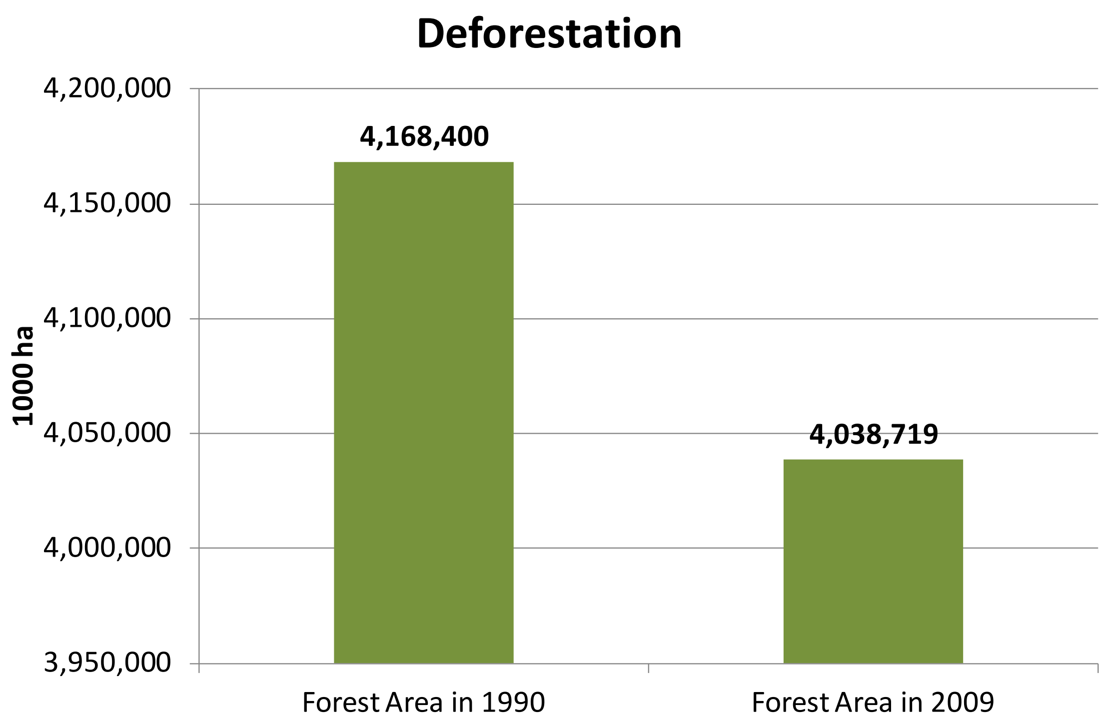


Source: FAOSTAT - http://faostat.fao.org (Food Supply → Crops Primary Equivalent & Livestock and Fish Primary Equivalent)



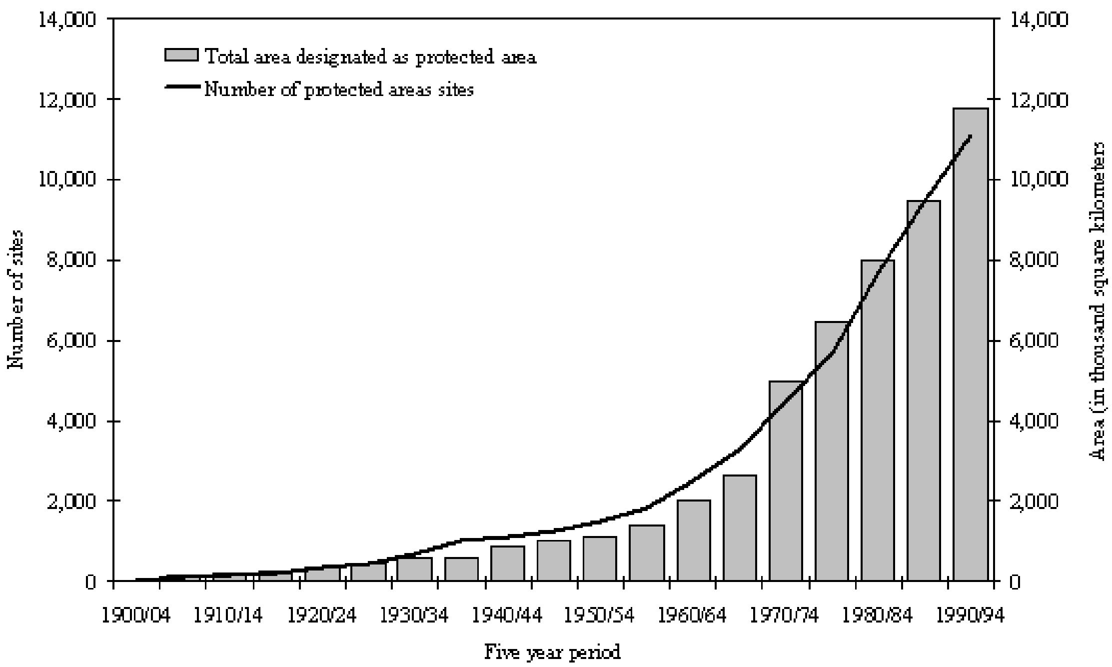
Deforestation

Over the last 20 years the forest land area decreased by 130 million ha which on average equals to 6.5 million ha per year. This phenomenon is highly related to food security issue. An additional factor is the use of biomass for energy purposes.



Source: FAOSTAT - http://faostat.fao.org (Resource → Land)

There is an ongoing effort to protect forest (e.g. for the CO2 storage purposes) however it seems that the institutionalization of this process is not fast enough.



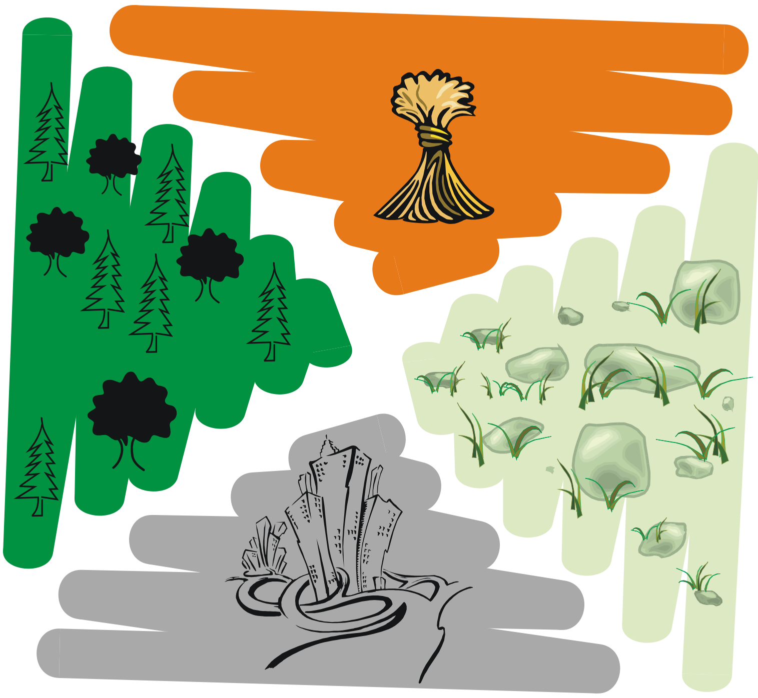
Source: Forest product market developments: the outlook for forest product markets to 2010 and the implications for improving management of the global forest estate (http://www.fao.org/docrep/003/x4108e/X4108E11.htm#P3941_174357)

System conceptualization

Land area in the Felix model is defined following FAOSTAT glossary as area of the country excluding area under inland water bodies. Three main categories are distinguished:

- Agricultural area – which consists the sum of areas under arable land, permanent crops and permanent meadows and pastures
- Forest area
- Other land – land not classified as Agricultural area and Forest area.

Additionally Urban and Industrial Land was distinguished from Other land as a separate category for the analysis purposes.



It is assumed that each land category can expand over the other category. Different extent of effort is required for each type of transformation however (e.g. Urban and Industrial Land to become a Forest area might take more effort than for Forest area to become Agricultural area).
A well observed phenomenon over the past century was Agriculture taking over Forest and Other land areas. More Agriculture area allows for grater yield.
Additionally mechanization and automation of work, new management practices as well as fertilization influenced land fertility and increased the yield level.

The yield can be allocated for as food for animals, which in turn can fulfill demand for animal calories, food for people, i.e. vegetal calories, or the crops might be used for energy production purposes. It is worth noticing that the most significant fraction of land is used to provide the food for animals.

Expansion of agricultural over Forest area decreased forest available space and freed the CO_2 stored in the trees (topic of the next subsection of this report).

Forest includes areas of primary forest and managed forest. Both areas are harvested to provide wood and biomass for energy purposes. Various management practices might increase biomass yield from harvested areas.

Over the past century an increasing part of the forest area has been institutionalized as protected area. Protected forest area is excluded from being harvested.

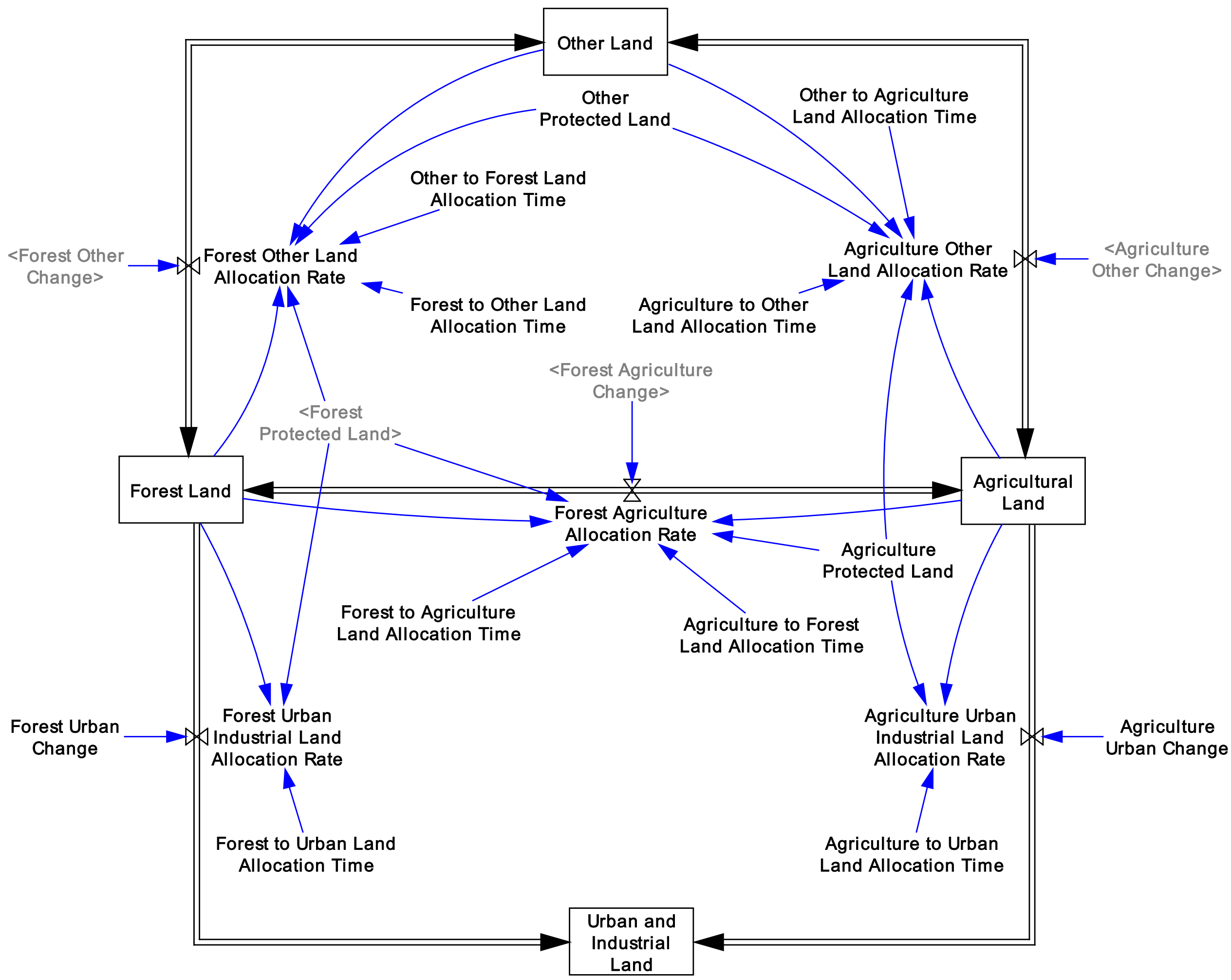
Model formulation

Each area category was modeled as a stock. The stocks levels increase due to inflows and decrease due to outflows. Apart from *Urban and Industrial Land*, which can only increase, all other areas can gain more space or lose it due to land transformation.

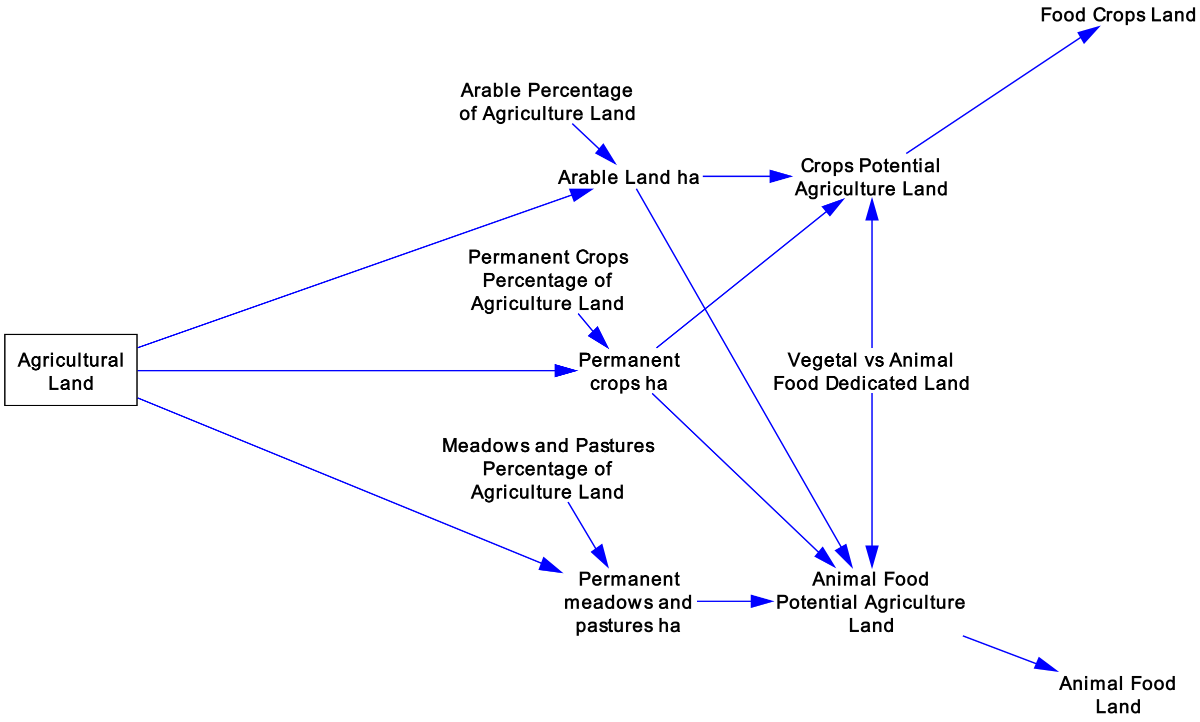
The areas transformation flows rates are modeled to be time dependent natural processes. For instance, abandoning any human activities in a part of agriculture land and allowing certain duration of time the agriculture land will be covered by grass, later by shrubs, yet later by trees and eventually it will be classified as forest. The easier it is for the natural process to transform the area the transformation time is set to a lower value.

In case of Forest Other Change, Forest Agriculture Change and Agriculture Other Change apart from natural transformation processes there are additional forces driving and increasing the rate of expansion or shrinking of the Forest, Other and Agriculture land areas.

Some of the Other Land and Forest Land areas are protected. In case of Forest Land the protected area increases successively. The protected areas are excluded from any transformation processes.



Under the *Agricultural Land*, following the FAOSTAT framework, three specific types of land can be distinguished – *Arable Land*, *Permanent Crops* and *Permanent Meadows and Pastures*. Entirely or partially those land areas can be dedicated to produce food crops animal food referred to in the model as *Food Crops Land* and *Animal Food Land*.



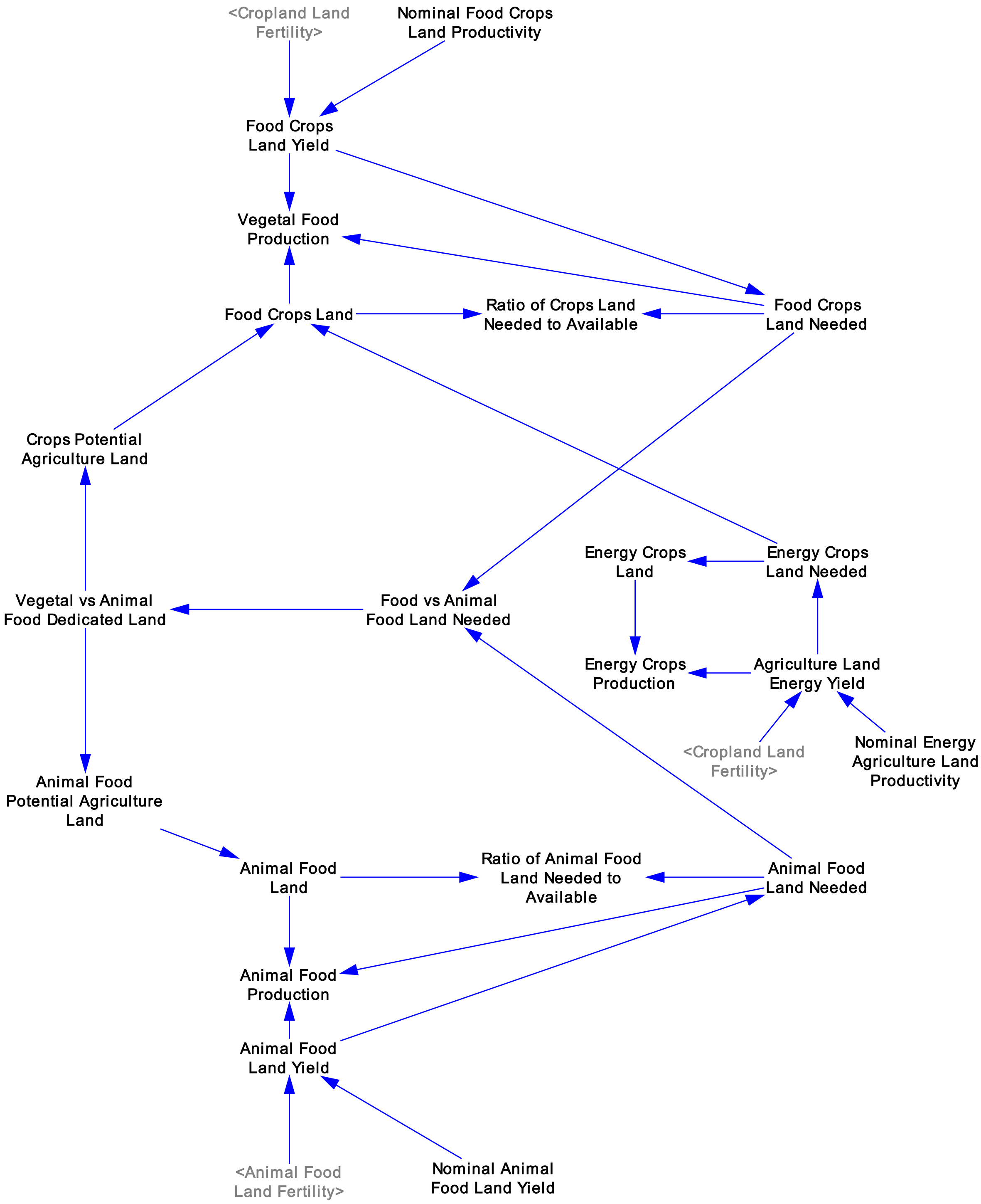
Food Crops Land multiplied by *Food Crops Land Yield* determines *Vegetal Food Production*. It is also assumed that the area of land used to food crops production is not greater than *Food Crops Land Needed*.
Similarly *Animal Food Land* multiplied by *Animal Food Land Yield* determines *Animal Food Production*. The area of land used to animal food production is not greater than *Animal Food Land Needed*.

Food Crops Land Yield and *Animal Food Land Yield* dependent on *Cropland Land Fertility* and *Animal Food Land Fertility* respectively. The land fertility factors are multipliers of a year 1900 reference values (*Nominal Food Crops Land Productivity* and *Nominal Animal Food Land Yield*).

The model also assumes that upon emergence of any demand for crops to be used as energy production resources that crops will be arbitrary produced on *Food Crops Land*, decreasing at the same time production of food crops.

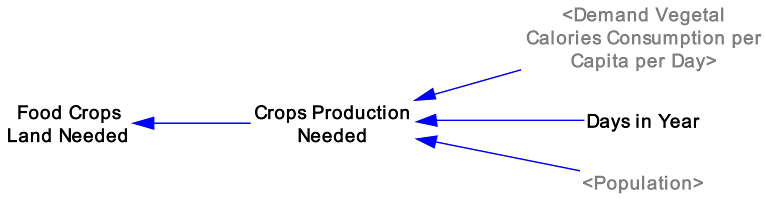
Food Crops Land Needed compared to *Animal Food Land Needed* determine in a dynamic way a split between *Crops Potential Agriculture Land* and *Animal Food Potential Agriculture Land*.

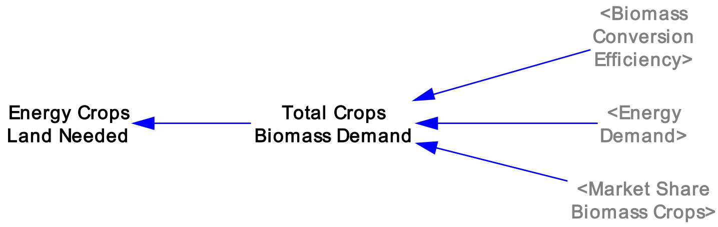
Any discrepancies between *Food Crops Land* and *Food Crops Land Needed* as well as between *Animal Food Land* and *Animal Food Land Needed* generate ratios that drive land areas transformation processes (to be described later).

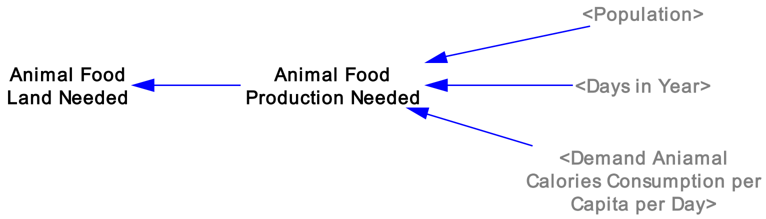


Food Crops Land Needed and *Animal Food Land Needed* are determined by the volume of *Population*, its daily demand for vegetal and animal calories and the number of days in a year.

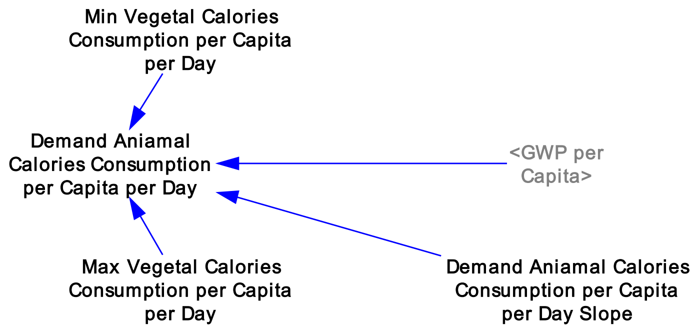
Energy Crops Land Needed is determined by *Total Crops Biomass Demand* described by total *Energy Demand*, *Market Share Biomass Crops* and *Biomass Conversion Efficiency*.

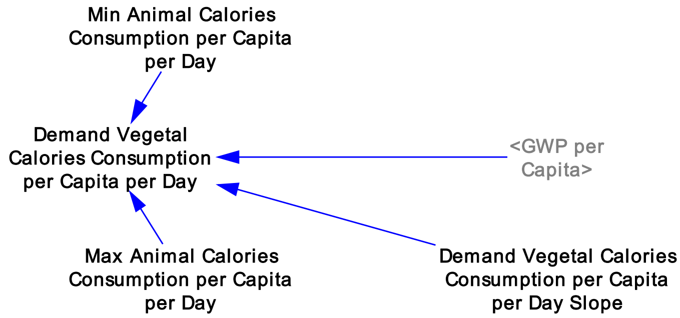




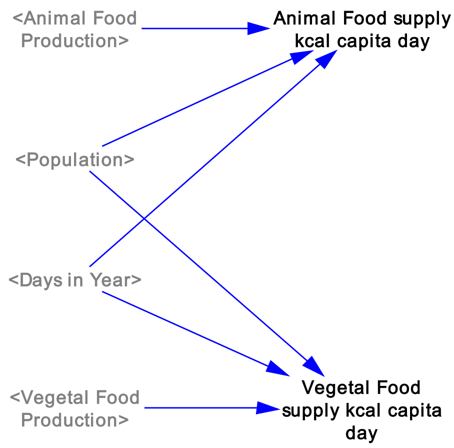


Apart from securing the basic need for food the demand of humans for vegetal and animal calories is associated with the wealth of population demonstrated by *GWP per Capita*.

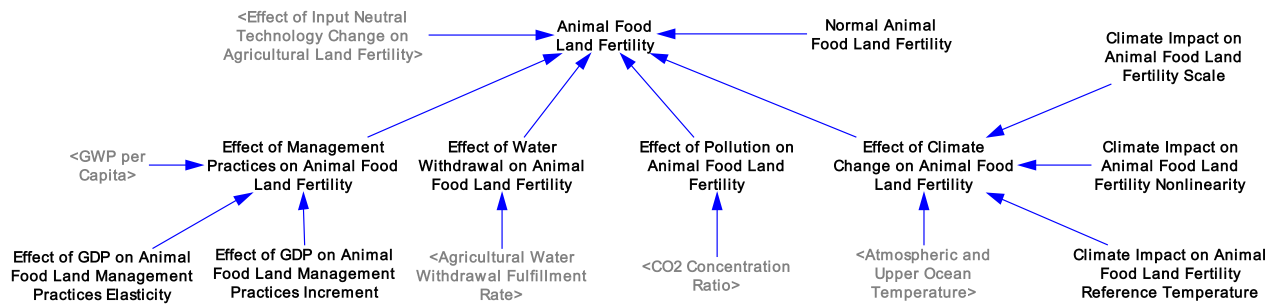


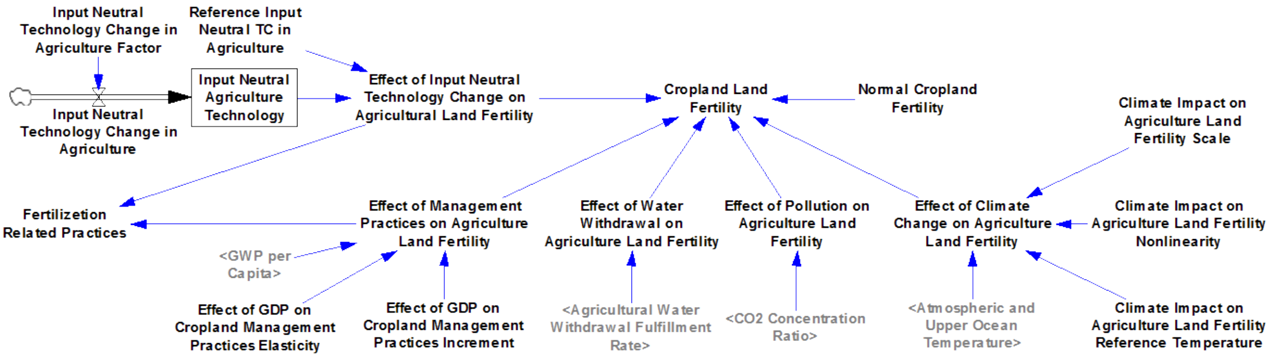


The supply side of food production per capita per day is calculated by comparing total *Vegetal Food Production* and *Animal Food Production* to the volume of population and the number of days in a year.

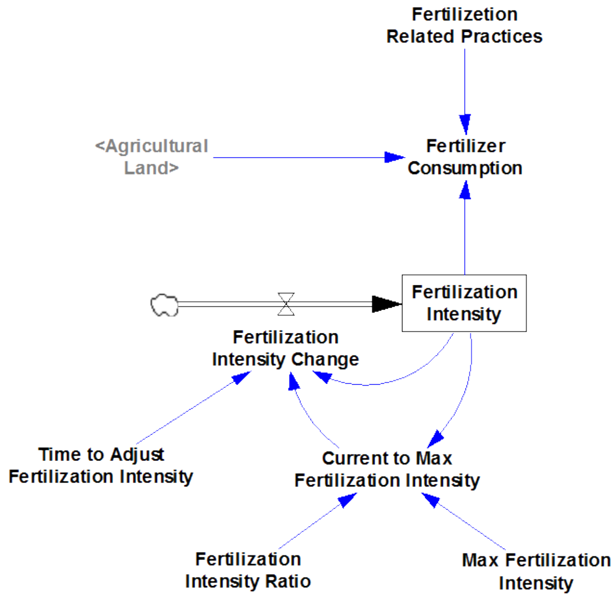


Going back to *Animal Food Land Fertility* and *Cropland Land Fertility* those factors depend on a number of phenomena – neutral technology change translating into constant increase of the fertility, effect of land use management practices associated with the population wealth and expressed by *GWP per Capita*, water availability for agriculture purposes, pollution associated with CO2 concentration, and the effect of climate change represented here by Atmospheric and Upper Ocean Temperature.
Animal Food Land Fertility and *Cropland Land Fertility* are modeled separately since the strengths of certain effects differ.
It is also worth to notice that in case of cropland management practices and technology change *Fertilization Related Practices* are tracked.





Fertilization Related Practices over *Agricultural Land* with specific *Fertilization Intensity* constitute *Fertilizer Consumption* indicator.

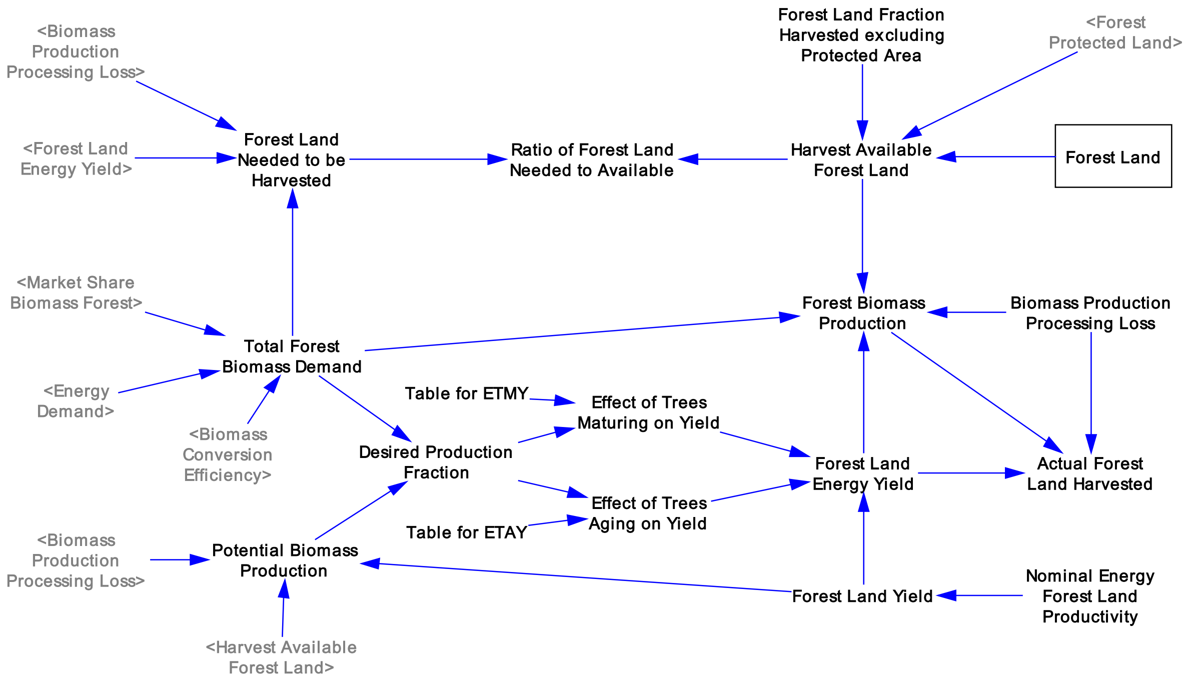


Excluding the *Forest Protected Land* a fraction of the *Forest Land* is dedicated to be harvested. The harvested land area multiplied by unit forest land yield and accounting for the production and transformation losses constitutes *Forest Biomass Production*. The model assumes that the production of biomass is not greater than the *Total Forest Biomass Demand*.

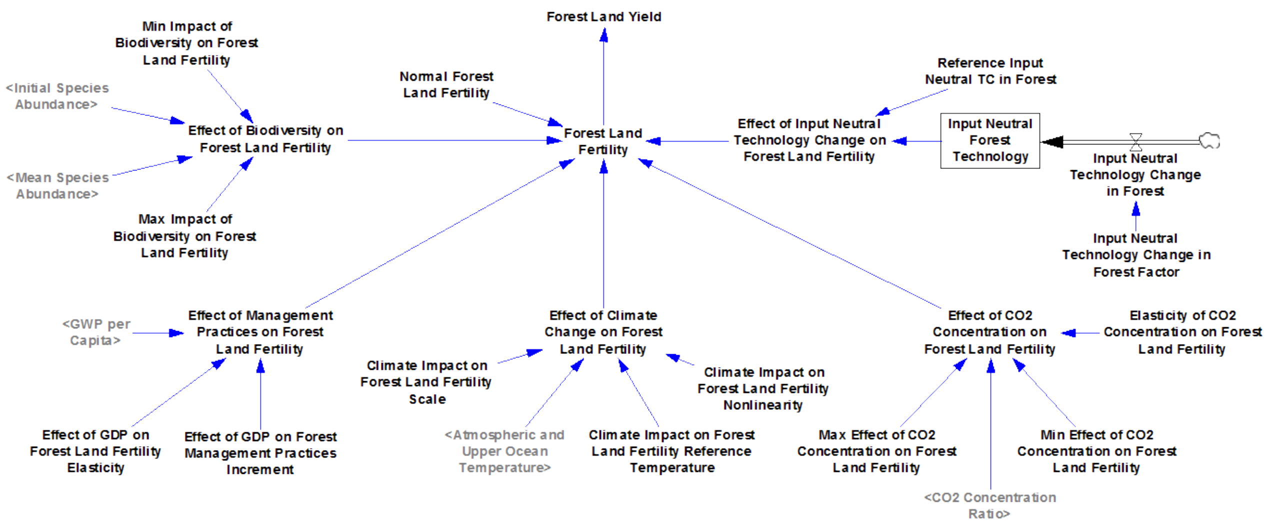
Forest Land Energy Yield is determined by fertility of the land – Forest Land Yield, and by biomass accumulated in the trees of different age – young tress providing little biomass, mature the most and very old tress very little. The land fertility factor is a multiplier of a reference value (*Normal Forest Land Fertility*) set for the start of the model time.

Total Forest Biomass Demand depends on total Energy demand and the share of the forest biomass in the energy market.

Discrepancy between *Forest Land Needed to be Harvested* and *Harvest Available Forest Land* create demand for more *Forest Land* represented in the model by *Ratio of Forest Land Needed to Available*.



Forest Land Fertility depends on a number of effects – neutral technology change translating into constant increase of the fertility, impact of change in biodiversity, effect of forest management practices modeled as dependent on the population wealth, impact of climate change determined by the global temperature change, and effect of CO2 concentration.

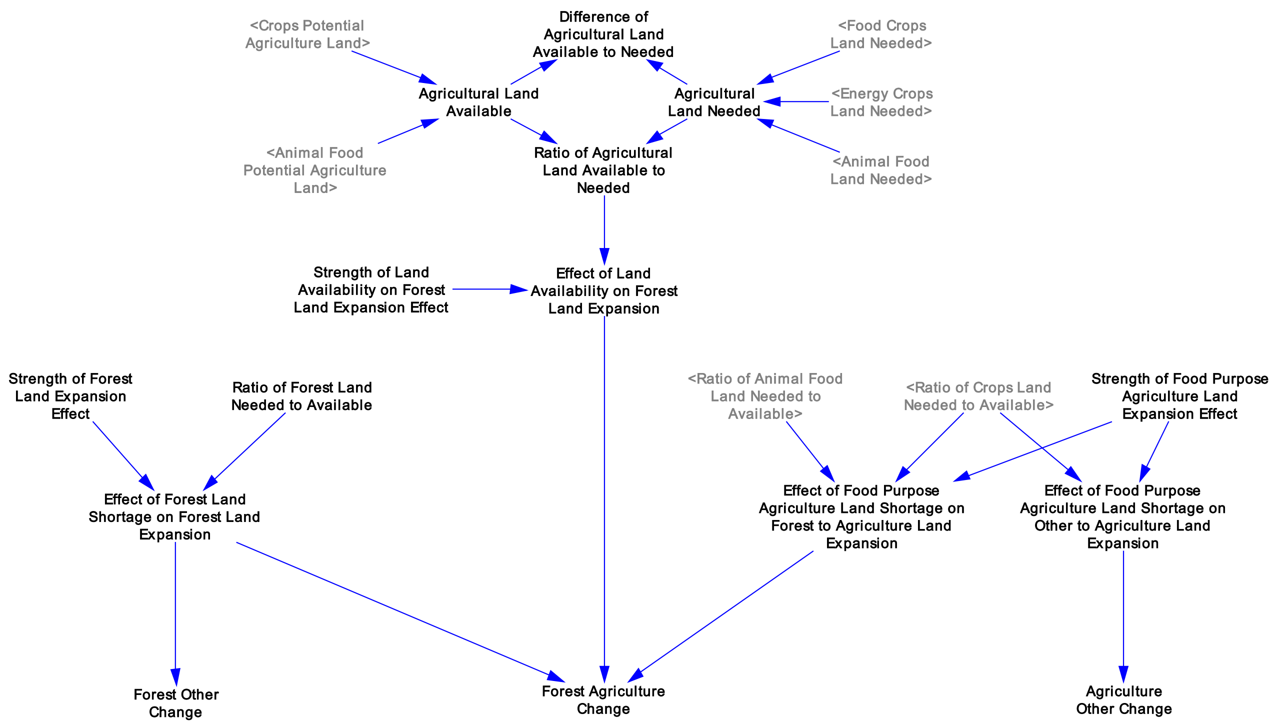


Mentioned earlier Ratio of Forest Land Needed to Available, scaled by Strength of Forest Land Expansion Effect created the driver for transformation between Forest Land and Other Land. The sign of the Forest Other Change variable value, '+' or '–', determines whether the Forest expands over Other Land or the Other Land takes over Forest Land.

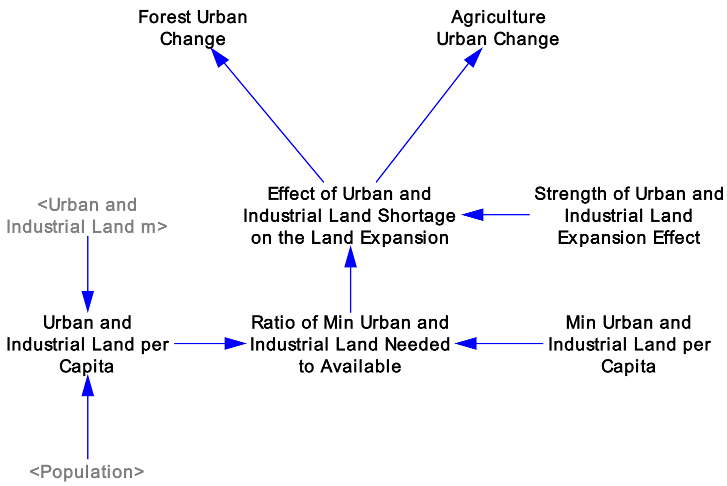
In case of land transformation between Forest and Agricultural areas there are three factors driving it. The first one is exactly the same as in case of Forest-Other land trade-off which drives transformation towards Forest Land.

The same sign is associated with *Effect of Land Availability on Forest Land Expansion*. If there is any agricultural land not used the *Ratio of Agricultural Land Available to Needed* scaled by *Strength of Land Availability on Forest Land Expansion Effect* drives afforestation.
Eventually *Ratio of Crops Land Needed to Available* and *Ratio of Animal Food Land Needed to Available* scaled by *Strength of Food Purpose Agriculture Land Expansion Effect* create demand for Agricultural Land at the expense of Forest Land.

Additionally the scaled *Ratio of Crops Land Needed to Available* forces expansion of *Agricultural Land* at the expense of *Other Land*.

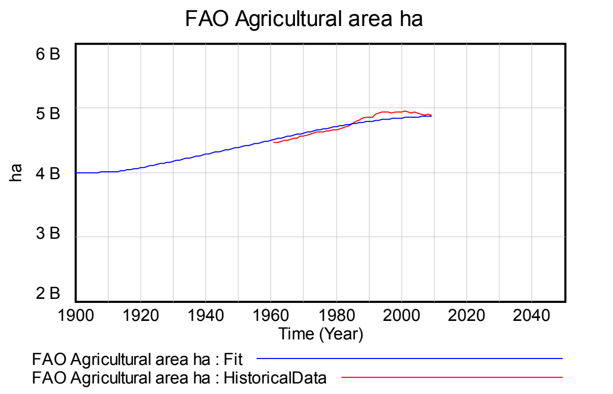


The expansion of the Urban and Industrial Land over Forest and Agricultural Land is modeled to be driven by population growth and the effect of securing each individual with a minimal living area.



Simulation

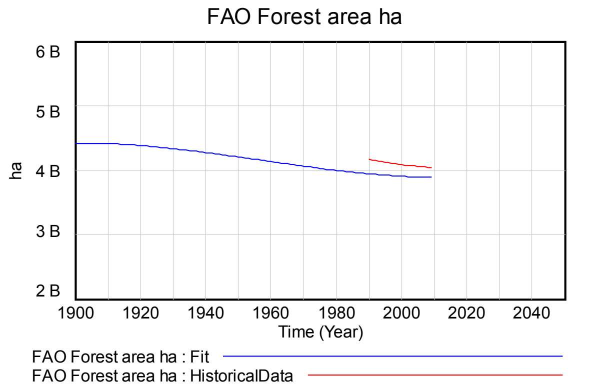
The graphs over time below illustrate the fit of selected variables of the Land Use model sector to historical data.



Summary Statistics for Historical Fit – Agricultural Area

n (Count)	49
R^2 (Coefficient of Determination)	0.95845
MAPE (Mean Absolute Percent Error)	0.01185
MSE (Mean Square Error)	3.91E+15
RMSE (Root Mean Square Error)	62569315.25
UM (Bias component of MSE)	0.04672
US (Variation component of MSE)	0.75804
UC (Covariation component of MSE)	0.19524

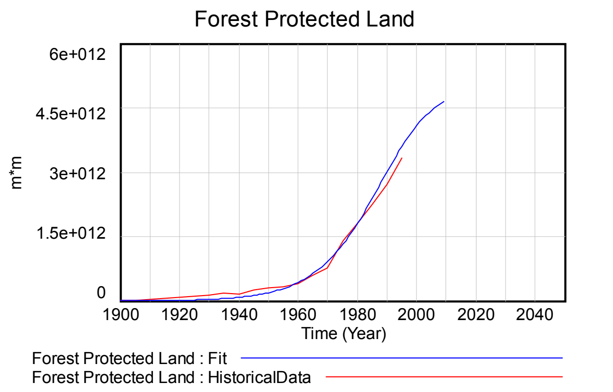
Source of Historical Data:
FAOSTAT (Resources – Resources – Land); http://faostat.fao.org



Summary Statistics for Historical Fit – Forest Area

n (Count)	20
R^2 (Coefficient of Determination)	0.99682
MAPE (Mean Absolute Percent Error)	0.04517
MSE (Mean Square Error)	3.48E+16
RMSE (Root Mean Square Error)	186664021.91
UM (Bias component of MSE)	0.98514
US (Variation component of MSE)	0.01480
UC (Covariation component of MSE)	0.00006

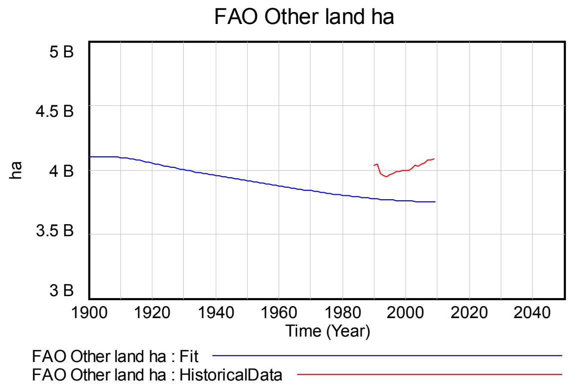
Source of Historical Data:
FAOSTAT (Resources – Resources – Land); http://faostat.fao.org



Summary Statistics for Historical Fit – Forest Protected Land

n (Count)	20
R^2 (Coefficient of Determination)	0.99497
MAPE (Mean Absolute Percent Error)	0.37807
MSE (Mean Square Error)	1.54E+22
RMSE (Root Mean Square Error)	124144397153.33
UM (Bias component of MSE)	0.00020
US (Variation component of MSE)	0.65605
UC (Covariation component of MSE)	0.34375

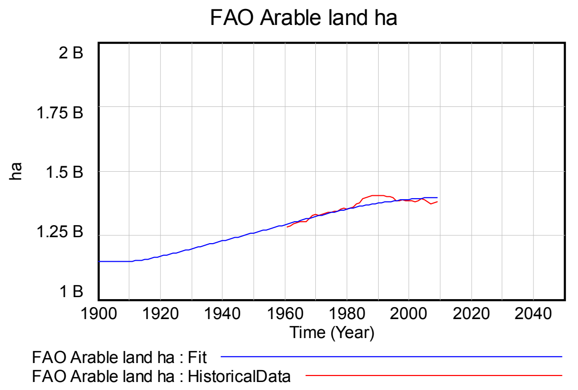
Source of Historical Data:
Forest product market developments: the outlook for forest product markets to 2010 and the implications for improving management of the global forest estate (http://www.fao.org/docrep/003/x4108e/X4108E11.htm# P3941_174357)



Summary Statistics for Historical Fit – Other Land

n (Count)	20
R^2 (Coefficient of Determination)	0.33198
MAPE (Mean Absolute Percent Error)	0.06266
MSE (Mean Square Error)	6.56E+16
RMSE (Root Mean Square Error)	256151411.57
UM (Bias component of MSE)	0.96711
US (Variation component of MSE)	0.01720
UC (Covariation component of MSE)	0.01569

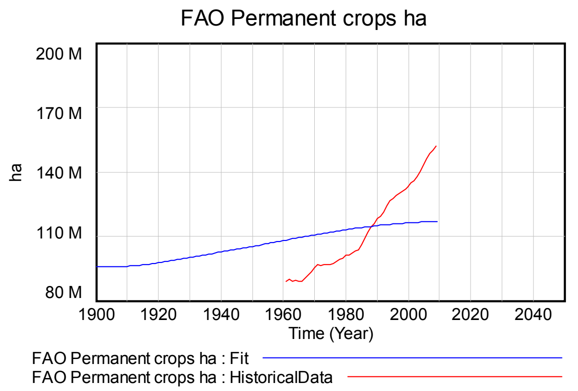
Source of Historical Data:
FAOSTAT (Resources – Resources – Land);
http://faostat.fao.org



Summary Statistics for Historical Fit – Arable Land

n (Count)	49
R^2 (Coefficient of Determination)	0.83675
MAPE (Mean Absolute Percent Error)	0.00827
MSE (Mean Square Error)	2.29E+14
RMSE (Root Mean Square Error)	15137138.6
UM (Bias component of MSE)	0.05529
US (Variation component of MSE)	0.09033
UC (Covariation component of MSE)	0.85438

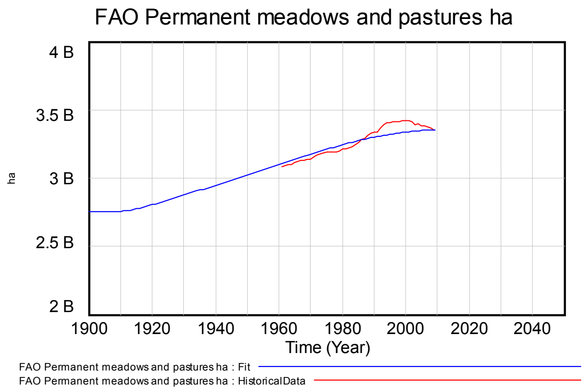
Source of Historical Data:
FAOSTAT (Resources – Resources – Land);
http://faostat.fao.org



Summary Statistics for Historical Fit – Permanent Crops

n (Count)	49
R^2 (Coefficient of Determination)	0.86442
MAPE (Mean Absolute Percent Error)	0.13624
MSE (Mean Square Error)	2.91E+14
RMSE (Root Mean Square Error)	17055984.7
UM (Bias component of MSE)	0.00117
US (Variation component of MSE)	0.97390
UC (Covariation component of MSE)	0.02493

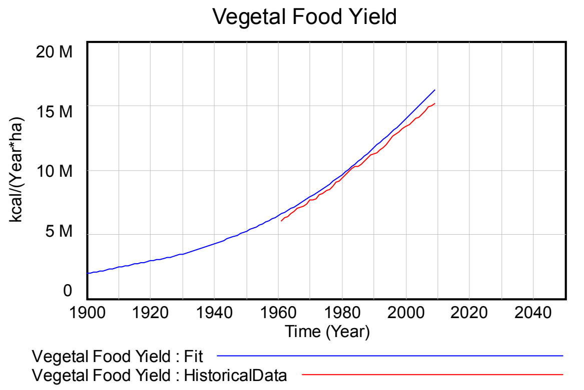
Source of Historical Data:
FAOSTAT (Resources – Resources – Land);
http://faostat.fao.org



Summary Statistics for Historical Fit – Permanent Meadows and Pastures

n (Count)	49
R^2 (Coefficient of Determination)	0.93175
MAPE (Mean Absolute Percent Error)	0.01190
MSE (Mean Square Error)	2.16E+15
RMSE (Root Mean Square Error)	46500577.84
UM (Bias component of MSE)	0.05146
US (Variation component of MSE)	0.66972
UC (Covariation component of MSE)	0.27882

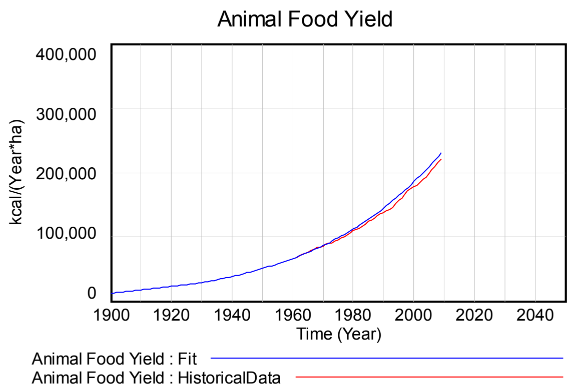
Source of Historical Data:
FAOSTAT (Resources – Resources – Land);
http://faostat.fao.org



<u>Summary Statistics for Historical Fit – Vegetal Food Yield</u>

n (Count)	49
R^2 (Coefficient of Determination)	0.99752
MAPE (Mean Absolute Percent Error)	0.04697
MSE (Mean Square Error)	2.90E+11
RMSE (Root Mean Square Error)	538894.6
UM (Bias component of MSE)	0.83738
US (Variation component of MSE)	0.09593
UC (Covariation component of MSE)	0.06669

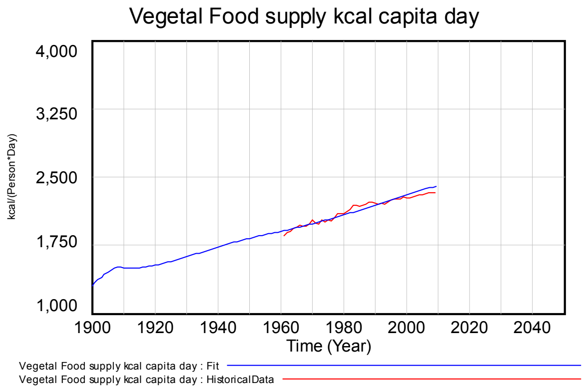
Source of Historical Data:
Calculated based on FAOSTAT data on Land (Resources – Resources – Land), Vegetal Products supply (Food Supply – Crops Primary Equivalent) and Population (Resources – Population – Annual time series); http://faostat.fao.org



<u>Summary Statistics for Historical Fit – Animal Food Yield</u>

n (Count)	49
R^2 (Coefficient of Determination)	0.99897
MAPE (Mean Absolute Percent Error)	0.03482
MSE (Mean Square Error)	3.97E+07
RMSE (Root Mean Square Error)	6298.64
UM (Bias component of MSE)	0.62836
US (Variation component of MSE)	0.31689
UC (Covariation component of MSE)	0.05476

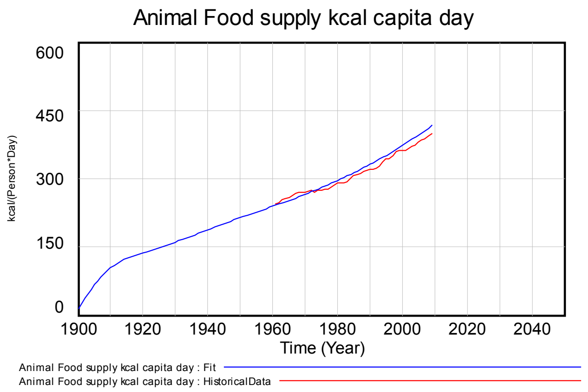
Source of Historical Data:
Calculated based on FAOSTAT data on Land (Resources – Resources – Land), Animal Products supply (Food Supply – Livestock and Fish Primary Equivalent: Eggs, Meat, Milk-Excluding Butter) and Population (Resources – Population – Annual time series); http://faostat.fao.org



<u>Summary Statistics for Historical Fit – Vegetal Food Supply</u>

n (Count)	49
R^2 (Coefficient of Determination)	0.94672
MAPE (Mean Absolute Percent Error)	0.01305
MSE (Mean Square Error)	1.21E+03
RMSE (Root Mean Square Error)	34.77814
UM (Bias component of MSE)	0.01192
US (Variation component of MSE)	0.08061
UC (Covariation component of MSE)	0.90747

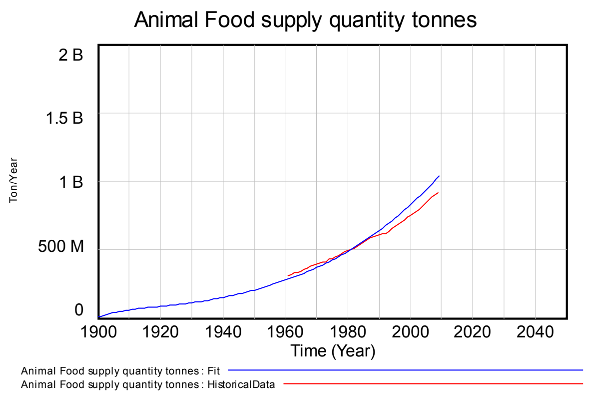
Source of Historical Data:
FAOSTAT (Food Supply – Crops Primary Equivalent: Vegetal Products); http://faostat.fao.org



<u>Summary Statistics for Historical Fit – Animal Food Supply</u>

n (Count)	49
R^2 (Coefficient of Determination)	0.98999
MAPE (Mean Absolute Percent Error)	0.03077
MSE (Mean Square Error)	1.19E+02
RMSE (Root Mean Square Error)	10.91966
UM (Bias component of MSE)	0.40683
US (Variation component of MSE)	0.40236
UC (Covariation component of MSE)	0.19081

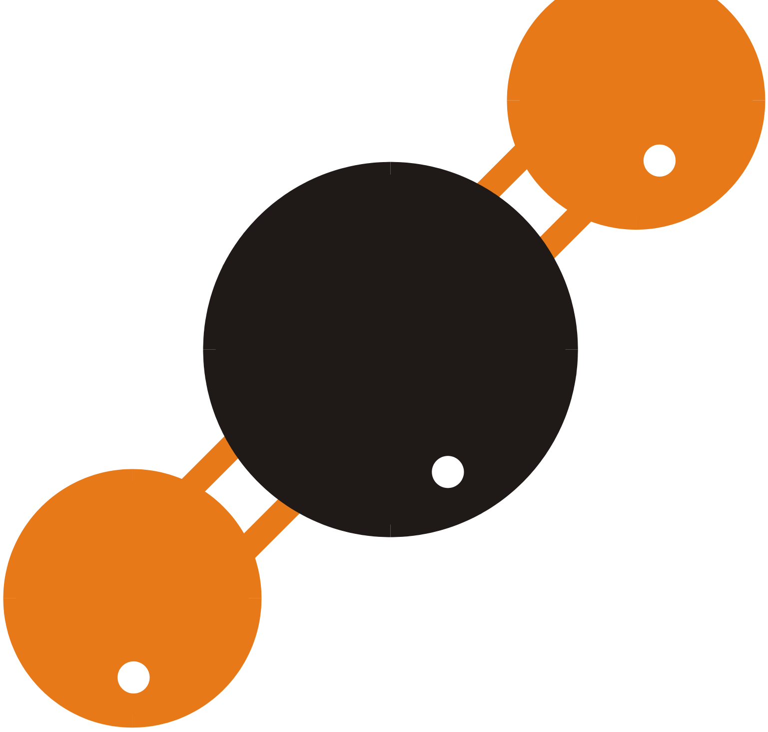
Source of Historical Data:
FAOSTAT (Food Supply – Livestock and Fish Primary Equivalent : Eggs, Meat, Milk-Excluding Butter); http://faostat.fao.org



Summary Statistics for Historical Fit – Animal Food Supply (ton)

n (Count)	49
R^2 (Coefficient of Determination)	0.99763
MAPE (Mean Absolute Percent Error)	0.06736
MSE (Mean Square Error)	3.03E+15
RMSE (Root Mean Square Error)	55086501.37
UM (Bias component of MSE)	0.21576
US (Variation component of MSE)	0.75404
UC (Covariation component of MSE)	0.03019

Source of Historical Data:
FAOSTAT (Food Supply – Livestock and Fish Primary Equivalent : Eggs, Meat, Milk-Excluding Butter); http://faostat.fao.org



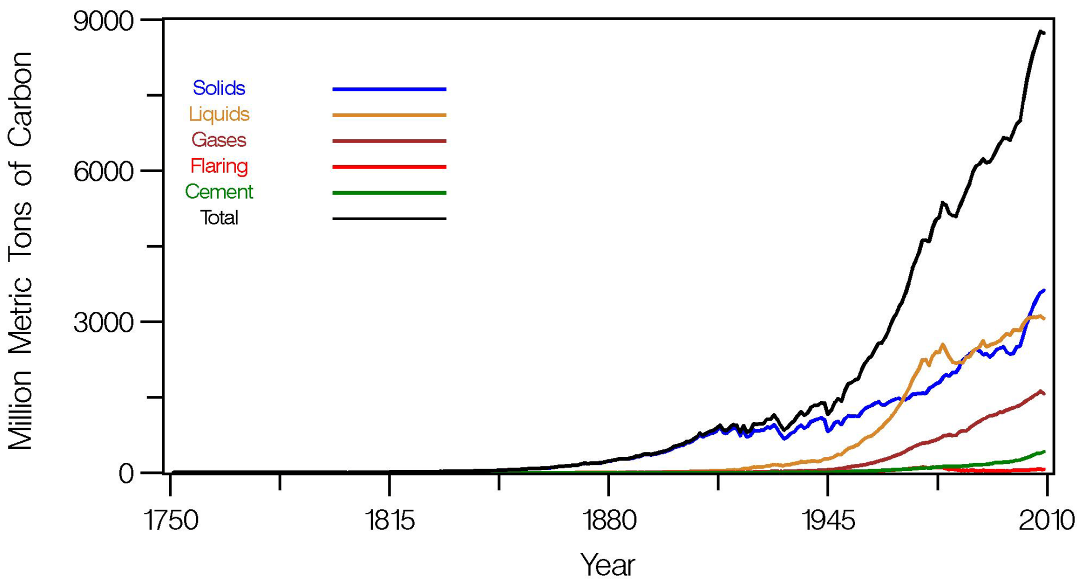
Carbon Cycle

Dynamic problems definition

Human activities related to land use and energy production (mainly from burning fossil fuels) lead to increased concentration of CO2 in atmosphere. CO2 emissions from human activities are considered the single largest anthropogenic factor contributing to climate change[2].

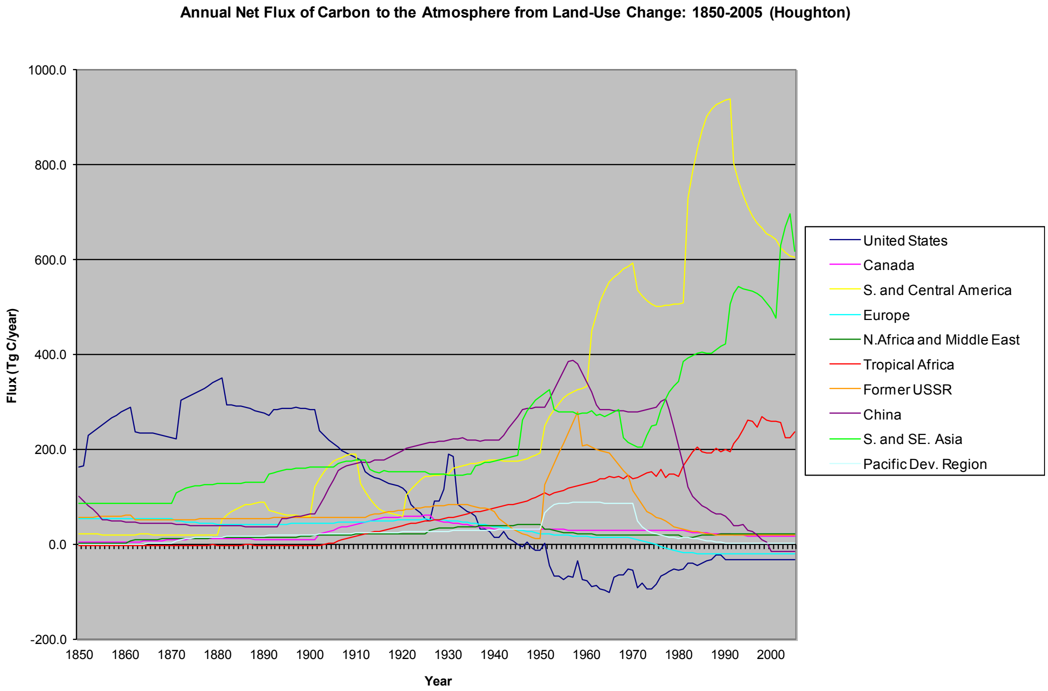
Human activities related CO2 emissions

The study shows that prior to 1750, the atmospheric concentration of CO2 had been relatively stable between 260 and 280 ppm for 10 kyr (Denman et al., 2007). Since 1750, the concentration of CO2 in the atmosphere has risen, at an increasing rate, from around 280 ppm to nearly 380 ppm in 2005. The increase in atmospheric CO2 concentration results primarily from burning of fossil fuels, cement production, deforestation and changes in land use and management as illustrated on the following two reference graphs.



Source: Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011

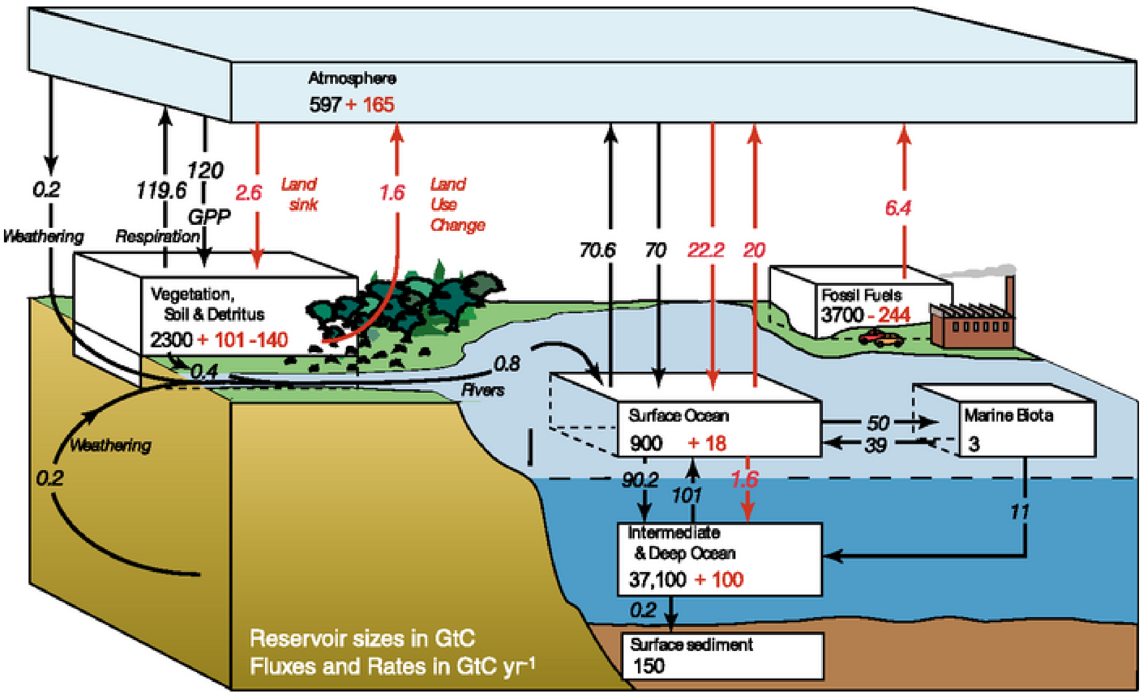
2 Interovermental Panel on Climate Change – http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-2-1.html



Source: Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

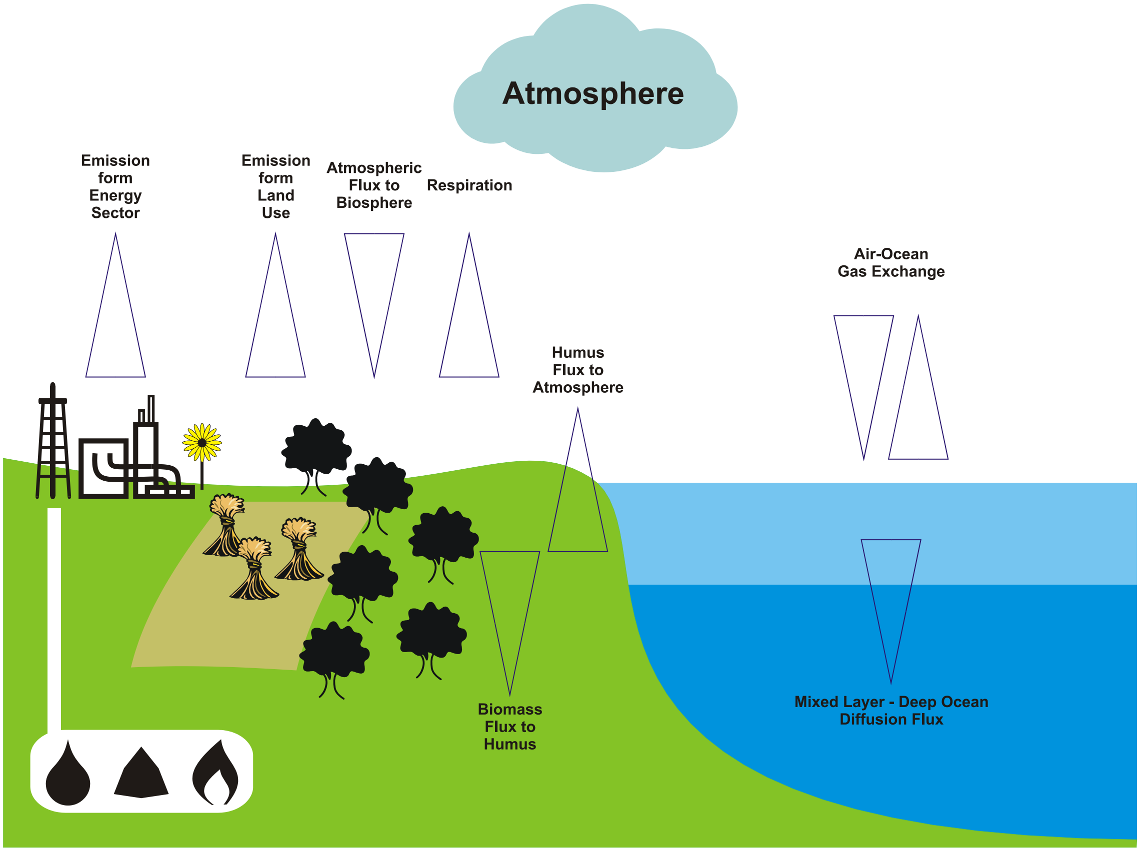
System conceptualization

IPCC Fourth Assessment Report (Denman et al., 2007) illustrates the global carbon cycle for the 1990s: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red.



Source: IPCC Fourth Assessment Report: Climate Change 2007

For the purpose of this study some of the fluxes existing in the ecosystem has been aggregated or simplified. The picture below represents the conceptualized fluxes and storages to be represented in the FeliX model.

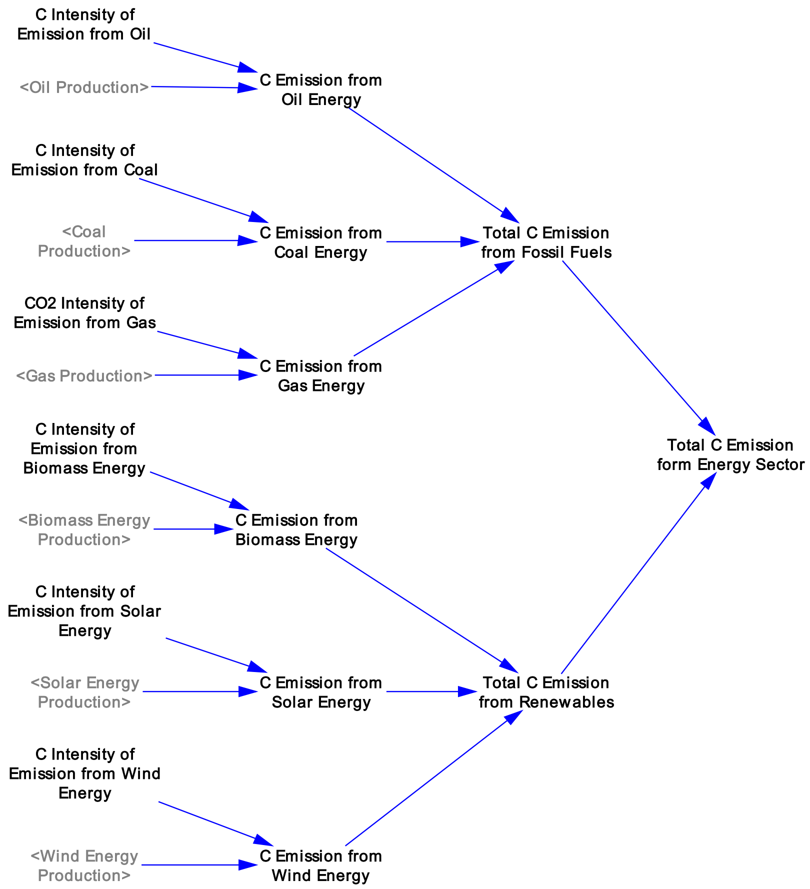


Emission from Energy Sector flux is assumed to include CO2 emission from both fossil fuels and renewable energy sources.
Emission form Land Use flux is conceptualized to consist of forest land change and agriculture land change.

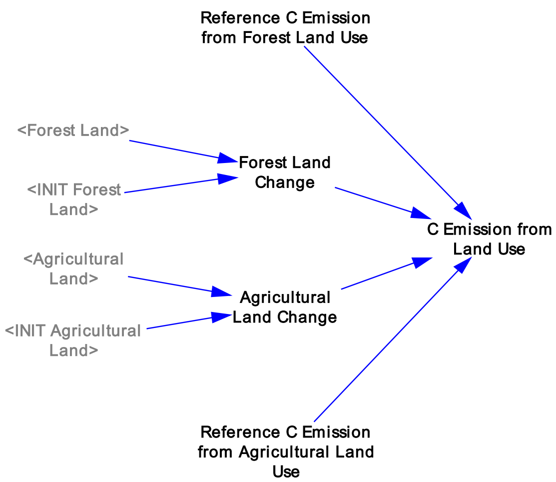
Model formulation

Production of the energy from all sources is associated with carbon emission. The intensity of carbon production from various sources of energy was compared with Global Energy Assessment (GEA, 2012).

Carbon emission from fossil fuels sums up to *Total C Emission from Fossil Fuels*, whereas carbon emission from renewable energy sources sums up to *Total C Emission from Renewables*. *Total C Emission from Fossil Fuels* and *Total C Emission from Renewables* constitute *Total C Emission form Energy Sector*.



Changes to the Forest Land area and Agriculture Land area are also associated with carbon emission. Those emissions constitute *C Emission from Land Use*.



Total C Emission form Energy Sector and *C Emission from Land Use* are accumulated as *Total C Emission* flux in atmosphere (*C in Atmosphere*). The Carbon Cycle component of this sector is based on FREE model (Fiddaman, 1997, 2002) and C-ROADS model (Sterman, 2012) which in turn refers to IMAGE 1.0 model by Goudriaan and Ketner (1984) and model by Oeschger, Siegenthaler et al. (1975).

The carbon cycle model is an eddy diffusion model with stocks of carbon in the atmosphere, biosphere, mixed ocean layer, and four deep ocean layers. Carbon in biosphere is captured in biomass and humus which simplifies the structure proposed by Goudriaan and Ketner (1984). Carbon in Biomass (*C in Biomass*) stock includes leaves, branches, stems, roots whereas Carbon in Humus (*C in Humus*) includes litter and humus. Charcoal is neglected due to its long lifetime.

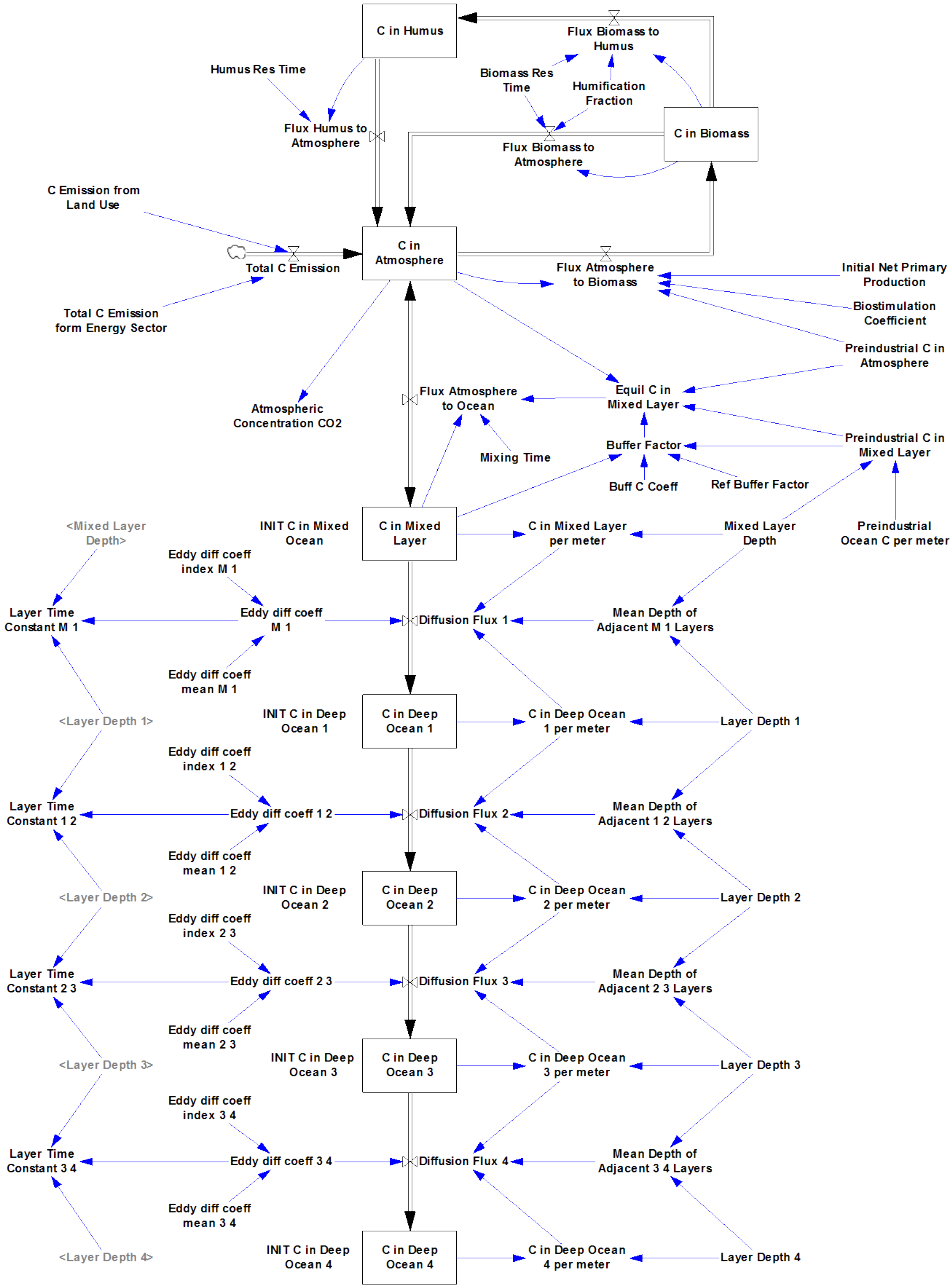
As the concentration of *C in Atmosphere* rises it forces increase of the uptake by ocean and biosphere. *Flux Atmosphere to Biomass* is modeled according to Wullschleger, Post and King (1995) formula and grows logarithmically as the concentration of *C in Atmosphere* increases. The effects of the current biomass stock and human disturbance are not considered. This is a subject for further model development.

The residence of *C in Biomass* depends on average life-span. The outflow of carbon from biomass stock is partitioned between *Flux Biomass to Atmosphere* and *Flux Biomass to Humus* according to *Humification Fraction*.

The outflow from *C in Humus* is equal to its content divided by its average life-span (*Humus Residence Time*).

The *C in Atmosphere* and *C in Mixed Ocean Layer* adjust to this equilibrium taking into consideration buffer or Revelle factor, a measure of the resistance to atmospheric carbon dioxide being absorbed by the ocean surface layer. The buffer factor itself rises with the atmospheric concentration which decreases ocean absorption capacity.

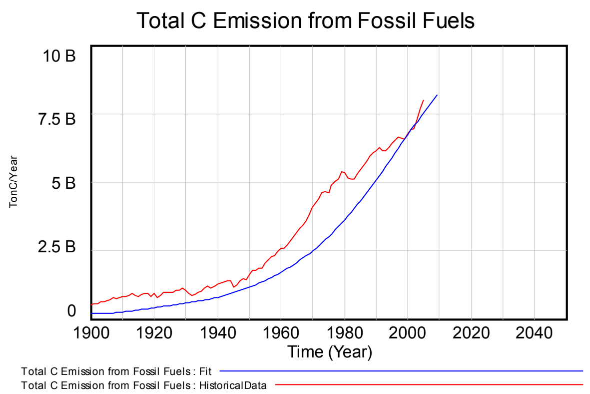
Deep Ocean Diffusion Fluxes are modeled as a simple eddy-diffusion structure.



Note: Detailed equations behind each model variable are presented in the Appendix.

Simulation

The graphs over time below illustrate the fit of selected variables of the Carbon Cycle model sector to historical data.

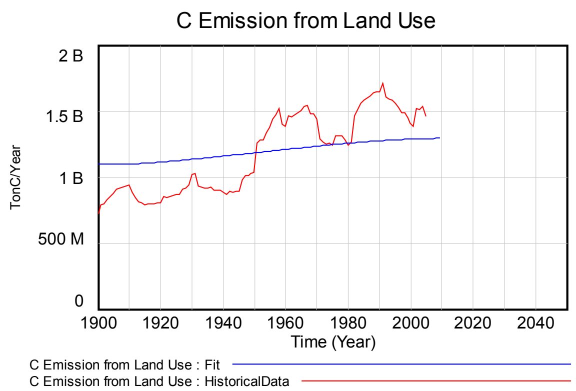


Summary Statistics for Historical Fit – Total C Emission from Fossil Fuels

n (Count)	106
R^2 (Coefficient of Determination)	0.85921
MAPE (Mean Absolute Percent Error)	0.35570
MSE (Mean Square Error)	7.10E+17
RMSE (Root Mean Square Error)	842698139.47

Note: Alternative calculation of R^2 was used (R^2=1-sum of squares of residuals/total sum of squares).

Source of Historical Data:
Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011

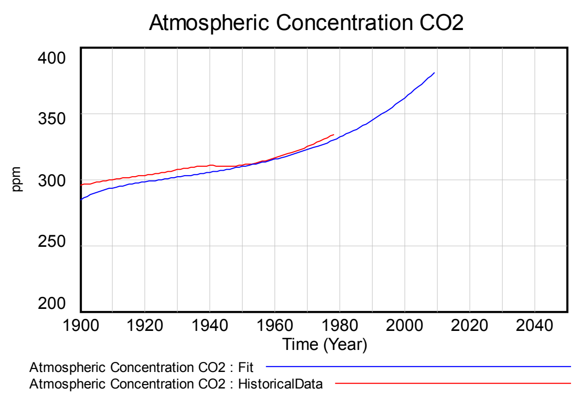


Summary Statistics for Historical Fit – C Emission from Land Use

n (Count)	106
R^2 (Coefficient of Determination)	0.3541
MAPE (Mean Absolute Percent Error)	0.19636
MSE (Mean Square Error)	5.55E+16
RMSE (Root Mean Square Error)	235673881.43

Note: Alternative calculation of R^2 was used(R^2=1-sum of squares of residuals/total sum of squares).

Source of Historical Data:
Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.



Summary Statistics for Historical Fit – Atmospheric Concentration CO2

n (Count)	79
R^2 (Coefficient of Determination)	0.97434
MAPE (Mean Absolute Percent Error)	0.01357
MSE (Mean Square Error)	2.29E+01
RMSE (Root Mean Square Error)	4.78063
UM (Bias component of MSE)	0.75678
US (Variation component of MSE)	0.12267
UC (Covariation component of MSE)	0.12055

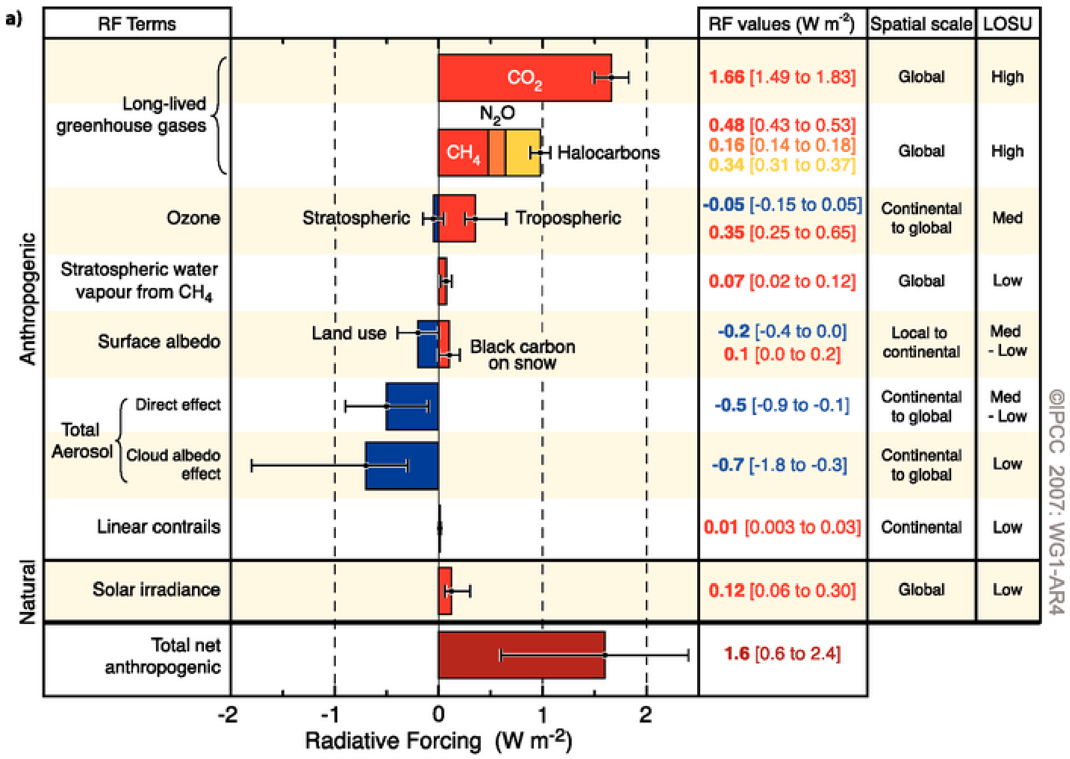
Source of Historical Data:
Etheridge, D.M., Steele, L.P., Langenfelds, R.L., Francey, R.J., Barnola, J.-M., Morgan, V.I. 1998. Historical CO2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A

Climate

Dynamic problems definition

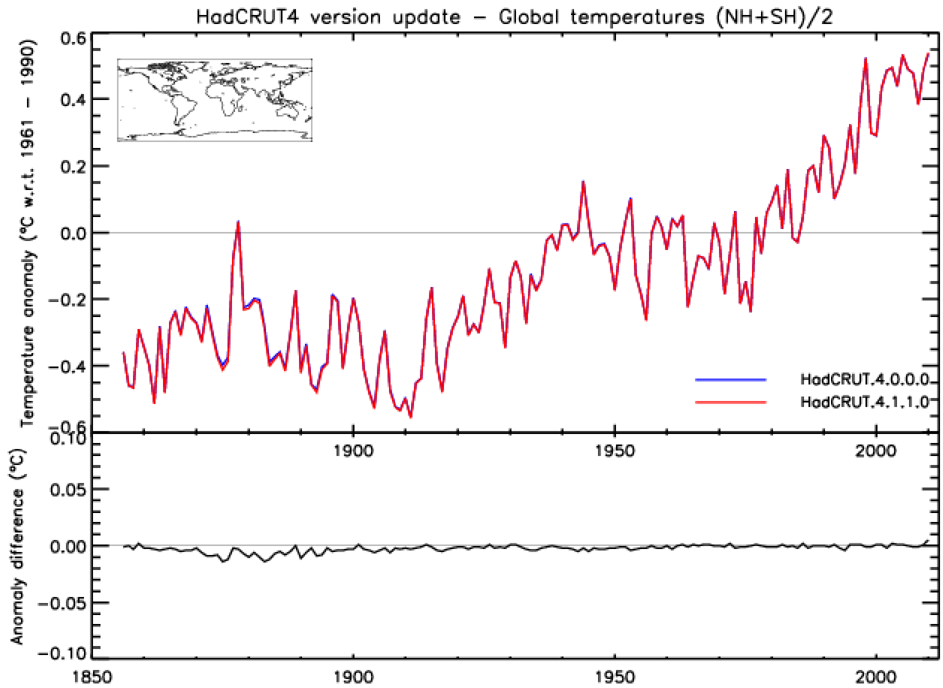
Carbon emission from human activities is considered a single largest anthropogenic factor contributing to the Earth temperature increase. Small changes in the average temperature can translate to large shifts in climate and weather which in turn might impact human life and economy.

Impact of carbon concentration
IPCC reports on global mean radiative forcings (RF) and their 90% confidence intervals in 2005 for various agents and mechanisms.

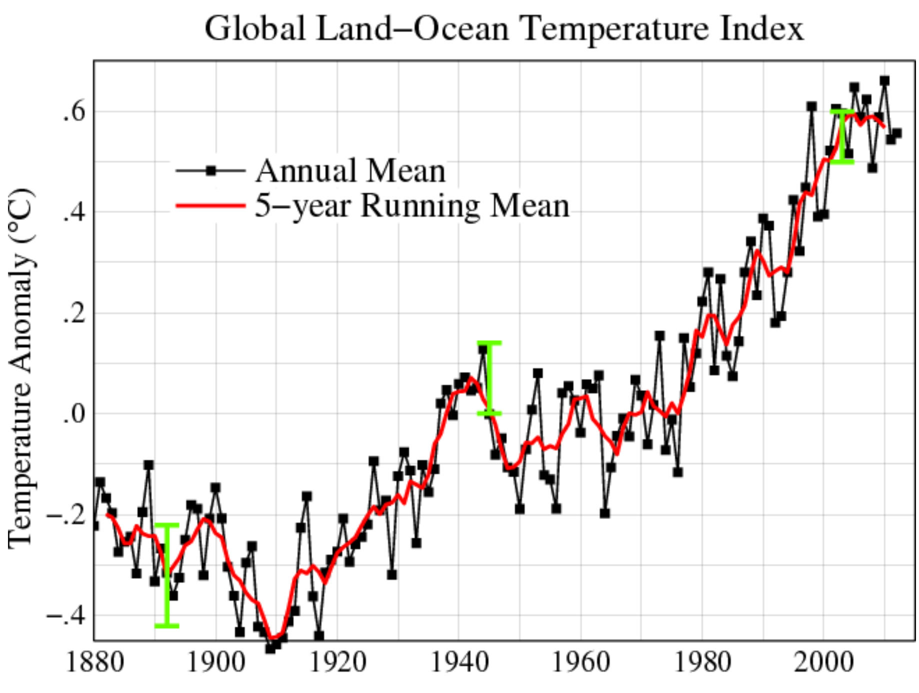


Source: IPCC Fourth Assessment Report: Climate Change 2007

The increase in radiative forcings as compared to the preindustrial era is being followed by increase in temperature.



Source: Met Office Hadley Centre
http://www.metoffice.gov.uk/hadobs/hadcrut4/data/versions/HadCRUT.4.1.1.0_release_notes.html

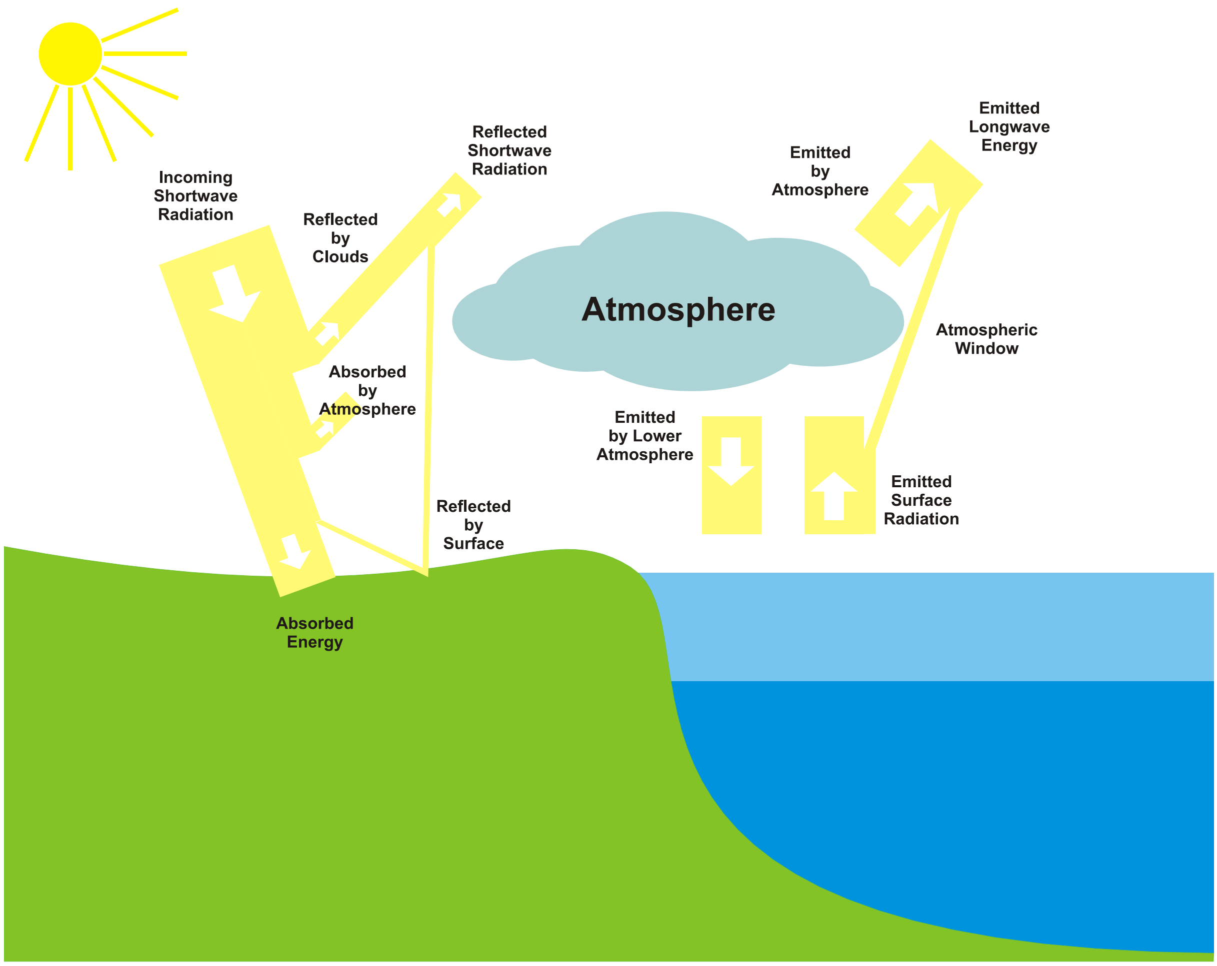


Source: NASA Goddard Institute for Space Studies, http://data.giss.nasa.gov/gistemp/graphs_v3/

Increasing global temperatures have been accompanied by changes in weather and climate resulting in many places in more floods, droughts, intense rain, and severe heat waves. The oceans are warming and becoming more acidic, ice caps are melting, and sea levels are rising. All those changes are becoming more pronounced and more challenging for the society.

System conceptualization

The incoming shortwave radiation from the Sun is reflected off clouds, some is absorbed by the atmosphere, and some passes through to the Earth's surface. The radiation that passes through the atmosphere is either reflected off snow, ice, or other surfaces or is absorbed by the surface.
Heat resulting from the absorption of incoming shortwave radiation is emitted as longwave radiation. Radiation from the warmed upper atmosphere, along with a small amount from the Earth's surface, radiates out to space. Most of the emitted longwave radiation from the Earth surface warms the lower atmosphere, which in turn warms the surface.



Increasing concentrations of greenhouse gases such as carbon dioxide and methane increase the temperature of the lower atmosphere by restricting the outward passage of emitted radiation, resulting in temperature rising. This is the phenomena of interest to this study and around them the structure of the model is constructed.

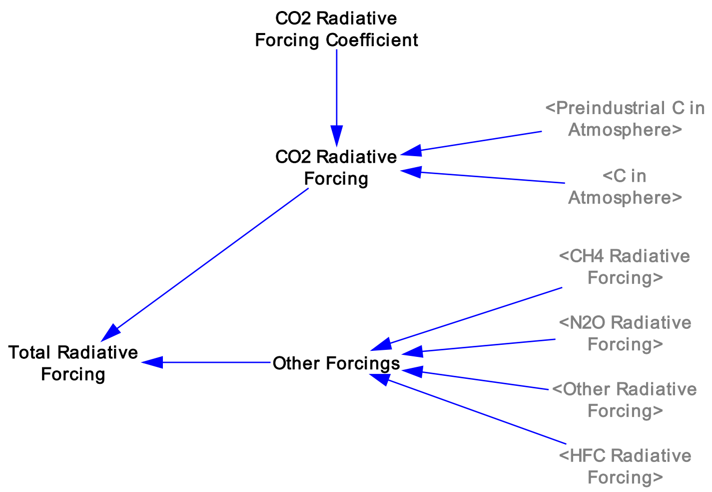
Model formulation

The structure of the Climate sector of the FeliX model is based on the C-ROADS model (Sterman, 2012) which in turn refers to FREE model (Fiddaman, 1997, 2002) and DICE model (Nordhaus 1992, 1994).

In the FeliX model the Earth's radiation budget is constrained only to the temperature change due to carbon dioxide (CO2), methane (CH4), nitrous oxide N2O, halocarbons and other forcings (aerosols, O3, etc.). CO2 emissions are endogenous variables as described in Carbon Cycle section of this report. The rest of forcings are generated exogenously based on historical data and the future projections from Representative Concentration Pathways (RCPs) prepared for the Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC).

The temperature change is governed by radiative forcings, feedback cooling due to outbound longwave radiation, and heat transfer from the atmosphere and upper ocean to the four deep ocean layers.

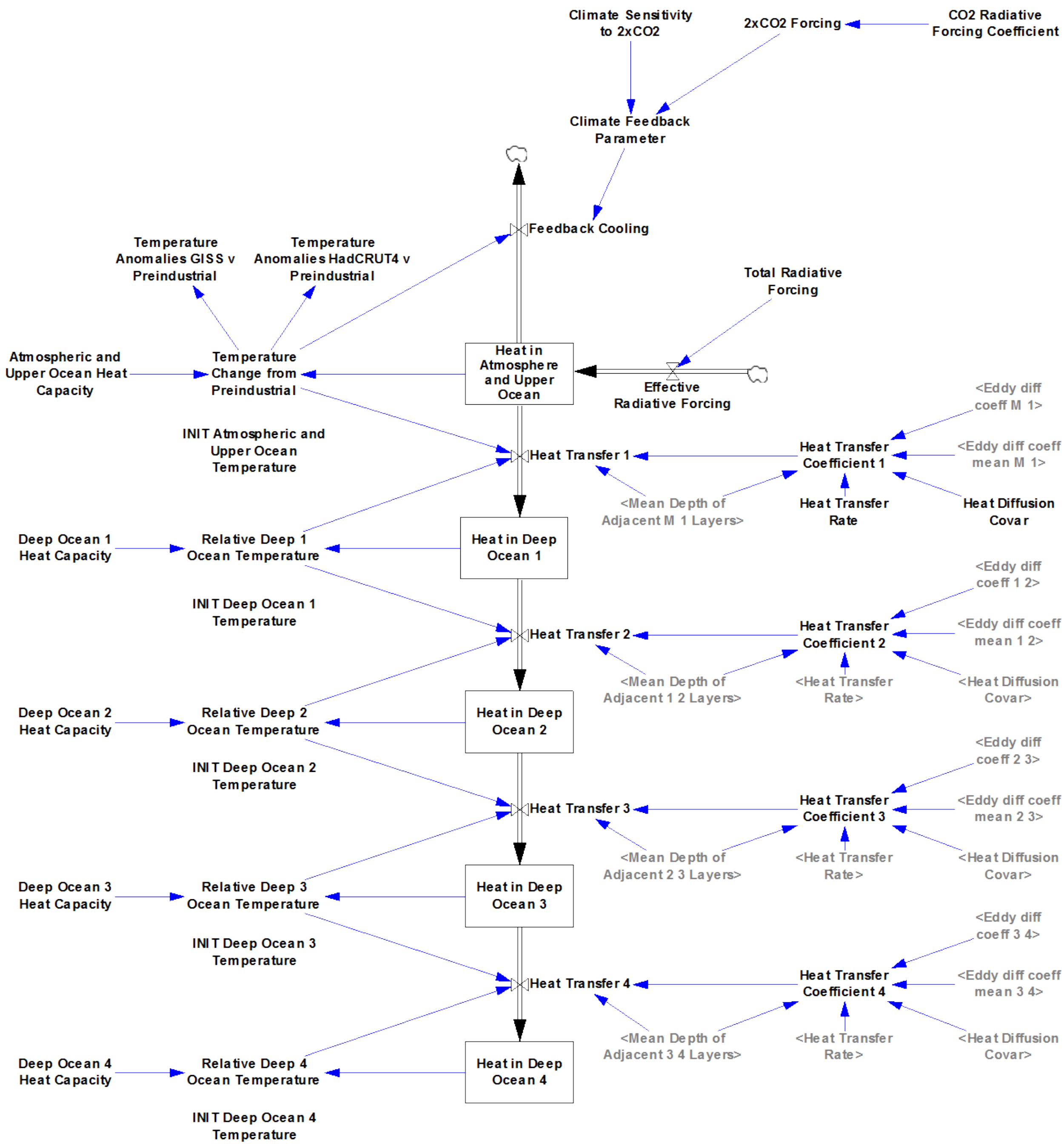
Total Radiative Forcing consist of *CO2 Radiative Forcing*, due to increasing concentration of carbon in atmosphere following CO2 emission from land use human activities and fossil fuels burning, and *Other Forcings*, which includes variables representing forcings from CH4, N2O, halocarbons and other gases and aerosols.



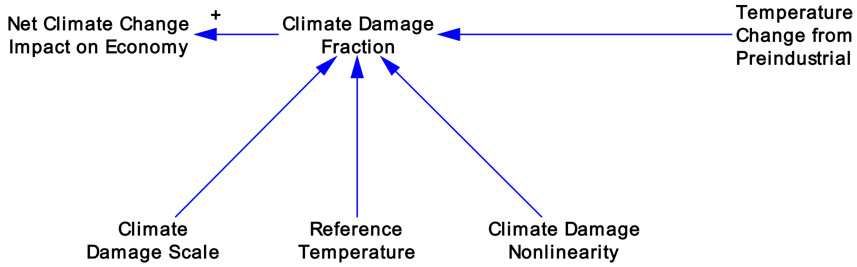
A negative feedback loop governs feedback mechanism of the atmosphere and the upper ocean and is associated with the outbound longwave radiation. The rate of cooling is determined by the climate sensitivity – a metric used to characterize the response of the global climate system to a given forcing, and is broadly defined as the equilibrium global mean surface temperature change following a doubling of atmospheric CO2 concentration[3].

[3] IPCC Fourth Assessment Report; http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch8s8-6.html

Another negative feedback loop governs heat transfer from atmosphere and upper ocean into the deep ocean. The transfer of heat into deeper layers of the ocean is modeled as a function of the eddy diffusion, which controls the movement of carbon through the deep ocean.

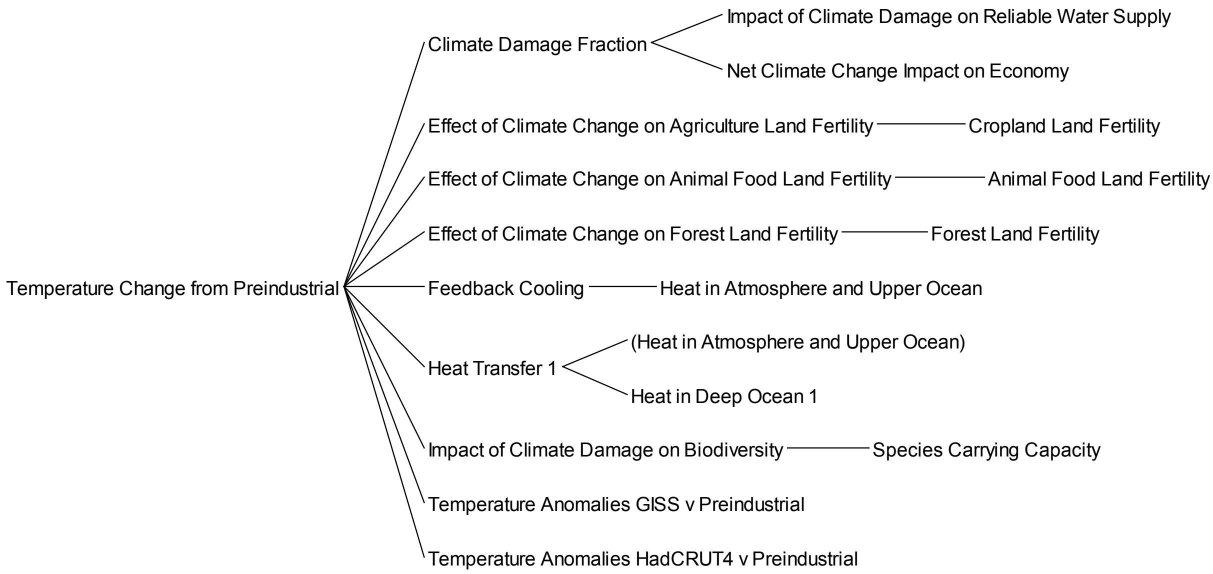


The calculation of *Net Climate Change Impact on Economy* assumes that the temperature change has a direct impact on the economy output.



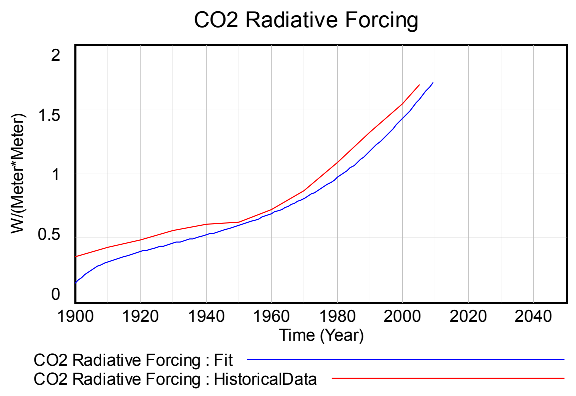
Note: Detailed equations behind each model variable are presented in the Appendix.

The following tree diagram illustrates the scope of impact of *the Temperature Change from Preindustrial* across the entire FeliX model.



Simulation

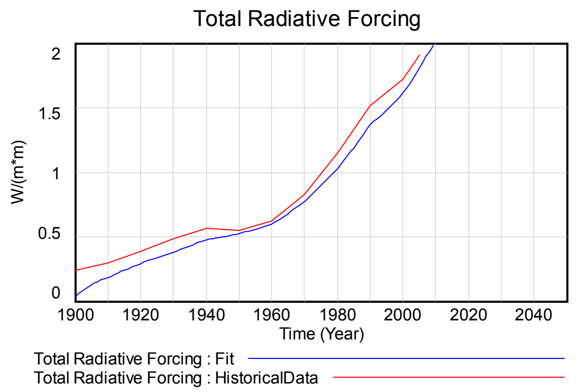
The graphs over time below illustrate the fit of selected variables of the Climate model sector to historical data.



Summary Statistics for Historical Fit – CO2 Radiative Forcing

n (Count)	12
R^2 (Coefficient of Determination)	0.98721
MAPE (Mean Absolute Percent Error)	0.15441
MSE (Mean Square Error)	1.22E-02
RMSE (Root Mean Square Error)	0.11041
UM (Bias component of MSE)	0.80415
US (Variation component of MSE)	0.00014
UC (Covariation component of MSE)	0.19571

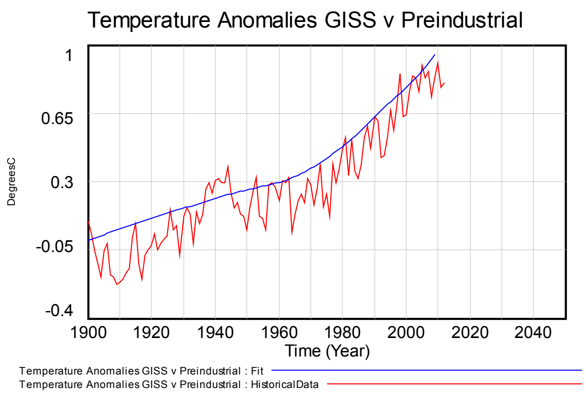
Source of Historical Data:
IIASA RCP Database
https://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome



Summary Statistics for Historical Fit – Total Radiative Forcing

n (Count)	12
R^2 (Coefficient of Determination)	0.99233
MAPE (Mean Absolute Percent Error)	0.19128
MSE (Mean Square Error)	1.18E-02
RMSE (Root Mean Square Error)	0.10873
UM (Bias component of MSE)	0.80143
US (Variation component of MSE)	0.00004
UC (Covariation component of MSE)	0.19853

Source of Historical Data:
IIASA RCP Database
https://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome

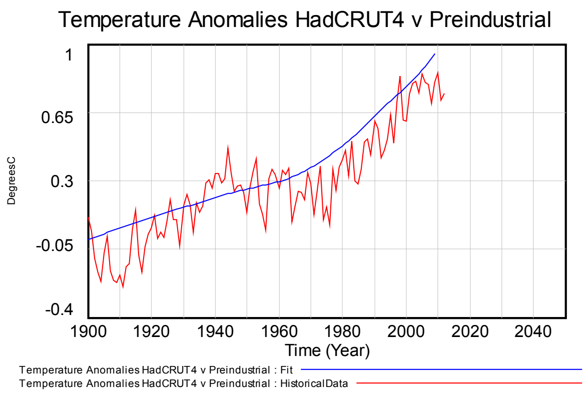


Summary Statistics for Historical Fit – Temperature Anomalies GISS v. Preindustrial

n (Count)	111
R^2 (Coefficient of Determination)	0.718802
MAPE (Mean Absolute Percent Error)	1.39568
MSE (Mean Square Error)	1.83E-02
RMSE (Root Mean Square Error)	0.13519

Note: Alternative calculation of R^2 was used(R^2=1-sum of squares of residuals/total sum of squares).

Source of Historical Data:
NASA Goddard Institute for Space Studies
http://data.giss.nasa.gov/gistemp/graphs_v3/

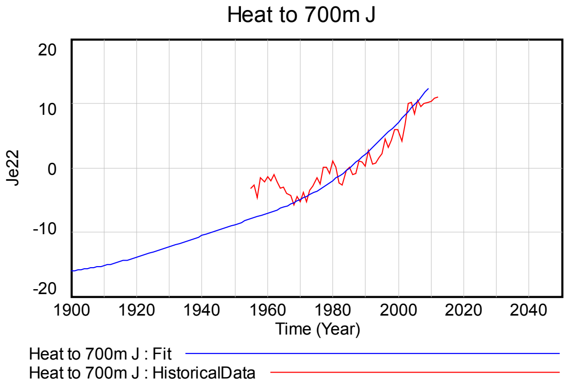


Summary Statistics for Historical Fit – Temperature Anomalies HadCRUT4 v. Preindustrial

n (Count)	111
R^2 (Coefficient of Determination)	0.672156
MAPE (Mean Absolute Percent Error)	1.04003
MSE (Mean Square Error)	1.89E-02
RMSE (Root Mean Square Error)	0.13741

Note: Alternative calculation of R^2 was used(R^2=1-sum of squares of residuals/total sum of squares).

Source of Historical Data:
Met Office Hadley Centre
http://www.metoffice.gov.uk/hadobs/hadcrut4/data/versions/HadCRUT.4.1.1.0_release_notes.html



Summary Statistics for Historical Fit – Heat to 700m J

n (Count)	56
R^2 (Coefficient of Determination)	0.86645
MAPE (Mean Absolute Percent Error)	4.04571
MSE (Mean Square Error)	6.74
RMSE (Root Mean Square Error)	2.59654
UM (Bias component of MSE)	0.04637
US (Variation component of MSE)	0.35544
UC (Covariation component of MSE)	0.59819

Source of Historical Data:

NOAA – Ocean heat content anomalies;
http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/
Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155.

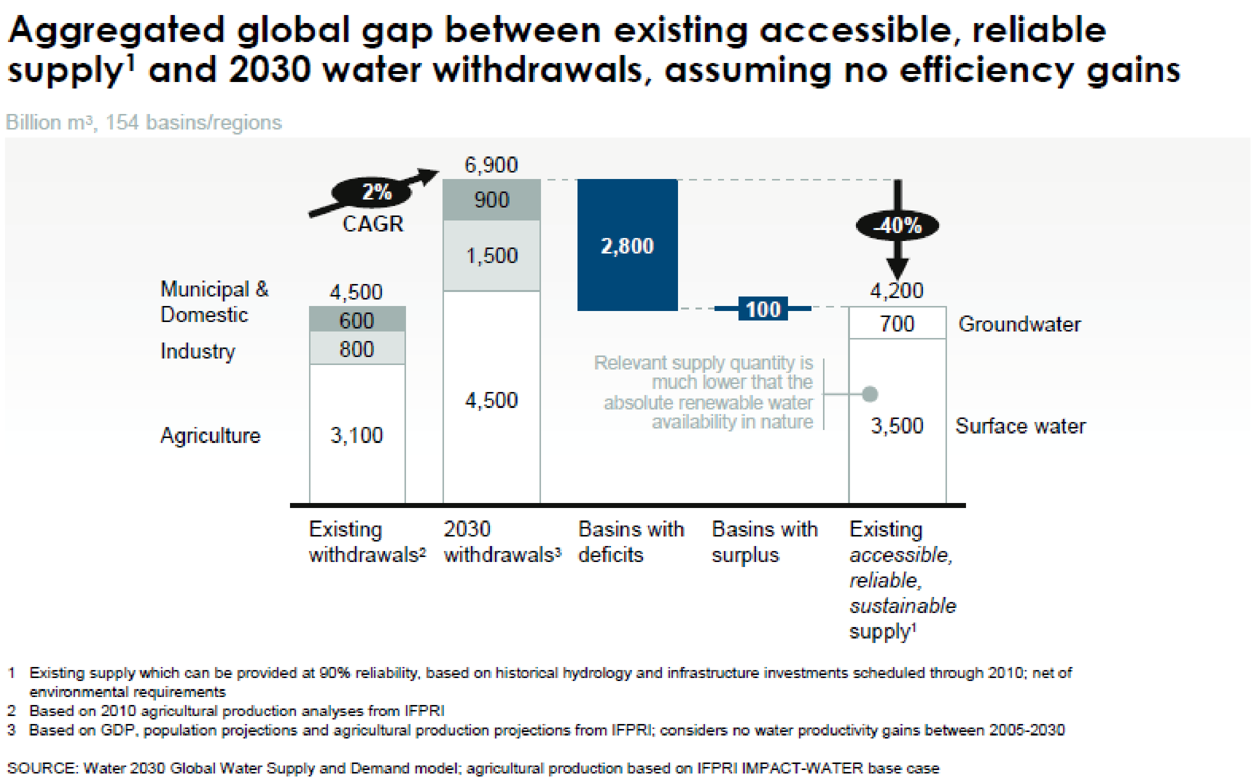
Water

Dynamic problems definition

Even thought the water is the greatest resource on the Earth only 3% of it is fresh water. 97% of the water on the Earth is salt water. The main dynamic problem to be considered in the model is the water scarcity.

Water scarcity

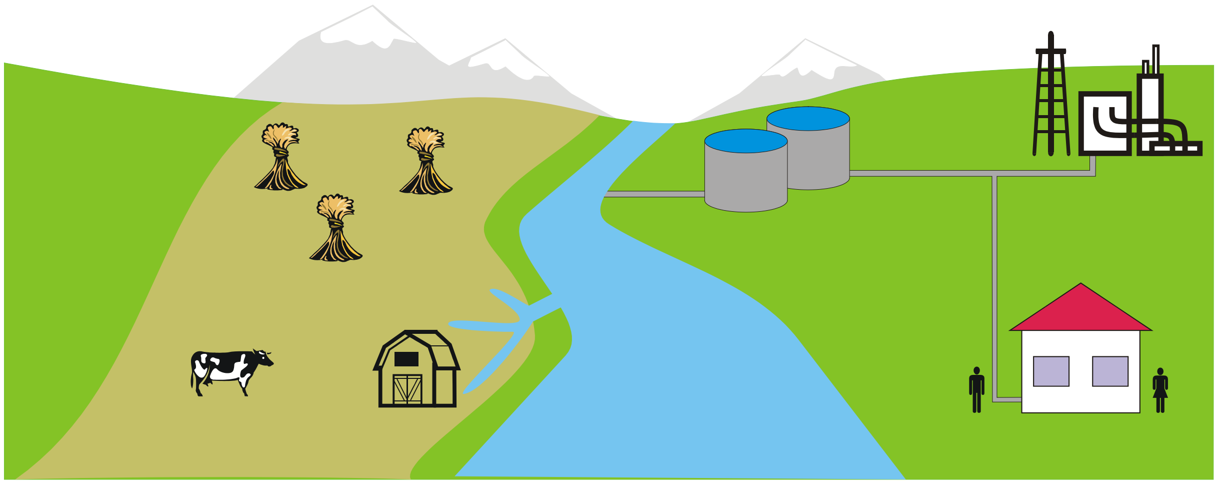
The study indicates that water demand already exceeds reliable water supply in many world regions. If no efficiency gains are assumed or change in water use achieved, global water requirements would grow from 4,500 billion m3 today (or 4.5 thousand cubic kilometers) to 6,900 billion m3 by 2030, under an average economic growth scenario[4]. To that change contribute all three major areas of water use – agriculture, industry and domestic.



4 2030 Water Resources Group, 2009. Charting Our Water Future - Economic frameworks to inform decision-making. http://www.mckinsey.com/App_Media/Reports/Water/Charting_Our_Water_Future_Full_Report_001.pdf

System conceptualization

Water infrastructure – distribution network, water treatment, irrigation systems – secures the reliability of water supply to satisfy the demand from agriculture, industry and domestic sector. Reliable water supply makes water resources available for withdrawal. Any damage to the infrastructure might decrease available water resources whereas infrastructure development increases availability of the resources.
Available water resources are used by customers in agriculture, industry and domestic sector. Some fraction of the used water can be recovered and re-used. The rest is lost.



The demand for water is driven by the volume of population, its wealth and also technology (e.g. irrigated vs. rainfed agricultural land).

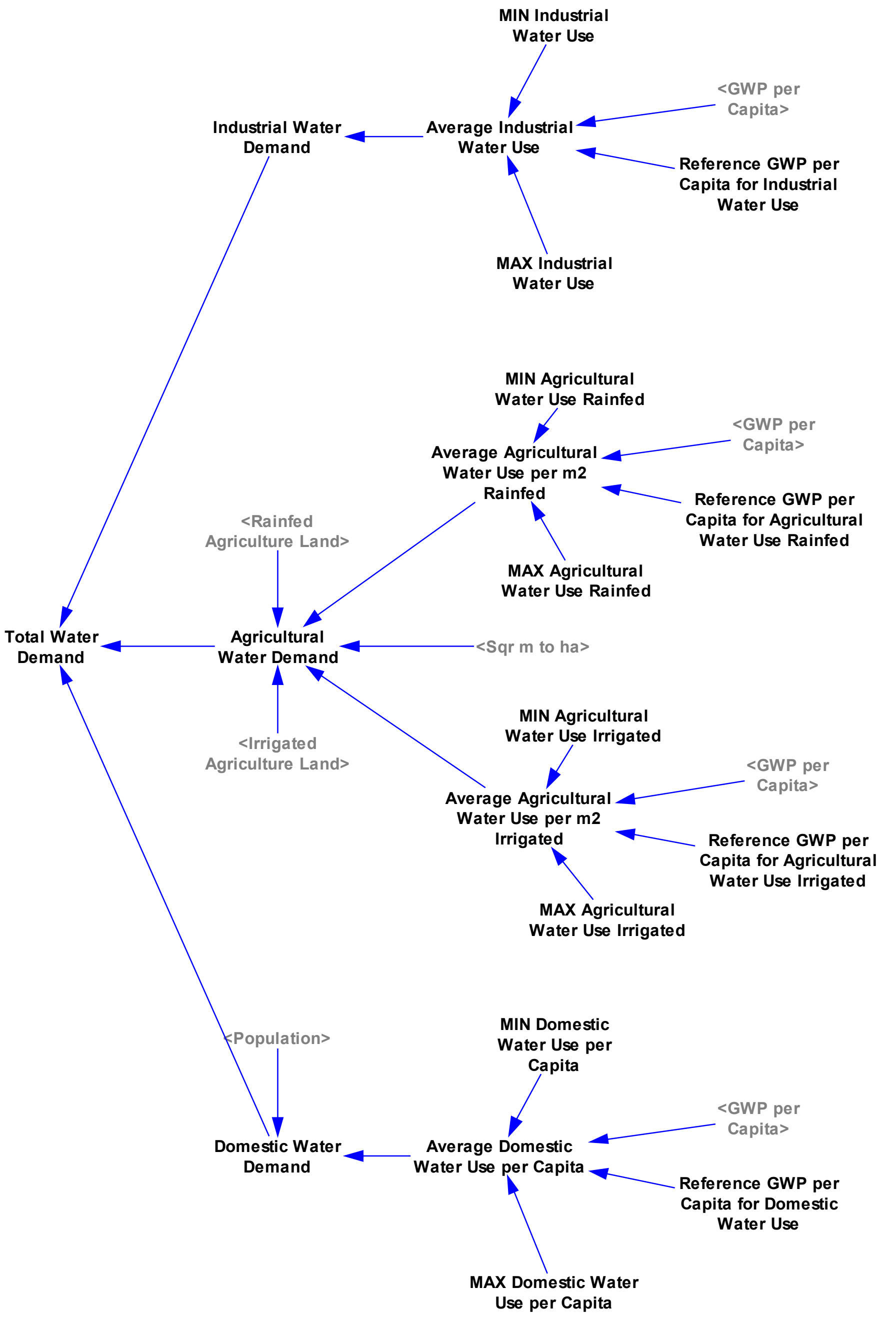
Model formulation

Total Water Demand consists of three variables – *Industrial Water Demand*, *Agricultural Water Demand* and *Domestic Water Demand*.

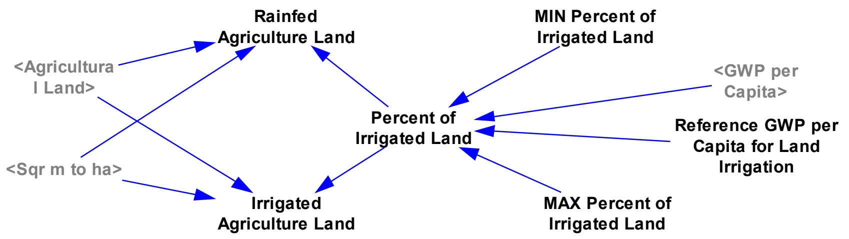
Industrial Water Demand is a function of the society wealth, represented by *GWP per Capita*, an assuming there are upper and lower limits for the *Average Industrial Water Use*.

Agricultural Water Demand is dependent on two ways of land watering – irrigation and rainfed. *Average Agricultural Water Use per m2 Rainfed* and *Average Agricultural Water Use per m2 Irrigated* are functions of *GWP per Capita*, but their upper and lower limits vary.

Domestic Water Demand is a function of the volume of *Population* and *Average Domestic Water Use per Capita*, which relates to *GWP per Capita*. The formula also assumes there is an upper and lower limit for the *Average Domestic Water Use per Capita*.



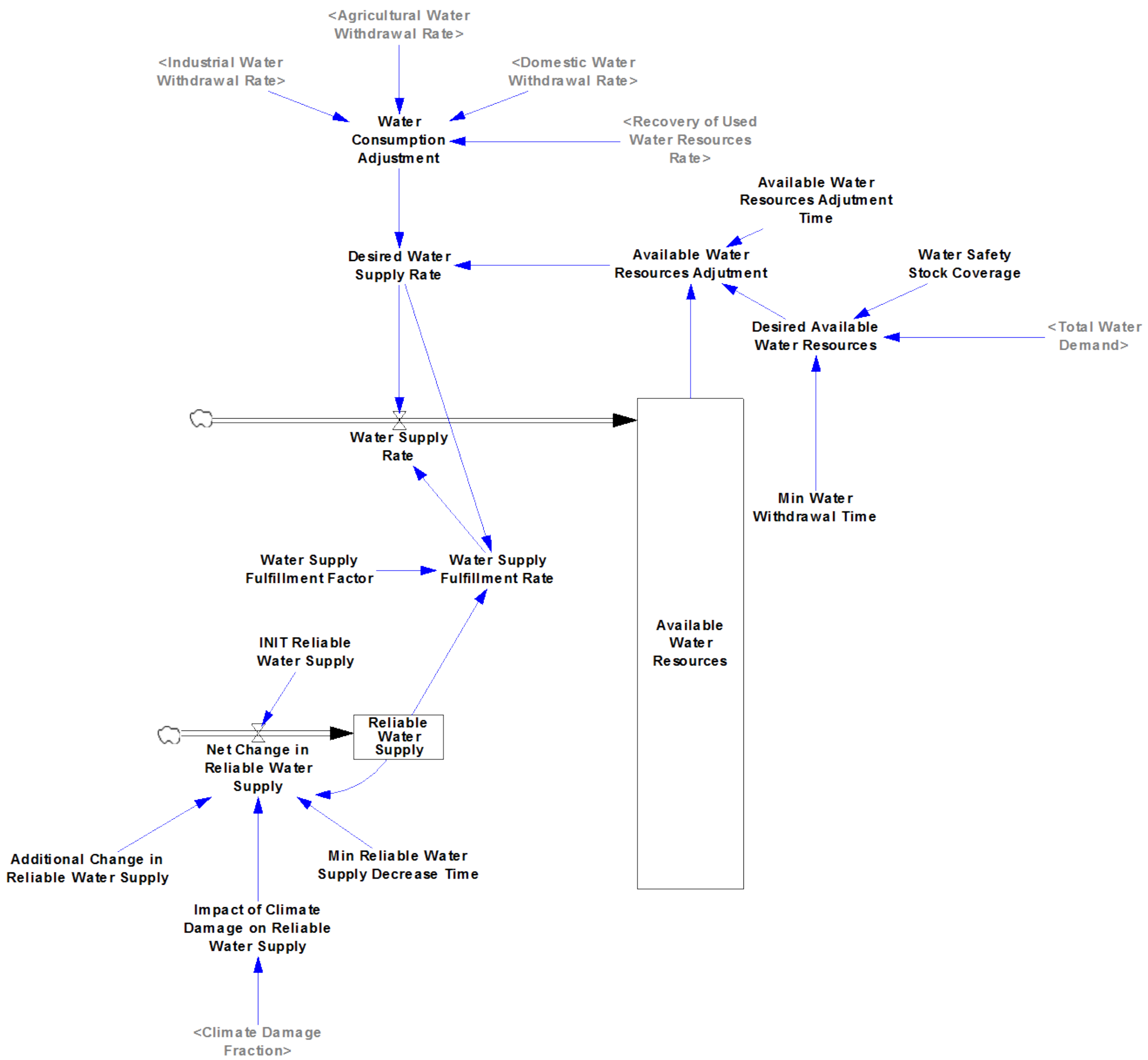
Percent of Irrigated Land is a function of GWP per Capita, which represents the society wealth and capability to provide irrigation system on their *Agriculture Land*.



Water resources are made available through *Water Supply Rate* which is a function of *Water Consumption Adjustment* (*Industrial, Agricultural and Domestic Water Withdrawal Rate* decreased by *Recovery of Used Water Resources Rate*) and *Available Water Resources Adjustment*, which takes into consideration dynamics of *Total Water Demand* and adds *Water Safety Stock Coverage* factor.

Additionally Water Supply Rate is adjusted by *Water Supply Fulfillment Rate* – a limiting factor which slows down the *Water Supply Rate* when *Desired Water Supply Rate* approaches *Reliable Water Supply* rate.

The *Reliable Water Supply* is vulnerable towards the consequences of the climate change. Furthermore the *Additional Change in Reliable Water Supply* variable allows for incorporating various positive or negative scenarios regarding *Net Change in Reliable Water Supply*.

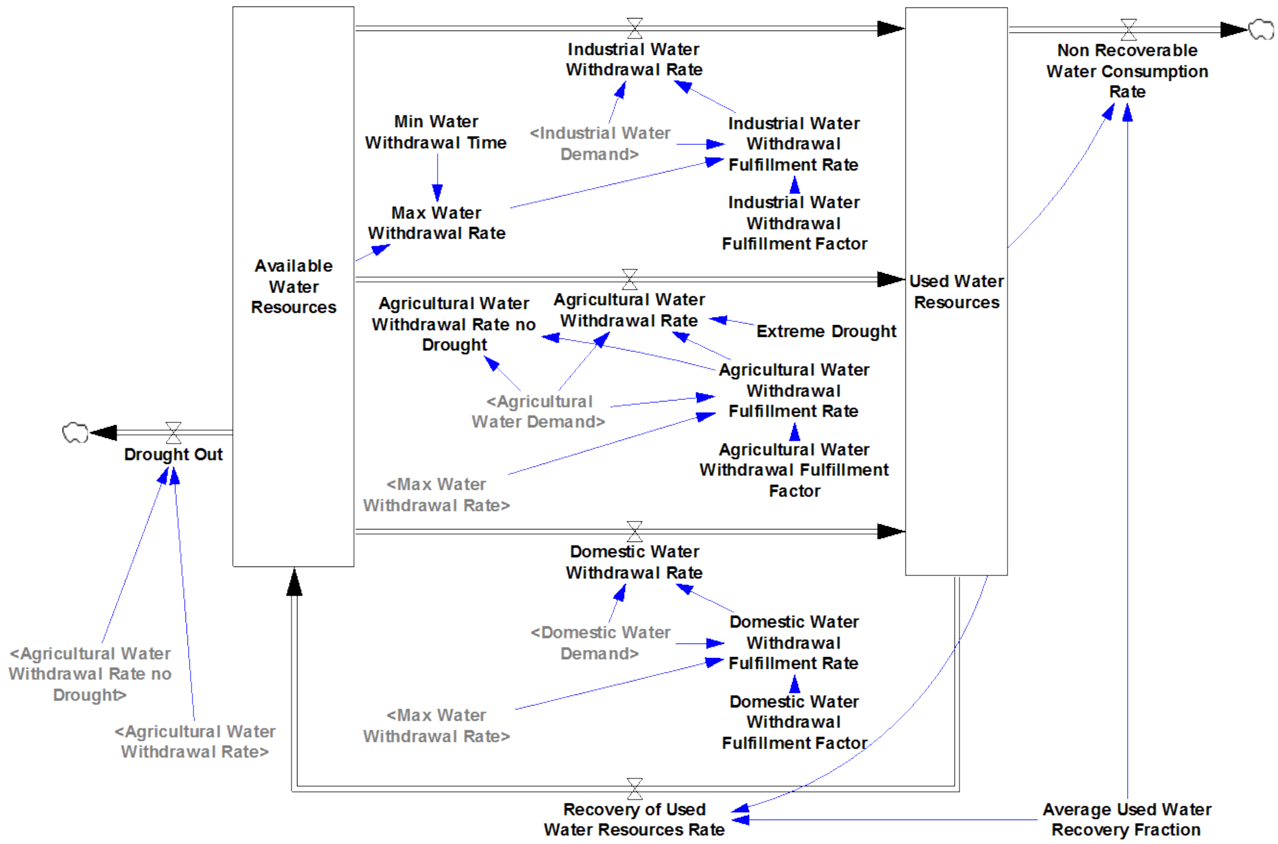


Industrial, Agricultural and Domestic Water Demand drives water resources withdrawal from Available Water Resources. When *Industrial, Agricultural and Domestic Water*

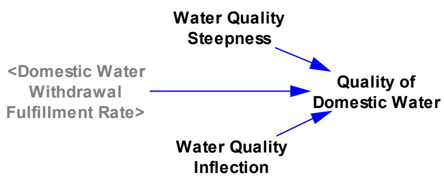
Demands approache *Max Water Withdrawal Rate* the *Industrial, Agriculture and Domestic Water Withdrawal Rate* slows down.

Industrial, Agriculture and Domestic Water Withdrawal Rates accumulate as *Used Water Resources*. A fraction of *Used Water Resources* represented by *Average Used Water Recovery Fraction* can be recovered and supply *Available Water Resources*.

Drought Out rate allows running additional scenarios representing extreme drought events related to *Agricultural Water Withdrawal Rate*.



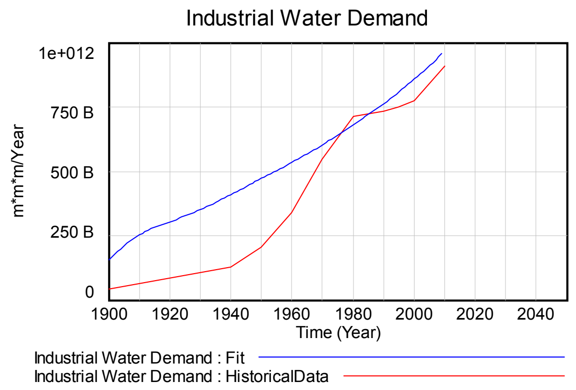
A nonlinear function models the dependency of Quality of Domestic Water to Domestic Water Withdrawal Fulfillment Rate. The relation between Domestic Water Withdrawal Fulfillment Rate and Quality of Domestic Water has positive polarity.



Note: Detailed equations behind each model variable are presented in the Appendix.

Simulation

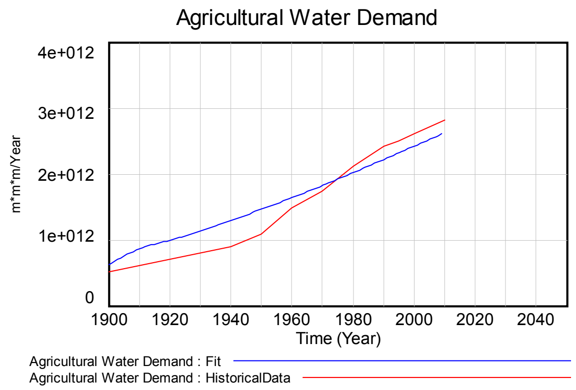
The graphs over time below illustrate the fit of selected variables of the Water model sector to historical data.



<u>Summary Statistics for Historical Fit – Industrial Water Demand</u>

n (Count)	9
R^2 (Coefficient of Determination)	0.91203
MAPE (Mean Absolute Percent Error)	0.77950
MSE (Mean Square Error)	2.42E+22
RMSE (Root Mean Square Error)	155691877763.1
UM (Bias component of MSE)	0.56211
US (Variation component of MSE)	0.17894
UC (Covariation component of MSE)	0.25896

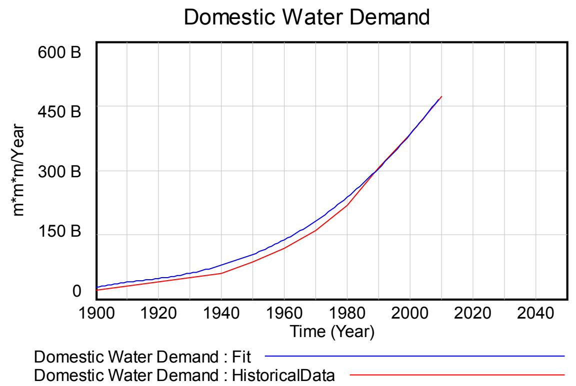
Source of Historical Data:
International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A – Dynamics of water use in the world (total) over the kinds of economic activities
http://webworld.unesco.org/water/ihp/db/shiklomanov/



<u>Summary Statistics for Historical Fit – Agricultural Water Demand</u>

n (Count)	9
R^2 (Coefficient of Determination)	0.95991
MAPE (Mean Absolute Percent Error)	0.15864
MSE (Mean Square Error)	5.22E+22
RMSE (Root Mean Square Error)	228442389927.34
UM (Bias component of MSE)	0.05138
US (Variation component of MSE)	0.60187
UC (Covariation component of MSE)	0.34675

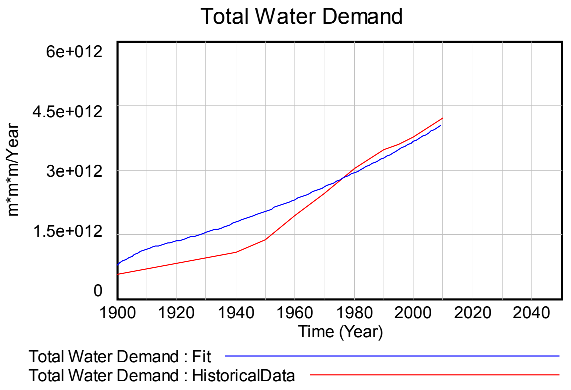
Source of Historical Data:
International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A – Dynamics of water use in the world (total) over the kinds of economic activities
http://webworld.unesco.org/water/ihp/db/shiklomanov/



<u>Summary Statistics for Historical Fit – Domestic Water Demand</u>

n (Count)	9
R^2 (Coefficient of Determination)	0.99769
MAPE (Mean Absolute Percent Error)	0.13449
MSE (Mean Square Error)	2.17E+20
RMSE (Root Mean Square Error)	14727781270.9
UM (Bias component of MSE)	0.63554
US (Variation component of MSE)	0.14626
UC (Covariation component of MSE)	0.21821

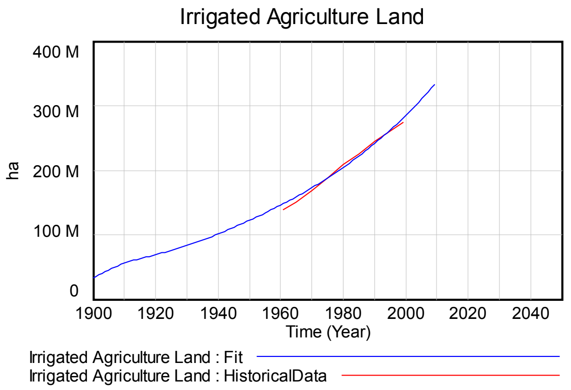
Source of Historical Data:
International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A – Dynamics of water use in the world (total) over the kinds of economic activities
http://webworld.unesco.org/water/ihp/db/shiklomanov/



<u>Summary Statistics for Historical Fit – Total Water Demand</u>

n (Count)	9
R^2 (Coefficient of Determination)	0.96295
MAPE (Mean Absolute Percent Error)	0.21391
MSE (Mean Square Error)	1.36E+23
RMSE (Root Mean Square Error)	369186833098
UM (Bias component of MSE)	0.23837
US (Variation component of MSE)	0.44769
UC (Covariation component of MSE)	0.31394

Source of Historical Data:
International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A – Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/



<u>Summary Statistics for Historical Fit – Irrigated Agriculture Land</u>

n (Count)	9
R^2 (Coefficient of Determination)	0.98924
MAPE (Mean Absolute Percent Error)	0.02604
MSE (Mean Square Error)	3.07E+13
RMSE (Root Mean Square Error)	5542349.24
UM (Bias component of MSE)	0.14848
US (Variation component of MSE)	0.14580
UC (Covariation component of MSE)	0.70572

Source of Historical Data:
Gleick,P.H., et al. The World's Water Volume 7: The Biennial Report on Freshwater Resources. Washington: Island Press, 2012.

Biodiversity

Dynamic problems definition

Changes in land cover, land use, climate impact have a significant effect on biodiversity – a variety of plants and animals on the earth. A threat associated with damage to even tiny plants may lead to irreversible consequences to food chains and the whole network of living things.

Changes to biodiversity

The studies on biodiversity indicate its significant loss in the last century. Furthermore the extinction of species seems to be greater than at any other time in human history. The graphs below indicate the changes in biodiversity over the last 300 years and additionally indicate a potential biodiversity level in various biomes.

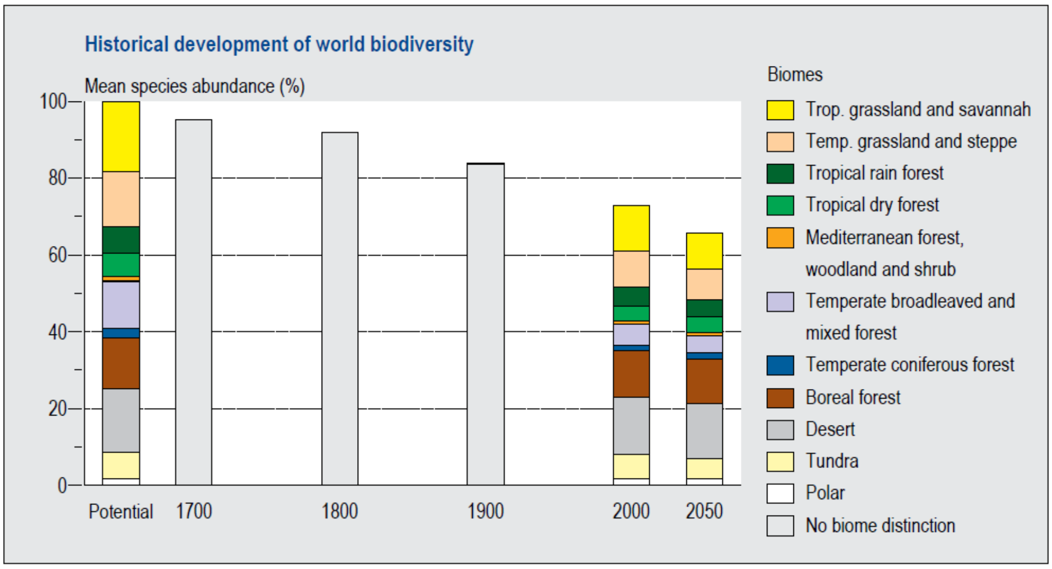


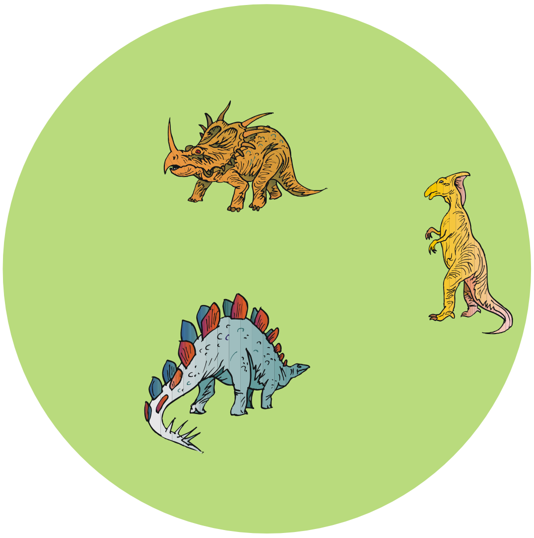
FIGURE 8: Trends in biodiversity from 1700–2050. Biodiversity is given in terms of mean abundance of the original species (MSA) per natural biome. Remaining biodiversity in man-made land-cover types (i.e. arable land and extensively used grassland) are included in the naturally occurring biome. Annexes 3 and 4 contain the regional historical biodiversity development (1700-2050) and the regional spatial biodiversity distribution (2000 and 2050).

Source: Secretariat of the Convention for Biological Diversity (CBD), Cross-roads of Life on Earth - Exploring means to meet the 2010 Biodiversity Target, 2007

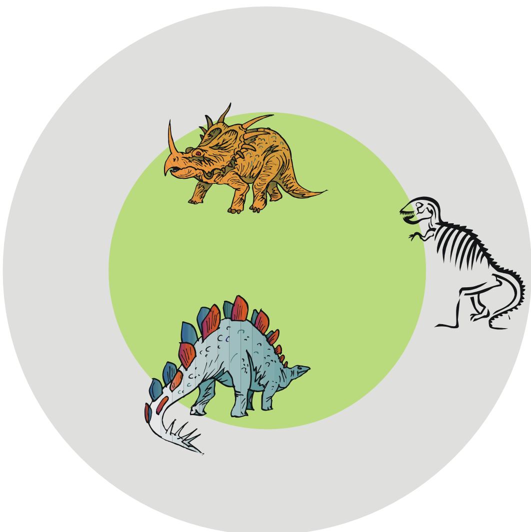
Factors listed as direct drivers of biodiversity change are land -use change (agriculture and forestry), climate change, bioenergy production, infrastructure development, nitrogen deposition and fertilizer use.

System conceptualization

The maximum population size of the species that the environment can sustain indefinitely is called carrying capacity. The carrying capacity may relate to food, habitat, water and other necessities required for various species to exist. The species regenerate and die. Due to species dependencies in the food chain network there might be fluctuations in specific species volume of existence but from the longer time perspective there exist equilibrium.

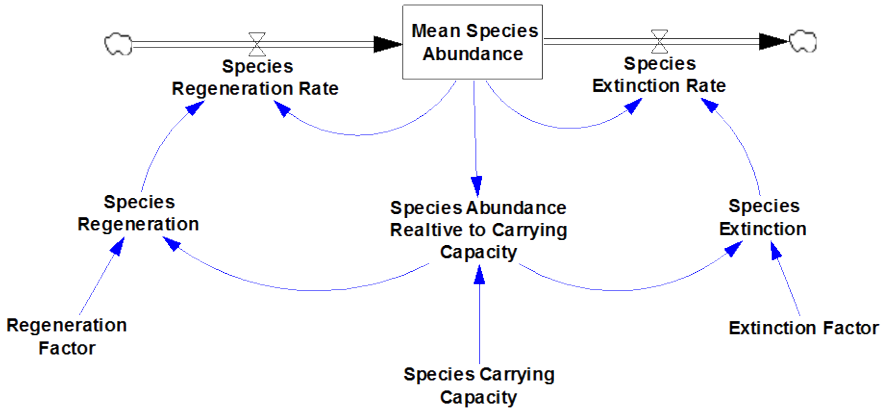


Changing the carrying capacity through for instance damage to one or many necessities of the species (e.g. the planet temperature) might lead to greater or complete extinction of some or all species.

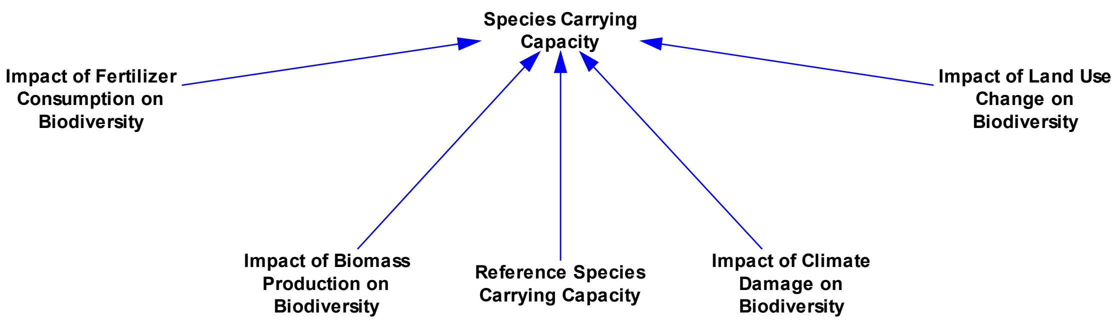


Model formulation

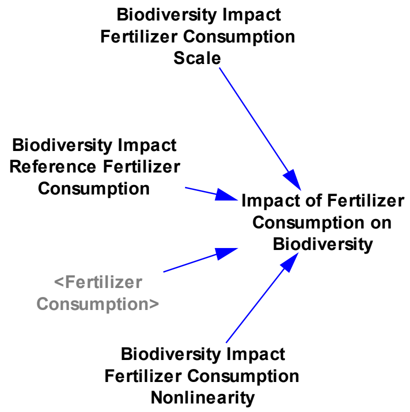
The basis for the Biodiversity model sector is a simple population with carrying capacity structure. The stock is representing global and encompassing all biomes Mean Species Abundance. The stock is increased by Species Regeneration Rate and decreased by Species Extinction Rate.
Mean Species Abundance approaching Species Carrying Capacity limits the Species Regeneration Rate and intensifies Species Extinction Rate.



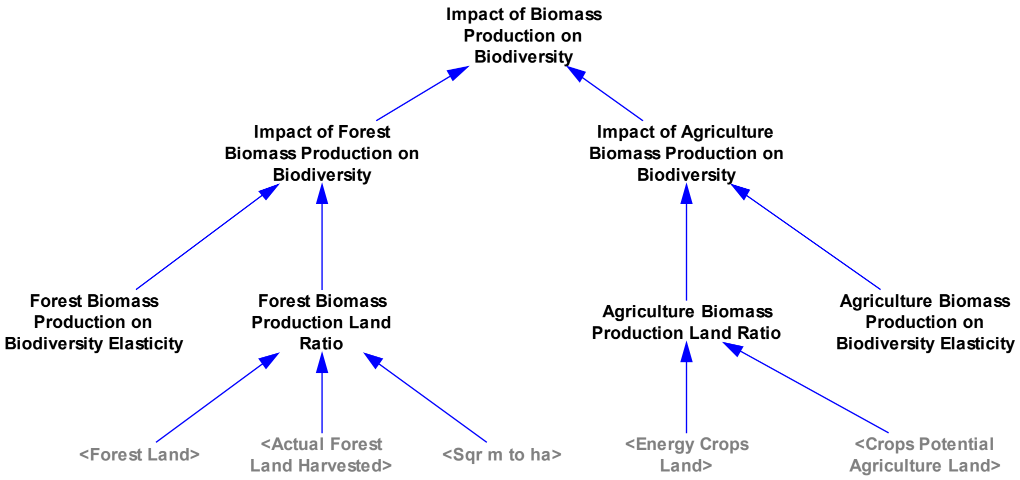
Species Carrying Capacity is a function of Reference Species Carrying Capacity, representing maximum sustained population size, and influencing factors related to fertilizers consumption, biomass production for energy purposes, climate damage and land use change.



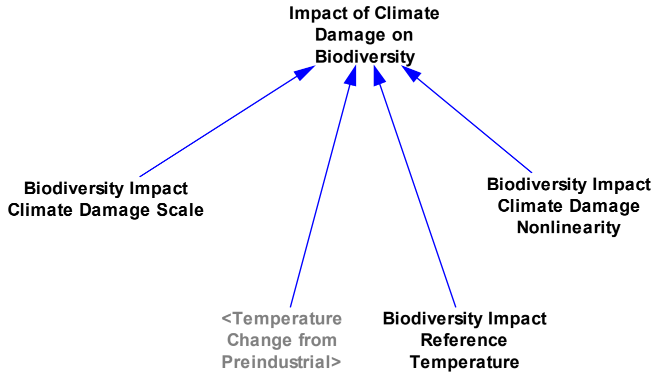
Impact of Fertilizer Consumption on Biodiversity is a nonlinear function of Fertilizer Consumption (nitrogen, phosphate and potash fertilizers).



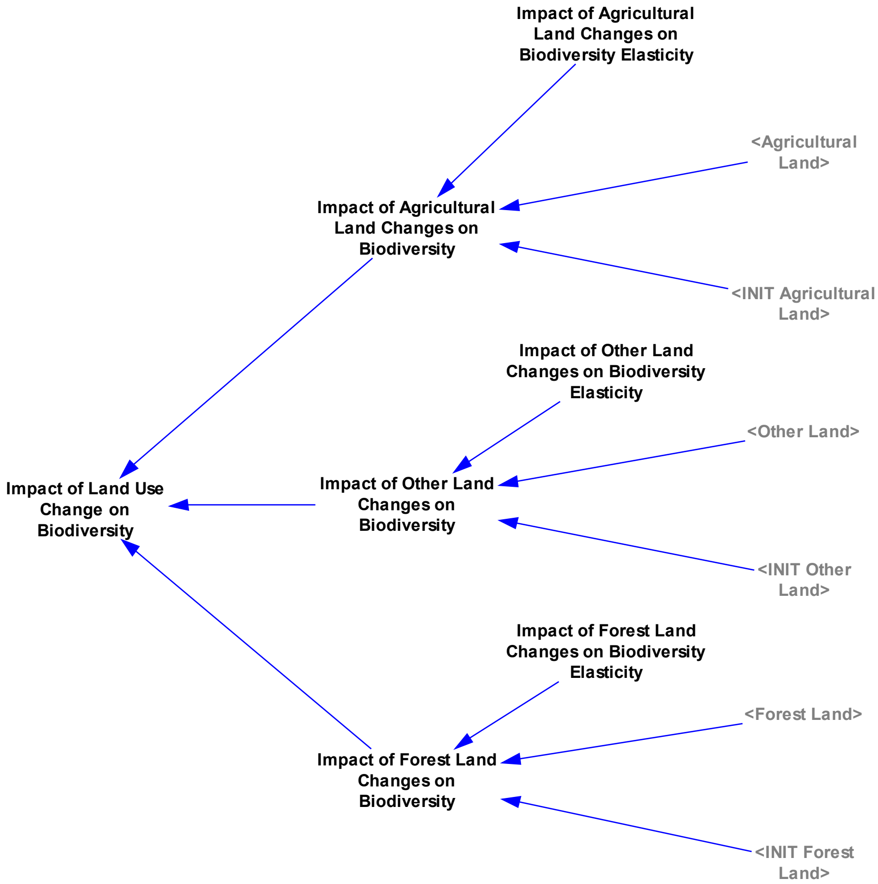
Impact of Biomass Production on Biodiversity consists of Impact of Forest Biomass Production on Biodiversity and Impact of Agriculture Biomass Production on Biodiversity. Both, impact from forest and agriculture biomass production, are nonlinear functions of related land areas.



Impact of Climate Damage on Biodiversity is a nonlinear function of Temperature Change from Preindustrial. The structure is adopted from climate impact on economy.



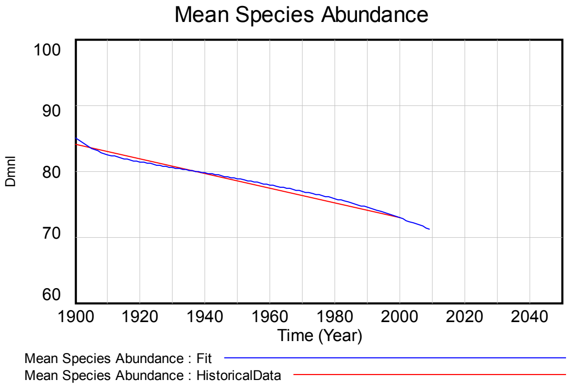
Impact of Land Use Change on Biodiversity takes into consideration changes of Agricultural Land, Other Land and Forest land compared to their initial areas.



Note: Detailed equations behind each model variable are presented in the Appendix.

Simulation

The graph over time below illustrates the fit of selected variable of the Biodiversity model sector to historical data.



Summary Statistics for Historical Fit – Mean Species Abundance

n (Count)	2
R^2 (Coefficient of Determination)	1.00000
MAPE (Mean Absolute Percent Error)	0.00679
MSE (Mean Square Error)	0.508
RMSE (Root Mean Square Error)	0.71243
UM (Bias component of MSE)	0.37885
US (Variation component of MSE)	0.62115
UC (Covariation component of MSE)	0.00000

Note: The test based only on 2 data points – subject to data availability.

Source of Historical Data:
Secretariat of the Convention for Biological Diversity (CBD), Cross-roads of Life on Earth - Exploring means to meet the 2010 Biodiversity Target, 2007

Simulation Scenarios

According to the project methodology, once the model is build and calibrated to the historical data, Business as Usual Scenario is constructed. Next, that scenario is compared to other scenarios constructed to satisfy ‘what if’ questions of researchers, policy makers and other interested parties.

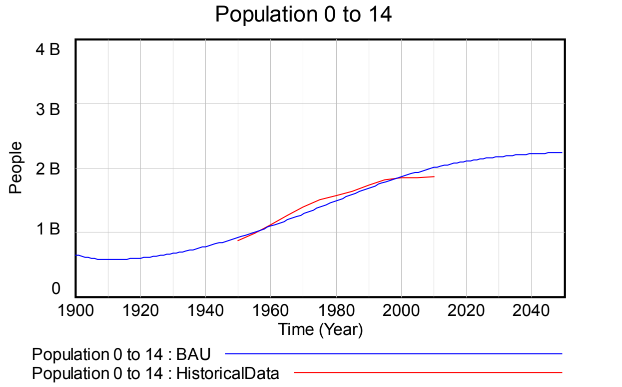
Business as Usual Scenario

Business as Usual (BAU) scenario was constructed by extending the simulation time scale up to year 2050. The values of all parameters across the model are kept the same as in the model calibration period to historical data.

The following series of graphs present Business as Usual scenario for selected in the previous chapters model variables. For all those variables historical data are available. The BAU scenario informs how the phenomena captured by the model variables and illustrated in the graphs would change over the next 40 years if no changes are made to the current situation – no new policies are introduces, no new limits are established – and the currently observable trends continue to drive the Earth system.

The BAU scenario also assumes the RCP2.6 projection (2.6W/m2 projection in the year 2100) for radiative forcings other than CO2 (CO2 radiative forcing is generated endogenously in the FeliX model).

Population



Reported Values

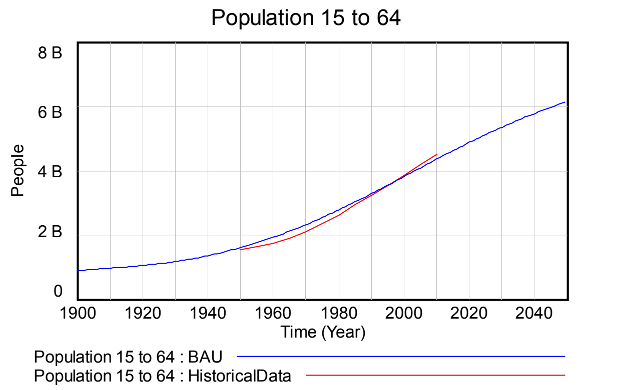
Population 0 to 14 (@1900): 650000000 <people>

Population 0 to 14 (@2010): 1998891520 <people>

Population 0 to 14 (@2050): 2239598080 <people>

% change (1900 v. 2010): 308 <%>

% change (2010 v. 2050): 112 <%>



<u>Reported Values</u>

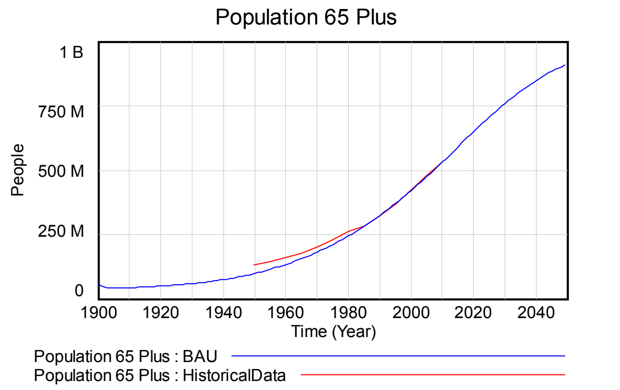
Population 15 to 64 (@1900): 890000000 <people>

Population 15 to 64 (@2010): 4355372032 <people>

Population 15 to 64 (@2050): 6149469696 <people>

% change (1900 v. 2010): 489 <%>

% change (2010 v. 2050): 141 <%>



<u>Reported Values</u>

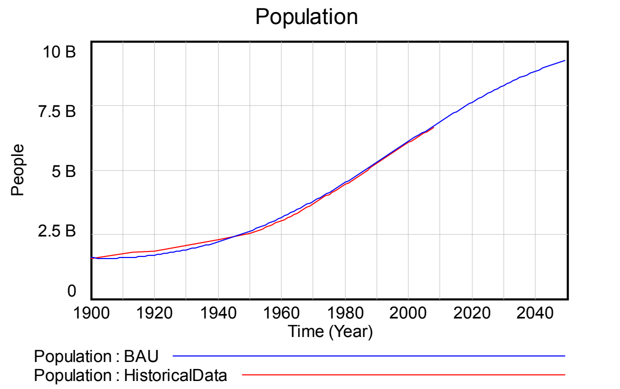
Population 65 Plus (@1900): 60000000 <people>

Population 65 Plus (@2010): 531359008 <people>

Population 65 Plus (@2050): 923582400 <people>

% change (1900 v. 2010): 886 <%>

% change (2010 v. 2050): 174 <%>



<u>Reported Values</u>

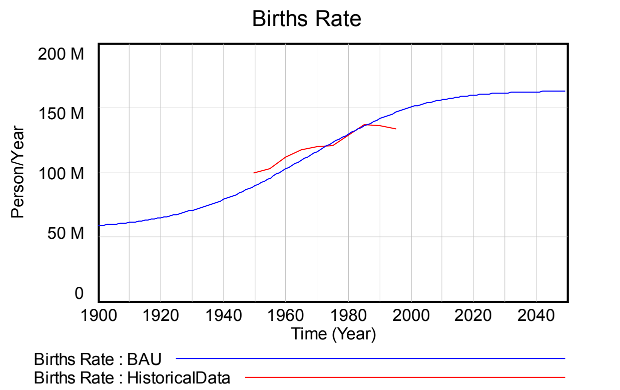
Population (@1900): 1600000000 <people>

Population (@2010): 6885622272 <people>

Population (@2050): 9312649216 <people>

% change (1900 v. 2010): 430 <%>

% change (2010 v. 2050): 135 <%>



<u>Reported Values</u>

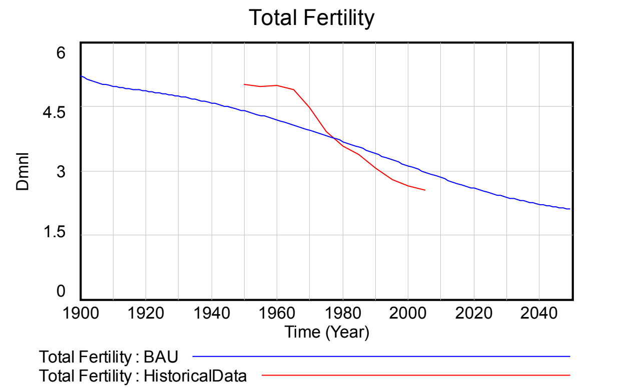
Births Rate (@1900): 58664520 <people/year>

Births Rate (@2010): 156369664 <people/year>

Births Rate (@2050): 162813328 <people/year>

% change (1900 v. 2010): 267 <%>

% change (2010 v. 2050): 104 <%>



Reported Values

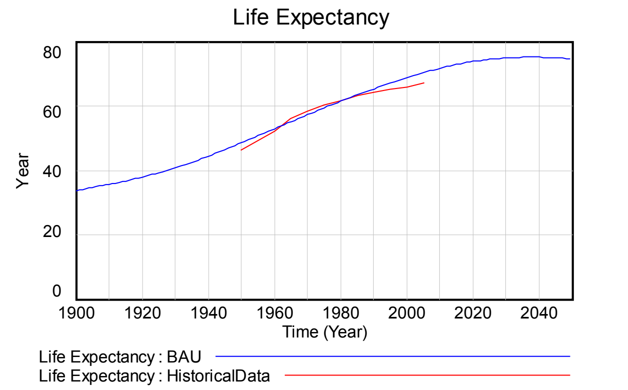
Total Fertility (@1900): 5.204 <dmnl>

Total Fertility (@2010): 2.834 <dmnl>

Total Fertility (@2050): 2.09 <dmnl>

% change (1900 v. 2010): 54 <%>

% change (2010 v. 2050): 74 <%>



Reported Values

Life Expectancy (@1900): 33.63 <year>

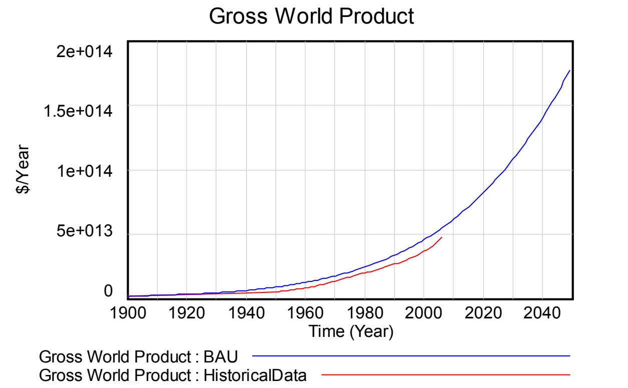
Life Expectancy (@2010): 71.69 <year>

Life Expectancy (@2050): 75.14 <year>

% change (1900 v. 2010): 213 <%>

% change (2010 v. 2050): 105 <%>

Economy



Reported Values

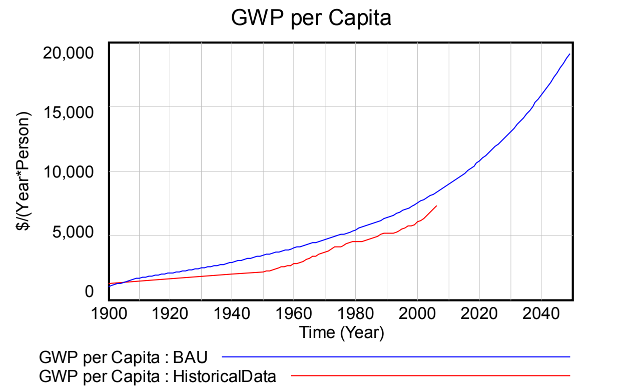
Gross World Product (@1900): 1587950125056 <$/year>

Gross World Product (@2010): 61638287818752 <$/year>

Gross World Product (@2050): 180939791532032 <$/year>

% change (1900 v. 2010): 3882 <%>

% change (2010 v. 2050): 294 <%>



Reported Values

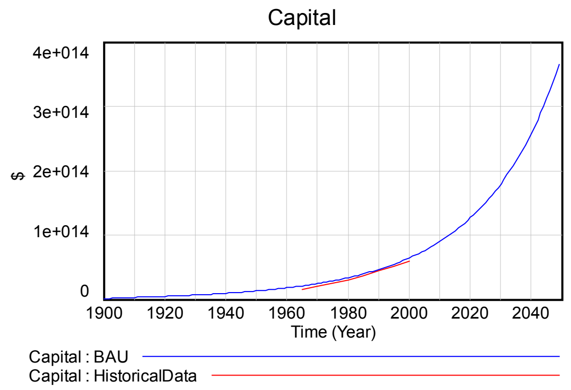
Capital (@1900): 1300000014336 <$>

Capital (@2010): 89856856293376 <$>

Capital (@2050): 377532826255360 <$>

% change (1900 v. 2010): 6912 <%>

% change (2010 v. 2050): 420 <%>



Reported Values

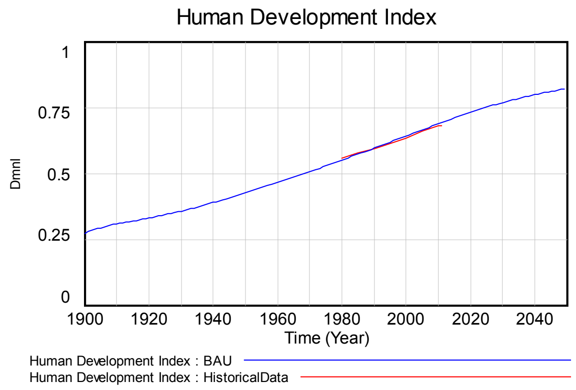
Value (1900):

Value (2010):

Vale (2050):

Change between 1900 – 2050:

Change between 2010 – 2050:



Reported Values

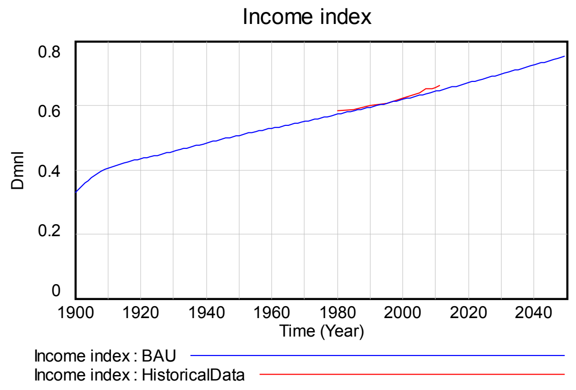
Human Development Index (@1900): 0.274 <dmnl>

Human Development Index (@2010): 0.688 <dmnl>

Human Development Index (@2050): 0.824 <dmnl>

% change (1900 v. 2010): 251 <%>

% change (2010 v. 2050): 120 <%>



Reported Values

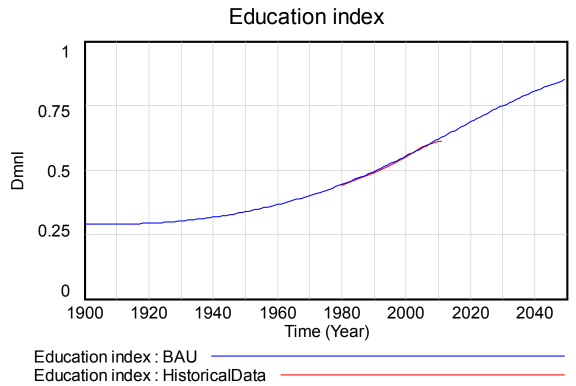
Income Index (@1900): 0.329 <dmnl>

Income Index (@2010): 0.644 <dmnl>

Income Index (@2050): 0.755 <dmnl>

% change (1900 v. 2010): 196 <%>

% change (2010 v. 2050): 117 <%>



Reported Values

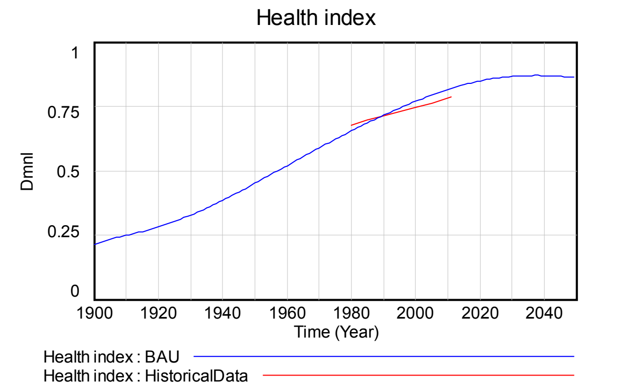
Education Index (@1900): 0.29 <dmnl>

Education Index (@2010): 0.62 <dmnl>

Education Index (@2050): 0.854 <dmnl>

% change (1900 v. 2010): 214 <%>

% change (2010 v. 2050): 138 <%>



<u>Reported Values</u>

Health Index (@1900): 0.215 <dmnl>

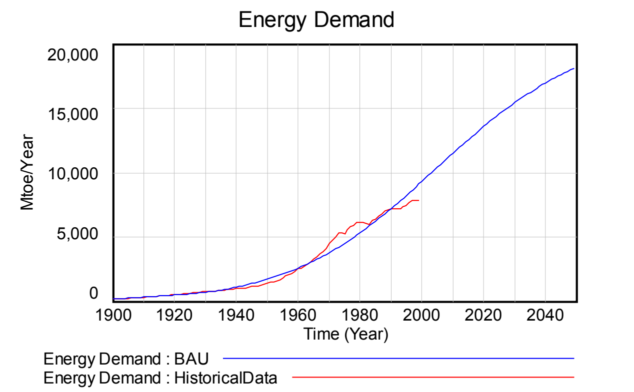
Health Index (@2010): 0.815 <dmnl>

Health Index (@2050): 0.87 <dmnl>

% change (1900 v. 2010): 379 <%>

% change (2010 v. 2050): 107 <%>

Energy



<u>Reported Values</u>

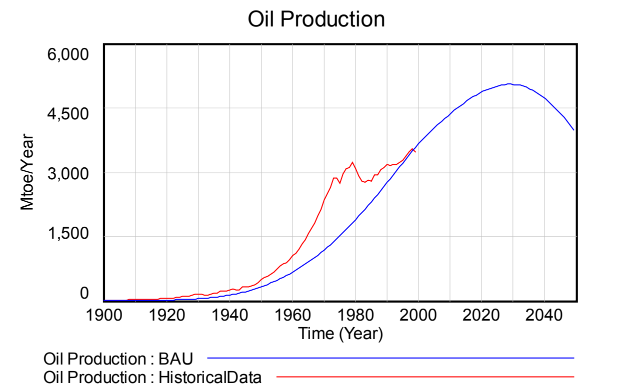
Energy Demand (@1900): 181 <mtoe/year>

Energy Demand (@2010): 11496 <mtoe/year>

Energy Demand (@2050): 18197 <mtoe/year>

% change (1900 v. 2010): 6351 <%>

% change (2010 v. 2050): 158 <%>



<u>Reported Values</u>

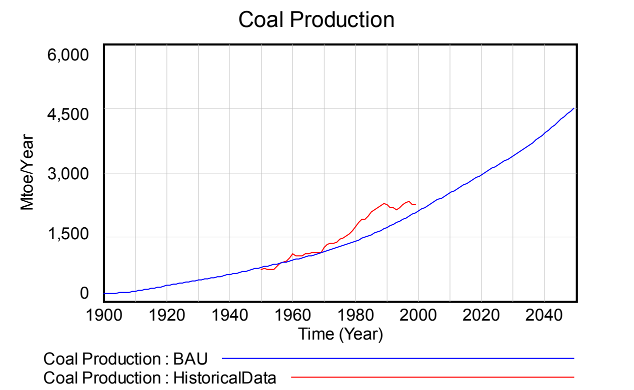
Oil Production (@1900): 4 <mtoe/year>

Oil Production (@2010): 4373 <mtoe/year>

Oil Production (@2050): 3914 <mtoe/year>

% change (1900 v. 2010): 109325 <%>

% change (2010 v. 2050): 90 <%>



<u>Reported Values</u>

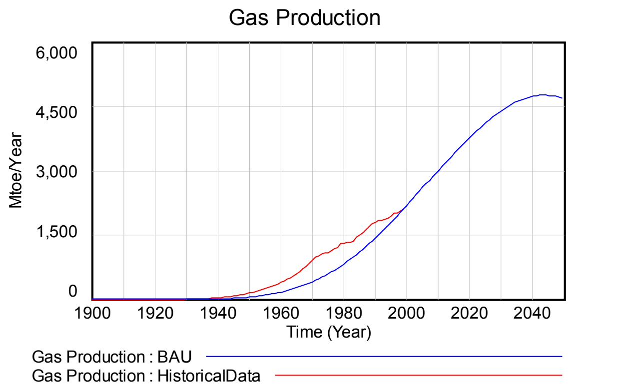
Coal Production (@1900): 175 <mtoe/year>

Coal Production (@2010): 2533 <mtoe/year>

Coal Production (@2050): 4544 <mtoe/year>

% change (1900 v. 2010): 1447 <%>

% change (2010 v. 2050): 179 <%>



Reported Values

Gas Production (@1900): 0 <mtoe/year>

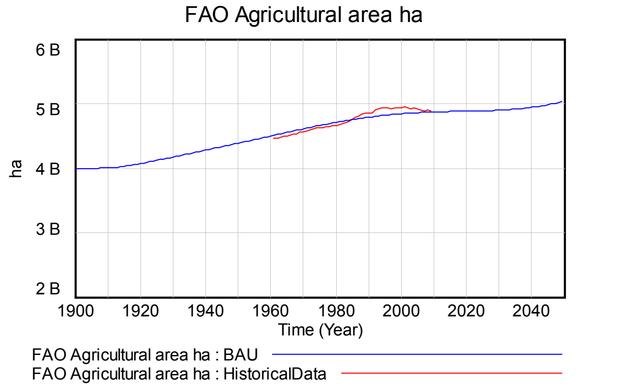
Gas Production (@2010): 3013 <mtoe/year>

Gas Production (@2050): 4683 <mtoe/year>

% change (1900 v. 2010): 301300 <%>

% change (2010 v. 2050): 155 <%>

Land Use



Reported Values

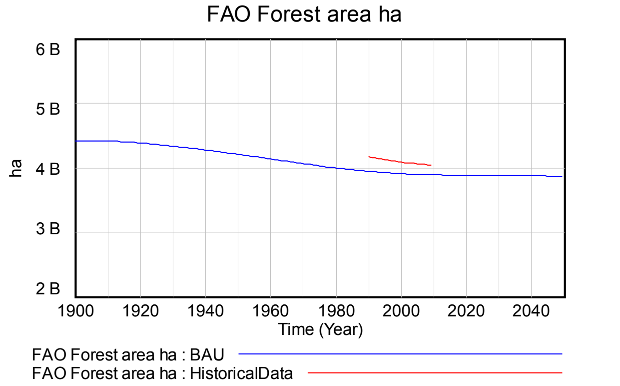
FAO Agricultural area ha (@1900): 3999999744 <ha>

FAO Agricultural area ha (@2010): 4871836672 <ha>

FAO Agricultural area ha (@2050): 4996419072 <ha>

% change (1900 v. 2010): 122 <%>

% change (2010 v. 2050): 103 <%>



Reported Values

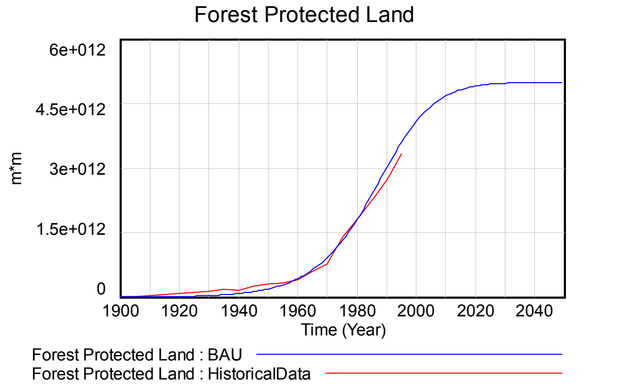
FAO Forest area ha (@1900): 4409999872 <ha>

FAO Forest area ha (@2010): 3888076288 <ha>

FAO Forest area ha (@2050): 3872361472 <ha>

% change (1900 v. 2010): 88 <%>

% change (2010 v. 2050): 100 <%>



Reported Values

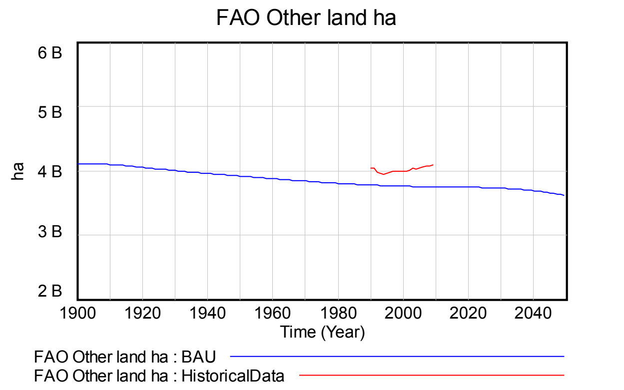
Forest Protected Land (@1900): 2822540032 <ha>

Forest Protected Land (@2010): 4681673211904 <ha>

Forest Protected Land (@2050): 4998130827264 <ha>

% change (1900 v. 2010): 165867 <%>

% change (2010 v. 2050): 107 <%>



Reported Values

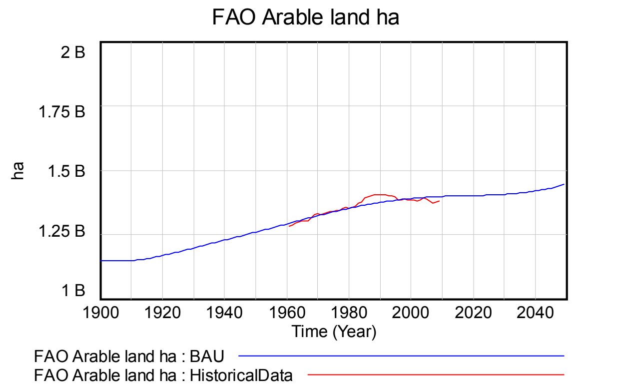
FAO Other land ha (@1900): 4100000000 <ha>

FAO Other land ha (@2010): 3750032128 <ha>

FAO Other land ha (@2050): 3641191424 <ha>

% change (1900 v. 2010): 91 <%>

% change (2010 v. 2050): 97 <%>



Reported Values

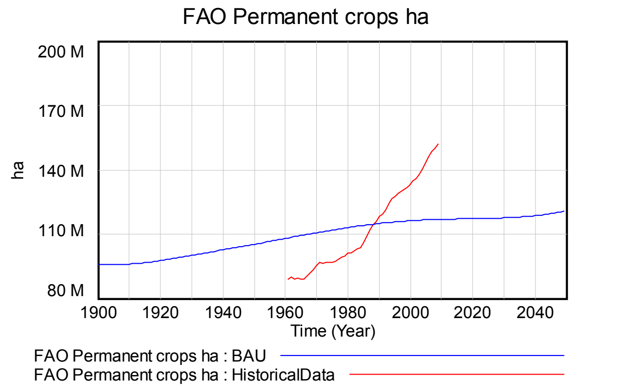
FAO Arable land ha (@1900): 1147999872 <ha>

FAO Arable land ha (@2010): 1398217216 <ha>

FAO Arable land ha (@2050): 1433972224 <ha>

% change (1900 v. 2010): 122 <%>

% change (2010 v. 2050): 103 <%>



Reported Values

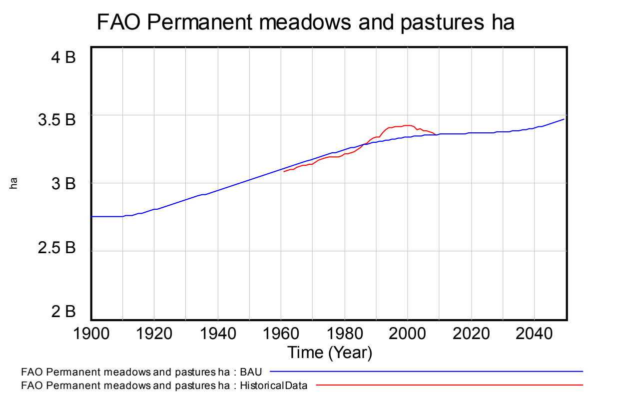
FAO Permanent crops ha (@1900): 95999992 <ha>

FAO Permanent crops ha (@2010): 116924088 <ha>

FAO Permanent crops ha (@2050): 119914056 <ha>

% change (1900 v. 2010): 122 <%>

% change (2010 v. 2050): 103 <%>



Reported Values

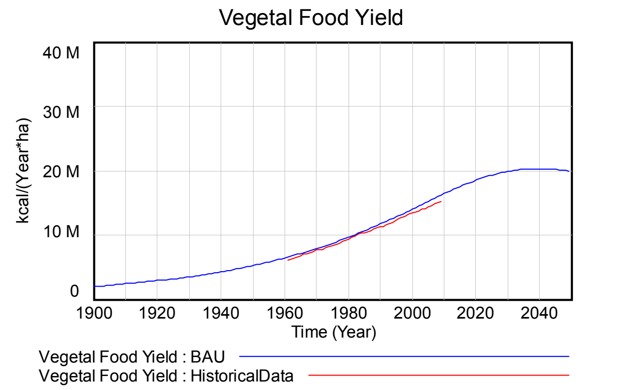
FAO Permanent meadows and pastures ha (@1900): 2755999744 <ha>

FAO Permanent meadows and pastures ha (@2010): 3356695552 <ha>

FAO Permanent meadows and pastures ha (@2050): 3442532608 <ha>

% change (1900 v. 2010): 122 <%>

% change (2010 v. 2050): 103 <%>



Reported Values

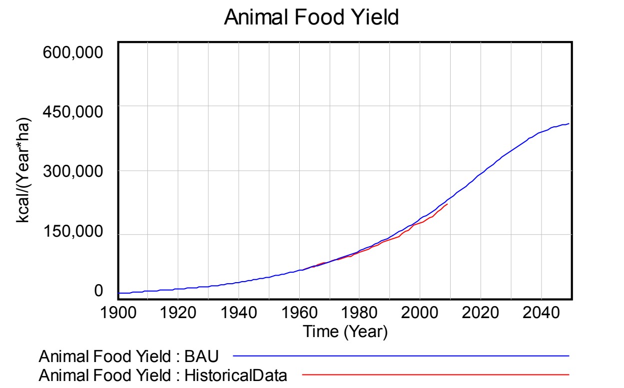
Vegetal Food Yield (@1900): 1957745 <kcal/(year*ha)>

Vegetal Food Yield (@2010): 16409304 <kcal/(year*ha)>

Vegetal Food Yield (@2050): 20778154 <kcal/(year*ha)>

% change (1900 v. 2010): 838 <%>

% change (2010 v. 2050): 127 <%>



Reported Values

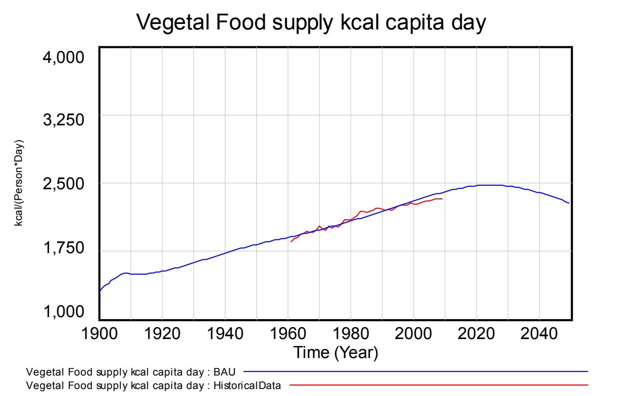
Animal Food Yield (@1900): 12186 <kcal/(year*ha)>

Animal Food Yield (@2010): 234997 <kcal/(year*ha)>

Animal Food Yield (@2050): 427467 <kcal/(year*ha)>

% change (1900 v. 2010): 1928 <%>

% change (2010 v. 2050): 182 <%>



Reported Values

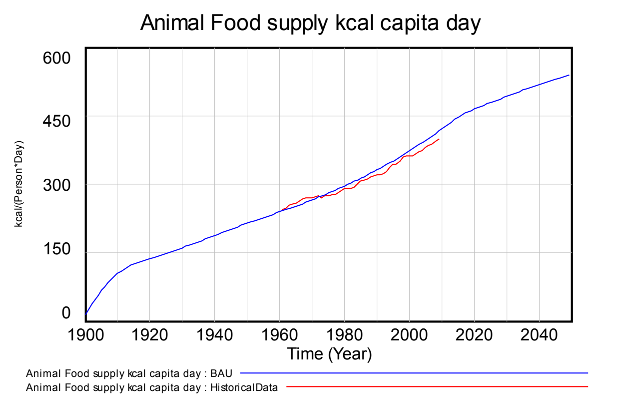
Vegetal Food supply kcal capita day (@1900): 1309 <kcal/(person*day)>

Vegetal Food supply kcal capita day (@2010): 2408 <kcal/(person*day)>

Vegetal Food supply kcal capita day (@2050): 2354 <kcal/(person*day)>

% change (1900 v. 2010): 184 <%>

% change (2010 v. 2050): 98 <%>



Reported Values

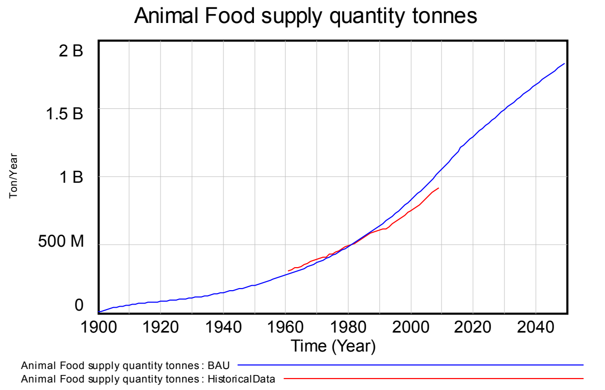
Animal Food supply kcal capita day (@1900): 16 <kcal/(person*day)>

Animal Food supply kcal capita day (@2010): 421 <kcal/(person*day)>

Animal Food supply kcal capita day (@2050): 542 <kcal/(person*day)>

% change (1900 v. 2010): 2631 <%>

% change (2010 v. 2050): 129 <%>



Reported Values

Animal Food supply quantity tonnes (@1900): 9093713 <ton/year>

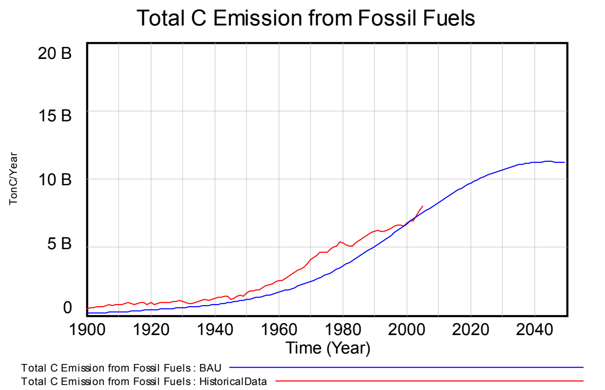
Animal Food supply quantity tonnes (@2010): 1057342208 <ton/year>

Animal Food supply quantity tonnes (@2050): 1841559552 <ton/year>

% change (1900 v. 2010): 11627 <%>

% change (2010 v. 2050): 174 <%>

Carbon Cycle



Reported Values

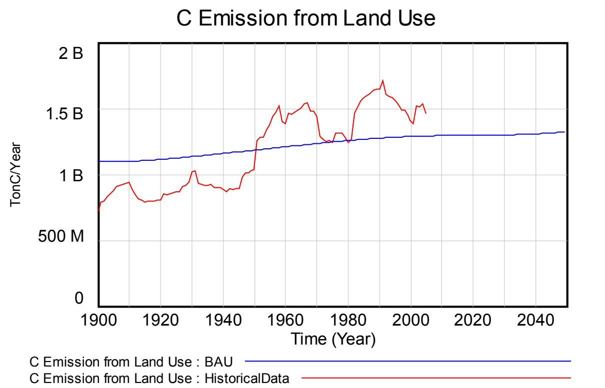
Total C Emission from Fossil Fuels (@1900): 192667680 <tonC/year>

Total C Emission from Fossil Fuels (@2010): 8316642816 <tonC/year>

Total C Emission from Fossil Fuels (@2050): 7746059264 <tonC/year>

% change (1900 v. 2010): 4317 <%>

% change (2010 v. 2050): 93 <%>



Reported Values

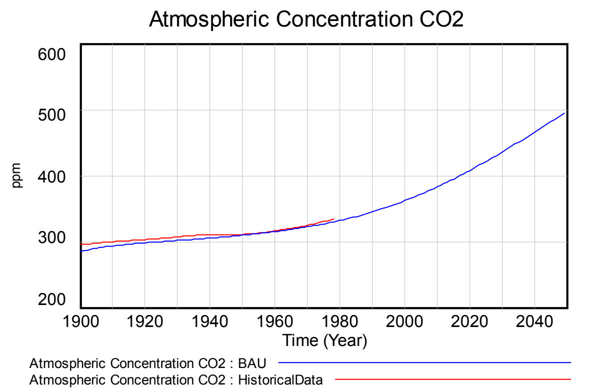
C Emission from Land Use (@1900): 1100000000 <tonC/year>

C Emission from Land Use (@2010): 1294930944 <tonC/year>

C Emission from Land Use (@2050): 1316779264 <tonC/year>

% change (1900 v. 2010): 118 <%>

% change (2010 v. 2050): 102 <%>



Reported Values

Atmospheric Concentration CO2 (@1900): 285 <ppm>

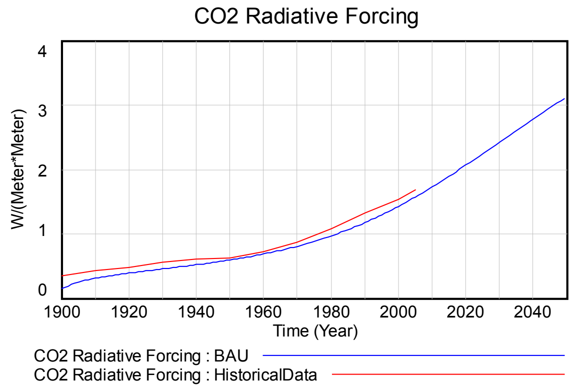
Atmospheric Concentration CO2 (@2010): 383 <ppm>

Atmospheric Concentration CO2 (@2050): 477 <ppm>

% change (1900 v. 2010): 134 <%>

% change (2010 v. 2050): 125 <%>

Climate



Reported Values

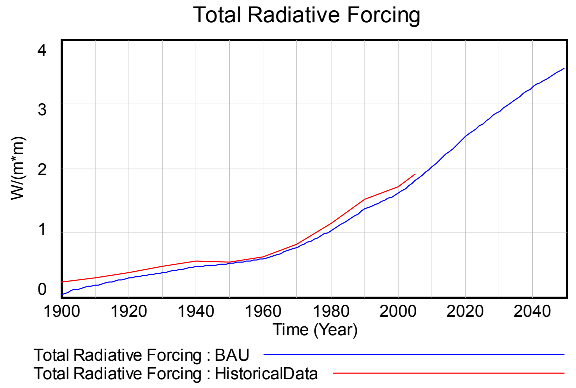
CO2 Radiative Forcing (@1900): 0.147 <watt/m*m>

CO2 Radiative Forcing (@2010): 1.73 < watt/m*m>

CO2 Radiative Forcing (@2050): 2.907 < watt/m*m>

% change (1900 v. 2010): 1177 <%>

% change (2010 v. 2050): 168 <%>



Reported Values

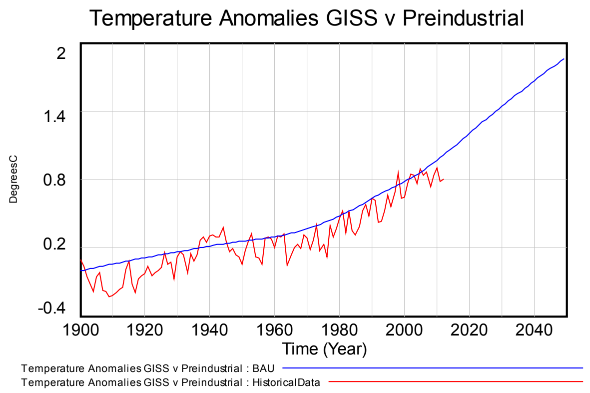
Total Radiative Forcing (@1900): 0.036 <watt/m*m>

Total Radiative Forcing (@2010): 2.02 <watt/m*m>

Total Radiative Forcing (@2050): 3.356 <watt/m*m>

% change (1900 v. 2010): 5611 <%>

% change (2010 v. 2050): 166 <%>



Reported Values

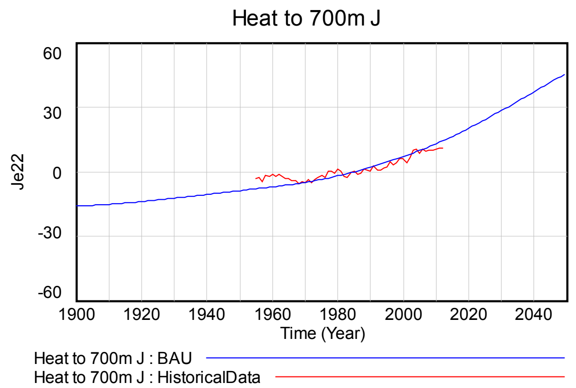
Temperature Anomalies GISS v Preindustrial (@1900): 0 <degreeC>

Temperature Anomalies GISS v Preindustrial (@2010): 0.966 <degreeC>

Temperature Anomalies GISS v Preindustrial (@2050): 1.789 <degreeC>

% change (1900 v. 2010): 966 <%>

% change (2010 v. 2050): 185 <%>



Reported Values

Heat to 700m J (@1900): -16 <Je22>

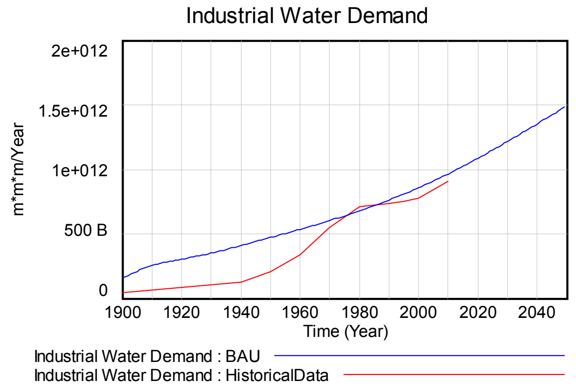
Heat to 700m J (@2010): 12.928 <Je22>

Heat to 700m J (@2050): 44.401 <Je22>

% change (1900 v. 2010): -81 <%>

% change (2010 v. 2050): 343 <%>

Water



Reported Values

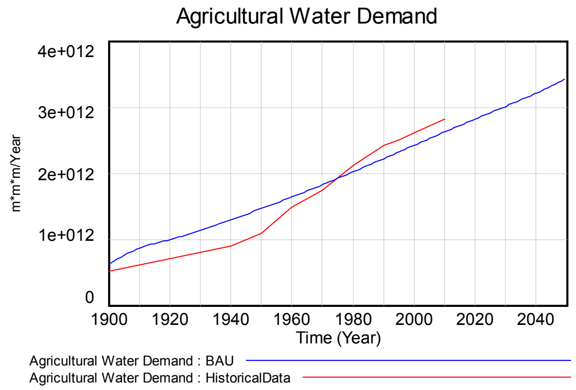
Industrial Water Demand (@1900): 154448658432 <m*m*m/year>

Industrial Water Demand (@2010): 965806981120 <m*m*m/year>

Industrial Water Demand (@2050): 1493337636864 <m*m*m/year>

% change (1900 v. 2010): 625 <%>

% change (2010 v. 2050): 155 <%>



Reported Values

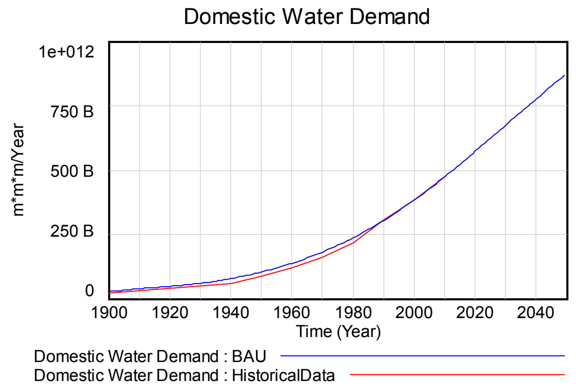
Agricultural Water Demand (@1900): 618888298496 <m*m*m/year>

Agricultural Water Demand (@2010): 2623122440192 <m*m*m/year>

Agricultural Water Demand (@2050): 3403296276480 <m*m*m/year>

% change (1900 v. 2010): 424 <%>

% change (2010 v. 2050): 130 <%>



Reported Values

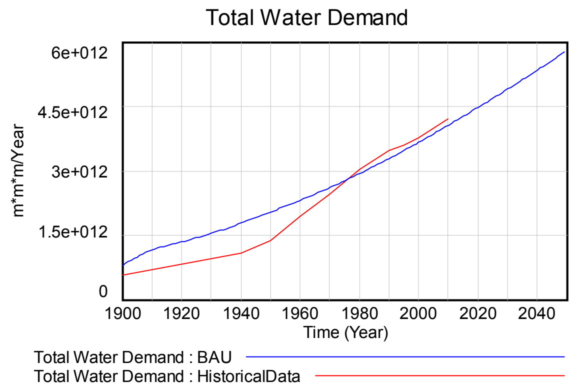
Domestic Water Demand (@1900): 27501830144 <m*m*m/year>

Domestic Water Demand (@2010): 473496256512 <m*m*m/year>

Domestic Water Demand (@2050): 876567592960 <m*m*m/year>

% change (1900 v. 2010): 1722 <%>

% change (2010 v. 2050): 185 <%>



Reported Values

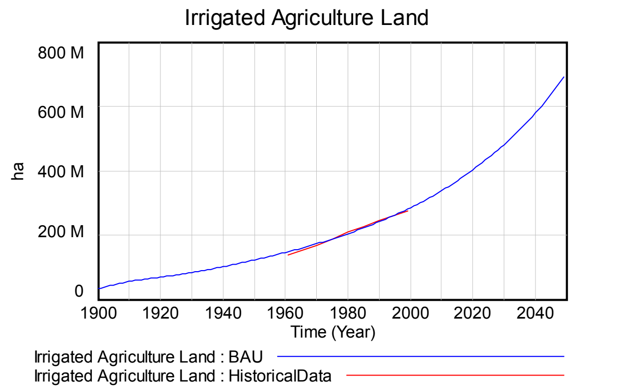
Total Water Demand (@1900): 800838778880 <m*m*m/year>

Total Water Demand (@2010): 4062425907200 <m*m*m/year>

Total Water Demand (@2050): 5773202030592 <m*m*m/year>

% change (1900 v. 2010): 507 <%>

% change (2010 v. 2050): 142 <%>



Reported Values

Irrigated Agriculture Land (@1900): 32810928 <ha>

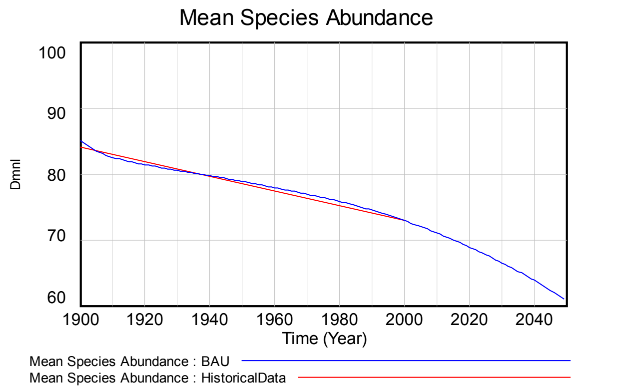
Irrigated Agriculture Land (@2010): 338192864 <ha>

Irrigated Agriculture Land (@2050): 696241536 <ha>

% change (1900 v. 2010): 1031 <%>

% change (2010 v. 2050): 206 <%>

Biodiversity



Reported Values

Mean Species Abundance (@1900): 85 <dmnl>

Mean Species Abundance (@2010): 71.055 <dmnl>

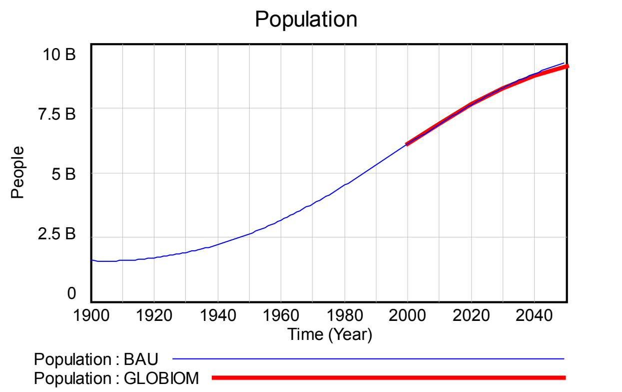
Mean Species Abundance (@2050): 60.934 <dmnl>

% change (1900 v. 2010): 84 <%>

% change (2010 v. 2050): 86 <%>

Comparison to other BAU scenarios

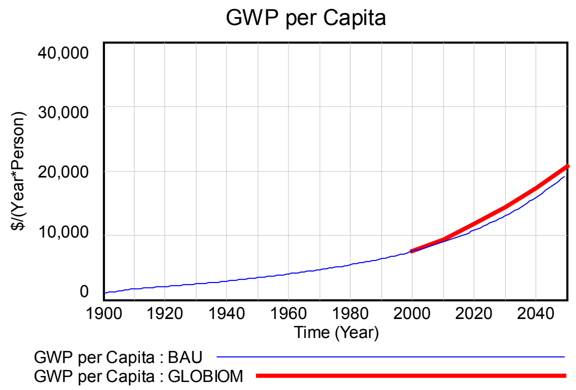
Many models and assessments generate predictions regarding the future development. In the following graphs the FeliX model results are compared to some results of GLOBIOM model developed at IIASA as well as Representative Concentration Pathways (RCPs) prepared for the Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC).



Summary Statistics for Other Scenarios Fit – Population

n (Count)	6
R^2 (Coefficient of Determination)	0.99796
MAPE (Mean Absolute Percent Error)	0.00594
MSE (Mean Square Error)	7.40E+15
RMSE (Root Mean Square Error)	86020776.2
UM (Bias component of MSE)	0.29876
US (Variation component of MSE)	0.38127
UC (Covariation component of MSE)	0.31997

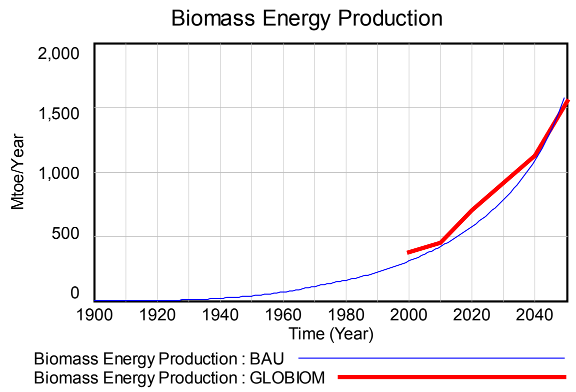
Source of Other Scenarios Data:
GLOBIOM model – WWF Living Forest Report Simulator



Summary Statistics for Other Scenarios Fit – GWP per Capita

n (Count)	6
R^2 (Coefficient of Determination)	0.99587
MAPE (Mean Absolute Percent Error)	0.06202
MSE (Mean Square Error)	1.12E+06
RMSE (Root Mean Square Error)	1056.76
UM (Bias component of MSE)	0.75621
US (Variation component of MSE)	0.17462
UC (Covariation component of MSE)	0.06917

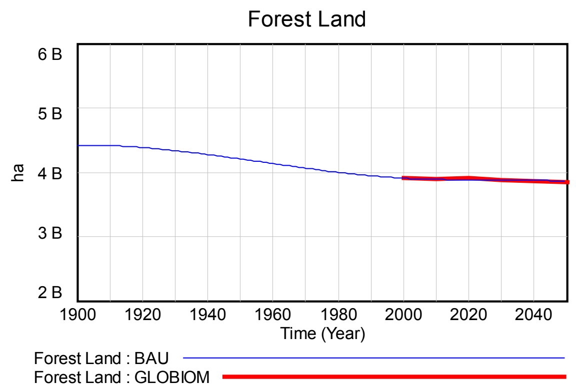
Source of Other Scenarios Data:
GLOBIOM model – WWF Living Forest Report Simulator



Summary Statistics for Other Scenarios Fit – Biomass Energy Production

n (Count)	6
R^2 (Coefficient of Determination)	0.98313
MAPE (Mean Absolute Percent Error)	0.10386
MSE (Mean Square Error)	7.57E+03
RMSE (Root Mean Square Error)	87
UM (Bias component of MSE)	0.24183
US (Variation component of MSE)	0.34976
UC (Covariation component of MSE)	0.40841

Source of Other Scenarios Data:
GLOBIOM model – WWF Living Forest Report Simulator



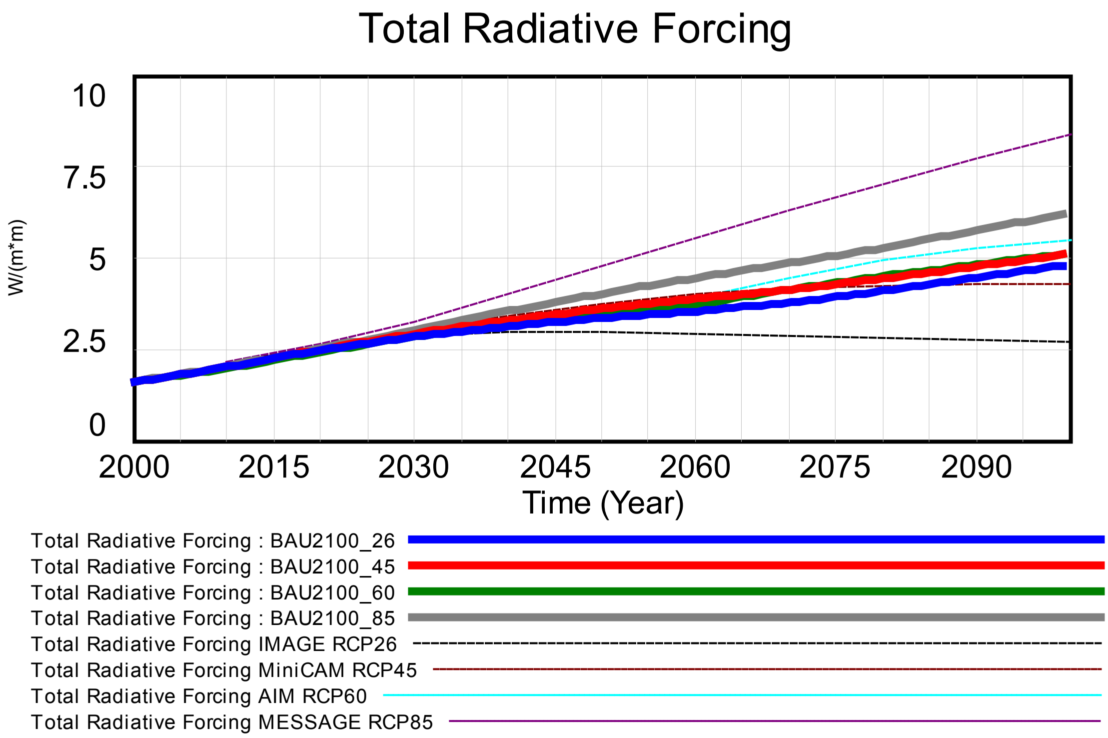
Summary Statistics for Other Scenarios Fit – Forest Land

n (Count)	6
R^2 (Coefficient of Determination)	0.75827
MAPE (Mean Absolute Percent Error)	0.00297
MSE (Mean Square Error)	2.10E+14
RMSE (Root Mean Square Error)	14488810.63
UM (Bias component of MSE)	0.00013
US (Variation component of MSE)	0.47471
UC (Covariation component of MSE)	0.52516

Source of Other Scenarios Data:
GLOBIOM model – WWF Living Forest Report Simulator

In order to compare Total Radiative Forcing generated by the FeliX model against Representative Concentration Pathways (RCPs) the Business as Usual scenario time scale was extended to year 2100 (scenario name: BAU2100). The time scale extension will be supportive in the scenarios comparison, since the four RCPs – RCP2.6, RCP4.5, RCP6, and RCP8.5 – are named after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6.0, and 8.5 W/m2, respectively).

In FeliX model the CO2 radiative forcing is generated endogenously. Methane (CH4), nitrous oxide N2O, halocarbons and other forcings (aerosols, O3, etc.) come from RCPs projections. Thus the FeliX BAU2100 was run four times (BAU2100_26, BAU2100_45, BAU2100_60, BAU2100_85) to account for various projections of forcings other than CO2.



With obtained values 4.799W/m2, 5.084W/m2, 5.095W/m2, 6.180W/m2 for BAU2100_26, BAU2100_45, BAU2100_60, BAU2100_85 respectively, the FeliX model results are close to AIM RCP6.0 results (5.481W/m2 in 2100) and MiniCAM RCP4.5 (4.309W/m2 in 2100).

Impact Simulation Scenarios

Based on some assumptions regarding potential or necessary policies, future targets or just to satisfy ‘what if’ research questions a variety of simulation scenarios might be constructed. Since the model consists of interrelated Population, Economy, Energy, Land Use, Carbon Cycle, Climate, Water, Biodiversity sectors that cover all nine Societal Benefits Areas, the outcome of the simulation scenarios aim at conducting integrated assessment of investigated changes as compared to Business as Usual scenario.

GEO Scenarios

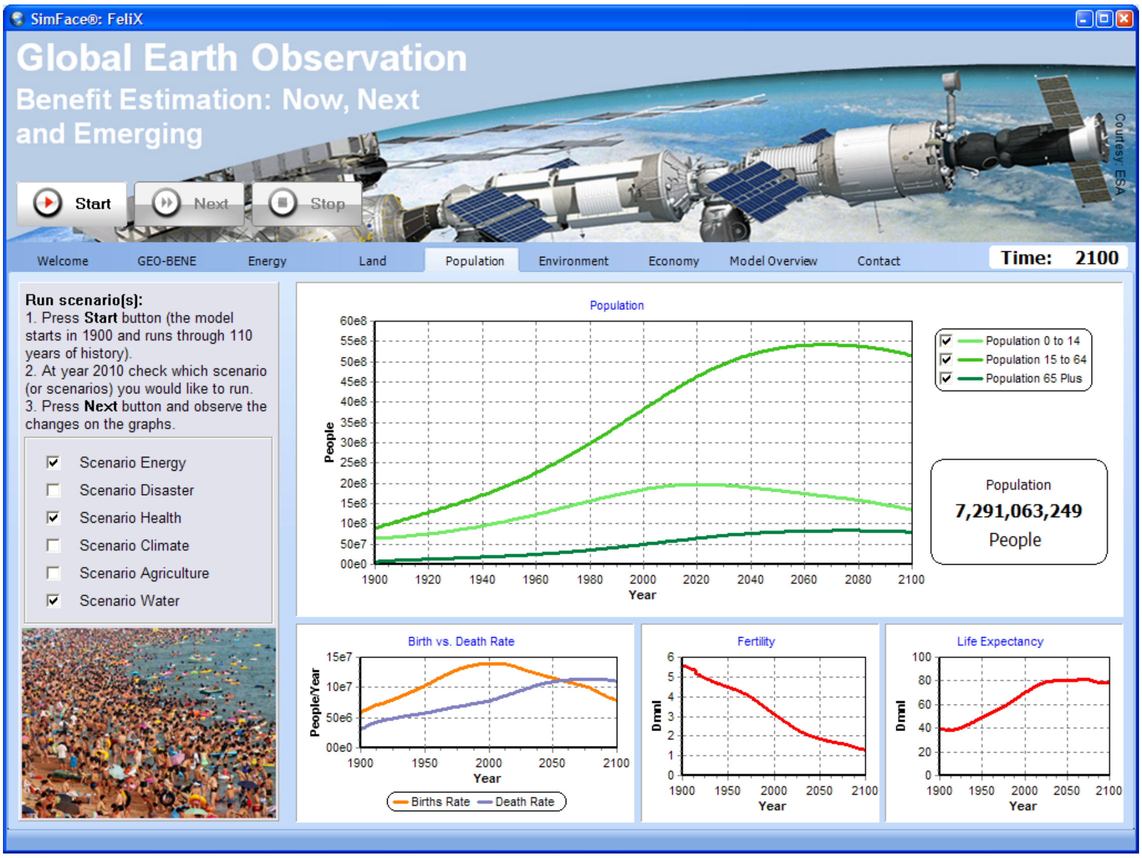
Over the course of the FeliX model use a set of simulation scenarios were constructed. In GEOBENE project these were thematic scenarios around Energy, Disaster, Health, Climate, Agriculture and Water. For the purpose of the EuroGEOSS project first storylines were constructed which in turn were used to define simulation scenarios under Drought, Biodiversity and Forest themes. The scenarios and their results are further described in Rydzak et al. (2009), Rydzak et al. (2010) and Obersteiner et al. (2012).

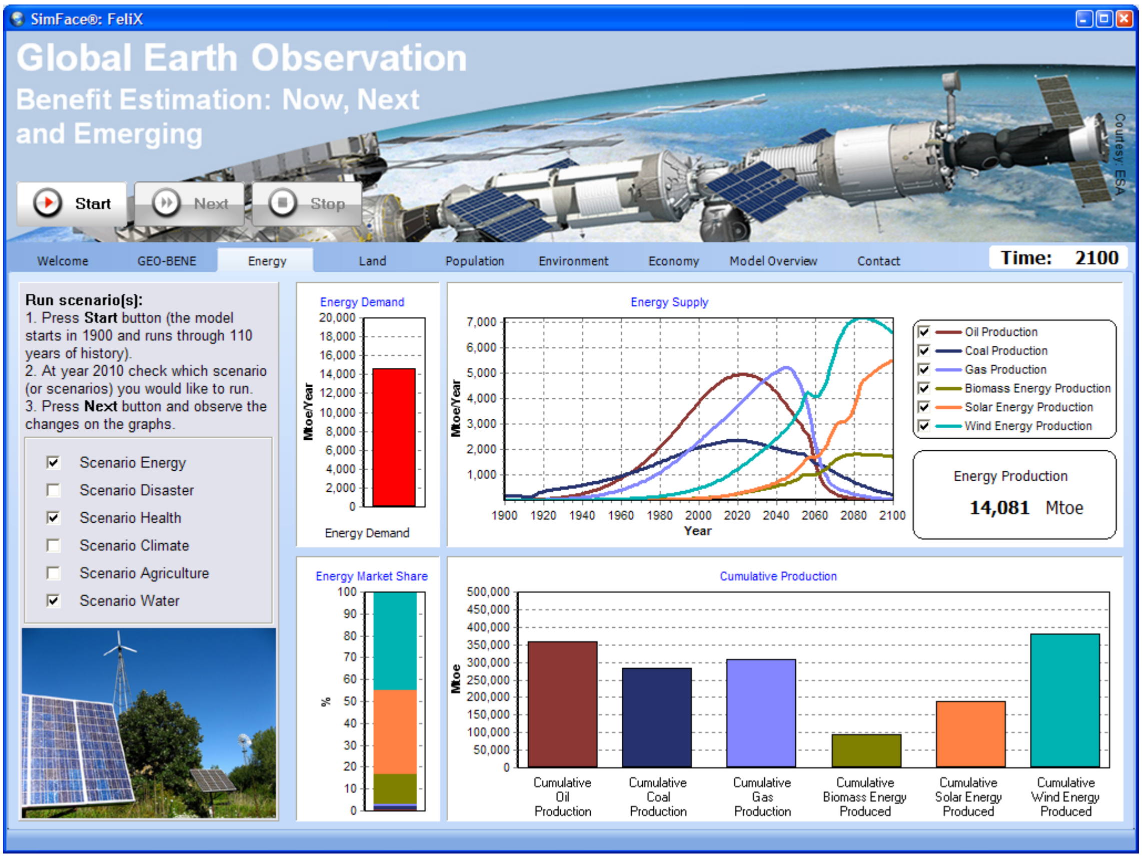
Apart from the System Dynamics model, scenario storylines and results of GEO simulation scenarios in the course of the projects simulators were developed. Their role was to support decision makers in gaining deeper understanding of the volume of the problems and the dynamics of phenomena being considered due to many interrelations in the complex Earth system.

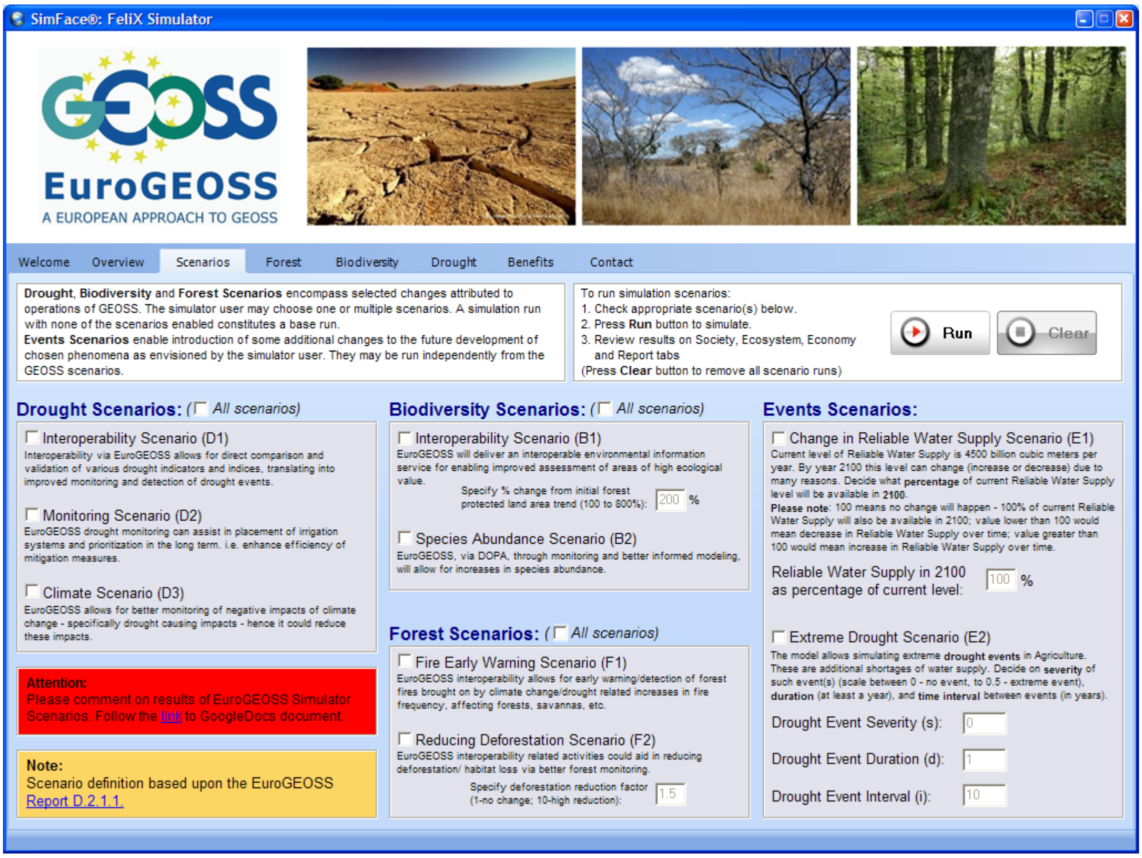
The simulators were developed using Vention[5] software allowing import of the System Dynamics models and building Graphical User Interfaces. Such simulators help those without modeling and simulation background get acquainted with a given problem without a need to first learn how to use simulation software.

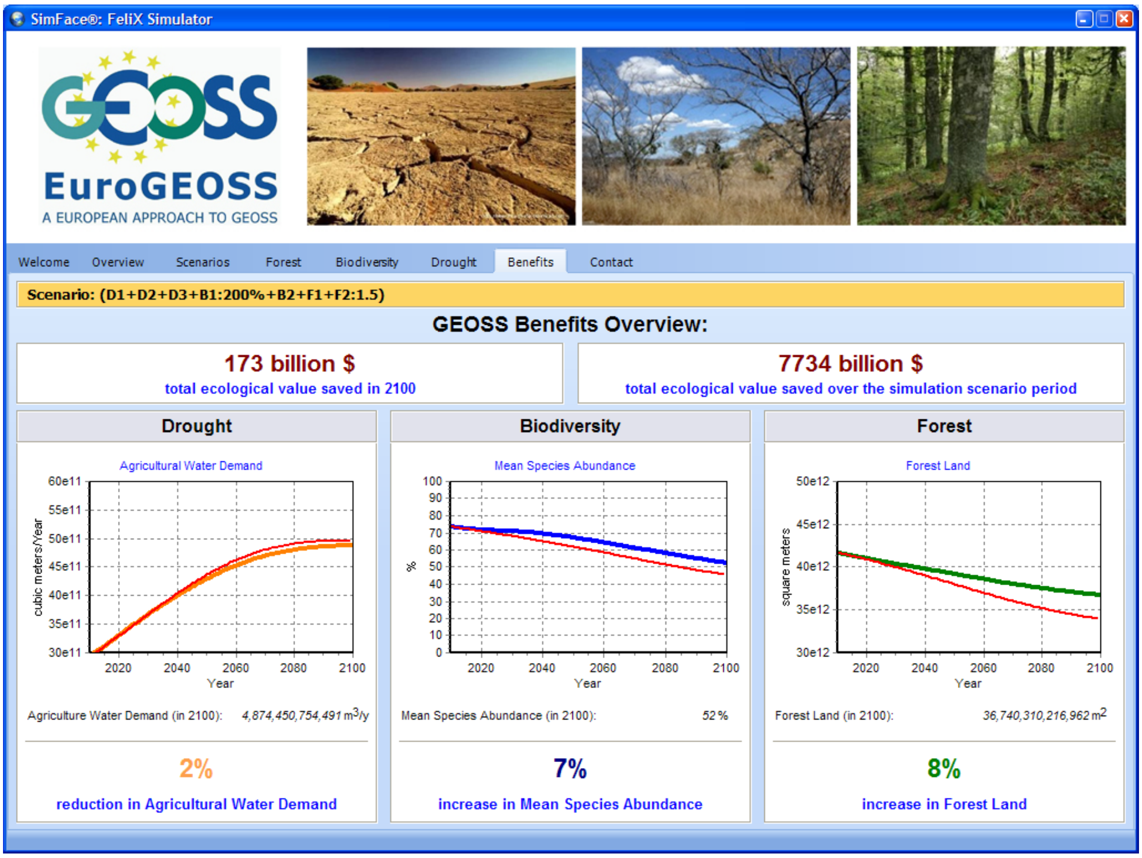
Both simulators are available to download free of charge. The simulator developed for EuroGEOSS purposes additionally encourages subject matter experts to provide comments regarding results of particular simulation scenarios. This kind of the dialog might not only help further develop the model itself but might be beneficial towards working out workable solutions to challenges being faced nowadays.

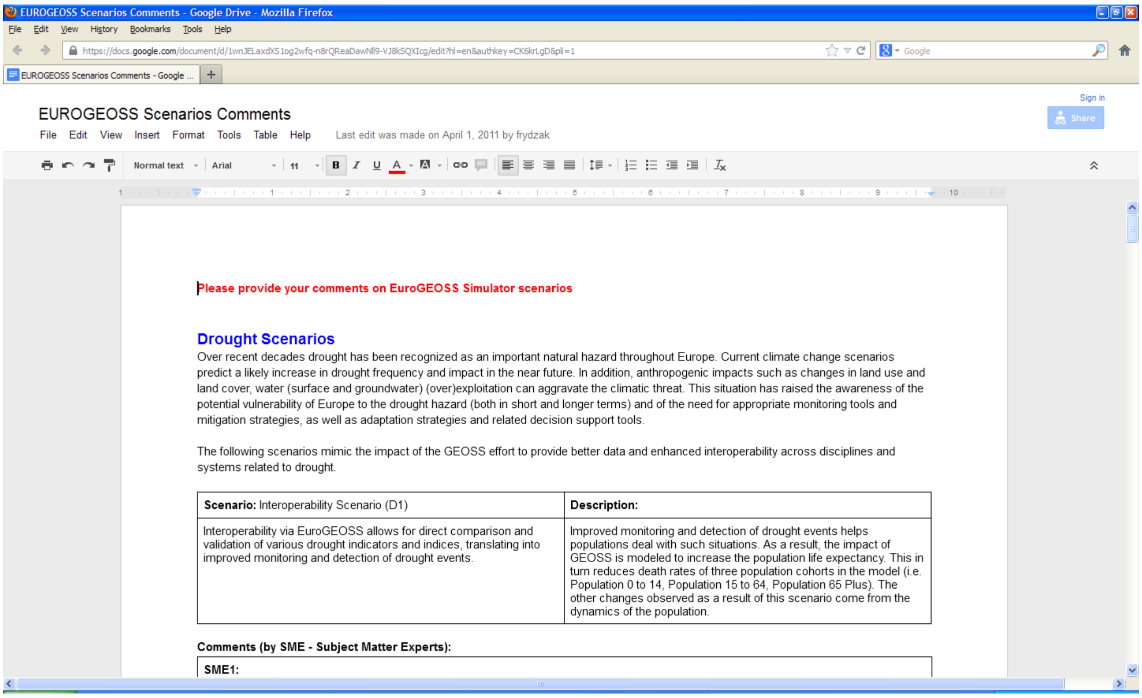
5 Vention is a product developed in Centre for Systems Solutions; www.crs.org.pl


SimFace®: FeliX
Global Earth Observation
Benefit Estimation: Now, Next and Emerging
Start
Next
Stop
Courtesy: ESA
Welcome
GEO-BENE
Energy
Land
Population
Environment
Economy
Model Overview
Contact
Time: 2100
Run scenario(s):
1. Press Start button (the model starts in 1900 and runs through 110 years of history).
2. At year 2010 check which scenario (or scenarios) you would like to run.
3. Press Next button and observe the changes on the graphs.
Scenario Energy
Scenario Disaster
Scenario Health
Scenario Climate
Scenario Agriculture
Scenario Water
Population
People
Year
Population 0 to 14
Population 15 to 64
Population 65 Plus
Population
7,291,063,249
People
Birth vs. Death Rate
People/Year
Births Rate
Death Rate
Fertility
Dmnl
Life Expectancy


SimFace®: FeliX
Global Earth Observation
Benefit Estimation: Now, Next and Emerging
Start
Next
Stop
Courtesy: ESA
Welcome
GEO-BENE
Energy
Land
Population
Environment
Economy
Model Overview
Contact
Time: 2100
Run scenario(s):
1. Press Start button (the model starts in 1900 and runs through 110 years of history).
2. At year 2010 check which scenario (or scenarios) you would like to run.
3. Press Next button and observe the changes on the graphs.
Scenario Energy
Scenario Disaster
Scenario Health
Scenario Climate
Scenario Agriculture
Scenario Water
Energy Demand
Mtoe/Year
Energy Supply
Year
Oil Production
Coal Production
Gas Production
Biomass Energy Production
Solar Energy Production
Wind Energy Production
Energy Production
14,081 Mtoe
Energy Market Share
%
Cumulative Production
Mtoe
Cumulative Oil Production
Cumulative Coal Production
Cumulative Gas Production
Cumulative Biomass Energy Produced
Cumulative Solar Energy Produced
Cumulative Wind Energy Produced


SimFace®: FeliX Simulator
GEOSS
EuroGEOSS
A EUROPEAN APPROACH TO GEOSS
Welcome Overview Scenarios Forest Biodiversity Drought Benefits Contact
Drought, Biodiversity and Forest Scenarios encompass selected changes attributed to operations of GEOSS. The simulator user may choose one or multiple scenarios. A simulation run with none of the scenarios enabled constitutes a base run.
Events Scenarios enable introduction of some additional changes to the future development of chosen phenomena as envisioned by the simulator user. They may be run independently from the GEOSS scenarios.
To run simulation scenarios:
1. Check appropriate scenario(s) below.
2. Press Run button to simulate.
3. Review results on Society, Ecosystem, Economy and Report tabs
(Press Clear button to remove all scenario runs)
Run
Clear
Drought Scenarios: (All scenarios)
Interoperability Scenario (D1)
Interoperability via EuroGEOSS allows for direct comparison and validation of various drought indicators and indices, translating into improved monitoring and detection of drought events.
Monitoring Scenario (D2)
EuroGEOSS drought monitoring can assist in placement of irrigation systems and prioritization in the long term. i.e. enhance efficiency of mitigation measures.
Climate Scenario (D3)
EuroGEOSS allows for better monitoring of negative impacts of climate change - specifically drought causing impacts - hence it could reduce these impacts.
Attention:
Please comment on results of EuroGEOSS Simulator Scenarios. Follow the link to GoogleDocs document.
Note:
Scenario definition based upon the EuroGEOSS Report D.2.1.1.
Biodiversity Scenarios: (All scenarios)
Interoperability Scenario (B1)
EuroGEOSS will deliver an interoperable environmental information service for enabling improved assessment of areas of high ecological value.
Specify % change from initial forest protected land area trend (100 to 800%): 200 %
Species Abundance Scenario (B2)
EuroGEOSS, via DOPA, through monitoring and better informed modeling, will allow for increases in species abundance.
Forest Scenarios: (All scenarios)
Fire Early Warning Scenario (F1)
EuroGEOSS interoperability allows for early warning/detection of forest fires brought on by climate change/drought related increases in fire frequency, affecting forests, savannas, etc.
Reducing Deforestation Scenario (F2)
EuroGEOSS interoperability related activities could aid in reducing deforestation/ habitat loss via better forest monitoring.
Specify deforestation reduction factor (1-no change; 10-high reduction): 1.5
Events Scenarios:
Change in Reliable Water Supply Scenario (E1)
Current level of Reliable Water Supply is 4500 billion cubic meters per year. By year 2100 this level can change (increase or decrease) due to many reasons. Decide what percentage of current Reliable Water Supply level will be available in 2100.
Please note: 100 means no change will happen - 100% of current Reliable Water Supply will also be available in 2100; value lower than 100 would mean decrease in Reliable Water Supply over time; value greater than 100 would mean increase in Reliable Water Supply over time.
Reliable Water Supply in 2100 as percentage of current level: 100 %
Extreme Drought Scenario (E2)
The model allows simulating extreme drought events in Agriculture. These are additional shortages of water supply. Decide on severity of such event(s) (scale between 0 - no event, to 0.5 - extreme event), duration (at least a year), and time interval between events (in years).
Drought Event Severity (s): 0
Drought Event Duration (d): 1
Drought Event Interval (i): 10


SimFace®: FeliX Simulator
GEOSS
EuroGEOSS
A EUROPEAN APPROACH TO GEOSS
Welcome Overview Scenarios Forest Biodiversity Drought Benefits Contact
Scenario: (D1+D2+D3+B1:200%+B2+F1+F2:1.5)
GEOSS Benefits Overview:
173 billion $
total ecological value saved in 2100
7734 billion $
total ecological value saved over the simulation scenario period
Drought
Agricultural Water Demand
cubic meters/Year
60e11
55e11
50e11
45e11
40e11
35e11
30e11
2020 2040 2060 2080 2100
Year
Agriculture Water Demand (in 2100): 4,874,450,754,491 m3/y
2%
reduction in Agricultural Water Demand
Biodiversity
Mean Species Abundance
%
100 90 80 70 60 50 40 30 20 10 0
2020 2040 2060 2080 2100
Year
Mean Species Abundance (in 2100): 52 %
7%
increase in Mean Species Abundance
Forest
Forest Land
square meters
50e12
45e12
40e12
35e12
30e12
2020 2040 2060 2080 2100
Year
Forest Land (in 2100): 36,740,310,216,962 m2
8%
increase in Forest Land



EUROGEOSS Scenarios Comments

Last edit was made on April 1, 2011 by frydzak

Please provide your comments on EuroGEOSS Simulator scenarios

Drought Scenarios

Over recent decades drought has been recognized as an important natural hazard throughout Europe. Current climate change scenarios predict a likely increase in drought frequency and impact in the near future. In addition, anthropogenic impacts such as changes in land use and land cover, water (surface and groundwater) (over)exploitation can aggravate the climatic threat. This situation has raised the awareness of the potential vulnerability of Europe to the drought hazard (both in short and longer terms) and of the need for appropriate monitoring tools and mitigation strategies, as well as adaptation strategies and related decision support tools.

The following scenarios mimic the impact of the GEOSS effort to provide better data and enhanced interoperability across disciplines and systems related to drought.

Scenario: Interoperability Scenario (D1)	**Description:**
Interoperability via EuroGEOSS allows for direct comparison and validation of various drought indicators and indices, translating into improved monitoring and detection of drought events.	Improved monitoring and detection of drought events helps populations deal with such situations. As a result, the impact of GEOSS is modeled to increase the population life expectancy. This in turn reduces death rates of three population cohorts in the model (i.e. Population 0 to 14, Population 15 to 64, Population 65 Plus). The other changes observed as a result of this scenario come from the dynamics of the population.

Comments (by SME - Subject Matter Experts):

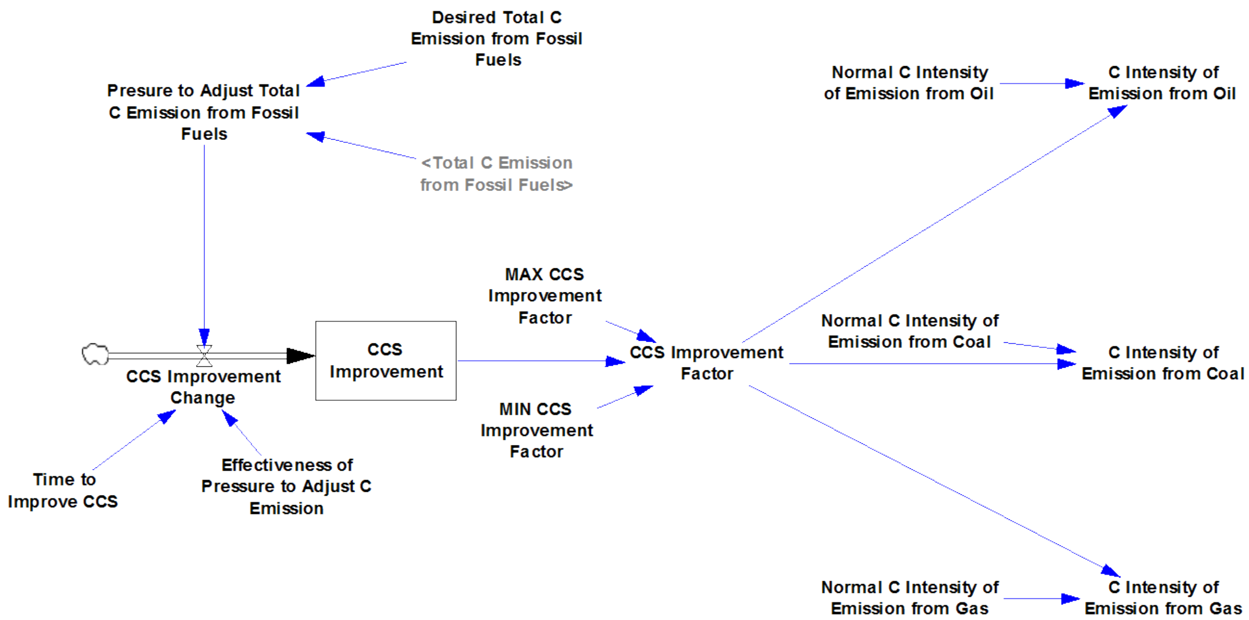
SME1:

CCS Scenario

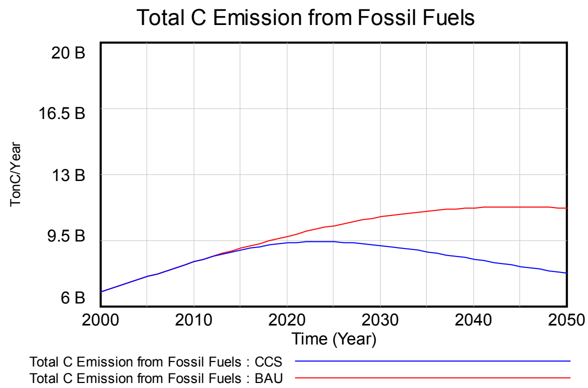
The current version of the model with extended and improved structure providing a better fit to historical data constitutes a purposefully simplified but comprehensive representation of the Earth system and offers an excellent platform to test a variety of dynamic scenarios and conduct integrated assessments. The simulation scenarios might be as simple as a change to one model parameter. This change can occur instantly or take full effect gradually over a time period. Other scenarios might incorporate changes to many parameters across the model structure or even modify existing or adding new structure (e.g. to model a new policy or phenomena).

As an illustration of simulation scenario that can be tested in the FeliX model a technological solution to decrease carbon emission to atmosphere – Carbon Capture and Storage (CCS) – will be tested in terms of its impact on climate but also the propagation of such potential solution across other aspects of human well being.

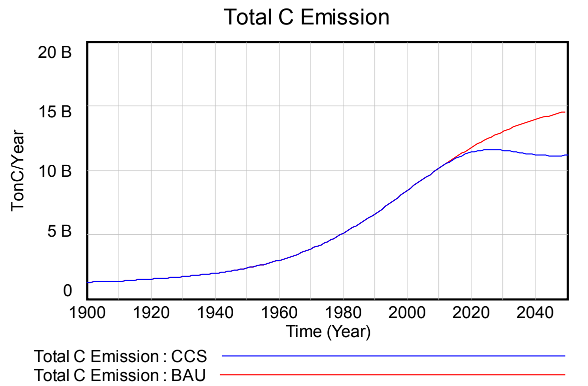
In the first step the model structure is adjusted to capture the CCS policy. Production of the energy from all sources is associated with carbon emission. In the CCS scenario the intensity of carbon production from fossil fuels is decreased by improvements in Carbon Capture and Storage. Once the *Total C Emission from Fossil Fuels* reaches a target level (*Desired Total C Emission from Fossil Fuels*) a pressure arises to improve CSS. This process takes time but eventually intensity of carbon production lowers compared to reference values. The changes to the model structure are presented in the diagram below. The detailed equations are presented in Appendix.



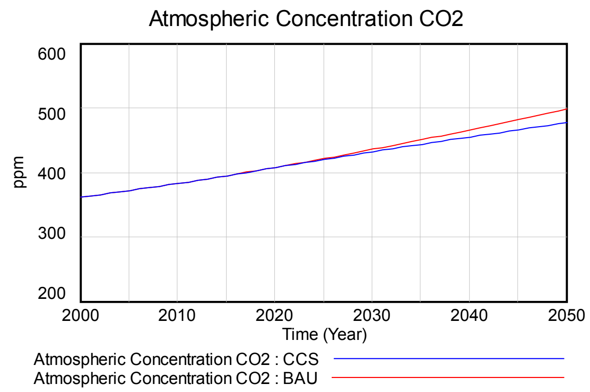
The simulation scenario is run for the target level (*Desired Total C Emission from Fossil Fuels*) set to 7.5 billion TonC/Year. The CCS scenario is compared against the Business as Usual scenario.



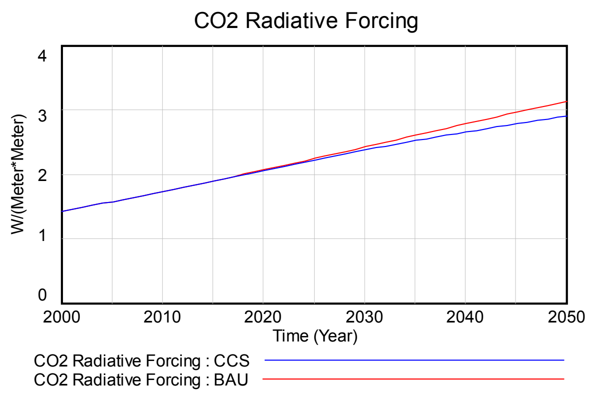
The *Total C Emission from Fossil Fuels* reaches the set limiting target level in year 2005. Arising pressure leads to CCS technology development and successive decrease of *Total C Emissions from Fossil Fuels* – Oil, Gas and Coal. By year 2050 the *Total C Emissions from Fossil Fuels* is decreased down to 7.8 billion TonC/Year.



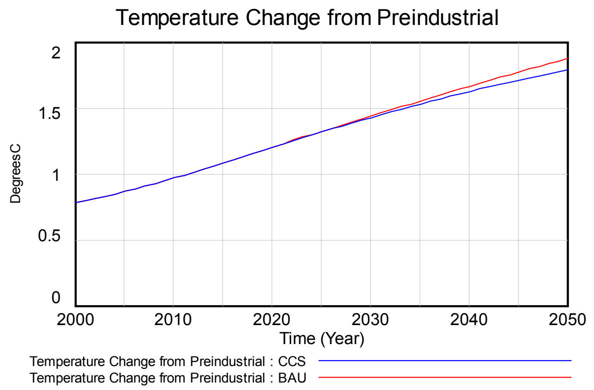
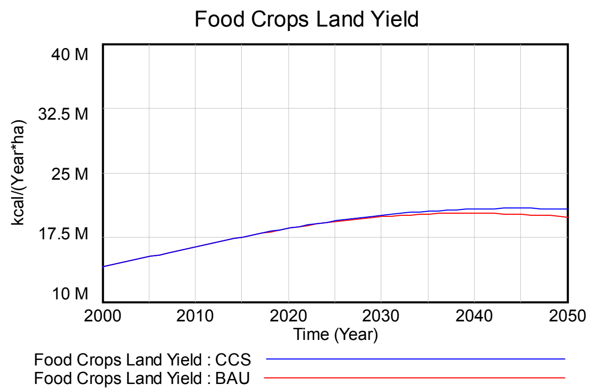
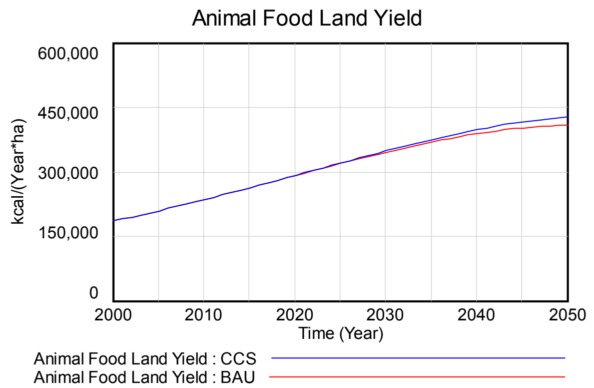
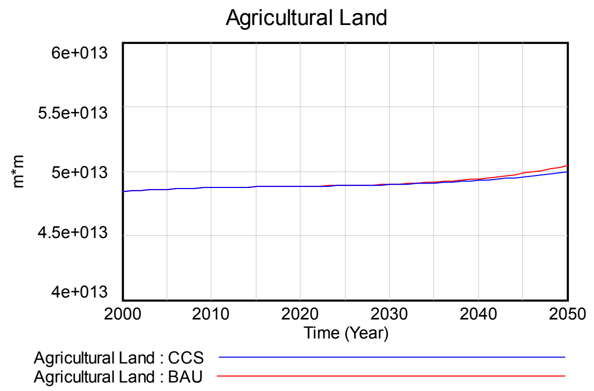
In year 2025, when *Total C Emission from Fossil Fuels* reaches its inflection point, also the *Total C Emission* starts to decrease. In year 2050 it reaches 11.16 billion TonC/Year, which is 3.4 billion TonC/Year less compared to BAU scenario.

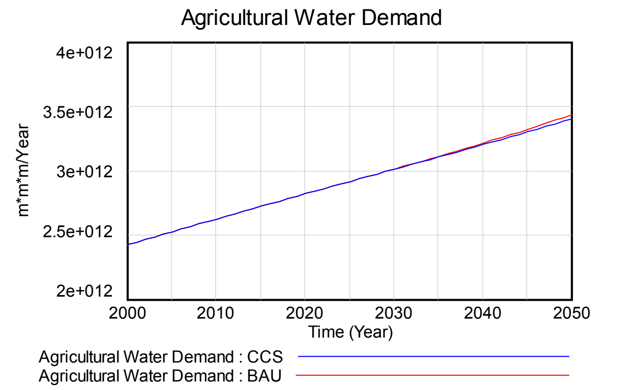
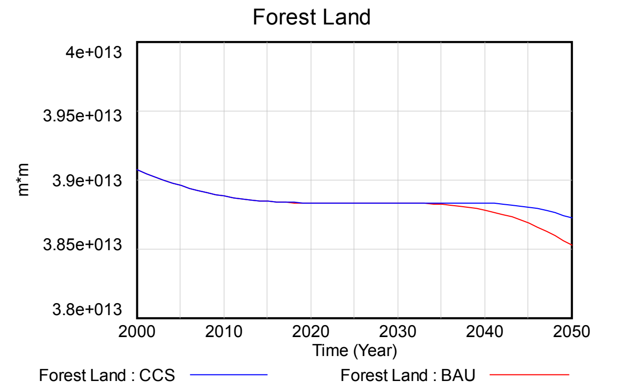
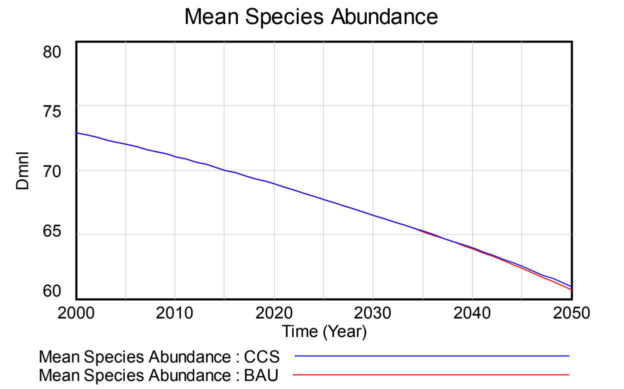


Even though the *Total C Emission* decreases the *Atmospheric Concentration of CO2* continues to increase but at a slower pace. This is a characteristic of a stock, which accumulate its inflows. The *Atmospheric Concentration of CO2* would decrease only when outflow rates are greater than inflow rates. In year 2050 the *Atmospheric Concentration of CO2* is equal 475ppm compared to 495ppm in BAU scenario.



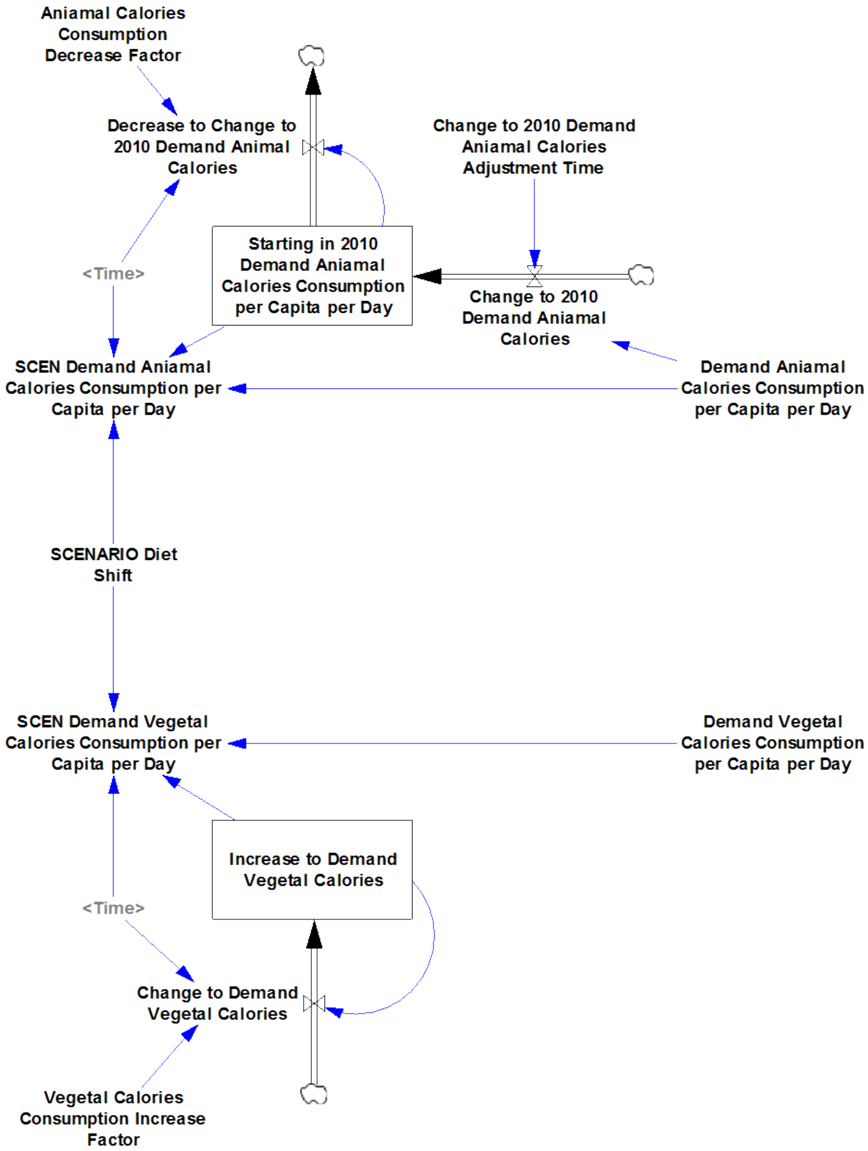
Lower CO2 concentration in the atmosphere leads to decrease in *CO2 Radiative Forcing*. In 2050 the forcing from CO2 reaches 2.88W/m2 compared to 3.1W/m2 in BAU scenario.

<table>
<tr>
<td>
</td>
<td>The decrease in CO2 Radiative Forcing translates into slower increase of Temperature Change from Preindustrial. In 2050 the temperature change is estimated to reach 1.77 C degrees, 0.08 C degrees than in BAU scenario.</td>
</tr>
<tr>
<td>
</td>
<td>Slower temperature change enables moving Food Crops Land Yield inflection point further into the future. In BAU scenario the Food Crops Land Yield is increasing until year 2039, after which it decreases. In case of CCS scenario the inflection point is moved by 6 years which enables reaching higher level of yield at the inflection point – 20.86 million kcal/(Year*ha), compared to 20.29 million kcal/(Year*ha) in BAU scenario.</td>
</tr>
<tr>
<td>
</td>
<td>Similarly Animal Land Yield is increased reaching 426 thousand kcal/(Year*ha) in year 2050, compared to 408 thousand kcal/(Year*ha) in BAU scenario.</td>
</tr>
<tr>
<td>
</td>
<td>Greater land yield requires using less Agricultural Land, which in CCS scenario for year 2050 is equal 49,882 billion m2, 426 billion m2 less than in BAU scenario.</td>
</tr>
</table>

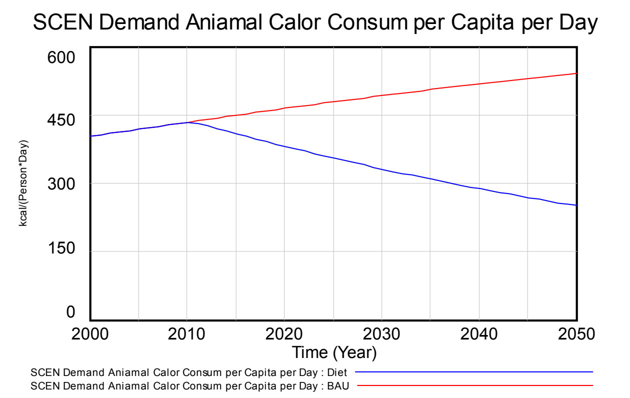
	In the aftermath of using less agriculture land the *Agriculture Water Demand* is also lower compared to BAU scenario. In year 2050 it reaches level of 3385.2 billion m3/Year, compared to demand in BAU scenario equal to 3414.6 billion m3/Year.
	Another consequence of greater land yield is lower need for deforestation and changing *Forest Land* to agricultural areas. As a consequence in year 2050 there is 38,741.2 billion m2 of *Forest Land*, 182 billion m2 more that in BAU scenario.
	Slowing changes of the temperature and land transformation slows decrease of biodiversity, measured by *Mean Species Abundance*. In CCS scenario for year 2050 the *Mean Species Abundance* decreased to 61.22 percent compared to 61 percent in BAU scenario.

Diet Change Scenario

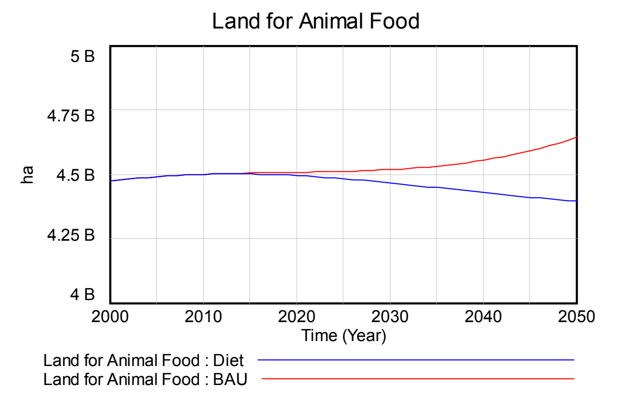
The diet change scenario was adapted from WWF Living Forest report Diet Shift scenario, assuming decrease in consumption of animal calories after year 2010.
In order to simulate this scenario the structure of the FeliX model was developed to include the animal calories consumption decrease after year 2010 and vegetal calories consumption increase after year 2010 to compensate for reduction in total calories consumption.



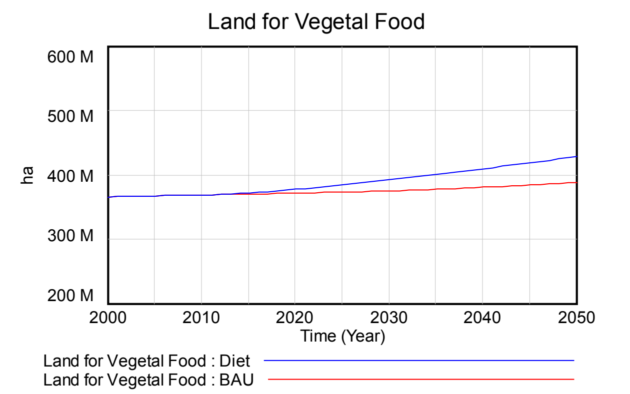
The results of the Diet Change scenario are compared to Business as Usual scenario over the 2000 – 2050 period.



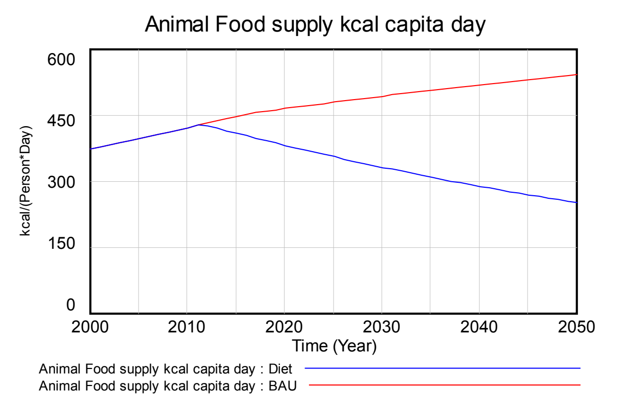
In BAU scenario in year 2010 average global demand for animal calories consumption per capita per day reaches 435 and continues to increase above 540 kcal per person per day in year 2050. In Diet Shift scenario after reaching a pick in 2010 the demand for animal calories decreases down to 250 kcal per person per day in year 2050.



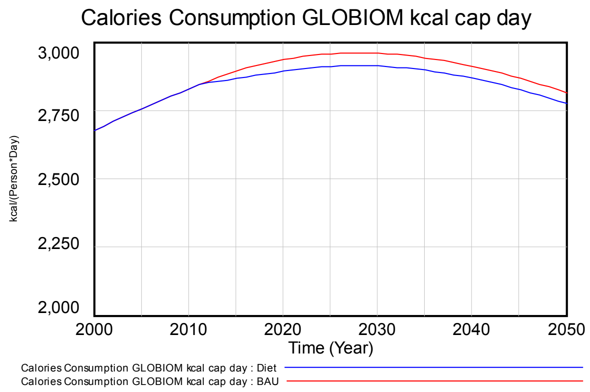
As a consequence of the demand for animal calories decrease the land area associated with the animal food production also decreases. The increasing Land for Animal Food trend is reversed with a pick around year 2012. In the Diet Shift scenario the Land for Animal Food in year 2050 reaches 4.4 billion hectares level (79 million hectares less than in year 2000).



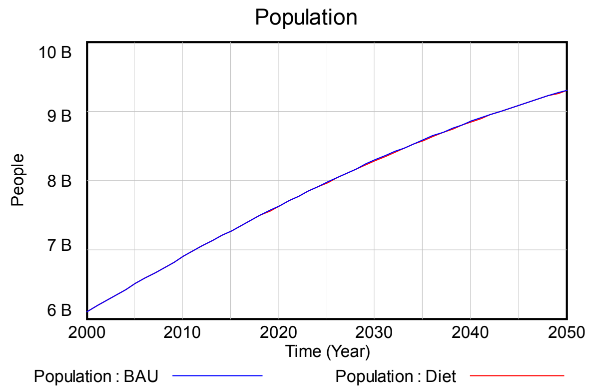
At the same time an increase in Land for Vegetal Food area is noticed. That change comes from the fact of substituting animal calories with vegetal calories. The land area on which crops are produced increases by the year 2050 to 428 million hectares (40 million hectares more than in case of the BAU scenario).



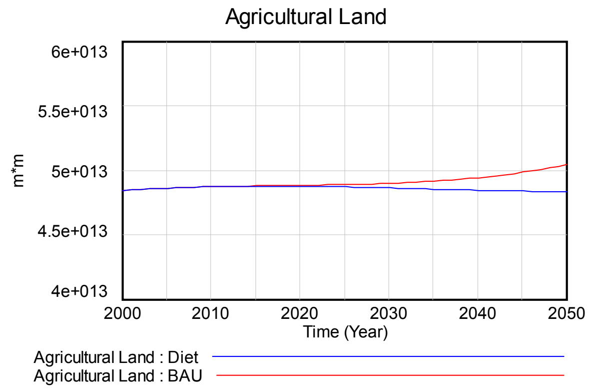
The decrease in animal calories demand allows the supply meet the demand.



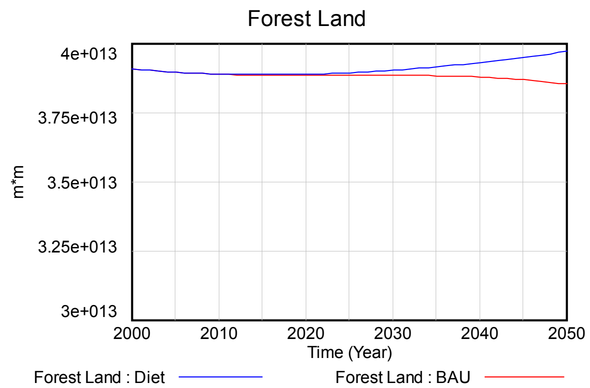
There can be noticed a decrease in total calories supply in Diet Change scenario compared against the BAU scenario. The reduction is achieved through dietary changes and waste reduction.



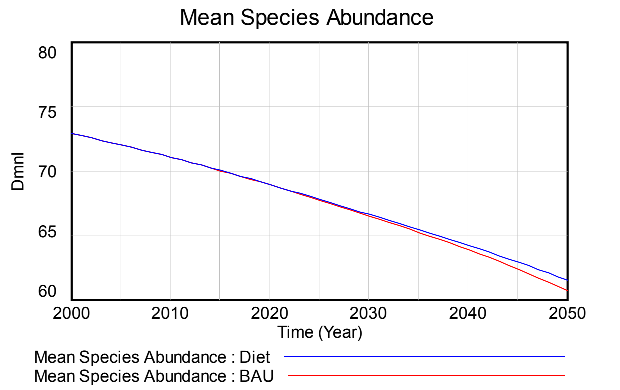
Animal calories consumption decrease and waste reduction do not have any significant effect on the population volume.



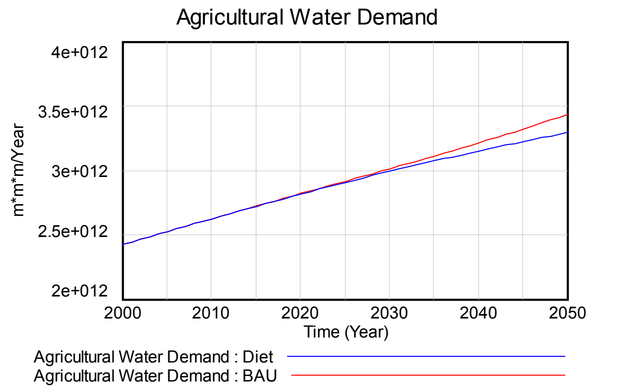
However, the diet change does have a noticeable effect on land use. The Agriculture Land area changes its growing trend and starts to decrease reaching in year 2050 the level of 4.5 million hectares (0.21 million hectares less compared to BAU scenario).



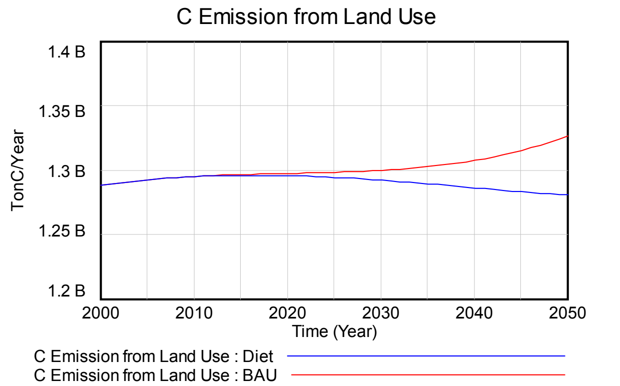
Stopping land transformation towards agricultural land is associated with saving Forest Land area, which start to grow and reaches by the year 2050 a level higher than in year 2000 – equal to 3.97 million hectares (0.12 million hectares more compared to BAU scenario).



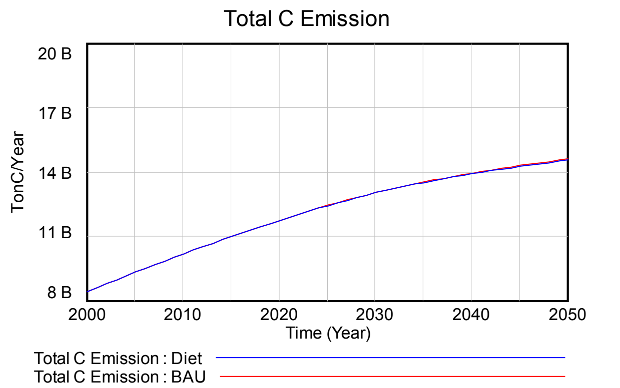
The diet shift and associated consequence have a positive effect on reducing biodiversity degradation. In Diet Change scenario the Mean Species Abundance in year 2050 is 0.8 percent higher compared to BAU scenario.



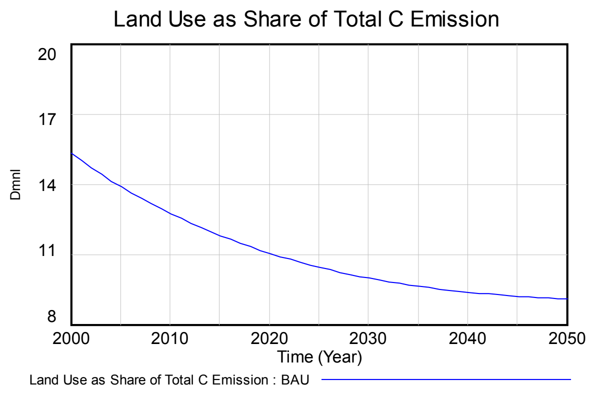
Changes in land use due to the diet shift are also followed by decrease in Agricultural Water Demand. Due to Diet Change scenario in year 2050 the Agricultural Water Demand reaches 3296 billion cubic meters, 142 billion cubic meters less than in BAU scenario.



Another effect of the diet change and associated land use changes is decrease in carbon emission down to 1.28 billion tons of carbon per year, 46 million tons of carbon per year less compared to BAU scenario.



However, the change in carbon emission from land use does not have a significant effect on the total carbon emission.

	With an increasing carbon emission from fossil fuels, by the year 2050 emission from land use constitutes only about 9 percent of total carbon emission to atmosphere. Thus in the current configuration of the green house gasses emission sources the Diet Change scenario as modeled for the purposes of this report does not have a significant impact on decreasing pace of climate change.

Summary

The FeliX (Full of Economic-Environment Linkages and Integration dX/dt) model is a System Dynamics type of model consisting of a set of interrelated differential equations allowing for computer simulation that produces quantitative results.

The FeliX model is purposefully simplified 'mock-up' of a complex Earth system capturing vital mechanisms and phenomena related to the nine societal benefits areas (SBAs) – disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. The SBAs are addressed in eight model sectors – Population, Economy, Energy, Land Use, Carbon Cycle, Climate, Water and Biodiversity.

The main dynamic problems addressed by the model include:

- Population Development
- Population Ageing
- Development jeopardized by ecosystem changes
- Alternative measures of development
- Increasing energy demand
- Investment in energy technology and production capacity to meet demand
- Fossil fuels securing most of the needs for energy
- Alternative sources of energy competing for market share
- Food security
- Deforestation
- Human activities related CO2 emissions
- Impact of carbon concentration
- Water scarcity
- Changes to biodiversity

The model was calibrated to historical data for the period 1900 – 2010 (subject to data availability). The Business as Usual scenario was constructed as a reference scenario for GEOSS and other integrated scenarios developed for the purposes of global impact assessment.

This report includes a thorough demonstration of the FeliX model structure – dynamic problems definitions, system conceptualization, model formulation, and generated through simulation dynamic behavior of the model structure. It draws at work conducted in European Commission Framework Programs projects GEO-BENE, EuroGEOSS and EnerGEO. There are pointed out tools – understanding enhancement and decision support simulators – developed in the course of conducted research on the impact of Global Earth Observation.

The scope of the FeliX model makes it possible to go beyond the GEO study, test other than GEOSS scenarios and assess their impact across all nine SBAs. This report presents exemplary integrated scenarios that can be tested in the FeliX model.

The appendix to this report provides technical documentation of the model – variables description and detailed equations behind the FeliX model structure.

Appendix

The Appendix provides the detailed information on the FeliX model variables and equations. The variables are grouped in 16 groups. Electronic version of this report allows an easy navigation across the Appendix by clicking variables names.

Types:	**S** : Stock (88)	**SM** : Smooth (1)	**SI** : Stock Initial (23)	**I** : Initial (11)	**L** : Lookup (28)
	C : Constant (476)	**F** : Flow (37)	**A** : Auxiliary (661)	**Sub**: Subscripts (0)	**D** : Data (0)
Groups:	**Biodiversity** (33)	**Carbon** (116)	**Climate** (117)	**Control** (4)	**Economy** (35)
	Energy (100)	**Energy Biomass** (66)	**Energy Coal** (81)	**Energy Gas** (80)	**Energy Oil** (80)
	Energy Solar (68)	**Energy Wind** (68)	**Indexes** (28)	**Land** (262)	**Population** (64)
	Water (63)				

Group (16)	**Type** (8)	**Variable Name and Description** (1265)
Biodiversity	A	**Agriculture Biomass Production Land Ratio** (Dmnl) = Energy Crops Land/Crops Potential Agriculture Land **Description:** *Ratio of agricultural land area being used for crops biomass production.* **Used by:** • Impact of Agriculture Biomass Production on Biodiversity - Nonlinear function representing impact of crops biomass production on species carrying capacity.
Biodiversity	C	**Agriculture Biomass Production on Biodiversity Elasticity** (Dmnl) = 2 **Description:** *Elasticity of impact of crops biomass production on species carrying capacity.* **Used by:** • Impact of Agriculture Biomass Production on Biodiversity - Nonlinear function representing impact of crops biomass production on species carrying capacity.
Biodiversity	C	**Biodiversity Impact Climate Damage Nonlinearity** (Dmnl) = 1.5 **Description:** *Elasticity of impact of climate risk on species carrying capacity.* **Used by:** • Impact of Climate Damage on Biodiversity - Nonlinear function representing impact of climate risk on species carrying capacity.
Biodiversity	C	**Biodiversity Impact Climate Damage Scale** (Dmnl) = 0.1 **Description:** *The maximum fractional impact of climate risk on species carrying capacity.* **Used by:** • Impact of Climate Damage on Biodiversity - Nonlinear function representing impact of climate risk on species carrying capacity.
Biodiversity	C	**Biodiversity Impact Fertilizer Consumption Nonlinearity** (Dmnl) = 1.5 **Description:** *Elasticity of impact of fertilization consumption on species carrying capacity.* **Used by:** • Impact of Fertilizer Consumption on Biodiversity - Nonlinear function representing impact of fertilization practices on species carrying capacity.
Biodiversity	C	**Biodiversity Impact Fertilizer Consumption Scale** (Dmnl) = 0.2 **Description:** *The maximum fractional impact of fertilization practices on species carrying*

		capacity. **Used by:** • Impact of Fertilizer Consumption on Biodiversity - Nonlinear function representing impact of fertilization practices on species carrying capacity.
Biodiversity	C	**Biodiversity Impact Reference Fertilizer Consumption** (TonNutrient/Year) = 4e+008 **Description:** *Value against which the fertilization consumption is compared to in order to determine its impact on species carrying capacity.* **Used by:** • Impact of Fertilizer Consumption on Biodiversity - Nonlinear function representing impact of fertilization practices on species carrying capacity.
Biodiversity	C	**Biodiversity Impact Reference Temperature** (DegreesC) = 3 **Description:** *Value against which the temperature anomalies are compared to in order to determine its impact on species carrying capacity.* **Used by:** • Impact of Climate Damage on Biodiversity - Nonlinear function representing impact of climate risk on species carrying capacity.
Biodiversity	C	**Extinction Factor** (1/Year) = 0.01 **Description:** *The minimum fractional extinction rate.* **Used by:** • Species Extinction - The fractional species extinctionrate is an increasing function of the ratio of species abundance carrying capacity. A power function is assumed.
Biodiversity	A	**Forest Biomass Production Land Ratio** (Dmnl) = Actual Forest Land Harvested/(Forest Land*Sqr m to ha) **Description:** *Ratio of forest land area being used for biomass production.* **Used by:** • Impact of Forest Biomass Production on Biodiversity - Nonlinear function representing impact of forest biomass production on species carrying capacity.
Biodiversity	C	**Forest Biomass Production on Biodiversity Elasticity** (Dmnl) = 2 **Description:** *Elasticity of impact of forest biomass production on species carrying capacity.* **Used by:** • Impact of Forest Biomass Production on Biodiversity - Nonlinear function representing impact of forest biomass production on species carrying capacity.
Biodiversity	A	**Impact of Agricultural Land Changes on Biodiversity** (Dmnl) = (1/(Agricultural Land/INIT Agricultural Land))^Impact of Agricultural Land Changes on Biodiversity Elasticity **Description:** *Nonlinear function representing impact of agricultural land use change on species carrying capacity.* **Used by:** • Impact of Land Use Change on Biodiversity - Total impact of land use change on species carrying capacity.
Biodiversity	C	**Impact of Agricultural Land Changes on Biodiversity Elasticity** (Dmnl) = 0.1 **Description:** *Elasticity of impact of agricultural land use change on species carrying capacity.* **Used by:** • Impact of Agricultural Land Changes on Biodiversity - Nonlinear function representing impact of agricultural land use change on species carrying capacity.
Biodiversity	A	**Impact of Agriculture Biomass Production on Biodiversity** (Dmnl) = (1-Agriculture Biomass Production Land Ratio)^Agriculture Biomass Production on Biodiversity Elasticity **Description:** *Nonlinear function representing impact of crops biomass production on species carrying capacity.* **Used by:** • Impact of Biomass Production on Biodiversity - Total impact of forest and crops biomass production on species carrying capacity.
Biodiversity	A	**Impact of Biomass Production on Biodiversity** (Dmnl) = Impact of Agriculture Biomass Production on Biodiversity*Impact of Forest Biomass

		Production on Biodiversity **Description:** *Total impact of forest and crops biomass production on species carrying capacity.* **Used by:** • Species Carrying Capacity - The carrying capacity defines the equilibrium or maximum sustainable species population. It is impacted by fertilization, biomas production, climate risk and land use change.
Biodiversity	A	**Impact of Climate Damage on Biodiversity** (Dmnl) = 1/(1+Biodiversity Impact Climate Damage Scale*(Temperature Change from Preindustrial/Biodiversity Impact Reference Temperature)^Biodiversity Impact Climate Damage Nonlinearity) **Description:** *Nonlinear function representing impact of climate risk on species carrying capacity.* **Used by:** • Species Carrying Capacity - The carrying capacity defines the equilibrium or maximum sustainable species population. It is impacted by fertilization, biomas production, climate risk and land use change.
Biodiversity	A	**Impact of Fertilizer Consumption on Biodiversity** (Dmnl) = 1/(1+Biodiversity Impact Fertilizer Consumption Scale*(Fertilizer Consumption/Biodiversity Impact Reference Fertilizer Consumption)^Biodiversity Impact Fertilizer Consumption Nonlinearity) **Description:** *Nonlinear function representing impact of fertilization practices on species carrying capacity.* **Used by:** • Species Carrying Capacity - The carrying capacity defines the equilibrium or maximum sustainable species population. It is impacted by fertilization, biomas production, climate risk and land use change.
Biodiversity	A	**Impact of Forest Biomass Production on Biodiversity** (Dmnl) = (1-Forest Biomass Production Land Ratio)^Forest Biomass Production on Biodiversity Elasticity **Description:** *Nonlinear function representing impact of forest biomass production on species carrying capacity.* **Used by:** • Impact of Biomass Production on Biodiversity - Total impact of forest and crops biomass production on species carrying capacity.
Biodiversity	A	**Impact of Forest Land Changes on Biodiversity** (Dmnl) = (Forest Land/INIT Forest Land)^(Impact of Forest Land Changes on Biodiversity Elasticity) **Description:** *Nonlinear function representing impact of forest land use change on species carrying capacity.* **Used by:** • Impact of Land Use Change on Biodiversity - Total impact of land use change on species carrying capacity.
Biodiversity	C	**Impact of Forest Land Changes on Biodiversity Elasticity** (Dmnl) = 0.1 **Description:** *Elasticity of impact of forest land use change on species carrying capacity.* **Used by:** • Impact of Forest Land Changes on Biodiversity - Nonlinear function representing impact of forest land use change on species carrying capacity.
Biodiversity	A	**Impact of Land Use Change on Biodiversity** (Dmnl) = Impact of Agricultural Land Changes on Biodiversity*Impact of Forest Land Changes on Biodiversity*Impact of Other Land Changes on Biodiversity **Description:** *Total impact of land use change on species carrying capacity.* **Used by:** • Species Carrying Capacity - The carrying capacity defines the equilibrium or maximum sustainable species population. It is impacted by fertilization, biomas production, climate risk and land use change.
Biodiversity	A	**Impact of Other Land Changes on Biodiversity** (Dmnl) = (Other Land/INIT Other Land)^Impact of Other Land Changes on Biodiversity Elasticity **Description:** *Nonlinear function representing impact of other land use change on species carrying capacity.* **Used by:** • Impact of Land Use Change on Biodiversity - Total impact of land use change on

		species carrying capacity.
Biodiversity	C	**Impact of Other Land Changes on Biodiversity Elasticity** (Dmnl) = 0.1 **Description:** *Elasticity of impact of other land use change on species carrying capacity.* **Used by:** • Impact of Other Land Changes on Biodiversity - Nonlinear function representing impact of other land use change on species carrying capacity.
Biodiversity	C	**Initial Species Abundance** (Dmnl) = 85 **Description:** *Mean species abundance in year 1900.* **Used by:** • Mean Species Abundance - Mean abundance of original species relative to their abundance in undisturbed ecosystems. Source of Historical Data: Secretariat of the Convention for Biological Diversity (CBD), Cross-roads of Life on Earth - Exploring means to meet the 2010 Biodiversity Target, 2007 • Effect of Biodiversity on Forest Land Fertility - Impact of mean species abundance on forest land fertility. Scaled between minimal and maximal impact. Relative level is the value of mean species abundance in year 1900. • Impact of Biodiversity on Health - Impact of changes in biodiversity on health. Scaled between minimum and maximum impact. • Impact of Biodiversity on Economy - The fraction of ecomomy output loss due to changes in biodiversity.
Biodiversity	S	**Mean Species Abundance** (Dmnl) = Initial Species Abundance + ∫ (Species Regeneration Rate-Species Extinction Rate) **Description:** *Mean abundance of original species relative to their abundance in undisturbed ecosystems. Source of Historical Data: Secretariat of the Convention for Biological Diversity (CBD), Cross-roads of Life on Earth - Exploring means to meet the 2010 Biodiversity Target, 2007* **Used by:** • Species Abundance Realtive to Carrying Capacity - The ratio of species abundance to carrying capacity determines the fractional regeneration and extinction rates. • Species Extinction Rate - Average rate of species extinction. • Species Regeneration Rate - Average rate of species regeneration. • Effect of Biodiversity on Forest Land Fertility - Impact of mean species abundance on forest land fertility. Scaled between minimal and maximal impact. Relative level is the value of mean species abundance in year 1900. • Impact of Biodiversity on Health - Impact of changes in biodiversity on health. Scaled between minimum and maximum impact. • Impact of Biodiversity on Economy - The fraction of ecomomy output loss due to changes in biodiversity.
Biodiversity	C	**Reference Species Carrying Capacity** (Dmnl) = 81 **Description:** *Reference species carrying capacity for year 1900.* **Used by:** • Species Carrying Capacity - The carrying capacity defines the equilibrium or maximum sustainable species population. It is impacted by fertilization, biomas production, climate risk and land use change.
Biodiversity	C	**Regeneration Factor** (1/Year) = 0.04 **Description:** *The maximum fractional net regeneration rate.* **Used by:** • Species Regeneration - The fractional species regeneration rate is a declining function of the species abundance relative to the carrying capacity. A logistic function is used.
Biodiversity	A	**Species Abundance Realtive to Carrying Capacity** (Dmnl) = Mean Species Abundance/Species Carrying Capacity **Description:** *The ratio of species abundance to carrying capacity determines the fractional regeneration and extinction rates.* **Used by:** • Species Regeneration - The fractional species regeneration rate is a declining

		function of the species abundance relative to the carrying capacity. A logistic function is used. • Species Extinction - The fractional species extinctionrate is an increasing function of the ratio of species abundance carrying capacity. A power function is assumed.
Biodiversity	A	**Species Carrying Capacity** (Dmnl) = Reference Species Carrying Capacity*Impact of Biomass Production on Biodiversity*Impact of Climate Damage on Biodiversity*Impact of Fertilizer Consumption on Biodiversity*Impact of Land Use Change on Biodiversity **Description:** *The carrying capacity defines the equilibrium or maximum sustainable species population. It is impacted by fertilization, biomas production, climate risk and land use change.* **Used by:** • Species Abundance Realtive to Carrying Capacity - The ratio of species abundance to carrying capacity determines the fractional regeneration and extinction rates.
Biodiversity	A	**Species Extinction** (Dmnl/Year) = Extinction Factor*(1+Species Abundance Realtive to Carrying Capacity^2) **Description:** *The fractional species extinctionrate is an increasing function of the ratio of species abundance carrying capacity. A power function is assumed.* **Used by:** • Species Extinction Rate - Average rate of species extinction.
Biodiversity	A	**Species Extinction Rate** (1/Year) = Mean Species Abundance*Species Extinction **Description:** *Average rate of species extinction.* **Used by:** • Mean Species Abundance - Mean abundance of original species relative to their abundance in undisturbed ecosystems. Source of Historical Data: Secretariat of the Convention for Biological Diversity (CBD), Cross-roads of Life on Earth - Exploring means to meet the 2010 Biodiversity Target, 2007
Biodiversity	A	**Species Regeneration** (Dmnl/Year) = Regeneration Factor*(1-(1/(1+EXP(-7*(Species Abundance Realtive to Carrying Capacity-1))))) **Description:** *The fractional species regeneration rate is a declining function of the species abundance relative to the carrying capacity. A logistic function is used.* **Used by:** • Species Regeneration Rate - Average rate of species regeneration.
Biodiversity	F,A	**Species Regeneration Rate** (1/Year) = Mean Species Abundance*Species Regeneration **Description:** *Average rate of species regeneration.* **Used by:** • Mean Species Abundance - Mean abundance of original species relative to their abundance in undisturbed ecosystems. Source of Historical Data: Secretariat of the Convention for Biological Diversity (CBD), Cross-roads of Life on Earth - Exploring means to meet the 2010 Biodiversity Target, 2007
Carbon	A	**Agricultural Land Change** (Dmnl) = Agricultural Land/INIT Agricultural Land **Description:** *Ratio of agricultural land area change compared to its initial area in year 1900.* **Used by:** • C Emission from Land Use - Total carbon emission from forest and agricultural land use change. Source of Historical Data:Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.
Carbon	C	**Atmospheric CO2 Law Dome 1850** (ppm) = 284.7 **Description:** *Historical CO2 record derived from a spline fit (20 year cutoff) of the Law Dome DE08 and DE08-2 ice cores for year 1850* **Used by:** • INIT C in Atmosphere - Initial carbon in atmosphere.
Carbon	A	**Atmospheric Concentration CO2** (ppm) = C in Atmosphere/GtC to TonC/ppm to GtC **Description:** *Converts weight of CO2 in atmosphere to concentration (ppm CO2). Source of Historical Data:Etheridge, D.M., Steele, L.P., Langenfelds, R.L., Francey, R.J., Barnola, J.-M.,*

		Morgan, V.I. 1998. Historical CO2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A
Carbon	C	**Biomass Res Time** (Year) = 10.6 **Description:** *Average residence time of carbon in biomass.* **Used by:** • INIT C in Biomass - Initial carbon in biomass. • Flux Biomass to Humus - Carbon flux from biomass to humus. • Flux Biomass to Atmosphere - Carbon flux from biomass to atmosphere.
Carbon	C	**Biostimulation Coefficient** (Dmnl) = 0.35 **Description:** *Coefficient for response of primary production to carbon concentration.* **Used by:** • Flux Atmosphere to Biomass - Carbon flux from atmosphere to biosphere (from primary production)
Carbon	C	**Buff C Coeff** (Dmnl) = 3.92 **Description:** *Coefficient of carbon concentration influence on buffer factor.* **Used by:** • Buffer Factor - Buffer factor for atmosphere/mixed ocean carbon equilibration.
Carbon	A	**Buffer Factor** (Dmnl) = Ref Buffer Factor*(C in Mixed Layer/Preindustrial C in Mixed Layer)^Buff C Coeff **Description:** *Buffer factor for atmosphere/mixed ocean carbon equilibration.* **Used by:** • Equil C in Mixed Layer - Equilibrium carbon content of mixed layer.
Carbon	A	**C Concentration Ratio** (Dmnl) = C in Atmosphere/INIT C in Atmosphere **Description:** *Current to initial carbon concentration in atmosphere.* **Used by:** • Effect of Pollution on Animal Food Land Fertility - Impact of carbon concentration on land fertility related to animal food. • Effect of Pollution on Agriculture Land Fertility - Impact of carbon concentration on cropland fertility. • Effect of CO2 Concentration on Forest Land Fertility - Impact of carbon concentration on forest land fertility. Scaled between minimal and maximal impact. • Change in Impact of Climate Risk on Life Expectancy - Change in Impact of Climate Risk on Life Expectancy.
Carbon	A	**C Emission from Biomass Energy** (TonC/Year) = Biomass Energy Production*C Intensity of Emission from Biomass Energy **Description:** *Total carbon emission from biomass energy production and it use.* **Used by:** • Total C Emission from Renewables - Total carbon emission from renewable energy sources.
Carbon	A	**C Emission from Coal Energy** (TonC/Year) = Coal Production*C Intensity of Emission from Coal **Description:** *Total carbon emission from coal energy production and it use.* **Used by:** • Total C Emission from Fossil Fuels - Total carbon emission from fossil fuels. Source of Historical Data:Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011
Carbon	A	**C Emission from Gas Energy** (TonC/Year) = Gas Production*C Intensity of Emission from Gas **Description:** *Total carbon emission from gas energy production and it use.* **Used by:** • Total C Emission from Fossil Fuels - Total carbon emission from fossil fuels. Source

		of Historical Data:Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011
Carbon	A	**C Emission from Land Use** (TonC/Year) = (Reference C Emission from Agricultural Land Use*Agricultural Land Change) + ((2-Forest Land Change)*Reference C Emission from Forest Land Use) **Description:** *Total carbon emission from forest and agricultural land use change. Source of Historical Data:Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.* **Used by:** • Land Use as Share of Total C Emission - Carbon emission from forest and agricultural land use change as a percentage of total carbon emission. • Total C Emission - Emissions of carbon from energy use and other sources.
Carbon	A	**C Emission from Oil Energy** (TonC/Year) = Oil Production*C Intensity of Emission from Oil **Description:** *Total carbon emission from oil production and it use.* **Used by:** • Total C Emission from Fossil Fuels - Total carbon emission from fossil fuels. Source of Historical Data:Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011
Carbon	A	**C Emission from Solar Energy** (TonC/Year) = Solar Energy Production*C Intensity of Emission from Solar Energy **Description:** *Total carbon emission from solar energy production and it use.* **Used by:** • Total C Emission from Renewables - Total carbon emission from renewable energy sources.
Carbon	A	**C Emission from Wind Energy** (TonC/Year) = Wind Energy Production*C Intensity of Emission from Wind Energy **Description:** *Total carbon emission from wind energy production and it use.* **Used by:** • Total C Emission from Renewables - Total carbon emission from renewable energy sources.
Carbon	S	**C in Atmosphere** (TonC) = INIT C in Atmosphere + ∫ (Flux Biomass to Atmosphere+Flux Humus to Atmosphere+Total C Emission-Flux Atmosphere to Biomass-Flux Atmosphere to Ocean) **Description:** *Carbon in atmosphere.* **Used by:** • Atmospheric Concentration CO2 - Converts weight of CO2 in atmosphere to concentration (ppm CO2). Source of Historical Data:Etheridge, D.M., Steele, L.P., Langenfelds, R.L., Francey, R.J., Barnola, J.-M., Morgan, V.I. 1998. Historical CO2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A • C Concentration Ratio - Current to initial carbon concentration in atmosphere. • Equil C in Mixed Layer - Equilibrium carbon content of mixed layer. • Flux Atmosphere to Biomass - Carbon flux from atmosphere to biosphere (from primary production) • R - Ratio of the current carbon in atmosphere to its preindustrial content. • CO2 Radiative Forcing - Radiative forcing from CO2 in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome
Carbon	S	**C in Biomass** (TonC) = INIT C in Biomass + ∫ (Flux Atmosphere to Biomass-Flux Biomass to Atmosphere-Flux Biomass to Humus) **Description:** *Carbon in biosphere (biomass, litter, and humus)*

		Used by: • Flux Biomass to Humus - Carbon flux from biomass to humus. • Flux Biomass to Atmosphere - Carbon flux from biomass to atmosphere.
Carbon	S	**C in Deep Ocean 1** (TonC) = INIT C in Deep Ocean 1 + ∫ (Diffusion Flux 1-Diffusion Flux 2) **Description:** *Carbon in the first layer of deep ocean.* **Used by:** • C in Deep Ocean 1 per meter - Carbon in the first ocean layer per its meter.
Carbon	A	**C in Deep Ocean 1 per meter** (TonC/Meter) = C in Deep Ocean 1/Layer Depth 1 **Description:** *Carbon in the first ocean layer per its meter.* **Used by:** • Diffusion Flux 2 - Diffusion flux between the first and the second ocean layers. • Diffusion Flux 1 - Diffusion flux between mixed and the first ocean layers.
Carbon	S	**C in Deep Ocean 2** (TonC) = INIT C in Deep Ocean 2 + ∫ (Diffusion Flux 2-Diffusion Flux 3) **Description:** *Carbon in the second layer of deep ocean.* **Used by:** • C in Deep Ocean 2 per meter - Carbon in the second ocean layer per its meter.
Carbon	A	**C in Deep Ocean 2 per meter** (TonC/Meter) = C in Deep Ocean 2/Layer Depth 2 **Description:** *Carbon in the second ocean layer per its meter.* **Used by:** • Diffusion Flux 3 - Diffusion flux between the second and the third ocean layers. • Diffusion Flux 2 - Diffusion flux between the first and the second ocean layers.
Carbon	S	**C in Deep Ocean 3** (TonC) = INIT C in Deep Ocean 3 + ∫ (Diffusion Flux 3-Diffusion Flux 4) **Description:** *Carbon in the third layer of deep ocean.* **Used by:** • C in Deep Ocean 3 per meter - Carbon in the third ocean layer per its meter.
Carbon	A	**C in Deep Ocean 3 per meter** (TonC/Meter) = C in Deep Ocean 3/Layer Depth 3 **Description:** *Carbon in the third ocean layer per its meter.* **Used by:** • Diffusion Flux 3 - Diffusion flux between the second and the third ocean layers. • Diffusion Flux 4 - Diffusion flux between the third and the fourth ocean layers.
Carbon	S	**C in Deep Ocean 4** (TonC) = INIT C in Deep Ocean 4 + ∫ (Diffusion Flux 4) **Description:** *Carbon in the fourth layer of deep ocean.* **Used by:** • C in Deep Ocean 4 per meter - Carbon in the fourth ocean layer per its meter.
Carbon	A	**C in Deep Ocean 4 per meter** (TonC/Meter) = C in Deep Ocean 4/Layer Depth 4 **Description:** *Carbon in the fourth ocean layer per its meter.* **Used by:** • Diffusion Flux 4 - Diffusion flux between the third and the fourth ocean layers.
Carbon	S	**C in Humus** (TonC) = INIT C in Humus + ∫ (Flux Biomass to Humus-Flux Humus to Atmosphere) **Description:** *Carbon in humus.* **Used by:** • Flux Humus to Atmosphere - Carbon flux from humus to atmosphere.
Carbon	S	**C in Mixed Layer** (TonC) = INIT C in Mixed Ocean + ∫ (Flux Atmosphere to Ocean-Diffusion Flux 1) **Description:** *Carbon in mixed layer.* **Used by:** • C in Mixed Layer per meter - Carbon in mixed layer per its meter.

		• Buffer Factor - Buffer factor for atmosphere/mixed ocean carbon equilibration. • Flux Atmosphere to Ocean - Carbon flux from atmosphere to mixed ocean layer.
Carbon	A	**C in Mixed Layer per meter** (TonC/Meter) = C in Mixed Layer/Mixed Layer Depth **Description:** *Carbon in mixed layer per its meter.* **Used by:** • Diffusion Flux 1 - Diffusion flux between mixed and the first ocean layers.
Carbon	C	**C Intensity of Emission from Biomass Energy** (TonC/Mtoe) = 1.278e+006 **Description:** *Carbon intensity from biomass energy production and it use.* **Used by:** • Default C Intensity of Emission from Biomass - Carbon intensity from biomass energy production and it use. • C Emission from Biomass Energy - Total carbon emission from biomass energy production and it use.
Carbon	A	**C Intensity of Emission from Coal** (TonC/Mtoe) = Normal C Intensity of Emission from Coal*(1-CCS Improvement Factor) **Description:** *Carbon intensity from coal energy production and it use.* **Used by:** • C Emission from Coal Energy - Total carbon emission from coal energy production and it use.
Carbon	A	**C Intensity of Emission from Gas** (TonC/Mtoe) = Normal C Intensity of Emission from Gas*(1-CCS Improvement Factor) **Description:** *Carbon intensity from gas energy production and it use.* **Used by:** • C Emission from Gas Energy - Total carbon emission from gas energy production and it use.
Carbon	A	**C Intensity of Emission from Oil** (TonC/Mtoe) = Normal C Intensity of Emission from Oil*(1-CCS Improvement Factor) **Description:** *Carbon intensity from oil energy production and it use.* **Used by:** • C Emission from Oil Energy - Total carbon emission from oil production and it use.
Carbon	C	**C Intensity of Emission from Solar Energy** (TonC/Mtoe) = 43200 **Description:** *Carbon intensity from solar energy production and it use.* **Used by:** • C Emission from Solar Energy - Total carbon emission from solar energy production and it use.
Carbon	C	**C Intensity of Emission from Wind Energy** (TonC/Mtoe) = 27000 **Description:** *Carbon intensity from wind energy production and it use.* **Used by:** • C Emission from Wind Energy - Total carbon emission from wind energy production and it use.
Carbon	S	**CCS Improvement** (Dmnl) = 0 + ∫ (CCS Improvement Change) **Description:** *Accumulated improvement of carbon capture and storage technology.* **Used by:** • CCS Improvement Factor - Impact of carbon capture and storage on carbon intensity of emissions from fossil fuels. Scaled between min and max improvement factor.
Carbon	A	**CCS Improvement Change** (1/Year) = DELAY3(Presure to Adjust Total C Emission from Fossil Fuels*Effectiveness of Pressure to Adjust C Emission,Time to Improve CCS) **Description:** *Change in improvement of carbon capture and storage technology.* **Used by:** • CCS Improvement - Accumulated improvement of carbon capture and storage technology.
Carbon	A	**CCS Improvement Factor** (Dmnl)

		= MIN CCS Improvement Factor+(MAX CCS Improvement Factor-MIN CCS Improvement Factor)*(CCS Improvement/(CCS Improvement+1)) **Description:** *Impact of carbon capture and storage on carbon intensity of emissions from fossil fuels. Scaled between min and max improvement factor.* **Used by:** • C Intensity of Emission from Oil - Carbon intensity from oil energy production and it use. • C Intensity of Emission from Coal - Carbon intensity from coal energy production and it use. • C Intensity of Emission from Gas - Carbon intensity from gas energy production and it use.
Carbon	C	**CCS Scenario** (Dmnl [0,1,1]) = 0 **Description:** *Carbon capture and storage scenario trigger* **Used by:** • Presure to Adjust Total C Emission from Fossil Fuels - Pressure to adjust the level of carbon emission from fossil fuels is the emission level rises above the acceptable level.
Carbon	A	**Default C Intensity of Emission from Biomass** (kgCO2/GJ) = C Intensity of Emission from Biomass Energy*Ton C to kg CO2/Mtoe to GJ **Description:** *Carbon intensity from biomass energy production and it use.*
Carbon	A	**Default C Intensity of Emission from Coal** (kgCO2/GJ) = Normal C Intensity of Emission from Coal*Ton C to kg CO2/Mtoe to GJ **Description:** *Initial carbon intensity of production from coal technologies.*
Carbon	A	**Default C Intensity of Emission from Gas** (kgCO2/GJ) = Normal C Intensity of Emission from Gas*Ton C to kg CO2/Mtoe to GJ **Description:** *Initial carbon intensity of production from gas technologies.*
Carbon	A	**Default C Intensity of Emission from Oil** (kgCO2/GJ) = Normal C Intensity of Emission from Oil*Ton C to kg CO2/Mtoe to GJ **Description:** *Initial carbon intensity of production from oil technologies.*
Carbon	C	**Desired Total C Emission from Fossil Fuels** (TonC/Year) = 7.5e+009 **Description:** *The upper level of acceptable total carbon emission from fossil fuels.* **Used by:** • Presure to Adjust Total C Emission from Fossil Fuels - Pressure to adjust the level of carbon emission from fossil fuels is the emission level rises above the acceptable level.
Carbon	F,A	**Diffusion Flux 1** (TonC/Year) = (C in Mixed Layer per meter-C in Deep Ocean 1 per meter)*Eddy diff coeff M 1/Mean Depth of Adjacent M 1 Layers **Description:** *Diffusion flux between mixed and the first ocean layers.* **Used by:** • C in Deep Ocean 1 - Carbon in the first layer of deep ocean. • C in Mixed Layer - Carbon in mixed layer.
Carbon	F,A	**Diffusion Flux 2** (TonC/Year) = (C in Deep Ocean 1 per meter-C in Deep Ocean 2 per meter)*Eddy diff coeff 1 2/Mean Depth of Adjacent 1 2 Layers **Description:** *Diffusion flux between the first and the second ocean layers.* **Used by:** • C in Deep Ocean 2 - Carbon in the second layer of deep ocean. • C in Deep Ocean 1 - Carbon in the first layer of deep ocean.
Carbon	F,A	**Diffusion Flux 3** (TonC/Year) = (C in Deep Ocean 2 per meter-C in Deep Ocean 3 per meter)*Eddy diff coeff 2 3/Mean Depth of Adjacent 2 3 Layers **Description:** *Diffusion flux between the second and the third ocean layers.* **Used by:** • C in Deep Ocean 2 - Carbon in the second layer of deep ocean. • C in Deep Ocean 3 - Carbon in the third layer of deep ocean.

Carbon	A	**Diffusion Flux 4** (TonC/Year) = (C in Deep Ocean 3 per meter-C in Deep Ocean 4 per meter)*Eddy diff coeff 3 4/Mean Depth of Adjacent 3 4 Layers **Description:** *Diffusion flux between the third and the fourth ocean layers.* **Used by:** • C in Deep Ocean 4 - Carbon in the fourth layer of deep ocean. • C in Deep Ocean 3 - Carbon in the third layer of deep ocean.
Carbon	A	**Eddy diff coeff 1 2** (Meter*Meter/Year) = Eddy diff coeff index 1 2*Eddy diff coeff mean 1 2 **Description:** *Coefficient of carbon diffusion to the second layer of deep ocean.* **Used by:** • Layer Time Constant 1 2 - Time constant of exchange between the first and the second ocean layers. • Diffusion Flux 2 - Diffusion flux between the first and the second ocean layers. • Heat Transfer Coefficient 2 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	A	**Eddy diff coeff 2 3** (Meter*Meter/Year) = Eddy diff coeff index 2 3*Eddy diff coeff mean 2 3 **Description:** *Coefficient of carbon diffusion to the third layer of deep ocean.* **Used by:** • Diffusion Flux 3 - Diffusion flux between the second and the third ocean layers. • Layer Time Constant 2 3 - Time constant of exchange between the second and the third ocean layers. • Heat Transfer Coefficient 3 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	A	**Eddy diff coeff 3 4** (Meter*Meter/Year) = Eddy diff coeff index 3 4*Eddy diff coeff mean 3 4 **Description:** *Coefficient of carbon diffusion to the fourth layer of deep ocean.* **Used by:** • Diffusion Flux 4 - Diffusion flux between the third and the fourth ocean layers. • Layer Time Constant 3 4 - Time constant of exchange between the third and the fourth ocean layers. • Heat Transfer Coefficient 4 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	C	**Eddy diff coeff index 1 2** (Dmnl) = 1 **Description:** *Index of coefficient for rate at which carbon is mixed in the ocean due to eddy motion, where 1 is equivalent to the expected value of 4400 meter/meter/year.* **Used by:** • Eddy diff coeff 1 2 - Coefficient of carbon diffusion to the second layer of deep ocean.
Carbon	C	**Eddy diff coeff index 2 3** (Dmnl) = 1 **Description:** *Index of coefficient for rate at which carbon is mixed in the ocean due to eddy motion, where 1 is equivalent to the expected value of 4400 meter/meter/year.* **Used by:** • Eddy diff coeff 2 3 - Coefficient of carbon diffusion to the third layer of deep ocean.
Carbon	C	**Eddy diff coeff index 3 4** (Dmnl) = 1 **Description:** *Index of coefficient for rate at which carbon is mixed in the ocean due to eddy motion, where 1 is equivalent to the expected value of 4400 meter/meter/year.* **Used by:** • Eddy diff coeff 3 4 - Coefficient of carbon diffusion to the fourth layer of deep ocean.
Carbon	C	**Eddy diff coeff index M 1** (Dmnl) = 1 **Description:** *Index of coefficient for rate at which carbon is mixed in the ocean due to eddy motion, where 1 is equivalent to the expected value of 4400 meter/meter/year.* **Used by:** • Eddy diff coeff M 1 - Coefficient of carbon diffusion to the first layer of deep ocean.

Carbon	A	**Eddy diff coeff M 1** (Meter*Meter/Year) = Eddy diff coeff index M 1*Eddy diff coeff mean M 1 **Description:** *Coefficient of carbon diffusion to the first layer of deep ocean.* **Used by:** • Layer Time Constant M 1 - Time constant of exchange between mixed and the first ocean layers. • Diffusion Flux 1 - Diffusion flux between mixed and the first ocean layers. • Heat Transfer Coefficient 1 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	C	**Eddy diff coeff mean 1 2** (Meter*Meter/Year) = 4400 **Description:** *Expected value at which carbon is mixed in the ocean due to eddy motion.* **Used by:** • Eddy diff coeff 1 2 - Coefficient of carbon diffusion to the second layer of deep ocean. • Heat Transfer Coefficient 2 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	C	**Eddy diff coeff mean 2 3** (Meter*Meter/Year) = 4400 **Description:** *Expected value at which carbon is mixed in the ocean due to eddy motion.* **Used by:** • Eddy diff coeff 2 3 - Coefficient of carbon diffusion to the third layer of deep ocean. • Heat Transfer Coefficient 3 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	C	**Eddy diff coeff mean 3 4** (Meter*Meter/Year) = 4400 **Description:** *Expected value at which carbon is mixed in the ocean due to eddy motion.* **Used by:** • Eddy diff coeff 3 4 - Coefficient of carbon diffusion to the fourth layer of deep ocean. • Heat Transfer Coefficient 4 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	C	**Eddy diff coeff mean M 1** (Meter*Meter/Year) = 4400 **Description:** *Expected value at which carbon is mixed in the ocean due to eddy motion.* **Used by:** • Eddy diff coeff M 1 - Coefficient of carbon diffusion to the first layer of deep ocean. • Heat Transfer Coefficient 1 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Carbon	C	**Effectiveness of Pressure to Adjust C Emission** (1/Year) = 0.07 **Description:** *Rate at which the gap between acceptable and current carbon emission from fossil fuels level is addressed.* **Used by:** • CCS Improvement Change - Change in improvement of carbon capture and storage technology.
Carbon	A	**Emission from Fossil Fuels per Capita** (TonC/(Year*Person)) = Total C Emission from Fossil Fuels/Population **Description:** *Carbon emission from energy production and it use per capita.*
Carbon	A	**Emission per Capita** (TonC/(Year*Person)) = Total C Emission/Population **Description:** *Emissions of carbon from energy use and other sources per capita.*
Carbon	A	**Equil C in Mixed Layer** (TonC) = Preindustrial C in Mixed Layer * (C in Atmosphere/Preindustrial C in Atmosphere)^(1/Buffer Factor) **Description:** *Equilibrium carbon content of mixed layer.* **Used by:** • Flux Atmosphere to Ocean - Carbon flux from atmosphere to mixed ocean layer.
Carbon	I,F	**Flux Atmosphere to Biomass** (TonC/Year) = Initial Net Primary Production*(1+Biostimulation Coefficient*LN(C in

		Atmosphere/Preindustrial C in Atmosphere)) **Description:** *Carbon flux from atmosphere to biosphere (from primary production)* **Used by:** • INIT C in Biomass - Initial carbon in biomass. • C in Atmosphere - Carbon in atmosphere. • C in Biomass - Carbon in biosphere (biomass, litter, and humus)
Carbon	F,A	**Flux Atmosphere to Ocean** (TonC/Year) = (Equil C in Mixed Layer-C in Mixed Layer)/Mixing Time **Description:** *Carbon flux from atmosphere to mixed ocean layer.* **Used by:** • C in Atmosphere - Carbon in atmosphere. • C in Mixed Layer - Carbon in mixed layer.
Carbon	F,A	**Flux Biomass to Atmosphere** (TonC/Year) = (C in Biomass/Biomass Res Time)*(1-Humification Fraction) **Description:** *Carbon flux from biomass to atmosphere.* **Used by:** • C in Atmosphere - Carbon in atmosphere. • C in Biomass - Carbon in biosphere (biomass, litter, and humus)
Carbon	F,A	**Flux Biomass to Humus** (TonC/Year) = (C in Biomass/Biomass Res Time)*Humification Fraction **Description:** *Carbon flux from biomass to humus.* **Used by:** • INIT C in Humus - Inital carbon in humus. • C in Biomass - Carbon in biosphere (biomass, litter, and humus) • C in Humus - Carbon in humus.
Carbon	F,A	**Flux Humus to Atmosphere** (TonC/Year) = C in Humus/Humus Res Time **Description:** *Carbon flux from humus to atmosphere.* **Used by:** • C in Atmosphere - Carbon in atmosphere. • C in Humus - Carbon in humus.
Carbon	A	**Forest Land Change** (Dmnl) = Forest Land/INIT Forest Land **Description:** *Ratio of forest land area change compared to its initial area in year 1900.* **Used by:** • C Emission from Land Use - Total carbon emission from forest and agricultural land use change. Source of Historical Data:Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.
Carbon	C	**GtC to TonC** (TonC/GtC) = 1e+009 **Description:** *1 GtC equals 1000000000 tons of carbon* **Used by:** • Atmospheric Concentration CO2 - Converts weight of CO2 in atmosphere to concentration (ppm CO2). Source of Historical Data:Etheridge, D.M., Steele, L.P., Langenfelds, R.L., Francey, R.J., Barnola, J.-M., Morgan, V.I. 1998. Historical CO2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A • INIT C in Atmosphere - Initial carbon in atmosphere.
Carbon	C	**Humification Fraction** (Dmnl) = 0.428 **Description:** *Fraction of carbon outflow from biomass that enters humus stock.* **Used by:** • Flux Biomass to Humus - Carbon flux from biomass to humus. • Flux Biomass to Atmosphere - Carbon flux from biomass to atmosphere.

Carbon	C	**Humus Res Time** (Year) = 27.8 **Description:** *Average carbon residence time in humus.* **Used by:** • INIT C in Humus - Inital carbon in humus. • Flux Humus to Atmosphere - Carbon flux from humus to atmosphere.
Carbon	A	**INIT C in Atmosphere** (TonC) = Atmospheric CO2 Law Dome 1850*GtC to TonC*ppm to GtC **Description:** *Initial carbon in atmosphere.* **Used by:** • C Concentration Ratio - Current to initial carbon concentration in atmosphere. • C in Atmosphere - Carbon in atmosphere.
Carbon	I	**INIT C in Biomass** (TonC) = INITIAL(Flux Atmosphere to Biomass*Biomass Res Time) **Description:** *Initial carbon in biomass.* **Used by:** • C in Biomass - Carbon in biosphere (biomass, litter, and humus)
Carbon	C	**INIT C in Deep Ocean 1** (TonC) = 3.115e+012 **Description:** *Initial carbon in the first layer of deep ocean.* **Used by:** • C in Deep Ocean 1 - Carbon in the first layer of deep ocean.
Carbon	C	**INIT C in Deep Ocean 2** (TonC) = 3.099e+012 **Description:** *Initial carbon in the second layer of deep ocean.* **Used by:** • C in Deep Ocean 2 - Carbon in the second layer of deep ocean.
Carbon	C	**INIT C in Deep Ocean 3** (TonC) = 1.3356e+013 **Description:** *Initial carbon in the third layer of deep ocean.* **Used by:** • C in Deep Ocean 3 - Carbon in the third layer of deep ocean.
Carbon	C	**INIT C in Deep Ocean 4** (TonC) = 1.8477e+013 **Description:** *Initial carbon in the fourth layer of deep ocean.* **Used by:** • C in Deep Ocean 4 - Carbon in the fourth layer of deep ocean.
Carbon	I	**INIT C in Humus** (TonC) = INITIAL(Flux Biomass to Humus*Humus Res Time) **Description:** *Inital carbon in humus.* **Used by:** • C in Humus - Carbon in humus.
Carbon	C	**INIT C in Mixed Ocean** (TonC) = 1.028e+012 **Description:** *Initial carbon in mixed ocean layer.* **Used by:** • C in Mixed Layer - Carbon in mixed layer.
Carbon	C	**Initial Net Primary Production** (TonC/Year) = 8.51771e+010 **Description:** *Initial net primary production.* **Used by:** • Flux Atmosphere to Biomass - Carbon flux from atmosphere to biosphere (from primary production)
Carbon	A	**Land Use as Share of Total C Emission** (Dmnl) = (C Emission from Land Use/Total C Emission)*100 **Description:** *Carbon emission from forest and agricultural land use change as a percentage of total carbon emission.*

Carbon	C	**Layer Depth 1** (Meter) = 300 **Description:** *Depth of the first ocean layer.* **Used by:** • Layer Time Constant 1 2 - Time constant of exchange between the first and the second ocean layers. • Layer Time Constant M 1 - Time constant of exchange between mixed and the first ocean layers. • C in Deep Ocean 1 per meter - Carbon in the first ocean layer per its meter. • Mean Depth of Adjacent 1 2 Layers - Mean depth of the first and the second ocean layers. • Mean Depth of Adjacent M 1 Layers - Mean depth of mixed and the first ocean layers. • Lower Layer Volume Vu 1 - Water equivalent volume of the first layer of deep ocean.
Carbon	C	**Layer Depth 2** (Meter) = 300 **Description:** *Depth of the second ocean layer.* **Used by:** • Layer Time Constant 1 2 - Time constant of exchange between the first and the second ocean layers. • C in Deep Ocean 2 per meter - Carbon in the second ocean layer per its meter. • Layer Time Constant 2 3 - Time constant of exchange between the second and the third ocean layers. • Mean Depth of Adjacent 2 3 Layers - Mean depth of the second and the third ocean layers. • Mean Depth of Adjacent 1 2 Layers - Mean depth of the first and the second ocean layers. • Lower Layer Volume Vu 2 - Water equivalent volume of the second layer of deep ocean.
Carbon	C	**Layer Depth 3** (Meter) = 1300 **Description:** *Depth of the third ocean layer.* **Used by:** • C in Deep Ocean 3 per meter - Carbon in the third ocean layer per its meter. • Layer Time Constant 2 3 - Time constant of exchange between the second and the third ocean layers. • Mean Depth of Adjacent 2 3 Layers - Mean depth of the second and the third ocean layers. • Layer Time Constant 3 4 - Time constant of exchange between the third and the fourth ocean layers. • Mean Depth of Adjacent 3 4 Layers - Mean depth of the third and the fourth ocean layers. • Lower Layer Volume Vu 3 - Water equivalent volume of the third layer of deep ocean.
Carbon	C	**Layer Depth 4** (Meter) = 1800 **Description:** *Depth of the fourth ocean layer.* **Used by:** • C in Deep Ocean 4 per meter - Carbon in the fourth ocean layer per its meter. • Layer Time Constant 3 4 - Time constant of exchange between the third and the fourth ocean layers. • Mean Depth of Adjacent 3 4 Layers - Mean depth of the third and the fourth ocean layers. • Lower Layer Volume Vu 4 - Water equivalent volume of the fourth layer of deep ocean.
Carbon	A	**Layer Time Constant 1 2** (Year) = Layer Depth 2/(Eddy diff coeff 1 2/((Layer Depth 1+Layer Depth 2)/2)) **Description:** *Time constant of exchange between the first and the second ocean layers.*

Carbon	A	**Layer Time Constant 2 3** (Year) = Layer Depth 3/(Eddy diff coeff 2 3/((Layer Depth 2+Layer Depth 3)/2)) **Description:** *Time constant of exchange between the second and the third ocean layers.*
Carbon	A	**Layer Time Constant 3 4** (Year) = Layer Depth 4/(Eddy diff coeff 3 4/((Layer Depth 3+Layer Depth 4)/2)) **Description:** *Time constant of exchange between the third and the fourth ocean layers.*
Carbon	A	**Layer Time Constant M 1** (Year) = Layer Depth 1/(Eddy diff coeff M 1/((Mixed Layer Depth+Layer Depth 1)/2)) **Description:** *Time constant of exchange between mixed and the first ocean layers.*
Carbon	C	**MAX CCS Improvement Factor** (Dmnl) = 1 **Description:** *Max impact of carbon capture and storage on carbon intensity of emissions from fossil fuels.* **Used by:** • CCS Improvement Factor - Impact of carbon capture and storage on carbon intensity of emissions from fossil fuels. Scaled between min and max improvement factor.
Carbon	A	**Mean Depth of Adjacent 1 2 Layers** (Meter) = (Layer Depth 1+Layer Depth 2)/2 **Description:** *Mean depth of the first and the second ocean layers.* **Used by:** • Diffusion Flux 2 - Diffusion flux between the first and the second ocean layers. • Heat Transfer Coefficient 2 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer 2 - Heat transfer from the first to the second layer of the deep ocean.
Carbon	A	**Mean Depth of Adjacent 2 3 Layers** (Meter) = (Layer Depth 2+Layer Depth 3)/2 **Description:** *Mean depth of the second and the third ocean layers.* **Used by:** • Diffusion Flux 3 - Diffusion flux between the second and the third ocean layers. • Heat Transfer Coefficient 3 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer 3 - Heat transfer from the second to the third layer of the deep ocean.
Carbon	A	**Mean Depth of Adjacent 3 4 Layers** (Meter) = (Layer Depth 3+Layer Depth 4)/2 **Description:** *Mean depth of the third and the fourth ocean layers.* **Used by:** • Diffusion Flux 4 - Diffusion flux between the third and the fourth ocean layers. • Heat Transfer Coefficient 4 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer 4 - Heat transfer from the third to the fourth layer of the deep ocean.
Carbon	A	**Mean Depth of Adjacent M 1 Layers** (Meter) = (Mixed Layer Depth+Layer Depth 1)/2 **Description:** *Mean depth of mixed and the first ocean layers.* **Used by:** • Diffusion Flux 1 - Diffusion flux between mixed and the first ocean layers. • Heat Transfer Coefficient 1 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer 1 - Heat transfer from the atmosphere & upper ocean to the first layer of the deep ocean.
Carbon	C	**MIN CCS Improvement Factor** (Dmnl) = 0 **Description:** *Min impact of carbon capture and storage on carbon intensity of emissions from fossil fuels.* **Used by:** • CCS Improvement Factor - Impact of carbon capture and storage on carbon intensity of emissions from fossil fuels. Scaled between min and max improvement factor.
Carbon	C	**Mixed Layer Depth** (Meter) = 100

		Description: *Mixed ocean layer depth.* **Used by:** • Layer Time Constant M 1 - Time constant of exchange between mixed and the first ocean layers. • C in Mixed Layer per meter - Carbon in mixed layer per its meter. • Mean Depth of Adjacent M 1 Layers - Mean depth of mixed and the first ocean layers. • Preindustrial C in Mixed Layer - Initial carbon content of mixed ocean layer. • Upper Layer Volume Vu - Water equivalent volume of the upper box, which is a weighted combination of land, atmosphere,and upper ocean volumes.
Carbon	C	**Mixing Time** (Year) = 1 **Description:** *Atmosphere - mixed ocean layer mixing time.* **Used by:** • Flux Atmosphere to Ocean - Carbon flux from atmosphere to mixed ocean layer.
Carbon	C	**Mtoe to GJ** (GJ/Mtoe) = 4.1868e+007 **Description:** *Conversion from Mtoe to GJ.* **Used by:** • Default C Intensity of Emission from Biomass - Carbon intensity from biomass energy production and it use. • Default C Intensity of Emission from Oil - Initial carbon intensity of production from oil technologies. • Default C Intensity of Emission from Coal - Initial carbon intensity of production from coal technologies. • Default C Intensity of Emission from Gas - Initial carbon intensity of production from gas technologies.
Carbon	C	**Normal C Intensity of Emission from Coal** (TonC/Mtoe) = 1.08e+006 **Description:** *Initial carbon intensity of production from coal technologies.* **Used by:** • Default C Intensity of Emission from Coal - Initial carbon intensity of production from coal technologies. • C Intensity of Emission from Coal - Carbon intensity from coal energy production and it use.
Carbon	C	**Normal C Intensity of Emission from Gas** (TonC/Mtoe) = 640000 **Description:** *Initial carbon intensity of production from gas technologies.* **Used by:** • Default C Intensity of Emission from Gas - Initial carbon intensity of production from gas technologies. • C Intensity of Emission from Gas - Carbon intensity from gas energy production and it use.
Carbon	C	**Normal C Intensity of Emission from Oil** (TonC/Mtoe) = 836500 **Description:** *Initial carbon intensity of production from oil technologies.* **Used by:** • Default C Intensity of Emission from Oil - Initial carbon intensity of production from oil technologies. • C Intensity of Emission from Oil - Carbon intensity from oil energy production and it use.
Carbon	C	**ppm to GtC** (GtC/ppm) = 2.13 **Description:** *1 ppm by volume of atmosphere CO2 equals 2.13 GtC* **Used by:** • Atmospheric Concentration CO2 - Converts weight of CO2 in atmosphere to concentration (ppm CO2). Source of Historical Data:Etheridge, D.M., Steele, L.P., Langenfelds, R.L., Francey, R.J., Barnola, J.-M., Morgan, V.I. 1998. Historical CO2

		records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A • INIT C in Atmosphere - Initial carbon in atmosphere.
Carbon	C	**Preindustrial C in Atmosphere** (TonC) = 5.9e+011 **Description:** *Preindustrial carbon content of atmosphere.* **Used by:** • Equil C in Mixed Layer - Equilibrium carbon content of mixed layer. • Flux Atmosphere to Biomass - Carbon flux from atmosphere to biosphere (from primary production) • R - Ratio of the current carbon in atmosphere to its preindustrial content. • CO2 Radiative Forcing - Radiative forcing from CO2 in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome
Carbon	A	**Preindustrial C in Mixed Layer** (TonC) = Preindustrial Ocean C per meter*Mixed Layer Depth **Description:** *Initial carbon content of mixed ocean layer.* **Used by:** • Buffer Factor - Buffer factor for atmosphere/mixed ocean carbon equilibration. • Equil C in Mixed Layer - Equilibrium carbon content of mixed layer.
Carbon	C	**Preindustrial Ocean C per meter** (TonC/m) = 1.02373e+010 **Description:** *Preindustrial carbon content in ocean per meter.* **Used by:** • Preindustrial C in Mixed Layer - Initial carbon content of mixed ocean layer.
Carbon	A	**Presure to Adjust Total C Emission from Fossil Fuels** (Dmnl) = CCS Scenario*(MAX(0,(Total C Emission from Fossil Fuels/Desired Total C Emission from Fossil Fuels)-1)) **Description:** *Pressure to adjust the level of carbon emission from fossil fuels is the emission level rises above the acceptable level.* **Used by:** • CCS Improvement Change - Change in improvement of carbon capture and storage technology.
Carbon	C	**Ref Buffer Factor** (Dmnl) = 9.7 **Description:** *Normal buffer factor.* **Used by:** • Buffer Factor - Buffer factor for atmosphere/mixed ocean carbon equilibration.
Carbon	C	**Reference C Emission from Agricultural Land Use** (TonC/Year) = 6.5e+008 **Description:** *Reference value of carbon emission from unit agricultural land change.* **Used by:** • C Emission from Land Use - Total carbon emission from forest and agricultural land use change. Source of Historical Data:Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.
Carbon	C	**Reference C Emission from Forest Land Use** (TonC/Year) = 4.5e+008 **Description:** *Reference value of carbon emission from unit forest land change.* **Used by:** • C Emission from Land Use - Total carbon emission from forest and agricultural land use change. Source of Historical Data:Houghton, R.A. 2008. Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.
Carbon	C	**Time to Improve CCS** (Year)

		= 10 **Description:** *Average CCS technology development lead time.* **Used by:** • CCS Improvement Change - Change in improvement of carbon capture and storage technology.
Carbon	C	**Ton C to kg CO2** (kgCO2/TonC) = 3670 **Description:** *Conversion from TonC to kgCO2.* **Used by:** • Default C Intensity of Emission from Biomass - Carbon intensity from biomass energy production and it use. • Default C Intensity of Emission from Oil - Initial carbon intensity of production from oil technologies. • Default C Intensity of Emission from Coal - Initial carbon intensity of production from coal technologies. • Default C Intensity of Emission from Gas - Initial carbon intensity of production from gas technologies.
Carbon	F,A	**Total C Emission** (TonC/Year) = Total C Emission form Energy Sector+C Emission from Land Use **Description:** *Emissions of carbon from energy use and other sources.* **Used by:** • Land Use as Share of Total C Emission - Carbon emission from forest and agricultural land use change as a percentage of total carbon emission. • Emission per Capita - Emissions of carbon from energy use and other sources per capita. • C in Atmosphere - Carbon in atmosphere.
Carbon	A	**Total C Emission form Energy Sector** (TonC/Year) = Total C Emission from Fossil Fuels+Total C Emission from Renewables **Description:** *Total carbon emission from energy production and it use.* **Used by:** • Total C Emission - Emissions of carbon from energy use and other sources.
Carbon	A	**Total C Emission from Fossil Fuels** (TonC/Year) = C Emission from Coal Energy+C Emission from Gas Energy+C Emission from Oil Energy **Description:** *Total carbon emission from fossil fuels. Source of Historical Data:Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011* **Used by:** • Presure to Adjust Total C Emission from Fossil Fuels - Pressure to adjust the level of carbon emission from fossil fuels is the emission level rises above the acceptable level. • Emission from Fossil Fuels per Capita - Carbon emission from energy production and it use per capita. • Total C Emission form Energy Sector - Total carbon emission from energy production and it use.
Carbon	A	**Total C Emission from Renewables** (TonC/Year) = C Emission from Biomass Energy+C Emission from Solar Energy+C Emission from Wind Energy **Description:** *Total carbon emission from renewable energy sources.* **Used by:** • Total C Emission form Energy Sector - Total carbon emission from energy production and it use.
Climate	A	**2xCO2 Forcing** (W/(Meter*Meter)) = CO2 Radiative Forcing Coefficient*LN(2) **Description:** *Radiative forcing at 2x CO2 equivalent.* **Used by:** • Climate Feedback Parameter - Determines feedback effect from temperature increase.
Climate	C	**Area** (Meter*Meter)

		= 5.1e+014 **Description:** *Global surface area.* **Used by:** • Lower Layer Volume Vu 4 - Water equivalent volume of the fourth layer of deep ocean. • Deep Ocean 2 Heat Capacity - Volumetric heat capacity for the second layer of the deep ocean. • Deep Ocean 3 Heat Capacity - Volumetric heat capacity for the third layer of the deep ocean. • Deep Ocean 4 Heat Capacity - Volumetric heat capacity for the fourth layer of the deep ocean. • Heat to 700m J - Heat to 700 m in Joules*1e22 for the area covered by water. Source of Historical Data:NOAA Ocean heat content anomalies;http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155. • Atmospheric and Upper Ocean Heat Capacity - Volumetric heat capacity for the land, atmosphere, and, upper ocean layer. • Lower Layer Volume Vu 2 - Water equivalent volume of the second layer of deep ocean. • Lower Layer Volume Vu 3 - Water equivalent volume of the third layer of deep ocean. • Deep Ocean 1 Heat Capacity - Volumetric heat capacity for the first layer of the deep ocean. • Upper Layer Volume Vu - Water equivalent volume of the upper box, which is a weighted combination of land, atmosphere and upper ocean volumes. • Heat to 2000m J - Heat to 2000m in Joules*1e22 for the area covered by water. • Lower Layer Volume Vu 1 - Water equivalent volume of the first layer of deep ocean.
Climate	A	**Atmospheric and Upper Ocean Heat Capacity** (Year*W/(Meter*Meter*DegreesC)) = Upper Layer Volume Vu*Volumetric Heat Capacity/Area **Description:** *Volumetric heat capacity for the land, atmosphere, and, upper ocean layer.* **Used by:** • Temperature Change from Preindustrial - Temperature of the Atmosphere and Upper Ocean and how it has changed from preindustrial period. • Heat in Atmosphere and Upper Ocean - Temperature of the atmosphere and the mixed ocean layer.
Climate	A	**CH4 Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = TABLE CH4 Radiative Forcing AIM RCP60(Time*Dimentionless Time) **Description:** *Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).*
Climate	A	**CH4 Radiative Forcing History** (W/(Meter*Meter)) = TABLE CH4 Radiative Forcing(Time*Dimentionless Time) **Description:** *Historical data for radiative forcing from CH4 in the atmosphere.*
Climate	A	**CH4 Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = TABLE CH4 Radiative Forcing IMAGE RCP26(Time*Dimentionless Time) **Description:** *Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).*
Climate	A	**CH4 Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = TABLE CH4 Radiative Forcing MESSAGE RCP85(Time*Dimentionless Time) **Description:** *Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).*
Climate	A	**CH4 Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = TABLE CH4 Radiative Forcing MiniCAM RCP45(Time*Dimentionless Time) **Description:** *Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).*

Climate	A	**Climate Damage Fraction** (Dmnl) = 1/(1+Climate Damage Scale*(Temperature Change from Preindustrial/Reference Temperature)^Climate Damage Nonlinearity) **Description:** *Fraction of Output lost to combating Climate Change.* **Used by:** • Impact of Climate Damage on Reliable Water Supply - A parameter that determines the impact of climate risk on water resources or infrastructure availability to provide reliable water supply. • Net Climate Change Impact on Economy - The fraction of ecomomy output loss due to climate change.
Climate	C	**Climate Damage Nonlinearity** (Dmnl) = 2 **Description:** *Nonlinearity of Climate Damage Cost Fraction.* **Used by:** • Climate Damage Fraction - Fraction of Output lost to combating Climate Change.
Climate	C	**Climate Damage Scale** (Dmnl) = 0.013 **Description:** *Climate Damage Fraction at Reference Temperature.* **Used by:** • Climate Damage Fraction - Fraction of Output lost to combating Climate Change.
Climate	A	**Climate Feedback Parameter** (Watt/(Meter*Meter)/DegreesC) = 2xCO2 Forcing/Climate Sensitivity to 2xCO2 **Description:** *Determines feedback effect from temperature increase.* **Used by:** • Equilibrium Temperature - Ratio of Radiative Forcing to the Climate Feedback Parameter • Feedback Cooling - Feedback cooling of atmosphere/upper ocean system due to blackbody radiation.
Climate	C	**Climate Sensitivity to 2xCO2** (DegreesC) = 3 **Description:** *Equilibrium temperature change in response to a 2xCO2 equivalent change in radiative forcing. Deterministic = 3, Low=2, High =4.5.* **Used by:** • Climate Feedback Parameter - Determines feedback effect from temperature increase.
Climate	A	**CO2 Radiative Forcing** (W/(Meter*Meter)) = CO2 Radiative Forcing Coefficient*LN(C in Atmosphere/Preindustrial C in Atmosphere) **Description:** *Radiative forcing from CO2 in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome* **Used by:** • Equilibrium Temperature - Ratio of Radiative Forcing to the Climate Feedback Parameter • Total Radiative Forcing - Radiative forcing from various factors in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome
Climate	C	**CO2 Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = 0 **Description:** *Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).*
Climate	C	**CO2 Radiative Forcing Coefficient** (W/(m*m)) = 5.35 **Description:** *Coefficient to calculate forcing due to atmospheric gas using first-order approximation expression for carbon dioxide.* **Used by:** • 2xCO2 Forcing - Radiative forcing at 2x CO2 equivalent. • CO2 Radiative Forcing - Radiative forcing from CO2 in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome

Climate	C	**CO2 Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = 0 **Description:** *Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).*
Climate	C	**CO2 Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = 0 **Description:** *Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).*
Climate	C	**CO2 Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = 0 **Description:** *Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).*
Climate	A	**Deep Ocean 1 Heat Capacity** (Year*W/(Meter*Meter*DegreesC)) = Lower Layer Volume Vu 1*Volumetric Heat Capacity/Area **Description:** *Volumetric heat capacity for the first layer of the deep ocean.* **Used by:** • Relative Deep 1 Ocean Temperature - Temperature of the first layer of the deep ocean. • Heat in Deep Ocean 1 - Heat content of the first layer of the deep ocean.
Climate	A	**Deep Ocean 2 Heat Capacity** (Year*W/(Meter*Meter*DegreesC)) = Lower Layer Volume Vu 2*Volumetric Heat Capacity/Area **Description:** *Volumetric heat capacity for the second layer of the deep ocean.* **Used by:** • Relative Deep 2 Ocean Temperature - Temperature of the second layer of the deep ocean. • Heat in Deep Ocean 2 - Heat content of the second layer of the deep ocean.
Climate	A	**Deep Ocean 3 Heat Capacity** (Year*W/(Meter*Meter*DegreesC)) = Lower Layer Volume Vu 3*Volumetric Heat Capacity/Area **Description:** *Volumetric heat capacity for the third layer of the deep ocean.* **Used by:** • Relative Deep 3 Ocean Temperature - Temperature of the third layer of the deep ocean. • Heat in Deep Ocean 3 - Heat content of the third layer of the deep ocean.
Climate	A	**Deep Ocean 4 Heat Capacity** (Year*W/(Meter*Meter*DegreesC)) = Lower Layer Volume Vu 4*Volumetric Heat Capacity/Area **Description:** *Volumetric heat capacity for the fourth layer of the deep ocean.* **Used by:** • Relative Deep 4 Ocean Temperature - Temperature of the fourth layer of the deep ocean. • Heat in Deep Ocean 4 - Heat content of the fourth layer of the deep ocean.
Climate	C	**Density** (kg/(m*m*m)) = 1000 **Description:** *Density of water, i.e., mass per volume of water.* **Used by:** • Volumetric Heat Capacity - Volumetric heat capacity of water, i.e., amount of heat in watt*year required to raise 1 cubic meter of water by one degree C.
Climate	C	**Dimentionless Time** (1/Year) = 1 **Description:** *Parameter to make table data dimensionless.* **Used by:** • CH4 Radiative Forcing MiniCAM RCP45 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5). • CH4 Radiative Forcing AIM RCP60 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of

		the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0). • CH4 Radiative Forcing History - Historical data for radiative forcing from CH4 in the atmosphere. • HFC Radiative Forcing MESSAGE RCP85 - Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5). • HFC Radiative Forcing MiniCAM RCP45 - Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5). • N2O Radiative Forcing MESSAGE RCP85 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5). • N2O Radiative Forcing MiniCAM RCP45 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5). • CH4 Radiative Forcing IMAGE RCP26 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6). • N2O Radiative Forcing IMAGE RCP26 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6). • CH4 Radiative Forcing MESSAGE RCP85 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5). • N2O Radiative Forcing AIM RCP60 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0). • N2O Radiative Forcing History - Historical data for radiative forcing from N2O in the atmosphere. • Other Radiative Forcing MiniCAM RCP45 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5). • Other Radiative Forcing MESSAGE RCP85 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5). • HFC Radiative Forcing History - Historical data for radiative forcing from HFC in the atmosphere. • Other Radiative Forcing IMAGE RCP26 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6). • HFC Radiative Forcing AIM RCP60 - Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0). • HFC Radiative Forcing IMAGE RCP26 - Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6). • Other Radiative Forcing AIM RCP60 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0). • Other Radiative Forcing History - Historical data for radiative forcing from other

		factors in the atmosphere.
Climate	F,A	**Effective Radiative Forcing** (W/(Meter*Meter)) = Total Radiative Forcing **Description:** *Total radiative forcing from various factors in the atmosphere.* **Used by:** • Heat in Atmosphere and Upper Ocean - Temperature of the atmosphere and the mixed ocean layer.
Climate	A	**Equilibrium Temperature** (DegreesC) = CO2 Radiative Forcing/(Climate Feedback Parameter*LN(2)) **Description:** *Ratio of Radiative Forcing to the Climate Feedback Parameter*
Climate	F,A	**Feedback Cooling** (Watt/(Meter*Meter)) = Temperature Change from Preindustrial*Climate Feedback Parameter **Description:** *Feedback cooling of atmosphere/upper ocean system due to blackbody radiation.* **Used by:** • Heat in Atmosphere and Upper Ocean - Temperature of the atmosphere and the mixed ocean layer.
Climate	C	**Heat Diffusion Covar** (Dmnl) = 1 **Description:** *Heat transfer coefficient parameter.* **Used by:** • Heat Transfer Coefficient 3 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer Coefficient 4 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer Coefficient 2 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer Coefficient 1 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.
Climate	S	**Heat in Atmosphere and Upper Ocean** (Year*Watt/(Meter*Meter)) = INIT Atmospheric and Upper Ocean Temperature*Atmospheric and Upper Ocean Heat Capacity + ∫ (Effective Radiative Forcing-Feedback Cooling-Heat Transfer 1) **Description:** *Temperature of the atmosphere and the mixed ocean layer.* **Used by:** • Heat to 700m - Sum of the heat in the atmosphere and upper ocean and that in the top two layers of the deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean and 300 m each for layers 1 and 2. • Temperature Change from Preindustrial - Temperature of the Atmosphere and Upper Ocean and how it has changed from preindustrial period.
Climate	S	**Heat in Deep Ocean 1** (Year*Watt/(Meter*Meter)) = INIT Deep Ocean 1 Temperature*Deep Ocean 1 Heat Capacity + ∫ (Heat Transfer 1-Heat Transfer 2) **Description:** *Heat content of the first layer of the deep ocean.* **Used by:** • Relative Deep 1 Ocean Temperature - Temperature of the first layer of the deep ocean. • Heat to 700m - Sum of the heat in the atmosphere and upper ocean and that in the top two layers of the deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean and 300 m each for layers 1 and 2.
Climate	S	**Heat in Deep Ocean 2** (Year*Watt/(Meter*Meter)) = INIT Deep Ocean 2 Temperature*Deep Ocean 2 Heat Capacity + ∫ (Heat Transfer 2-Heat Transfer 3) **Description:** *Heat content of the second layer of the deep ocean.* **Used by:** • Relative Deep 2 Ocean Temperature - Temperature of the second layer of the deep ocean. • Heat to 700m - Sum of the heat in the atmosphere and upper ocean and that in the top two layers of the deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean and 300 m each for layers 1 and 2.

Climate	S	**Heat in Deep Ocean 3** (Year*Watt/(Meter*Meter)) = INIT Deep Ocean 3 Temperature*Deep Ocean 3 Heat Capacity + ∫ (Heat Transfer 3-Heat Transfer 4) **Description:** *Heat content of the third layer of the deep ocean.* **Used by:** • Relative Deep 3 Ocean Temperature - Temperature of the third layer of the deep ocean. • Heat to 2000m - Heat to 2000m in deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean, 300 m each for layers 1 and 2, and 1300 m for layer 3.
Climate	S	**Heat in Deep Ocean 4** (Year*Watt/(Meter*Meter)) = INIT Deep Ocean 4 Temperature*Deep Ocean 4 Heat Capacity + ∫ (Heat Transfer 4) **Description:** *Heat content of the fourth layer of the deep ocean.* **Used by:** • Relative Deep 4 Ocean Temperature - Temperature of the fourth layer of the deep ocean.
Climate	A	**Heat to 2000m** (Year*W/(Meter*Meter)) = Heat to 700m+Heat in Deep Ocean 3 **Description:** *Heat to 2000m in deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean, 300 m each for layers 1 and 2, and 1300 m for layer 3.* **Used by:** • Heat to 2000m J - Heat to 2000m in Joules*1e22 for the area covered by water.
Climate	A	**Heat to 2000m J** (Je22) = Heat to 2000m*J per W Year*(Area*(1-Land Area Fraction)) **Description:** *Heat to 2000m in Joules*1e22 for the area covered by water.*
Climate	A	**Heat to 700m** (Year*W/(Meter*Meter)) = Heat in Atmosphere and Upper Ocean*(1-Land Area Fraction)+Heat in Deep Ocean 1+Heat in Deep Ocean 2 **Description:** *Sum of the heat in the atmosphere and upper ocean and that in the top two layers of the deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean and 300 m each for layers 1 and 2.* **Used by:** • Heat to 700m J - Heat to 700 m in Joules*1e22 for the area covered by water. Source of Historical Data:NOAA Ocean heat content anomalies;http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155. • Heat to 2000m - Heat to 2000m in deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean, 300 m each for layers 1 and 2, and 1300 m for layer 3.
Climate	A	**Heat to 700m J** (Je22) = Heat to 700m*J per W Year*(Area*(1-Land Area Fraction))+Offset 700m Heat **Description:** *Heat to 700 m in Joules*1e22 for the area covered by water. Source of Historical Data:NOAA Ocean heat content anomalies;http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155.*
Climate	F,A	**Heat Transfer 1** (Watt/(Meter*Meter)) = (Temperature Change from Preindustrial-Relative Deep 1 Ocean Temperature)*Heat Transfer Coefficient 1/Mean Depth of Adjacent M 1 Layers **Description:** *Heat transfer from the atmosphere & upper ocean to the first layer of the deep ocean.* **Used by:** • Heat in Atmosphere and Upper Ocean - Temperature of the atmosphere and the mixed ocean layer. • Heat in Deep Ocean 1 - Heat content of the first layer of the deep ocean.
Climate	F,A	**Heat Transfer 2** (W/(Meter*Meter)) = (Relative Deep 1 Ocean Temperature-Relative Deep 2 Ocean Temperature)*Heat Transfer Coefficient 2/Mean Depth of Adjacent 1 2 Layers **Description:** *Heat transfer from the first to the second layer of the deep ocean.*

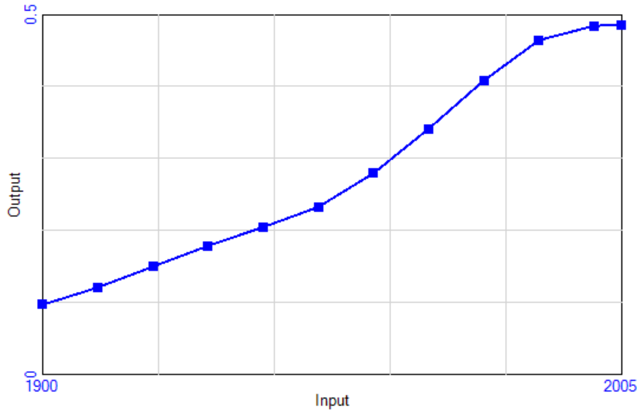
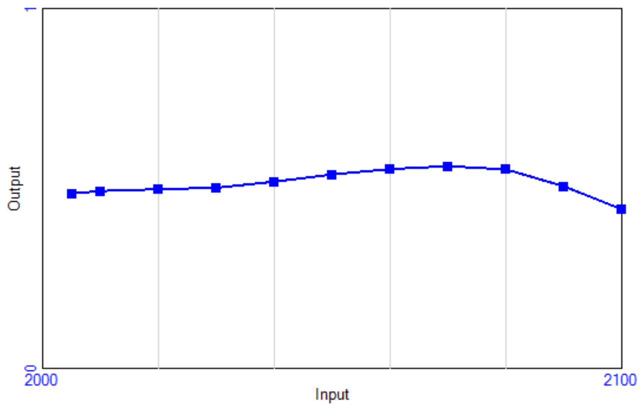
		Used by: • Heat in Deep Ocean 2 - Heat content of the second layer of the deep ocean. • Heat in Deep Ocean 1 - Heat content of the first layer of the deep ocean.
Climate	F,A	**Heat Transfer 3** (W/(Meter*Meter)) = (Relative Deep 2 Ocean Temperature-Relative Deep 3 Ocean Temperature)*Heat Transfer Coefficient 3/Mean Depth of Adjacent 2 3 Layers **Description:** *Heat transfer from the second to the third layer of the deep ocean.* **Used by:** • Heat in Deep Ocean 2 - Heat content of the second layer of the deep ocean. • Heat in Deep Ocean 3 - Heat content of the third layer of the deep ocean.
Climate	A	**Heat Transfer 4** (W/(Meter*Meter)) = (Relative Deep 3 Ocean Temperature-Relative Deep 4 Ocean Temperature)*Heat Transfer Coefficient 4/Mean Depth of Adjacent 3 4 Layers **Description:** *Heat transfer from the third to the fourth layer of the deep ocean.* **Used by:** • Heat in Deep Ocean 4 - Heat content of the fourth layer of the deep ocean. • Heat in Deep Ocean 3 - Heat content of the third layer of the deep ocean.
Climate	A	**Heat Transfer Coefficient 1** (W/(Meter*DegreesC)) = ((Heat Transfer Rate*Mean Depth of Adjacent M 1 Layers)*(Heat Diffusion Covar*(Eddy diff coeff M 1/Eddy diff coeff mean M 1)+(1-Heat Diffusion Covar))) **Description:** *The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.* **Used by:** • Heat Transfer 1 - Heat transfer from the atmosphere & upper ocean to the first layer of the deep ocean.
Climate	A	**Heat Transfer Coefficient 2** (W/(Meter*DegreesC)) = ((Heat Transfer Rate*Mean Depth of Adjacent 1 2 Layers)*(Heat Diffusion Covar*(Eddy diff coeff 1 2/Eddy diff coeff mean 1 2)+(1-Heat Diffusion Covar))) **Description:** *The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.* **Used by:** • Heat Transfer 2 - Heat transfer from the first to the second layer of the deep ocean.
Climate	A	**Heat Transfer Coefficient 3** (W/(Meter*DegreesC)) = ((Heat Transfer Rate*Mean Depth of Adjacent 2 3 Layers)*(Heat Diffusion Covar*(Eddy diff coeff 2 3/Eddy diff coeff mean 2 3)+(1-Heat Diffusion Covar))) **Description:** *The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.* **Used by:** • Heat Transfer 3 - Heat transfer from the second to the third layer of the deep ocean.
Climate	A	**Heat Transfer Coefficient 4** (W/(Meter*DegreesC)) = ((Heat Transfer Rate*Mean Depth of Adjacent 3 4 Layers)*(Heat Diffusion Covar*(Eddy diff coeff 3 4/Eddy diff coeff mean 3 4)+(1-Heat Diffusion Covar))) **Description:** *The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.* **Used by:** • Heat Transfer 4 - Heat transfer from the third to the fourth layer of the deep ocean.
Climate	C	**Heat Transfer Rate** (Watt/(Meter*Meter)/DegreesC) = 1.23 **Description:** *Rate of heat transfer between the surface and deep ocean.* **Used by:** • Heat Transfer Coefficient 3 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer Coefficient 4 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer Coefficient 2 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector. • Heat Transfer Coefficient 1 - The ratio of the actual to the mean of the heat transfer coefficient, which controls the movement of heat through the climate sector.

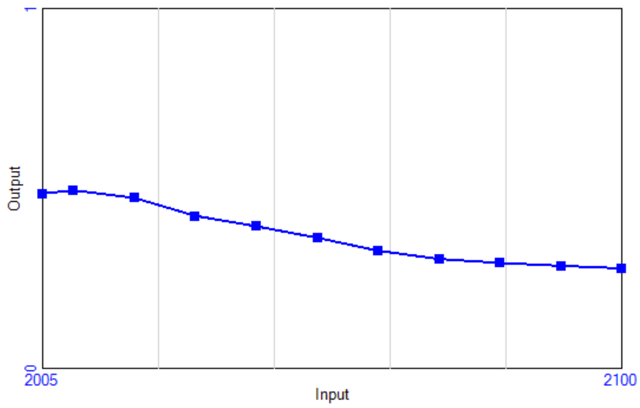
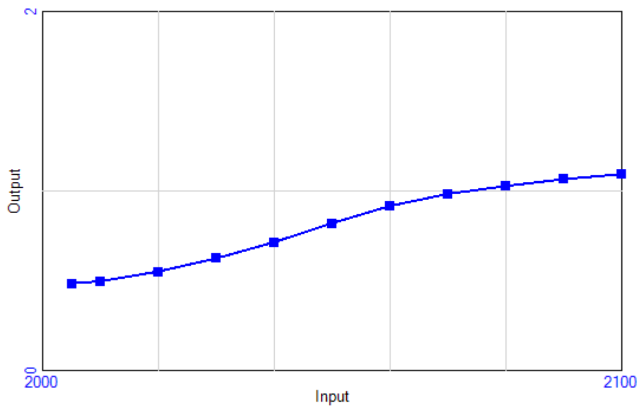
Climate	A	**HFC Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = TABLE HFC Radiative Forcing AIM RCP60(Time*Dimentionless Time) **Description:** *Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).*
Climate	A	**HFC Radiative Forcing History** (W/(Meter*Meter)) = TABLE HFC Radiative Forcing(Time*Dimentionless Time) **Description:** *Historical data for radiative forcing from HFC in the atmosphere.*
Climate	A	**HFC Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = TABLE HFC Radiative Forcing IMAGE RCP26(Time*Dimentionless Time) **Description:** *Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).*
Climate	A	**HFC Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = TABLE HFC Radiative Forcing MESSAGE RCP85(Time*Dimentionless Time) **Description:** *Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).*
Climate	A	**HFC Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = TABLE HFC Radiative Forcing MiniCAM RCP45(Time*Dimentionless Time) **Description:** *Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).*
Climate	SI,C	**INIT Atmospheric and Upper Ocean Temperature** (DegreesC) = 0 **Description:** *Initial value of Atmospheric and Upper Ocean Temperature.* **Used by:** • Heat in Atmosphere and Upper Ocean - Temperature of the atmosphere and the mixed ocean layer.
Climate	SI,C	**INIT Deep Ocean 1 Temperature** (DegreesC) = 0 **Description:** *Initial value of temperature in the first layer of deep ocean.* **Used by:** • Heat in Deep Ocean 1 - Heat content of the first layer of the deep ocean.
Climate	SI,C	**INIT Deep Ocean 2 Temperature** (DegreesC) = 0 **Description:** *Initial value of temperature in the second layer of deep ocean.* **Used by:** • Heat in Deep Ocean 2 - Heat content of the second layer of the deep ocean.
Climate	SI,C	**INIT Deep Ocean 3 Temperature** (DegreesC) = 0 **Description:** *Initial value of temperature in the third layer of deep ocean.* **Used by:** • Heat in Deep Ocean 3 - Heat content of the third layer of the deep ocean.
Climate	SI,C	**INIT Deep Ocean 4 Temperature** (DegreesC) = 0 **Description:** *Initial value of temperature in the fourth layer of deep ocean.* **Used by:** • Heat in Deep Ocean 4 - Heat content of the fourth layer of the deep ocean.
Climate	A	**J per W Year** (Je22/Watt/Year) = 365*24*60*60/1e+022 **Description:** *Convertion from watts*year to Joules*1e22.* **Used by:** • Heat to 700m J - Heat to 700 m in Joules*1e22 for the area covered by water. Source of Historical Data:NOAA Ocean heat content anomalies;http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155. • Heat to 2000m J - Heat to 2000m in Joules*1e22 for the area covered by water.

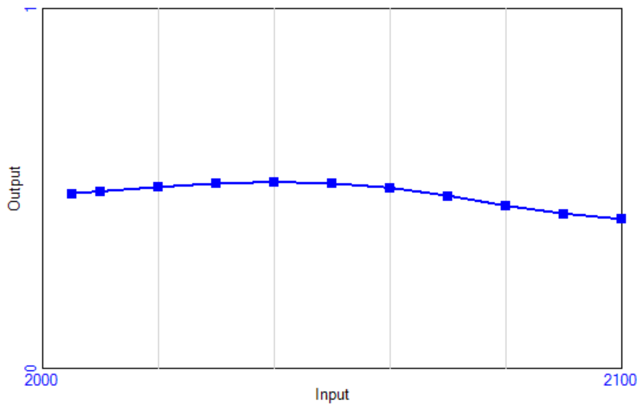
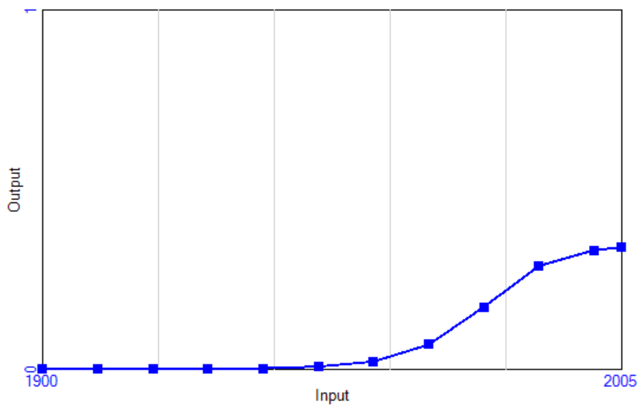
Climate	C	**Land Area Fraction** (Dmnl) = 0.292 **Description:** *Fraction of global surface area that is land.* **Used by:** • Lower Layer Volume Vu 4 - Water equivalent volume of the fourth layer of deep ocean. • Heat to 700m J - Heat to 700 m in Joules*1e22 for the area covered by water. Source of Historical Data:NOAA Ocean heat content anomalies;http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155. • Lower Layer Volume Vu 2 - Water equivalent volume of the second layer of deep ocean. • Lower Layer Volume Vu 3 - Water equivalent volume of the third layer of deep ocean. • Upper Layer Volume Vu - Water equivalent volume of the upper box, which is a weighted combination of land, atmosphere,and upper ocean volumes. • Heat to 2000m J - Heat to 2000m in Joules*1e22 for the area covered by water. • Heat to 700m - Sum of the heat in the atmosphere and upper ocean and that in the top two layers of the deep ocean. Assumes default layer thicknesses, i.e., 100 m for the mixed ocean and 300 m each for layers 1 and 2. • Lower Layer Volume Vu 1 - Water equivalent volume of the first layer of deep ocean.
Climate	C	**Land Thickness** (Meter) = 8.4 **Description:** *Effective land area heat capacity, expressed as equivalent water layer thickness.* **Used by:** • Upper Layer Volume Vu - Water equivalent volume of the upper box, which is a weighted combination of land, atmosphere,and upper ocean volumes.
Climate	A	**Lower Layer Volume Vu 1** (Meter*Meter*Meter) = Area*(1-Land Area Fraction)*Layer Depth 1 **Description:** *Water equivalent volume of the first layer of deep ocean.* **Used by:** • Deep Ocean 1 Heat Capacity - Volumetric heat capacity for the first layer of the deep ocean.
Climate	A	**Lower Layer Volume Vu 2** (Meter*Meter*Meter) = Area*(1-Land Area Fraction)*Layer Depth 2 **Description:** *Water equivalent volume of the second layer of deep ocean.* **Used by:** • Deep Ocean 2 Heat Capacity - Volumetric heat capacity for the second layer of the deep ocean.
Climate	A	**Lower Layer Volume Vu 3** (Meter*Meter*Meter) = Area*(1-Land Area Fraction)*Layer Depth 3 **Description:** *Water equivalent volume of the third layer of deep ocean.* **Used by:** • Deep Ocean 3 Heat Capacity - Volumetric heat capacity for the third layer of the deep ocean.
Climate	A	**Lower Layer Volume Vu 4** (Meter*Meter*Meter) = Area*(1-Land Area Fraction)*Layer Depth 4 **Description:** *Water equivalent volume of the fourth layer of deep ocean.* **Used by:** • Deep Ocean 4 Heat Capacity - Volumetric heat capacity for the fourth layer of the deep ocean.
Climate	C	**Mass Heat Capacity** (J/kg/DegreesC) = 4186 **Description:** *Specific heat of water, i.e., amount of heat in Joules per kg water required to raise the temperature by one C degree.* **Used by:** • Volumetric Heat Capacity - Volumetric heat capacity of water, i.e., amount of heat in

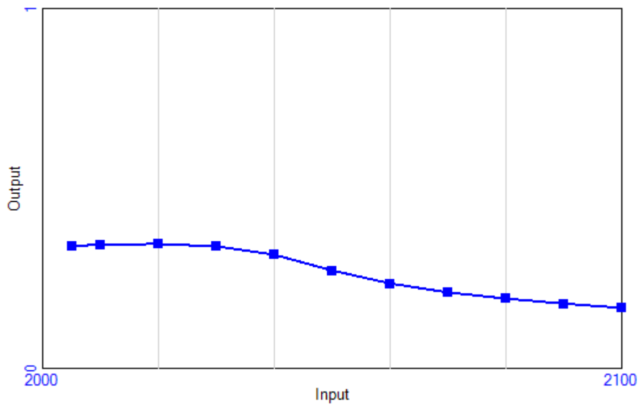
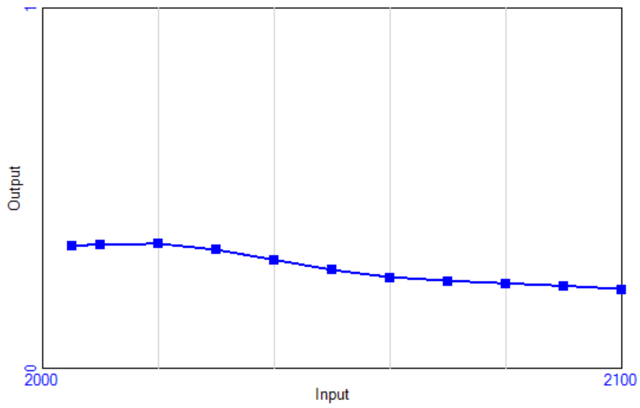
		watt*year required to raise 1 cubic meter of water by one degree C.
Climate	A	**N2O Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = TABLE N2O Radiative Forcing AIM RCP60(Time*Dimentionless Time) **Description:** *Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).*
Climate	A	**N2O Radiative Forcing History** (W/(Meter*Meter)) = TABLE N2O Radiative Forcing(Time*Dimentionless Time) **Description:** *Historical data for radiative forcing from N2O in the atmosphere.*
Climate	A	**N2O Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = TABLE N2O Radiative Forcing IMAGE RCP26(Time*Dimentionless Time) **Description:** *Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).*
Climate	A	**N2O Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = TABLE N2O Radiative Forcing MESSAGE RCP85(Time*Dimentionless Time) **Description:** *Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).*
Climate	A	**N2O Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = TABLE N2O Radiative Forcing MiniCAM RCP45(Time*Dimentionless Time) **Description:** *Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).*
Climate	A	**Net Climate Change Impact on Economy** (Dmnl) = Climate Damage Fraction **Description:** *The fraction of ecomomy output loss due to climate change.* **Used by:** • Gross World Product - Gross World Product taking into account climate change impact. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm
Climate	C	**Offset 700m Heat** (Je22) = -16 **Description:** *Calibration offset.* **Used by:** • Heat to 700m J - Heat to 700 m in Joules*1e22 for the area covered by water. Source of Historical Data:NOAA Ocean heat content anomalies;http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/Levitus S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems GRL, 36, L07608, doi:10.1029/2008GL037155.
Climate	A	**Other Forcings** (W/(Meter*Meter)) = CH4 Radiative Forcing+N2O Radiative Forcing+HFC Radiative Forcing+Other Radiative Forcing **Description:** *Radiative forcing from factors other than CO2 in the atmosphere.* **Used by:** • Total Radiative Forcing - Radiative forcing from various factors in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome
Climate	A	**Other Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = TABLE Other Radiative Forcing AIM RCP60(Time*Dimentionless Time) **Description:** *Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).*
Climate	A	**Other Radiative Forcing History** (W/(Meter*Meter)) = TABLE Other Radiative Forcing(Time*Dimentionless Time) **Description:** *Historical data for radiative forcing from other factors in the atmosphere.*
Climate	A	**Other Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = TABLE Other Radiative Forcing IMAGE RCP26(Time*Dimentionless Time) **Description:** *Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).*

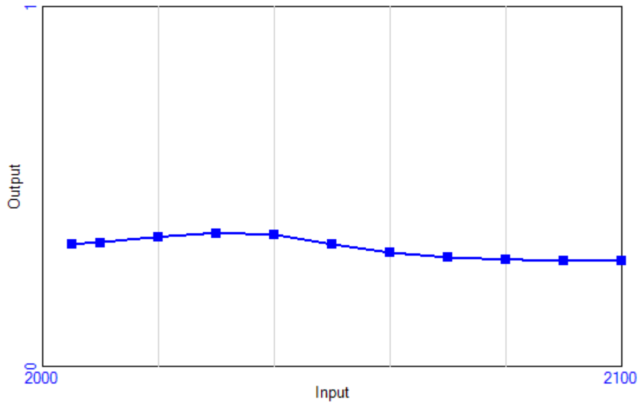
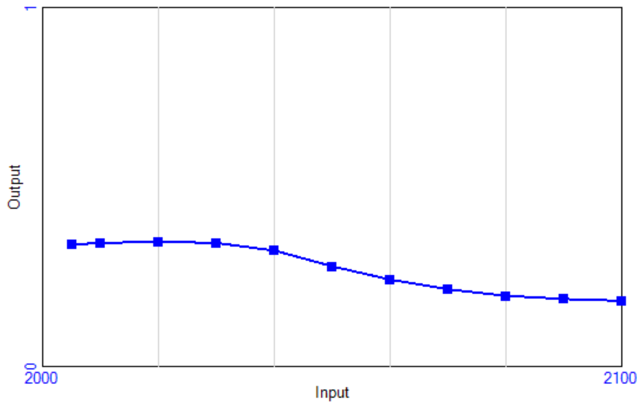
Climate	A	**Other Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = TABLE Other Radiative Forcing MESSAGE RCP85(Time*Dimentionless Time) **Description:** *Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).*
Climate	A	**Other Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = TABLE Other Radiative Forcing MiniCAM RCP45(Time*Dimentionless Time) **Description:** *Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).*
Climate	A	**R** (Dmnl) = C in Atmosphere/Preindustrial C in Atmosphere **Description:** *Ratio of the current carbon in atmosphere to its preindustrial content.* **Used by:** • Other Forcings - Radiative forcing from factors other than CO2 in the atmosphere.
Climate	C	**RCP Scenario** (Dmnl [1,4,1]) = 1 **Description:** *Trigger for Representative Concentration Pathways scenarios.*
Climate	C	**Reference Temperature** (DegreesC) = 3 **Description:** *Reference Temperature for Calculation of Climate Damages.* **Used by:** • Climate Damage Fraction - Fraction of Output lost to combating Climate Change.
Climate	A	**Relative Deep 1 Ocean Temperature** (DegreesC) = Heat in Deep Ocean 1/Deep Ocean 1 Heat Capacity **Description:** *Temperature of the first layer of the deep ocean.* **Used by:** • Heat Transfer 2 - Heat transfer from the first to the second layer of the deep ocean. • Heat Transfer 1 - Heat transfer from the atmosphere & upper ocean to the first layer of the deep ocean.
Climate	A	**Relative Deep 2 Ocean Temperature** (DegreesC) = Heat in Deep Ocean 2/Deep Ocean 2 Heat Capacity **Description:** *Temperature of the second layer of the deep ocean.* **Used by:** • Heat Transfer 2 - Heat transfer from the first to the second layer of the deep ocean. • Heat Transfer 3 - Heat transfer from the second to the third layer of the deep ocean.
Climate	A	**Relative Deep 3 Ocean Temperature** (DegreesC) = Heat in Deep Ocean 3/Deep Ocean 3 Heat Capacity **Description:** *Temperature of the third layer of the deep ocean.* **Used by:** • Heat Transfer 4 - Heat transfer from the third to the fourth layer of the deep ocean. • Heat Transfer 3 - Heat transfer from the second to the third layer of the deep ocean.
Climate	A	**Relative Deep 4 Ocean Temperature** (DegreesC) = Heat in Deep Ocean 4/Deep Ocean 4 Heat Capacity **Description:** *Temperature of the fourth layer of the deep ocean.* **Used by:** • Heat Transfer 4 - Heat transfer from the third to the fourth layer of the deep ocean.
Climate	C	**sec per Year** (sec/Year) = 3.1536e+007 **Description:** *Conversion from year to sec.* **Used by:** • Volumetric Heat Capacity - Volumetric heat capacity of water, i.e., amount of heat in watt*year required to raise 1 cubic meter of water by one degree C.
Climate	L	**TABLE CH4 Radiative Forcing** (W/(Meter*Meter)) = [(1900,0)-(2005,0.5)],(1900,0.097),(1910,0.121),(1920,0.15),(1930,0.179),(1940,0.205),(1950,0.233),(1960,0.28),(1970,0.342),(1980,0.409),(1990,0.465),(2000,0.485),(2005,0.486) **Description:** *Data series for historical data of CH4 radiative forcing.*

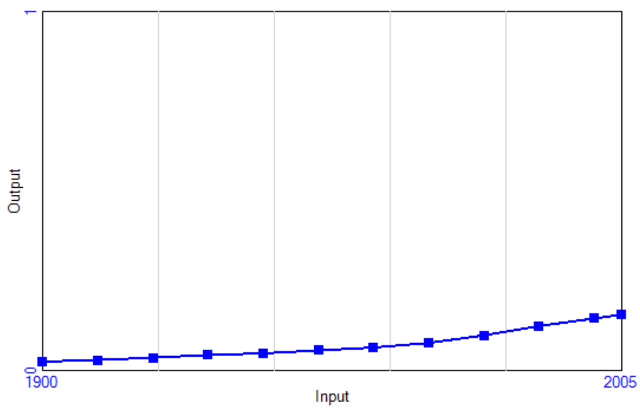
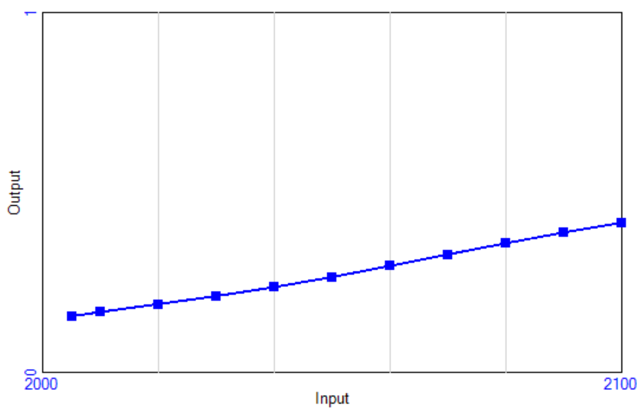
		Used by: • CH4 Radiative Forcing History - Historical data for radiative forcing from CH4 in the atmosphere. 
Climate	L	**TABLE CH4 Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.486),(2010,0.493),(2020,0.498),(2030,0.502),(2040,0.519),(2050,0.539),(2060,0.554),(2070,0.562),(2080,0.553),(2090,0.506),(2100,0.442) **Description:** *Data series for future projections of CH4 radiative forcing by AIM (RCP 6.0).* **Used by:** • CH4 Radiative Forcing AIM RCP60 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0). 
Climate	L	**TABLE CH4 Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = [(2005,0)-(2100,1)],(2005,0.486),(2010,0.495),(2020,0.474),(2030,0.424),(2040,0.395),(2050,0.363),(2060,0.327),(2070,0.304),(2080,0.293),(2090,0.285),(2100,0.278) **Description:** *Data series for future projections of CH4 radiative forcing by IMAGE (RCP 2.6).* **Used by:** • CH4 Radiative Forcing IMAGE RCP26 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).

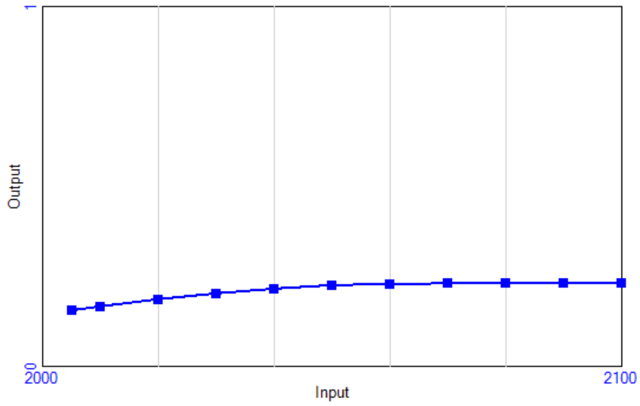
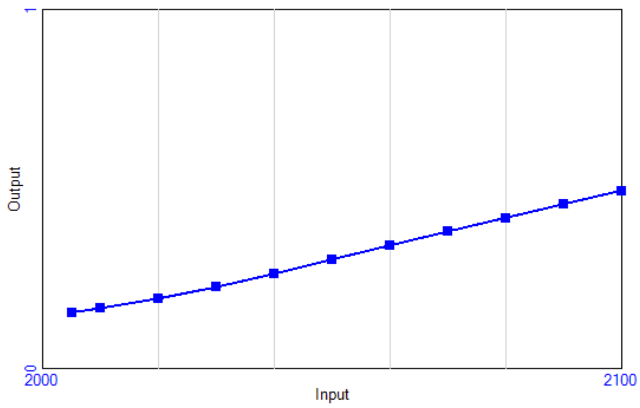
<table>
<tr><td></td><td></td><td>
</td></tr>
<tr><td>Climate</td><td>L</td><td>TABLE CH4 Radiative Forcing MESSAGE RCP85 (W/(Meter*Meter))
= [(2000,0)-(2100,2)],(2005,0.486),(2010,0.497),(2020,0.552),(2030,0.625),(2040,0.715),(2050,0.821),(2060,0.917),(2070,0.984),(2080,1.028),(2090,1.066),(2100,1.094)
Description: Data series for future projections of CH4 radiative forcing by MESSAGE (RCP 8.5).
Used by:
CH4 Radiative Forcing MESSAGE RCP85 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).

</td></tr>
<tr><td>Climate</td><td>L</td><td>TABLE CH4 Radiative Forcing MiniCAM RCP45 (W/(Meter*Meter))
= [(2000,0)-(2100,1)],(2005,0.486),(2010,0.492),(2020,0.504),(2030,0.514),(2040,0.518),(2050,0.514),(2060,0.502),(2070,0.48),(2080,0.452),(2090,0.43),(2100,0.415)
Description: Data series for future projections of CH4 radiative forcing by MiniCAM (RCP 4.5).
Used by:
CH4 Radiative Forcing MiniCAM RCP45 - Future projections of CH4 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).</td></tr>
</table>

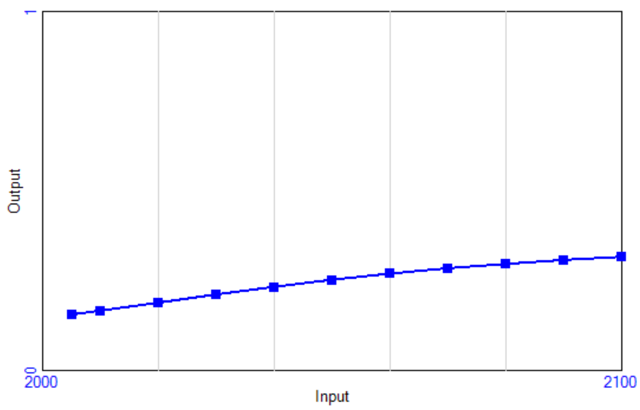
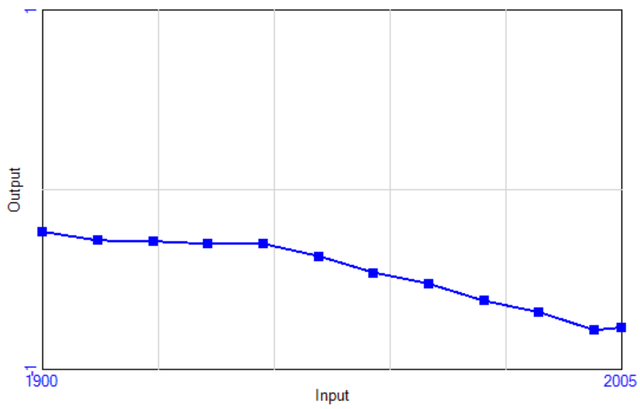
		
Climate	L	**TABLE HFC Radiative Forcing** (W/(Meter*Meter)) = [(1900,0)-(2005,1)],(1900,0.001),(1910,0.001),(1920,0.001),(1930,0.002),(1940,0.003),(1950,0.008),(1960,0.022),(1970,0.069),(1980,0.174),(1990,0.288),(2000,0.332),(2005,0.34) **Description:** *Data series for historical data of HFC radiative forcing.* **Used by:** • HFC Radiative Forcing History - Historical data for radiative forcing from HFC in the atmosphere. 
Climate	L	**TABLE HFC Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.34),(2010,0.344),(2020,0.346),(2030,0.339),(2040,0.316),(2050,0.272),(2060,0.236),(2070,0.211),(2080,0.194),(2090,0.18),(2100,0.168) **Description:** *Data series for future projections of HFC radiative forcing by AIM (RCP 6.0).* **Used by:** • HFC Radiative Forcing AIM RCP60 - Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).

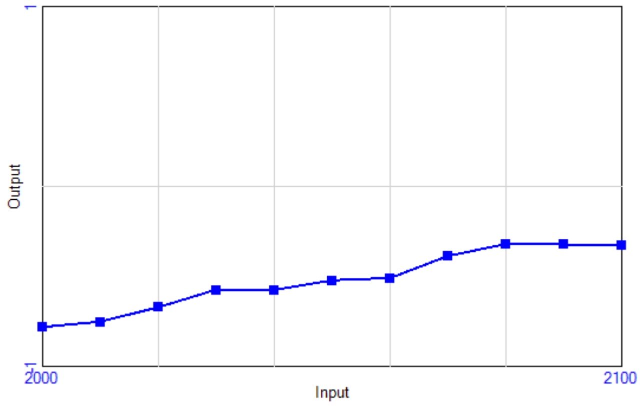
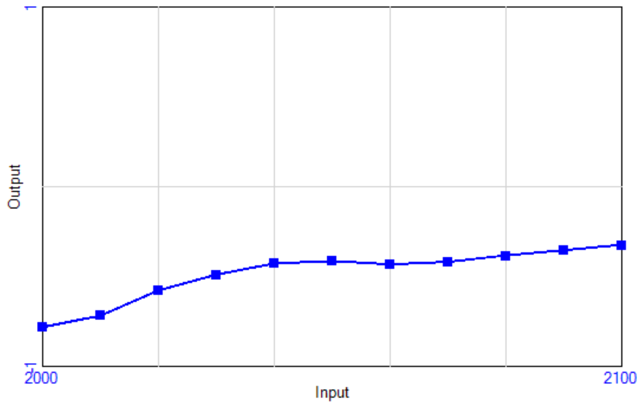
		
Climate	L	**TABLE HFC Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.34),(2010,0.344),(2020,0.346),(2030,0.329),(2040,0.301),(2050,0.273),(2060,0.253),(2070,0.243),(2080,0.236),(2090,0.229),(2100,0.22) **Description:** *Data series for future projections of HFC radiative forcing by IMAGE (RCP 2.6).* **Used by:** • HFC Radiative Forcing IMAGE RCP26 - Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6). 
Climate	L	**TABLE HFC Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.34),(2010,0.345),(2020,0.36),(2030,0.371),(2040,0.366),(2050,0.339),(2060,0.316),(2070,0.303),(2080,0.297),(2090,0.294),(2100,0.294) **Description:** *Data series for future projections of HFC radiative forcing by MESSAGE (RCP 8.5).* **Used by:** • HFC Radiative Forcing MESSAGE RCP85 - Future projections of CO2 radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).

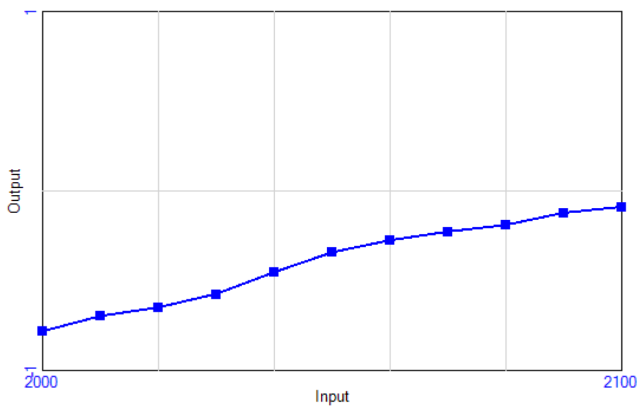
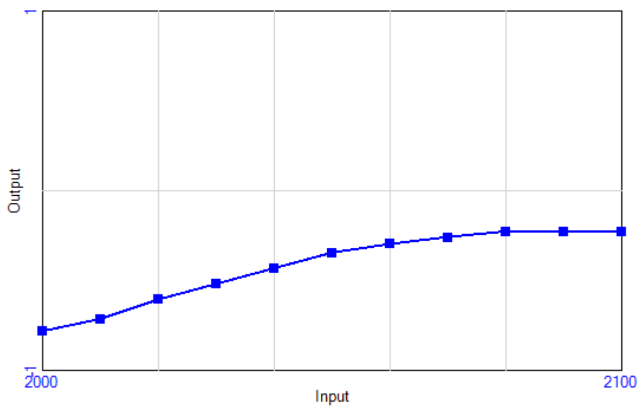
		
Climate	L	**TABLE HFC Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.34),(2010,0.344),(2020,0.348),(2030,0.344),(2040,0.323),(2050,0.279),(2060,0.242),(2070,0.215),(2080,0.197),(2090,0.188),(2100,0.183) **Description:** *Data series for future projections of HFC radiative forcing by MiniCAM (RCP 4.5).* **Used by:** • HFC Radiative Forcing MiniCAM RCP45 - Future projections of HFC radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5). 
Climate	L	**TABLE N2O Radiative Forcing** (W/(Meter*Meter)) = [(1900,0)-(2005,1)],(1900,0.025),(1910,0.029),(1920,0.036),(1930,0.043),(1940,0.048),(1950,0.056),(1960,0.064),(1970,0.077),(1980,0.098),(1990,0.124),(2000,0.145),(2005,0.156) **Description:** *Data series for historical data of N2O radiative forcing.* **Used by:** • N2O Radiative Forcing History - Historical data for radiative forcing from N2O in the atmosphere.

		
Climate	L	**TABLE N2O Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.156),(2010,0.168),(2020,0.19),(2030,0.212),(2040,0.237),(2050,0.265),(2060,0.296),(2070,0.328),(2080,0.359),(2090,0.389),(2100,0.416) **Description:** *Data series for future projections of N2O radiative forcing by AIM (RCP 6.0).* **Used by:** • N2O Radiative Forcing AIM RCP60 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0). 
Climate	L	**TABLE N2O Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = [(2000,0)-(2100,1)],(2005,0.156),(2010,0.167),(2020,0.187),(2030,0.203),(2040,0.216),(2050,0.226),(2060,0.229),(2070,0.231),(2080,0.232),(2090,0.232),(2100,0.232) **Description:** *Data series for future projections of N2O radiative forcing by IMAGE (RCP 2.6).* **Used by:** • N2O Radiative Forcing IMAGE RCP26 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).

<table>
<tr><td></td><td></td><td>
</td></tr>
<tr><td>Climate</td><td>L</td><td>TABLE N2O Radiative Forcing MESSAGE RCP85 (W/(Meter*Meter))
= [(2000,0)-(2100,1)],(2005,0.156),(2010,0.168),(2020,0.195),(2030,0.227),(2040,0.264),(2050,0.304),(2060,0.343),(2070,0.382),(2080,0.42),(2090,0.458),(2100,0.496)
Description: Data series for future projections of N2O radiative forcing by MESSAGE (RCP 8.5).
Used by:
N2O Radiative Forcing MESSAGE RCP85 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).

</td></tr>
<tr><td>Climate</td><td>L</td><td>TABLE N2O Radiative Forcing MiniCAM RCP45 (W/(Meter*Meter))
= [(2000,0)-(2100,1)],(2005,0.156),(2010,0.167),(2020,0.189),(2030,0.212),(2040,0.233),(2050,0.253),(2060,0.27),(2070,0.285),(2080,0.297),(2090,0.308),(2100,0.317)
Description: Data series for future projections of N2O radiative forcing by MiniCAM (RCP 4.5).
Used by:
N2O Radiative Forcing MiniCAM RCP45 - Future projections of N2O radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).</td></tr>
</table>

		
Climate	L	**TABLE Other Radiative Forcing** (W/(Meter*Meter)) = [(1900,-1)-(2005,1)],(1900,-0.234),(1910,-0.282),(1920,-0.287),(1930,-0.301),(1940,-0.301),(1950,-0.369),(1960,-0.461),(1970,-0.523),(1980,-0.618),(1990,-0.681),(2000,-0.781),(2005,-0.766) **Description:** *Data series for historical data of other factors radiative forcing.* **Used by:** • Other Radiative Forcing History - Historical data for radiative forcing from other factors in the atmosphere. 
Climate	L	**TABLE Other Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = [(2000,-1)-(2100,1)],(2000,-0.781),(2010,-0.751),(2020,-0.671),(2030,-0.573),(2040,-0.575),(2050,-0.521),(2060,-0.509),(2070,-0.386),(2080,-0.32),(2090,-0.322),(2100,-0.328) **Description:** *Data series for future projections of other factors radiative forcing by AIM (RCP 6.0).* **Used by:** • Other Radiative Forcing AIM RCP60 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).

		
Climate	L	**TABLE Other Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = [(2000,-1)-(2100,1)],(2000,-0.781),(2010,-0.717),(2020,-0.577),(2030,-0.489),(2040,-0.427),(2050,-0.413),(2060,-0.432),(2070,-0.418),(2080,-0.382),(2090,-0.353),(2100,-0.323) **Description:** *Data series for future projections of other factors radiative forcing by IMAGE (RCP 2.6).* **Used by:** • Other Radiative Forcing IMAGE RCP26 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6). 
Climate	L	**TABLE Other Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = [(2000,-1)-(2100,1)],(2000,-0.781),(2010,-0.696),(2020,-0.648),(2030,-0.573),(2040,-0.452),(2050,-0.341),(2060,-0.274),(2070,-0.226),(2080,-0.189),(2090,-0.121),(2100,-0.088) **Description:** *Data series for future projections of other factors radiative forcing by MESSAGE (RCP 8.5).* **Used by:** • Other Radiative Forcing MESSAGE RCP85 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).

		
Climate	L	**TABLE Other Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = [(2000,-1)-(2100,1)],(2000,-0.781),(2010,-0.713),(2020,-0.605),(2030,-0.518),(2040,-0.431),(2050,-0.344),(2060,-0.296),(2070,-0.257),(2080,-0.226),(2090,-0.227),(2100,-0.224) **Description:** *Data series for future projections of other factors radiative forcing by MiniCAM (RCP 4.5).* **Used by:** • Other Radiative Forcing MiniCAM RCP45 - Future projections of other radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5). 
Climate	A	**Temperature Anomalies GISS v Preindustrial** (DegreesC) = Temperature Change from Preindustrial **Description:** *Historical values of temperature anomalies of the Atmosphere and Upper Ocean as by GISS. Source: NASA Goddard Institute for Space Studies, http://data.giss.nasa.gov/gistemp/graphs_v3/*
Climate	A	**Temperature Anomalies HadCRUT4 v Preindustrial** (DegreesC) = Temperature Change from Preindustrial **Description:** *Historical values of temperature anomalies of the Atmosphere and Upper Ocean as by HadCRUT4. Source: Met Office Hadley Centre http://www.metoffice.gov.uk/hadobs/hadcrut4/data/versions/HadCRUT.4.1.1.0_release_notes.html*
Climate	A	**Temperature Change from Preindustrial** (DegreesC) = Heat in Atmosphere and Upper Ocean/Atmospheric and Upper Ocean Heat Capacity **Description:** *Temperature of the Atmosphere and Upper Ocean and how it has changed from preindustrial period.* **Used by:** • Impact of Climate Damage on Biodiversity - Nonlinear function representing impact of climate risk on species carrying capacity. • Effect of Climate Change on Animal Food Land Fertility - Impact of climate change risk on land fertility related to animal food. • Effect of Climate Change on Forest Land Fertility - Impact of climate change risk on

		forest land fertility. • Effect of Climate Change on Agriculture Land Fertility - Impact of climate change risk on cropland fertility. • Climate Damage Fraction - Fraction of Output lost to combating Climate Change. • Feedback Cooling - Feedback cooling of atmosphere/upper ocean system due to blackbody radiation. • Heat Transfer 1 - Heat transfer from the atmosphere & upper ocean to the first layer of the deep ocean. • Temperature Anomalies HadCRUT4 v Preindustrial - Historical values of temperature anomalies of the Atmosphere and Upper Ocean as by HadCRUT4. Source: Met Office Hadley Centre http://www.metoffice.gov.uk/hadobs/hadcrut4/data/versions/HadCRUT.4.1.1.0_release_notes.html • Temperature Anomalies GISS v Preindustrial - Historical values of temperature anomalies of the Atmosphere and Upper Ocean as by GISS. Source: NASA Goddard Institute for Space Studies, http://data.giss.nasa.gov/gistemp/graphs_v3/
Climate	A	**Total Radiative Forcing** (W/(m*m)) = CO2 Radiative Forcing+Other Forcings **Description:** *Radiative forcing from various factors in the atmosphere. Source of Historical Data:IIASA RCP Databasehttps://tntcat.iiasa.ac.at:8743/RcpDb/dsd?Action=htmlpage&page=welcome* **Used by:** • Effective Radiative Forcing - Total radiative forcing from various factors in the atmosphere.
Climate	C	**Total Radiative Forcing AIM RCP60** (W/(Meter*Meter)) = 0 **Description:** *Future projections of total radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by AIM (RCP 6.0).*
Climate	C	**Total Radiative Forcing IMAGE RCP26** (W/(Meter*Meter)) = 0 **Description:** *Future projections of total radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by IMAGE (RCP 2.6).*
Climate	C	**Total Radiative Forcing MESSAGE RCP85** (W/(Meter*Meter)) = 0 **Description:** *Future projections of total radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MESSAGE (RCP 8.5).*
Climate	C	**Total Radiative Forcing MiniCAM RCP45** (W/(Meter*Meter)) = 0 **Description:** *Future projections of total radiative forcing from Representative Concentration Pathways prepared for the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change by MiniCAM (RCP 4.5).*
Climate	A	**Upper Layer Volume Vu** (Meter*Meter*Meter) = Area*(Land Area Fraction*Land Thickness+(1-Land Area Fraction)*Mixed Layer Depth) **Description:** *Water equivalent volume of the upper box, which is a weighted combination of land, atmosphere,and upper ocean volumes.* **Used by:** • Atmospheric and Upper Ocean Heat Capacity - Volumetric heat capacity for the land, atmosphere, and, upper ocean layer.
Climate	A	**Volumetric Heat Capacity** (Year*W/(Meter*Meter*Meter*DegreesC)) = Mass Heat Capacity*Watt per J s/sec per Year*Density **Description:** *Volumetric heat capacity of water, i.e., amount of heat in watt*year required to raise 1 cubic meter of water by one degree C.* **Used by:** • Deep Ocean 2 Heat Capacity - Volumetric heat capacity for the second layer of the deep ocean. • Deep Ocean 3 Heat Capacity - Volumetric heat capacity for the third layer of the deep ocean. • Deep Ocean 4 Heat Capacity - Volumetric heat capacity for the fourth layer of the

		deep ocean. • Atmospheric and Upper Ocean Heat Capacity - Volumetric heat capacity for the land, atmosphere, and, upper ocean layer. • Deep Ocean 1 Heat Capacity - Volumetric heat capacity for the first layer of the deep ocean.
Climate	C	**Watt per J s** (W/(J/sec)) = 1 **Description:** *Conversion from J/s to watts.* **Used by:** • Volumetric Heat Capacity - Volumetric heat capacity of water, i.e., amount of heat in watt*year required to raise 1 cubic meter of water by one degree C.
Control	C	**FINAL TIME** (Year) = 2051 **Description:** *The final time for the simulation.*
Control	C	**INITIAL TIME** (Year) = 1900 **Description:** *The initial time for the simulation.* **Used by:** • Educational Attainment Change Rate Start - Start of increased investments in Educational Attainment. • Educational Attainment Change Rate Finish - End of fractional investments in Educational Attainment. • Wind Investment Fraction Finish - End of fractional investments in wind energy technology. • Wind Investment Fraction Start - Start of investments in wind energy technology. • Solar Investment Fraction Finish - End of fractional investments in solar energy technology. • Solar Investment Fraction Start - Start of investments in solar energy technology. • Biomass Investment Fraction Finish - End of fractional investments in biomass energy technology. • Biomass Investment Fraction Start - Start of investments in biomass energy technology. • Other Technologies - Factor productivity in other than energy sectors. • Time - Internally defined simulation time. • Time - Internally defined simulation time. • Time - Internally defined simulation time.
Control	C	**SAVEPER** (Year [0,?]) = 1 **Description:** *The frequency with which output is stored.*
Control	C	**TIME STEP** (Year [0,?]) = 0.01 **Description:** *The time step for the simulation.*
Economy	A	**Biomass Technology** (Dmnl) = ((Biomass Capacity Factor/MAXBCF)+(Biomass Installation Efficiency/MAXBIE))/2 **Description:** *Factor productivity in Biomass energy sector.* **Used by:** • Energy Technology - Factor productivity in energy sector.
Economy	S	**Capital** ($) = INIT Capital + ∫ (Net Capital Change Rate) **Description:** *Capital stock. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm* **Used by:** • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions.
Economy	C	**Capital Elasticity Output** (Dmnl) = 0.35

		Description: *Capital Elasticity of Output.* **Used by:** • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions.
Economy	A	**Coal Technology** (Dmnl) = ((Coal Fraction Discoverable/MAXCFD)+(Coal Fraction Recoverable/MAXCFR))/2 **Description:** *Factor productivity in Coal energy sector.* **Used by:** • Energy Technology - Factor productivity in energy sector.
Economy	A	**Current to Max Other Capital** (Dmnl) = Other Capital Change Ratio*(1-Other Capital Change/Reference Other Capital Change) **Description:** *Adjustment of current to reference other capital change.* **Used by:** • Net Change in Other Capital - Adjustment of capital changes in sectors other than energy.
Economy	A	**Energy Technology** (Dmnl) = (Oil Technology+Coal Technology+Gas Technology+Biomass Technology+Solar Technology+Wind Technology) **Description:** *Factor productivity in energy sector.* **Used by:** • Technology - Total factor productivity.
Economy	A	**Gas Technology** (Dmnl) = ((Gas Fraction Discoverable/MAXGFD)+(Gas Fraction Recoverable/MAXGFR))/2 **Description:** *Factor productivity in Gas energy sector.* **Used by:** • Energy Technology - Factor productivity in energy sector.
Economy	A	**GDP per Capita GLOBIOM usd** ($/(Year*Person)) = GWP per Capita **Description:** *Projection of GDP per Capita according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.*
Economy	A	**Gross World Product** ($/Year) = Reference Economy Output*Net Climate Change Impact on Economy*Impact of Biodiversity on Economy **Description:** *Gross World Product taking into account climate change impact. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm* **Used by:** • GWP per Capita - Gross World Product per Capita. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm • GWP Ratio - Gross World Product compared to Output in 1900 as a reference indicator.
Economy	A	**GWP per Capita** ($/(Year*Person)) = Gross World Product/Population **Description:** *Gross World Product per Capita. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm* **Used by:** • Income index - Index of achievement in GWP per Capita. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/ • Average Agricultural Water Use per m2 Irrigated - Nonlinear relation that describes average agricultural water use on irrigated part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level. • Average Agricultural Water Use per m2 Rainfed - Nonlinear relation that describes average agricultural water use on rainfed part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level. • Percent of Irrigated Land - Nonlinear relation that determines the area of irrigated land as percentage of total agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal percentage. • Average Domestic Water Use per Capita - Nonlinear relation that describes average

		domestic water use per capita as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level. • Average Industrial Water Use - Nonlinear relation that describes average industrial water use as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level. • Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level. • Demand Vegetal Calories Consumption per Capita per Day - Daily demand of vegetal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level. • Effect of Management Practices on Animal Food Land Fertility - Impact of agricultural land management practices on land fertility related to animal food. • Effect of Management Practices on Agriculture Land Fertility - Impact of agricultural land management practices on cropland fertility. • Effect of Management Practices on Forest Land Fertility - Impact of forest land management practices on forest land fertility. • Impact of GDP on Fertility - A nonlinear function representing the impact of population wealth, represented by GDP compared to reference GDP, on fertility. With increasing wealth the fertility decreases. • Impact of GWP on Health - Impact of wealth on health services availability. • Impact of GWP on Energy Demand per Capita - Impact of population wealth on energy demand per capita. • GDP per Capita GLOBIOM usd - Projection of GDP per Capita according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.
Economy	A	**GWP Ratio** (Dmnl) = Gross World Product/Output in 1900 **Description:** *Gross World Product compared to Output in 1900 as a reference indicator.*
Economy	A	**Impact of Biodiversity on Economy** (Dmnl) = Min Impact of Biodiversity on Economy+(Max Impact of Biodiversity on Economy-Min Impact of Biodiversity on Economy)*(Mean Species Abundance/Initial Species Abundance) **Description:** *The fraction of ecomomy output loss due to changes in biodiversity.* **Used by:** • Gross World Product - Gross World Product taking into account climate change impact. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm
Economy	C	**INIT Capital** ($) = 1.3e+012 **Description:** *Initial Capital Stock.* **Used by:** • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions. • Capital - Capital stock. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm
Economy	C	**INIT Other Capital Change** ($/Year) = 4e+010 **Description:** *Inital capital in other sectors.* **Used by:** • Other Capital Change - Capital change from other sector.
Economy	C	**Max Impact of Biodiversity on Economy** (Dmnl) = 1 **Description:** *Scaling factor indicating maximum impact of changes in biodiversity on economy output.* **Used by:** • Impact of Biodiversity on Economy - The fraction of ecomomy output loss due to changes in biodiversity.
Economy	C	**Min Impact of Biodiversity on Economy** (Dmnl) = 0.98 **Description:** *Scaling factor indicating minimal impact of changes in biodiversity on economy*

		output. **Used by:** • Impact of Biodiversity on Economy - The fraction of ecomomy output loss due to changes in biodiversity.
Economy	A	**Net Capital Change** ($/Year) = Net Energy Capital Change+Other Capital Change **Description:** *Net capital change.* **Used by:** • Net Capital Change Rate - Net Capital Stock change rate.
Economy	A	**Net Capital Change Rate** ($/Year) = Net Capital Change **Description:** *Net Capital Stock change rate.* **Used by:** • Capital - Capital stock. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm
Economy	A	**Net Change in Other Capital** ($/(Year*Year)) = (Other Capital Change*Current to Max Other Capital/Time to Adjust Other Capital) **Description:** *Adjustment of capital changes in sectors other than energy.* **Used by:** • Other Capital Change - Capital change from other sector.
Economy	A	**Net Energy Capital Change** ($/Year) = (Investment in Oil Exploration+Investment in Oil Production+Investment in Oil Technology+Investment in Coal Exploration+Investment in Coal Production+Investment in Coal Technology+Investment in Gas Exploration+Investment in Gas Production+Investment in Gas Technology+Investment in Biomass Capacity+Investment in Biomass Energy Technology+Investment in Solar Capacity+Investment in Solar Energy Technology+Investment in Wind Capacity+Investment in Wind Energy Technology) **Description:** *Capital change from energy sector.* **Used by:** • Net Capital Change - Net capital change.
Economy	A	**Oil Technology** (Dmnl) = ((Oil Fraction Discoverable/MAXOFD)+(Oil Fraction Recoverable/MAXOFR))/2 **Description:** *Factor productivity in Oil energy sector.* **Used by:** • Energy Technology - Factor productivity in energy sector.
Economy	S	**Other Capital Change** ($/Year) = INIT Other Capital Change + ∫ (Net Change in Other Capital) **Description:** *Capital change from other sector.* **Used by:** • Current to Max Other Capital - Adjustment of current to reference other capital change. • Net Change in Other Capital - Adjustment of capital changes in sectors other than energy. • Net Capital Change - Net capital change.
Economy	C	**Other Capital Change Ratio** (Dmnl) = 0.77 **Description:** *Strength of adjustment of current to reference capital change related to sectors other than energy.* **Used by:** • Current to Max Other Capital - Adjustment of current to reference other capital change.
Economy	A	**Other Technologies** (Dmnl) = Reference Other Technology*(1-Other Technology Inflection Point^Other Technology Steepness/(Other Technology Inflection Point^Other Technology Steepness+((Time-INITIAL TIME)/Year Period)^Other Technology Steepness)) **Description:** *Factor productivity in other than energy sectors.* **Used by:** • Technology - Total factor productivity.
Economy	C	**Other Technology Inflection Point** (Dmnl)

		= 100 **Description:** *Parameter determining inflection point of reference factor productivity in other than energy sectors.* **Used by:** • Other Technologies - Factor productivity in other than energy sectors.
Economy	C	**Other Technology Steepness** (Dmnl) = 3 **Description:** *Parameter determining intensity of reference factor productivity in other than energy sectors.* **Used by:** • Other Technologies - Factor productivity in other than energy sectors.
Economy	C	**Output in 1900** ($/Year) = 1.3e+012 **Description:** *Economy output in 1900.* **Used by:** • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions. • GWP Ratio - Gross World Product compared to Output in 1900 as a reference indicator.
Economy	A	**Reference Economy Output** ($/Year) = Output in 1900*Technology*(((Capital/INIT Capital)^Capital Elasticity Output)*(Labor Force/(INIT Population 15 to 64*Labor Force Participation Fraction))^(1-Capital Elasticity Output)) **Description:** *Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions.* **Used by:** • Gross World Product - Gross World Product taking into account climate change impact. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm
Economy	C	**Reference Other Capital Change** ($/Year) = 1e+015 **Description:** *Reference other capital change than from energy sector.* **Used by:** • Current to Max Other Capital - Adjustment of current to reference other capital change.
Economy	C	**Reference Other Technology** (Dmnl) = 1 **Description:** *Reference factor productivity in other than energy sectors.* **Used by:** • Other Technologies - Factor productivity in other than energy sectors.
Economy	A	**Solar Technology** (Dmnl) = ((Solar Conversion Efficiency/MAXSCE)+(Solar Installation Efficiency/MAXSIE))/2 **Description:** *Factor productivity in Solar energy sector.* **Used by:** • Energy Technology - Factor productivity in energy sector.
Economy	A	**Technology** (Dmnl) = Energy Technology+Other Technologies **Description:** *Total factor productivity.* **Used by:** • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions.
Economy	C	**Time to Adjust Other Capital** (Year) = 20 **Description:** *Time required to adjust capital changes in sectors other than energy.* **Used by:** • Net Change in Other Capital - Adjustment of capital changes in sectors other than energy.
Economy	A	**Wind Technology** (Dmnl) = ((Wind Capacity Factor/MAXWCF)+(Wind Installation Efficiency/MAXWIE))/2

		Description: *Factor productivity in Wind energy sector.* **Used by:** • Energy Technology - Factor productivity in energy sector.
Economy	C	**Year Period** (Year) = 1 **Description:** *Duration of one year.* **Used by:** • Deaths Rate 0 to 14 - The number of deaths per year among 0 to 14 population cohort. • Deaths Rate 15 to 64 - The number of deaths per year among 15 to 64 population cohort. • Deaths Rate 65 plus - The number of deaths per year among 65Plus population cohort. • Other Technologies - Factor productivity in other than energy sectors.
Energy	A	**Average Energy Price** ($/toe) = (Average Price Oil+Average Price Gas+Average Price Coal+Average Price Solar+Average Price Wind+Average Price Biomass)/Number of Energy Sources **Description:** *Average market energy price.* **Used by:** • Price Competitiveness Factor Biomass - Biomass energy price competitiveness as a ratio of biomass energy market price to average market energy price. • Price Competitiveness Factor Gas - Gas price competitiveness as a ratio of gas market price to average market energy price. • Price Competitiveness Factor Oil - Oil price competitiveness as a ratio of oil market price to average market energy price. • Price Competitiveness Factor Solar - Solar energy price competitiveness as a ratio of solar energy market price to average market energy price. • Price Competitiveness Factor Wind - Wind energy price competitiveness as a ratio of wind energy market price to average market energy price. • Price Competitiveness Factor Coal - Coal price competitiveness as a ratio of coal market price to average market energy price.
Energy	S	**Average Price Biomass** ($/toe) = INIT APB + ∫ (Change in Price Biomass) **Description:** *Average market biomass energy price.* **Used by:** • Price Competitiveness Factor Biomass - Biomass energy price competitiveness as a ratio of biomass energy market price to average market energy price. • Change in Price Biomass - Change in average market biomass energy price. • Average Energy Price - Average market energy price.
Energy	S	**Average Price Coal** ($/toe) = INIT APC + ∫ (Change in Price Coal) **Description:** *Average market coal price.* **Used by:** • Price Competitiveness Factor Coal - Coal price competitiveness as a ratio of coal market price to average market energy price. • Change in Price Coal - Change in average market coal price. • Average Energy Price - Average market energy price.
Energy	S	**Average Price Gas** ($/toe) = INIT APG + ∫ (Change in Price Gas) **Description:** *Average market gas price.* **Used by:** • Price Competitiveness Factor Gas - Gas price competitiveness as a ratio of gas market price to average market energy price. • Change in Price Gas - Change in average market gas price. • Average Energy Price - Average market energy price.
Energy	S	**Average Price Oil** ($/toe) = INIT APO + ∫ (Change in Price Oil)

		Description: *Average market oil price.* **Used by:** • Price Competitiveness Factor Oil - Oil price competitiveness as a ratio of oil market price to average market energy price. • Change in Price Oil - Change in average market oil price. • Average Energy Price - Average market energy price.
Energy	S	**Average Price Solar** ($/toe) = INIT APS + ∫ (Change in Price Solar) **Description:** *Average market solar energy price.* **Used by:** • Price Competitiveness Factor Solar - Solar energy price competitiveness as a ratio of solar energy market price to average market energy price. • Change in Price Solar - Change in average market solar energy price. • Average Energy Price - Average market energy price.
Energy	S	**Average Price Wind** ($/toe) = INIT APW + ∫ (Change in Price Wind) **Description:** *Average market wind energy price.* **Used by:** • Price Competitiveness Factor Wind - Wind energy price competitiveness as a ratio of wind energy market price to average market energy price. • Change in Price Wind - Change in average market wind energy price. • Average Energy Price - Average market energy price.
Energy	A	**Biomass Price toe** ($/toe) = Biomass Energy Price/toe per Mtoe **Description:** *Actual biomass energy price in dollars per toe.* **Used by:** • Change in Price Biomass - Change in average market biomass energy price.
Energy	A	**Carbon Price Change** (Dmnl) = (1-SCENARIO BioenergyPlus)*1+SCENARIO BioenergyPlus*(1+STEP(Factor of Carbon Price Change, 2010)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Price Competitiveness Factor Gas - Gas price competitiveness as a ratio of gas market price to average market energy price. • Price Competitiveness Factor Oil - Oil price competitiveness as a ratio of oil market price to average market energy price. • Price Competitiveness Factor Coal - Coal price competitiveness as a ratio of coal market price to average market energy price.
Energy	S	**Change in Market Share Biomass** (Dmnl) = Reference Change in Market Share Biomass*Effect of Price on Market Share Biomass + ∫ (Change Rate Due to Price Biomass) **Description:** *Change in biomass energy market share due to price competitiveness.* **Used by:** • Reference Change in Total Market Share - Reference Change in Total Market Share taking into account changes in specific energy sectors. • Market Share Biomass - Biomass energy market share among other energy sources. • Change Rate Due to Price Biomass - Ratio of change in biomass energy market share.
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) **Description:** *Change in coal energy market share due to price competitiveness.* **Used by:** • Reference Change in Total Market Share - Reference Change in Total Market Share taking into account changes in specific energy sectors. • Change Rate Due to Price Coal - Ratio of change in coal energy market share. • Market Share Coal - Coal market share among other energy sources.

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) **Description:** *Change in gas energy market share due to price competitiveness.* **Used by:** • Reference Change in Total Market Share - Reference Change in Total Market Share taking into account changes in specific energy sectors. • Change Rate Due to Price Gas - Ratio of change in gas energy market share. • Market Share Gas - Gas market share among other energy sources.
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) **Description:** *Change in oil energy market share due to price competitiveness.* **Used by:** • Reference Change in Total Market Share - Reference Change in Total Market Share taking into account changes in specific energy sectors. • Change Rate Due to Price Oil - Ratio of change in oil energy market share. • Market Share Oil - Oil market share among other energy sources.
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) **Description:** *Change in solar energy market share due to price competitiveness.* **Used by:** • Reference Change in Total Market Share - Reference Change in Total Market Share taking into account changes in specific energy sectors. • Market Share Solar - Solar energy market share among other energy sources. • Change Rate Due to Price Solar - Ratio of change in solar energy market share.
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) **Description:** *Change in wind energy market share due to price competitiveness.* **Used by:** • Reference Change in Total Market Share - Reference Change in Total Market Share taking into account changes in specific energy sectors. • Market Share Wind - Wind energy market share among other energy sources. • Change Rate Due to Price Wind - Ratio of change in wind energy market share.
Energy	A	**Change in Price Biomass** ($/(toe*Year)) = (Biomass Price toe-Average Price Biomass)/Time to Average Price Biomass **Description:** *Change in average market biomass energy price.* **Used by:** • Average Price Biomass - Average market biomass energy price.
Energy	A	**Change in Price Coal** ($/(toe*Year)) = (Coal Price toe-Average Price Coal)/Time to Average Price Coal **Description:** *Change in average market coal price.* **Used by:** • Average Price Coal - Average market coal price.
Energy	A	**Change in Price Gas** ($/(toe*Year)) = (Gas Price toe-Average Price Gas)/Time to Average Price Gas **Description:** *Change in average market gas price.* **Used by:** • Average Price Gas - Average market gas price.
Energy	A	**Change in Price Oil** ($/(Year*toe)) = (Oil Price toe-Average Price Oil)/Time to Average Price Oil **Description:** *Change in average market oil price.* **Used by:** • Average Price Oil - Average market oil price.
Energy	A	**Change in Price Solar** ($/(toe*Year))

		= (Solar Price toe-Average Price Solar)/Time to Average Price Solar **Description:** *Change in average market solar energy price.* **Used by:** • Average Price Solar - Average market solar energy price.
Energy	A	**Change in Price Wind** ($/(toe*Year)) = (Wind Price toe-Average Price Wind)/Time to Average Price Wind **Description:** *Change in average market wind energy price.* **Used by:** • Average Price Wind - Average market wind energy price.
Energy	A	**Change Rate Due to Price Biomass** (1/Year) = (Reference Change in Market Share Biomass*Effect of Price on Market Share Biomass-Change in Market Share Biomass)/Time to Adjust Market Share **Description:** *Ratio of change in biomass energy market share.* **Used by:** • Change in Market Share Biomass - Change in biomass energy market share due to price competitiveness.
Energy	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 **Description:** *Ratio of change in coal energy market share.* **Used by:** • Change in Market Share Coal - Change in coal energy market share due to price competitiveness.
Energy	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 **Description:** *Ratio of change in gas energy market share.* **Used by:** • Change in Market Share Gas - Change in gas energy market share due to price competitiveness.
Energy	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 **Description:** *Ratio of change in oil energy market share.* **Used by:** • Change in Market Share Oil - Change in oil energy market share due to price competitiveness.
Energy	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 **Description:** *Ratio of change in solar energy market share.* **Used by:** • Change in Market Share Solar - Change in solar energy market share due to price competitiveness.
Energy	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 **Description:** *Ratio of change in wind energy market share.* **Used by:** • Change in Market Share Wind - Change in wind energy market share due to price competitiveness.
Energy	A	**Coal Price toe** ($/toe) = Coal Price/toe per Mtoe **Description:** *Actual coal price in dollars per toe.* **Used by:** • Change in Price Coal - Change in average market coal price.
Energy	A	**Effect of Price on Market Share Biomass** (Dmnl) = Price Competitiveness Factor Biomass^(-Price Elasticity of Demand Biomass) **Description:** *Effect of biomass energy price competitiveness on market share.* **Used by:**

		• Change in Market Share Biomass - Change in biomass energy market share due to price competitiveness. • Change Rate Due to Price Biomass - Ratio of change in biomass energy market share.
Energy	A	**Effect of Price on Market Share Coal** (Dmnl) = Price Competitiveness Factor Coal^(-Price Elasticity of Demand Coal) **Description:** *Effect of coal energy price competitiveness on market share.* **Used by:** • Change Rate Due to Price Coal - Ratio of change in coal energy market share. • Change in Market Share Coal - Change in coal energy market share due to price competitiveness.
Energy	A	**Effect of Price on Market Share Gas** (Dmnl) = Price Competitiveness Factor Gas^(-Price Elasticity of Demand Gas) **Description:** *Effect of gas energy price competitiveness on market share.* **Used by:** • Change Rate Due to Price Gas - Ratio of change in gas energy market share. • Change in Market Share Gas - Change in gas energy market share due to price competitiveness.
Energy	A	**Effect of Price on Market Share Oil** (Dmnl) = Price Competitiveness Factor Oil^(-Price Elasticity of Demand Oil) **Description:** *Effect of oil energy price competitiveness on market share.* **Used by:** • Change Rate Due to Price Oil - Ratio of change in oil energy market share. • Change in Market Share Oil - Change in oil energy market share due to price competitiveness.
Energy	A	**Effect of Price on Market Share Solar** (Dmnl) = Price Competitiveness Factor Solar^(-Price Elasticity of Demand Solar) **Description:** *Effect of solar energy price competitiveness on market share.* **Used by:** • Change in Market Share Solar - Change in solar energy market share due to price competitiveness. • Change Rate Due to Price Solar - Ratio of change in solar energy market share.
Energy	A	**Effect of Price on Market Share Wind** (Dmnl) = Price Competitiveness Factor Wind^(-Price Elasticity of Demand Wind) **Description:** *Effect of wind energy price competitiveness on market share.* **Used by:** • Change Rate Due to Price Wind - Ratio of change in wind energy market share. • Change in Market Share Wind - Change in wind energy market share due to price competitiveness.
Energy	A	**Energy Demand** (Mtoe/Year) = Energy Demand per Capita*Population+Energy Demand 1900 Calibration **Description:** *Total world demand for energy determined by population and energy demand per capita. Source of historical data: International Energy Agency Key World Energy Statistics 2007* **Used by:** • Total Coal Demand - Total demand for coal resources. • Total Wind Demand - Total demand for wind energy. • Total Crops Biomass Demand - Total demand for energy crops accounting for biomass energy market share and reference technology development. • Total Forest Biomass Demand - Total demand for forest biomass accounting for forest biomass energy market share and reference technology development. • Total Solar Demand - Total demand for solar energy. • Total Biomass Demand - Total demand for energy from biomass. • Energy Demand Fulfillment Ratio - Ratio of energy production to energy demand indicating a level of energy demand fulfillment. • Total Gas Demand - Total demand for gas resources. • Total Oil Demand - Total demand for oil resources.

Energy	C	**Energy Demand 1900 Calibration** (Mtoe/Year) = 120 **Description:** *Energy demand calibration factor for year 1900.* **Used by:** • Energy Demand - Total world demand for energy determined by population and energy demand per capita. Source of historical data: International Energy Agency Key World Energy Statistics 2007
Energy	A	**Energy Demand Fulfillment Ratio** (Dmnl) = Energy Production/Energy Demand **Description:** *Ratio of energy production to energy demand indicating a level of energy demand fulfillment.*
Energy	A	**Energy Demand per Capita** (Mtoe/(Year*Person)) = Max Energy Demand per Capita*Impact of GWP on Energy Demand per Capita **Description:** *Energy demand per capita taking into consideration the change in population wealth.* **Used by:** • Energy Demand - Total world demand for energy determined by population and energy demand per capita. Source of historical data: International Energy Agency Key World Energy Statistics 2007
Energy	A	**Energy Production** (Mtoe/Year) = Coal Production+Gas Production+Oil Production+Biomass Energy Production+Solar Energy Production+Wind Energy Production **Description:** *Total energy production per year.* **Used by:** • Energy Demand Fulfillment Ratio - Ratio of energy production to energy demand indicating a level of energy demand fulfillment.
Energy	C	**Factor of Carbon Price Change** (Dmnl) = 99 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Carbon Price Change - WWF Scenario variable. Further development required.
Energy	A	**Gas Price toe** ($/toe) = Gas Price/toe per Mtoe **Description:** *Actual gas price in dollars per toe.* **Used by:** • Change in Price Gas - Change in average market gas price.
Energy	C	**Hours per Year** (Hour/Year) = 8760 **Description:** *Assumed total number of hours per year.* **Used by:** • Potential Wind Energy Production - Potential solar energy production per year due to available production capability and technical developments. • Time FL - Average time of sun availability.
Energy	A	**Impact of GWP on Energy Demand per Capita** (Dmnl) = 1-Impact of GWP per Capita on Energy Demand Inflection^Impact of GWP per Capita on Energy Demand Steepness/(Impact of GWP per Capita on Energy Demand Inflection^Impact of GWP per Capita on Energy Demand Steepness+(GWP per Capita/(Reference GWP per Capita for Energy Demand))^Impact of GWP per Capita on Energy Demand Steepness) **Description:** *Impact of population wealth on energy demand per capita.* **Used by:** • Energy Demand per Capita - Energy demand per capita taking into consideration the change in population wealth.
Energy	C	**Impact of GWP per Capita on Energy Demand Inflection** (Dmnl) = 0.3 **Description:** *A parameter determining the inflection point of the nonlinear function representing the impact of population wealth on energy demand.* **Used by:** • Impact of GWP on Energy Demand per Capita - Impact of population wealth on energy demand per capita.
Energy	C	**Impact of GWP per Capita on Energy Demand Steepness** (Dmnl)

		= 2.5 **Description:** *A parameter determining the steepness of the nonlinear function representing the impact of population wealth on energy demand.* **Used by:** • Impact of GWP on Energy Demand per Capita - Impact of population wealth on energy demand per capita.
Energy	C	**INIT APB** ($/toe) = 500 **Description:** *Initial average market biomass energy price.* **Used by:** • Average Price Biomass - Average market biomass energy price.
Energy	C	**INIT APC** ($/toe) = 4 **Description:** *Initial average market coal price.* **Used by:** • Average Price Coal - Average market coal price.
Energy	C	**INIT APG** ($/toe) = 50000 **Description:** *Initial average market gas price.* **Used by:** • Average Price Gas - Average market gas price.
Energy	C	**INIT APO** ($/toe) = 35 **Description:** *Initial average market oil price.* **Used by:** • Average Price Oil - Average market oil price.
Energy	C	**INIT APS** ($/toe) = 50000 **Description:** *Initial average market solar energy price.* **Used by:** • Average Price Solar - Average market solar energy price.
Energy	C	**INIT APW** ($/toe) = 50000 **Description:** *Initial average market wind energy price.* **Used by:** • Average Price Wind - Average market wind energy price.
Energy	C	**kW into GW** (kW/GW) = 1e+006 **Description:** *Coefficient to convert kilowatts into gigawatts.* **Used by:** • Max Wind Power Point GW - Wind Max Power Point measured in GW. • Total Wind Demand GW - Total demand for wind energy measured in GW. • Total Solar Demand GW - Total demand for solar energy measured in GW.
Energy	C	**kW into TW** (kW/TW) = 1e+010 **Description:** *Coefficient to convert kilowatts into terawatts.* **Used by:** • Max Wind Power Point TW - Wind Max Power Point measured in TW.
Energy	C	**kWh into Mtoe** (Mtoe/(kW*Hour)) = 8.6e-011 **Description:** *Coefficient to convert kWh into Mtoe.* **Used by:** • Potential Wind Energy Production - Potential solar energy production per year due to available production capability and technical developments. • Wind Energy Price per kWh - Actual wind energy price accounting for indicated wind energy price and effect of demand and supply measured in dollars per kWh. • Solar Energy Price per kWh - Actual solar energy price accounting for indicated solar energy price and effect of demand and supply measured in dollars per kWh.

		• Possible Solar Energy Production - Potential solar energy production per year due to available production capability, weather conditions and technical developments.
Energy	C	**kWh into Mtoe peak hour** (Mtoe/kW) = 8.6e-011 **Description:** *Coefficient to convert kWh into Mtoe peak hour.* **Used by:** • Total Wind Demand GW - Total demand for wind energy measured in GW. • Total Solar Demand GW - Total demand for solar energy measured in GW.
Energy	A	**Market Share Biomass** (Dmnl) = Change in Market Share Biomass/Reference Change in Total Market Share **Description:** *Biomass energy market share among other energy sources.* **Used by:** • Total Biomass Demand - Total demand for energy from biomass. • Market Share Biomass Crops - Energy crops specific biomass energy market share among other energy sources. • Market Share Biomass Forest - Forest specific biomass energy market share among other energy sources. • Total Energy Market - Total energy market share.
Energy	C	**Market Share Biomass Allocation** (Dmnl) = 0.7 **Description:** *Market share allocation between forest and energy crops biomass.* **Used by:** • Market Share Biomass Crops - Energy crops specific biomass energy market share among other energy sources. • Market Share Biomass Forest - Forest specific biomass energy market share among other energy sources.
Energy	A	**Market Share Biomass Crops** (Dmnl) = Market Share Biomass*(1-Market Share Biomass Allocation) **Description:** *Energy crops specific biomass energy market share among other energy sources.* **Used by:** • Total Crops Biomass Demand - Total demand for energy crops accounting for biomass energy market share and reference technology development.
Energy	A	**Market Share Biomass Forest** (Dmnl) = Market Share Biomass*Market Share Biomass Allocation **Description:** *Forest specific biomass energy market share among other energy sources.* **Used by:** • Total Forest Biomass Demand - Total demand for forest biomass accounting for forest biomass energy market share and reference technology development.
Energy	A	**Market Share Coal** (Dmnl) = Change in Market Share Coal/Reference Change in Total Market Share **Description:** *Coal market share among other energy sources.* **Used by:** • Total Coal Demand - Total demand for coal resources. • Total Energy Market - Total energy market share.
Energy	A	**Market Share Gas** (Dmnl) = Change in Market Share Gas/Reference Change in Total Market Share **Description:** *Gas market share among other energy sources.* **Used by:** • Total Energy Market - Total energy market share. • Total Gas Demand - Total demand for gas resources.
Energy	A	**Market Share Oil** (Dmnl) = Change in Market Share Oil/Reference Change in Total Market Share **Description:** *Oil market share among other energy sources.* **Used by:** • Total Energy Market - Total energy market share. • Total Oil Demand - Total demand for oil resources.

Energy	A	**Market Share Solar** (Dmnl) = Change in Market Share Solar/Reference Change in Total Market Share **Description:** *Solar energy market share among other energy sources.* **Used by:** • Total Solar Demand - Total demand for solar energy. • Total Energy Market - Total energy market share.
Energy	A	**Market Share Wind** (Dmnl) = Change in Market Share Wind/Reference Change in Total Market Share **Description:** *Wind energy market share among other energy sources.* **Used by:** • Total Wind Demand - Total demand for wind energy. • Total Energy Market - Total energy market share.
Energy	C	**Max Energy Demand per Capita** (Mtoe/(Year*Person)) = 2e-006 **Description:** *Maximal reference Energy Demand per Capita.* **Used by:** • Energy Demand per Capita - Energy demand per capita taking into consideration the change in population wealth.
Energy	C	**Mtoe per Ton** (Mtoe/Ton) = 4.9e-007 **Description:** *Coefficient to convert million tons of oil equivalent unit (Mtoe) into coal tons (Ton).* **Used by:** • Coal Price per Ton - Actual Coal Price per Ton.
Energy	C	**Number of Energy Sources** (Dmnl) = 6 **Description:** *Number of various energy sources to average energy price.* **Used by:** • Average Energy Price - Average market energy price.
Energy	A	**Oil Price toe** ($/toe) = Oil Price/toe per Mtoe **Description:** *Actual oil price in dollars per toe.* **Used by:** • Change in Price Oil - Change in average market oil price.
Energy	A	**Price Competitiveness Factor Biomass** (Dmnl) = (Average Price Biomass)/Average Energy Price **Description:** *Biomass energy price competitiveness as a ratio of biomass energy market price to average market energy price.* **Used by:** • Effect of Price on Market Share Biomass - Effect of biomass energy price competitiveness on market share.
Energy	A	**Price Competitiveness Factor Coal** (Dmnl) = Carbon Price Change*(Average Price Coal)/Average Energy Price **Description:** *Coal price competitiveness as a ratio of coal market price to average market energy price.* **Used by:** • Effect of Price on Market Share Coal - Effect of coal energy price competitiveness on market share.
Energy	A	**Price Competitiveness Factor Gas** (Dmnl) = Carbon Price Change*(Average Price Gas)/Average Energy Price **Description:** *Gas price competitiveness as a ratio of gas market price to average market energy price.* **Used by:** • Effect of Price on Market Share Gas - Effect of gas energy price competitiveness on market share.
Energy	A	**Price Competitiveness Factor Oil** (Dmnl) = Carbon Price Change*(Average Price Oil)/Average Energy Price **Description:** *Oil price competitiveness as a ratio of oil market price to average market energy price.*

		Used by: • Effect of Price on Market Share Oil - Effect of oil energy price competitiveness on market share.
Energy	A	**Price Competitiveness Factor Solar** (Dmnl) = (Average Price Solar)/Average Energy Price **Description:** *Solar energy price competitiveness as a ratio of solar energy market price to average market energy price.* **Used by:** • Effect of Price on Market Share Solar - Effect of solar energy price competitiveness on market share.
Energy	A	**Price Competitiveness Factor Wind** (Dmnl) = (Average Price Wind)/Average Energy Price **Description:** *Wind energy price competitiveness as a ratio of wind energy market price to average market energy price.* **Used by:** • Effect of Price on Market Share Wind - Effect of wind energy price competitiveness on market share.
Energy	C	**Price Elasticity of Demand Biomass** (Dmnl) = 0.8 **Description:** *Biomass energy price elasticity of demand.* **Used by:** • Effect of Price on Market Share Biomass - Effect of biomass energy price competitiveness on market share.
Energy	C	**Price Elasticity of Demand Coal** (Dmnl) = 0.89 **Description:** *Coal energy price elasticity of demand.* **Used by:** • Effect of Price on Market Share Coal - Effect of coal energy price competitiveness on market share.
Energy	C	**Price Elasticity of Demand Oil** (Dmnl) = 0.6 **Description:** *Oil energy price elasticity of demand.* **Used by:** • Effect of Price on Market Share Oil - Effect of oil energy price competitiveness on market share.
Energy	C	**Price Elasticity of Demand Solar** (Dmnl) = 1 **Description:** *Solar energy price elasticity of demand.* **Used by:** • Effect of Price on Market Share Solar - Effect of solar energy price competitiveness on market share.
Energy	C	**Price Elasticity of Demand Wind** (Dmnl) = 1 **Description:** *Wind energy price elasticity of demand.* **Used by:** • Effect of Price on Market Share Wind - Effect of wind energy price competitiveness on market share.
Energy	C	**Ramp Investment Period** (Year) = 100 **Description:** *Period of fractional investments in new energy technologies.* **Used by:** • Wind Investment Fraction Finish - End of fractional investments in wind energy technology. • Wind Investment Fraction Slope - Intensity of increase in investments in wind energy technology. • Solar Investment Fraction Slope - Intensity of increase in investments in solar energy technology. • Solar Investment Fraction Finish - End of fractional investments in solar energy technology.

		• Biomass Investment Fraction Finish - End of fractional investments in biomass energy technology. • Biomass Investment Fraction Slope - Intensity of increase in investments in biomass energy technology.
Energy	SI,C	**Reference Change in Market Share Biomass** (Dmnl) = 1 **Description:** *Reference change in biomass energy market share due to price competitiveness.* **Used by:** • Change in Market Share Biomass - Change in biomass energy market share due to price competitiveness. • Change Rate Due to Price Biomass - Ratio of change in biomass energy market share.
Energy	SI,C	**Reference Change in Market Share Coal** (Dmnl) = 1 **Description:** *Reference change in coal energy market share due to price competitiveness.* **Used by:** • Change Rate Due to Price Coal - Ratio of change in coal energy market share. • Change in Market Share Coal - Change in coal energy market share due to price competitiveness.
Energy	SI,C	**Reference Change in Market Share Gas** (Dmnl) = 1 **Description:** *Reference change in gas energy market share due to price competitiveness.* **Used by:** • Change Rate Due to Price Gas - Ratio of change in gas energy market share. • Change in Market Share Gas - Change in gas energy market share due to price competitiveness.
Energy	SI,C	**Reference Change in Market Share Oil** (Dmnl) = 1 **Description:** *Reference change in oil energy market share due to price competitiveness.* **Used by:** • Change Rate Due to Price Oil - Ratio of change in oil energy market share. • Change in Market Share Oil - Change in oil energy market share due to price competitiveness.
Energy	SI,C	**Reference Change in Market Share Solar** (Dmnl) = 1 **Description:** *Reference change in solar energy market share due to price competitiveness.* **Used by:** • Change in Market Share Solar - Change in solar energy market share due to price competitiveness. • Change Rate Due to Price Solar - Ratio of change in solar energy market share.
Energy	SI,C	**Reference Change in Market Share Wind** (Dmnl) = 1 **Description:** *Reference change in wind energy market share due to price competitiveness.* **Used by:** • Change Rate Due to Price Wind - Ratio of change in wind energy market share. • Change in Market Share Wind - Change in wind energy market share due to price competitiveness.
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+Change in Market Share Biomass **Description:** *Reference Change in Total Market Share taking into account changes in specific energy sectors.* **Used by:** • Market Share Biomass - Biomass energy market share among other energy sources. • Market Share Solar - Solar energy market share among other energy sources. • Market Share Wind - Wind energy market share among other energy sources.

		• Market Share Coal - Coal market share among other energy sources. • Market Share Gas - Gas market share among other energy sources. • Market Share Oil - Oil market share among other energy sources.
Energy	C	**Reference GWP per Capita for Energy Demand** ($/(Year*Person)) = 16000 **Description:** *A reference value against which the GDP per Capita is compared to in order to calculate the impact of population wealth on energy demand.* **Used by:** • Impact of GWP on Energy Demand per Capita - Impact of population wealth on energy demand per capita.
Energy	C	**SCENARIO BioenergyPlus** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Carbon Price Change - WWF Scenario variable. Further development required.
Energy	A	**Solar Price toe** ($/toe) = Solar Energy Price/toe per Mtoe **Description:** *Actual solar energy price in dollars per toe.* **Used by:** • Change in Price Solar - Change in average market solar energy price.
Energy	C	**Time to Adjust Market Share** (Year) = 10 **Description:** *Time to adjust changes in market share.* **Used by:** • Change Rate Due to Price Biomass - Ratio of change in biomass energy market share. • Change Rate Due to Price Solar - Ratio of change in solar energy market share. • Change Rate Due to Price Wind - Ratio of change in wind energy market share. • Change Rate Due to Price Gas - Ratio of change in gas energy market share. • Change Rate Due to Price Coal - Ratio of change in coal energy market share. • Change Rate Due to Price Oil - Ratio of change in oil energy market share.
Energy	C	**Time to Average Price Biomass** (Year) = 18 **Description:** *Time to average market biomass energy price.* **Used by:** • Change in Price Biomass - Change in average market biomass energy price.
Energy	C	**Time to Average Price Coal** (Year) = 5 **Description:** *Time to average market coal price.* **Used by:** • Change in Price Coal - Change in average market coal price.
Energy	C	**Time to Average Price Gas** (Year) = 5 **Description:** *Time to average market gas price.* **Used by:** • Change in Price Gas - Change in average market gas price.
Energy	C	**Time to Average Price Oil** (Year) = 5 **Description:** *Time to average market oil price.* **Used by:** • Change in Price Oil - Change in average market oil price.
Energy	C	**Time to Average Price Solar** (Year) = 15 **Description:** *Time to average market solar energy price.* **Used by:** • Change in Price Solar - Change in average market solar energy price.

Energy	C	**Time to Average Price Wind** (Year) = 20 **Description:** *Time to average market wind energy price.* **Used by:** • Change in Price Wind - Change in average market wind energy price.
Energy	A	**Total Energy Market** (Dmnl) = Market Share Oil+Market Share Gas+Market Share Coal+Market Share Solar+Market Share Wind+Market Share Biomass **Description:** *Total energy market share.*
Energy	C	**W into GW** (W/GW) = 1e+009 **Description:** *Coefficient to convert watts into gigawatts* **Used by:** • Max Power Point GW - Solar Max Power Point measured in GW.
Energy	A	**Wind Price toe** ($/toe) = Wind Energy Price/toe per Mtoe **Description:** *Actual wind energy price in dollars per toe.* **Used by:** • Change in Price Wind - Change in average market wind energy price.
Energy Biomass	C	**Average Annual Production per Capacity** (Mtoe/Year) = 0.116 **Description:** *Average annual energy production per unit of biomass installed capacity.* **Used by:** • Potential Biomass Energy Production from Infrastructure - Potential biomass energy production per year due to available production capability.
Energy Biomass	A	**Biomass Capacity Aging Rate** (1/Year) = Biomass Energy Installed Capacity/Biomass Capacity Aging Time **Description:** *Aging rate of biomass energy production capacities.* **Used by:** • Biomass Infrastructure Adjustment - Adjustment of Biomass Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process. • Biomass Energy Installed Capacity - Installed capacity to transform biomass into energy.
Energy Biomass	C	**Biomass Capacity Aging Time** (Year) = 20 **Description:** *Average biomass energy production capacity aging time.* **Used by:** • Investment in Biomass Capacity - Amount of resources dedicated to biomass capacity development. • Biomass Capacity Aging Rate - Aging rate of biomass energy production capacities.
Energy Biomass	A	**Biomass Capacity Factor** (Dmnl) = MINBCF+(MAXBCF-MINBCF)*(Biomass Energy Technology Ratio/(Biomass Energy Technology Ratio+1)) **Description:** *Parameter indicating what fraction of Biomass Conversion Efficiency it is possible to realize with the current state of technical developments.* **Used by:** • Potential Biomass Energy Production from Resources - Potential biomass energy production per year due to available resources and technical developments. • Biomass Technology - Factor productivity in Biomass energy sector.
Energy Biomass	C	**Biomass Conversion Efficiency** (Mtoe/Biomass ton) = 4.17e-007 **Description:** *Reference Biomass Conversion Efficiency indicating the greatest possibility of turning biomass into energy.* **Used by:** • Total Crops Biomass Demand - Total demand for energy crops accounting for biomass energy market share and reference technology development. • Total Forest Biomass Demand - Total demand for forest biomass accounting for forest biomass energy market share and reference technology development.

		• Potential Biomass Energy Production from Resources - Potential biomass energy production per year due to available resources and technical developments.
Energy Biomass	A	**Biomass Energy Demand to Supply Ratio** (Dmnl) = Total Biomass Demand/Potential Biomass Energy Production **Description:** *Biomass Energy Demand to Supply Ratio.*
Energy Biomass	S	**Biomass Energy Installed Capacity** (Dmnl) = INIT BIC + ∫ (Installation of Biomass Capacity Rate-Biomass Capacity Aging Rate) **Description:** *Installed capacity to transform biomass into energy.* **Used by:** • Impact of Learning on Biomass Unit Cost of Technology - Impact of learning curve on biomass energy cost. • Biomass Energy Installed Capacity Ratio - Ratio of installed biomass energy production capacities to reference capacity. • Potential Biomass Energy Production from Infrastructure - Potential biomass energy production per year due to available production capability. • Biomass Infrastructure Adjustment - Adjustment of Biomass Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process. • Biomass Capacity Aging Rate - Aging rate of biomass energy production capacities. • Efficiency of Biomass Installed Capacity - Total production efficiency of Biomass Installed Capacity. • Biomass Production to Installation Ratio - Ratio of biomass energy production to available production capacity.
Energy Biomass	A	**Biomass Energy Installed Capacity Ratio** (Dmnl) = MAX(0,1-(Biomass Energy Installed Capacity/Reference Biomass Energy Installed Capacity)) **Description:** *Ratio of installed biomass energy production capacities to reference capacity.* **Used by:** • Productivity of Investment in Biomass Capacity Installation - Productivity of biomass capacity installation taking into account the level of available capacities and technology development state.
Energy Biomass	A	**Biomass Energy Price** ($/Mtoe) = Indicated Biomass Energy Price*Effect of Biomass Energy Demand and Supply on Price **Description:** *Actual biomass energy price accounting for indicated biomass energy price and effect of demand and supply.* **Used by:** • Biomass Energy Revenue - Total revenue in biomass energy market. • Biomass Price toe - Actual biomass energy price in dollars per toe.
Energy Biomass	A	**Biomass Energy Production** (Mtoe/Year) = Biomass Energy Production Rate **Description:** *Total biomass energy production per year.* **Used by:** • C Emission from Biomass Energy - Total carbon emission from biomass energy production and it use. • Biomass Energy Revenue - Total revenue in biomass energy market. • Cumulative Biomass Energy Produced - Cumulative biomass energy that has been produced. • Biomass Production to Installation Ratio - Ratio of biomass energy production to available production capacity. • Energy Production - Total energy production per year.
Energy Biomass	A	**Biomass Energy Production Rate** (Mtoe/Year) = MIN(Potential Biomass Energy Production,Total Biomass Demand) **Description:** *Total biomass energy production per year accounting for demand and potential production due to available resources, production capability and technical developments.* **Used by:** • Biomass Energy Production - Total biomass energy production per year.
Energy Biomass	A	**Biomass Energy Revenue** ($/Year) = Biomass Energy Production*Biomass Energy Price

		Description: *Total revenue in biomass energy market.* **Used by:** • Investment in Biomass Energy Technology - Investments in development of biomass energy efficiency technology and production capability.
Energy Biomass	C	**Biomass Energy Technology Development Time** (Year) = 50 **Description:** *Average time required to turn investments into concrete biomass energy efficiency technology developments. Since the simulation starts in 1900 it is a significant time.* **Used by:** • Increase in Biomass Energy Technology Ratio - Increase in Biomass Energy Technology Ratio due to investments in biomass energy efficiency technology and their productivity.
Energy Biomass	S	**Biomass Energy Technology Ratio** (Dmnl) = INIT BETRN + ∫ (Increase in Biomass Energy Technology Ratio) **Description:** *Biomass Energy Technology Ratio increased due to investments in biomass energy efficiency.* **Used by:** • Biomass Capacity Factor - Parameter indicating what fraction of Biomass Conversion Efficiency it is possible to realize with the current state of technical developments.
Energy Biomass	C	**Biomass Final Investment** (Dmnl) = 0.03 **Description:** *Eventual average level of investments in biomass energy technology.* **Used by:** • Biomass Investment Fraction Slope - Intensity of increase in investments in biomass energy technology.
Energy Biomass	A	**Biomass Infrastructure Adjustment** (1/Year) = Biomass Capacity Aging Rate+(Desired Biomass Installed Capacity-Biomass Energy Installed Capacity)/Time to Adjust Biomass Infrastructure **Description:** *Adjustment of Biomass Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.* **Used by:** • Installation of Biomass Capacity Rate - Rate of new biomass capacity installation.
Energy Biomass	C	**Biomass Initial Investment** (Dmnl) = 0 **Description:** *Initial level of fractional investments in biomass energy technology.* **Used by:** • Biomass Investment Fraction Slope - Intensity of increase in investments in biomass energy technology.
Energy Biomass	A	**Biomass Installation Efficiency** (Dmnl) = MINBIE+(MAXBIE-MINBIE)*(Biomass Installation Technology Ratio/(Biomass Installation Technology Ratio+1)) **Description:** *Parameter indicating biomass energy capacity installation efficiency at the current state of technical developments.* **Used by:** • Productivity of Investment in Biomass Capacity Installation - Productivity of biomass capacity installation taking into account the level of available capacities and technology development state. • Fraction Invested in Biomass Energy Installation - Fraction of investments in biomass energy technology dedicated to capacity. • Biomass Technology - Factor productivity in Biomass energy sector.
Energy Biomass	C	**Biomass Installation Technology Development Time** (Year) = 100 **Description:** *Average time required to turn investments into concrete biomass energy production capacity. Since the simulation starts in 1900 it is a significant time.* **Used by:** • Increase in Biomass Installation Technology Ratio - Increase in Biomass Installation Technology Ratio due to investments in biomass energy capacity.
Energy Biomass	S	**Biomass Installation Technology Ratio** (Dmnl) = INIT BITRN + ∫ (Increase in Biomass Installation Technology Ratio) **Description:** *Biomass Installation Technology Ratio increased due to investments in biomass*

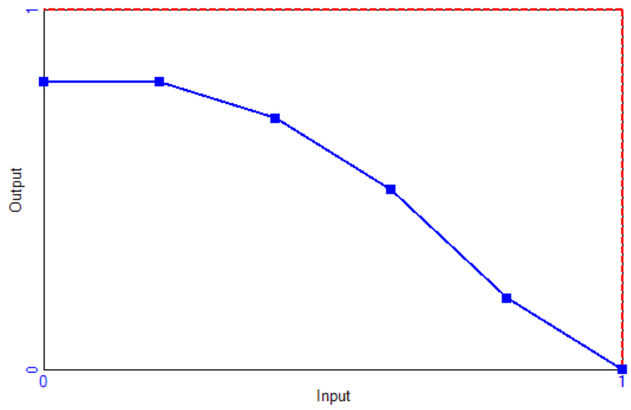
		energy capacity efficiency. **Used by:** • Biomass Installation Efficiency - Parameter indicating biomass energy capacity installation efficiency at the current state of technical developments.
Energy Biomass	I	**Biomass Investment Fraction Finish** (Year) = INITIAL TIME+Ramp Investment Period **Description:** *End of fractional investments in biomass energy technology.* **Used by:** • Fraction of Revenue Invested in Biomass Technology - Parameter to take into account historical increase of the biomass energy significance and over time greater resources dedicated to the technology development.
Energy Biomass	A	**Biomass Investment Fraction Slope** (1/Year) = ABS(Biomass Final Investment-Biomass Initial Investment)/Ramp Investment Period **Description:** *Intensity of increase in investments in biomass energy technology.* **Used by:** • Fraction of Revenue Invested in Biomass Technology - Parameter to take into account historical increase of the biomass energy significance and over time greater resources dedicated to the technology development.
Energy Biomass	I	**Biomass Investment Fraction Start** (Year) = INITIAL TIME **Description:** *Start of investments in biomass energy technology.* **Used by:** • Fraction of Revenue Invested in Biomass Technology - Parameter to take into account historical increase of the biomass energy significance and over time greater resources dedicated to the technology development.
Energy Biomass	A	**Biomass Learning Curve Strength** (Dmnl) = LN(1 - Fraction for Biomass Learning Curve Strength)/LN(2) **Description:** *Strength of biomass learning curve with which the biomass energy costs are influenced..* **Used by:** • Impact of Learning on Biomass Unit Cost of Technology - Impact of learning curve on biomass energy cost.
Energy Biomass	A	**Biomass Production** (Biomass ton/Year) = Forest Biomass Production+Energy Crops Production **Description:** *Total biomass production from forest and energy crops.* **Used by:** • Potential Biomass Energy Production from Resources - Potential biomass energy production per year due to available resources and technical developments.
Energy Biomass	A	**Biomass Production to Installation Ratio** (Mtoe/Year) = Biomass Energy Production/Biomass Energy Installed Capacity **Description:** *Ratio of biomass energy production to available production capacity.* **Used by:** • Unit Cost of Biomass Energy Production - Unit cost of biomass capacity installation per energy unit.
Energy Biomass	A	**Cost of Biomass Energy** ($/Mtoe) = Unit Cost of Biomass Capacity Installation+Unit Cost of Biomass Energy Production **Description:** *Cost of biomass energy production assuming an impact of learning curve.* **Used by:** • Indicated Biomass Energy Price - Indicated biomass energy price accounting for unit cost and gross margin.
Energy Biomass	S	**Cumulative Biomass Energy Produced** (Mtoe) = 0 + ∫ (Biomass Energy Production) **Description:** *Cumulative biomass energy that has been produced.*
Energy Biomass	C	**Desired Biomass Energy Gross Margin** (Dmnl) = 0.2 **Description:** *Desired Gross Margin per unit of biomass energy.* **Used by:** • Indicated Biomass Energy Price - Indicated biomass energy price accounting for unit cost and gross margin.

Energy Biomass	A	**Desired Biomass Installed Capacity** (Dmnl) = Total Biomass Demand/Efficiency of Biomass Installed Capacity **Description:** *Desired Biomass Installed Capacity accounting for Total Biomass Demand and Efficiency of Biomass Installed Capacity.* **Used by:** • Biomass Infrastructure Adjustment - Adjustment of Biomass Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Biomass	A	**Effect of Biomass Energy Demand and Supply on Price** (Dmnl) = (Total Biomass Demand/Potential Biomass Energy Production)^Sensitivity of Biomass Energy Price to Supply and Demand **Description:** *Effect of Biomass Demand and Supply ratio on actual biomass energy price.* **Used by:** • Biomass Energy Price - Actual biomass energy price accounting for indicated biomass energy price and effect of demand and supply.
Energy Biomass	C	**Effectiveness of Investment in Biomass Energy Technology** (1/$) = 1e-009 **Description:** *Effectiveness of resources dedicated to biomass energy efficiency technology development.* **Used by:** • Increase in Biomass Energy Technology Ratio - Increase in Biomass Energy Technology Ratio due to investments in biomass energy efficiency technology and their productivity.
Energy Biomass	C	**Effectiveness of Investment in Biomass Installation Technology** (1/$) = 1e-010 **Description:** *Effectiveness of resources dedicated to biomass energy capacity efficiency technology development.* **Used by:** • Increase in Biomass Installation Technology Ratio - Increase in Biomass Installation Technology Ratio due to investments in biomass energy capacity.
Energy Biomass	A	**Efficiency of Biomass Installed Capacity** (Mtoe/Year) = ZIDZ(Potential Biomass Energy Production from Infrastructure,Biomass Energy Installed Capacity) **Description:** *Total production efficiency of Biomass Installed Capacity.* **Used by:** • Investment in Biomass Capacity - Amount of resources dedicated to biomass capacity development. • Desired Biomass Installed Capacity - Desired Biomass Installed Capacity accounting for Total Biomass Demand and Efficiency of Biomass Installed Capacity.
Energy Biomass	C	**Fraction for Biomass Learning Curve Strength** (Dmnl) = 0.01 **Description:** *Fraction for Biomass Learning Curve Strength indicating by what percentage the biomass energy cost will drop for each doubling of biomass installed capacity.* **Used by:** • Biomass Learning Curve Strength - Strength of biomass learning curve with which the biomass energy costs are influenced..
Energy Biomass	A	**Fraction Invested in Biomass Energy Installation** (Dmnl) = Table for FIBEI(Biomass Installation Efficiency) **Description:** *Fraction of investments in biomass energy technology dedicated to capacity.* **Used by:** • Investment in Biomass Energy Installation - Total investments in biomass energy capacity. • Investment in Biomass Energy Efficiency - Total investments in biomass energy efficiency technology.
Energy Biomass	A	**Fraction of Revenue Invested in Biomass Technology** (Dmnl) = RAMP(Biomass Investment Fraction Slope, Biomass Investment Fraction Start , Biomass Investment Fraction Finish) **Description:** *Parameter to take into account historical increase of the biomass energy significance and over time greater resources dedicated to the technology development.* **Used by:** • Investment in Biomass Energy Technology - Investments in development of biomass

		energy efficiency technology and production capability.
Energy Biomass	A	**Impact of Learning on Biomass Unit Cost of Technology** (Dmnl) = (Biomass Energy Installed Capacity/INIT BIC)^Biomass Learning Curve Strength **Description:** *Impact of learning curve on biomass energy cost.* **Used by:** • Unit Cost of Biomass Capacity Installation - Unit Cost of Biomass Capacity Installation. Determined by Productivity of Investment in Biomass Capacity Installation.
Energy Biomass	A	**Increase in Biomass Energy Technology Ratio** (1/Year) = DELAY3(Investment in Biomass Energy Efficiency*Effectiveness of Investment in Biomass Energy Technology, Biomass Energy Technology Development Time) **Description:** *Increase in Biomass Energy Technology Ratio due to investments in biomass energy efficiency technology and their productivity.* **Used by:** • Biomass Energy Technology Ratio - Biomass Energy Technology Ratio increased due to investments in biomass energy efficiency.
Energy Biomass	A	**Increase in Biomass Installation Technology Ratio** (1/Year) = DELAY3(Investment in Biomass Energy Installation*Effectiveness of Investment in Biomass Installation Technology, Biomass Installation Technology Development Time) **Description:** *Increase in Biomass Installation Technology Ratio due to investments in biomass energy capacity.* **Used by:** • Biomass Installation Technology Ratio - Biomass Installation Technology Ratio increased due to investments in biomass energy capacity efficiency.
Energy Biomass	A	**Indicated Biomass Energy Price** ($/Mtoe) = Cost of Biomass Energy*(1+Desired Biomass Energy Gross Margin) **Description:** *Indicated biomass energy price accounting for unit cost and gross margin.* **Used by:** • Biomass Energy Price - Actual biomass energy price accounting for indicated biomass energy price and effect of demand and supply.
Energy Biomass	C	**INIT BETRN** (Dmnl) = 0 **Description:** *Initial Biomass Energy Technology Ratio.* **Used by:** • Biomass Energy Technology Ratio - Biomass Energy Technology Ratio increased due to investments in biomass energy efficiency.
Energy Biomass	C	**INIT BIC** (Dmnl) = 40 **Description:** *Initial installed capacity to transform biomass into energy.* **Used by:** • Impact of Learning on Biomass Unit Cost of Technology - Impact of learning curve on biomass energy cost. • Biomass Energy Installed Capacity - Installed capacity to transform biomass into energy.
Energy Biomass	C	**INIT BITRN** (Dmnl) = 0 **Description:** *Initial Biomass Installation Technology Ratio.* **Used by:** • Biomass Installation Technology Ratio - Biomass Installation Technology Ratio increased due to investments in biomass energy capacity efficiency.
Energy Biomass	C	**INIT Unit Cost of Biomass Capacity Installation** ($/Mtoe) = 2e+006 **Description:** *Initial unit cost per unit biomass capacity installation.* **Used by:** • Unit Cost of Biomass Capacity Installation - Unit Cost of Biomass Capacity Installation. Determined by Productivity of Investment in Biomass Capacity Installation.
Energy Biomass	F,A	**Installation of Biomass Capacity Rate** (1/Year) = MAX(0,Biomass Infrastructure Adjustment*Productivity of Investment in Biomass Capacity Installation)

		Description: *Rate of new biomass capacity installation.* **Used by:** • Investment in Biomass Capacity - Amount of resources dedicated to biomass capacity development. • Biomass Energy Installed Capacity - Installed capacity to transform biomass into energy.
Energy Biomass	A	**Investment in Biomass Capacity** ($/Year) = Installation of Biomass Capacity Rate*Unit Cost of Biomass Capacity Installation*Efficiency of Biomass Installed Capacity*Biomass Capacity Aging Time **Description:** *Amount of resources dedicated to biomass capacity development.* **Used by:** • Net Energy Capital Change - Capital change from energy sector.
Energy Biomass	A	**Investment in Biomass Energy Efficiency** ($/Year) = Investment in Biomass Energy Technology*(1-Fraction Invested in Biomass Energy Installation) **Description:** *Total investments in biomass energy efficiency technology.* **Used by:** • Increase in Biomass Energy Technology Ratio - Increase in Biomass Energy Technology Ratio due to investments in biomass energy efficiency technology and their productivity.
Energy Biomass	A	**Investment in Biomass Energy Installation** ($/Year) = Investment in Biomass Energy Technology*Fraction Invested in Biomass Energy Installation **Description:** *Total investments in biomass energy capacity.* **Used by:** • Increase in Biomass Installation Technology Ratio - Increase in Biomass Installation Technology Ratio due to investments in biomass energy capacity.
Energy Biomass	A	**Investment in Biomass Energy Technology** ($/Year) = Fraction of Revenue Invested in Biomass Technology*Biomass Energy Revenue **Description:** *Investments in development of biomass energy efficiency technology and production capability.* **Used by:** • Investment in Biomass Energy Installation - Total investments in biomass energy capacity. • Investment in Biomass Energy Efficiency - Total investments in biomass energy efficiency technology. • Net Energy Capital Change - Capital change from energy sector.
Energy Biomass	C	**MAXBCF** (Dmnl) = 1 **Description:** *Maximal possible value of Biomass Capacity Factor.* **Used by:** • Biomass Capacity Factor - Parameter indicating what fraction of Biomass Conversion Efficiency it is possible to realize with the current state of technical developments. • Biomass Technology - Factor productivity in Biomass energy sector.
Energy Biomass	C	**MAXBIE** (Dmnl) = 1 **Description:** *Maximal value of Biomass Installation Efficiency factor.* **Used by:** • Biomass Installation Efficiency - Parameter indicating biomass energy capacity installation efficiency at the current state of technical developments. • Biomass Technology - Factor productivity in Biomass energy sector.
Energy Biomass	C	**MINBCF** (Dmnl) = 0.4 **Description:** *Minimal and initial value of Biomass Capacity Factor.* **Used by:** • Biomass Capacity Factor - Parameter indicating what fraction of Biomass Conversion Efficiency it is possible to realize with the current state of technical developments.
Energy Biomass	C	**MINBIE** (Dmnl) = 0.5 **Description:** *Minimal and initial value of Biomass Installation Efficiency factor.*

		Used by: • Biomass Installation Efficiency - Parameter indicating biomass energy capacity installation efficiency at the current state of technical developments.
Energy Biomass	A	**Potential Biomass Energy Production** (Mtoe/Year) = MIN(Potential Biomass Energy Production from Infrastructure,Potential Biomass Energy Production from Resources) **Description:** *Potential biomass energy production per year due to available resources, production capability and technical developments.* **Used by:** • Biomass Energy Production Rate - Total biomass energy production per year accounting for demand and potential production due to available resources, production capability and technical developments. • Effect of Biomass Energy Demand and Supply on Price - Effect of Biomass Demand and Supply ratio on actual biomass energy price. • Biomass Energy Demand to Supply Ratio - Biomass Energy Demand to Supply Ratio.
Energy Biomass	A	**Potential Biomass Energy Production from Infrastructure** (Mtoe/Year) = Biomass Energy Installed Capacity*Average Annual Production per Capacity **Description:** *Potential biomass energy production per year due to available production capability.* **Used by:** • Potential Biomass Energy Production - Potential biomass energy production per year due to available resources, production capability and technical developments. • Efficiency of Biomass Installed Capacity - Total production efficiency of Biomass Installed Capacity.
Energy Biomass	A	**Potential Biomass Energy Production from Resources** (Mtoe/Year) = Biomass Production*Biomass Conversion Efficiency*Biomass Capacity Factor **Description:** *Potential biomass energy production per year due to available resources and technical developments.* **Used by:** • Potential Biomass Energy Production - Potential biomass energy production per year due to available resources, production capability and technical developments.
Energy Biomass	A	**Productivity of Investment in Biomass Capacity Installation** (Dmnl) = Biomass Energy Installed Capacity Ratio*Biomass Installation Efficiency **Description:** *Productivity of biomass capacity installation taking into account the level of available capacities and technology development state.* **Used by:** • Installation of Biomass Capacity Rate - Rate of new biomass capacity installation.
Energy Biomass	C	**Reference Biomass Energy Installed Capacity** (Dmnl) = 5e+011 **Description:** *Reference biomass capacity.* **Used by:** • Biomass Energy Installed Capacity Ratio - Ratio of installed biomass energy production capacities to reference capacity.
Energy Biomass	C	**Reference Cost of Biomass Energy Production** ($/Year) = 5e+007 **Description:** *Reference cost of unit biomass energy production per year.* **Used by:** • Unit Cost of Biomass Energy Production - Unit cost of biomass capacity installation per energy unit.
Energy Biomass	C	**Sensitivity of Biomass Energy Price to Supply and Demand** (Dmnl) = 0 **Description:** *Sensitivity of Biomass Energy Price to Supply and Demand ratio.* **Used by:** • Effect of Biomass Energy Demand and Supply on Price - Effect of Biomass Demand and Supply ratio on actual biomass energy price.
Energy Biomass	L	**Table for FIBEI** (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) **Description:** *Table determining order by which technology investments are dedicated to energy and installation efficiency. For small Biomass Installation Efficiency, in order to secure*

		sufficient production capacity, more investments are directed to infrastructure. Once the Biomass Installation Efficiency increases the investments are redirected to energy efficiency technologies. **Used by:** • Fraction Invested in Biomass Energy Installation - Fraction of investments in biomass energy technology dedicated to capacity. 
Energy Biomass	C	**Time to Adjust Biomass Infrastructure** (Year) = 5 **Description:** *Time to adjust Biomass Infrastructure to the desired level.* **Used by:** • Biomass Infrastructure Adjustment - Adjustment of Biomass Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Biomass	A	**Total Biomass Demand** (Mtoe/Year) = Energy Demand*Market Share Biomass **Description:** *Total demand for energy from biomass.* **Used by:** • Biomass Energy Production Rate - Total biomass energy production per year accounting for demand and potential production due to available resources, production capability and technical developments. • Effect of Biomass Energy Demand and Supply on Price - Effect of Biomass Demand and Supply ratio on actual biomass energy price. • Biomass Energy Demand to Supply Ratio - Biomass Energy Demand to Supply Ratio. • Desired Biomass Installed Capacity - Desired Biomass Installed Capacity accounting for Total Biomass Demand and Efficiency of Biomass Installed Capacity.
Energy Biomass	A	**Unit Cost of Biomass Capacity Installation** ($/Mtoe) = INIT Unit Cost of Biomass Capacity Installation*Impact of Learning on Biomass Unit Cost of Technology **Description:** *Unit Cost of Biomass Capacity Installation. Determined by Productivity of Investment in Biomass Capacity Installation.* **Used by:** • Investment in Biomass Capacity - Amount of resources dedicated to biomass capacity development. • Cost of Biomass Energy - Cost of biomass energy production assuming an impact of learning curve.
Energy Biomass	A	**Unit Cost of Biomass Energy Production** ($/Mtoe) = Reference Cost of Biomass Energy Production/Biomass Production to Installation Ratio **Description:** *Unit cost of biomass capacity installation per energy unit.* **Used by:** • Cost of Biomass Energy - Cost of biomass energy production assuming an impact of learning curve.
Energy Coal	A	**Adjustment for Identified Coal Resource** (Mtoe/Year) = (Required Identified Coal Resources-Identified Coal Resources)/Identified Coal Resources Adjustment Time

		Description: *Adjustment of Identified Coal Resource to the desired level over a specified adjustment time.* **Used by:** • Desired Coal Exploration Rate - Desired Coal exploration rate due to Total Coal Demand and Identified Coal Resources safety coverage.
Energy Coal	S	**Average Coal Production** (Mtoe/Year) = 191.404 + ∫ (Change in Average Coal Production) **Description:** *Average total coal production per year.* **Used by:** • Change in Average Coal Production - Change in Average Coal Production. • Coal Production Coverage - Ratio indicating coal coverage in years for discovered resources and at the current average coal production. • Coal Revenue - Total revenue in coal market.
Energy Coal	A	**Change in Average Coal Production** (Mtoe/(Year*Year)) = (Coal Production-Average Coal Production)/Time to Average Coal Production **Description:** *Change in Average Coal Production.* **Used by:** • Average Coal Production - Average total coal production per year.
Energy Coal	A	**Change in Coal Productivity of Investment** (toe/(Year*$)) = (Productivity of Investment in Coal Exploration-Coal Productivity of Investment)/Coal Production Coverage **Description:** *Change in Coal Productivity of Investment.* **Used by:** • Coal Productivity of Investment - Factor indicating productivity of investments in coal production.
Energy Coal	A	**Change in Effective Investment in Coal Exploration** ($/(Year*Year)) = (Investment in Coal Exploration-Effective Investment in Coal Exploration)/Investment in Coal Exploration Delay **Description:** *Change in Effective Investment in Coal Exploration.* **Used by:** • Effective Investment in Coal Exploration - Effective investments dedicated for coal resources exploration.
Energy Coal	A	**Change in Effective Investment in Coal Production** ($/(Year*Year)) = (Investment in Coal Production-Effective Investment in Coal Production)/Investment in Coal Production Delay **Description:** *Change in Effective Investment in Coal Production.* **Used by:** • Effective Investment in Coal Production - Effective investments dedicated for coal resources production.
Energy Coal	A	**Coal Cost** ($/Mtoe) = Unit Cost of Coal Exploration+Unit Cost of Coal Production **Description:** *Cost of unit coal resources as a sum of unit exploration and production costs.* **Used by:** • Coal Gross Margin - Actual coal gross margin. • Indicated Coal Price - Indicated coal price accounting for exploration and production cost and gross margin.
Energy Coal	A	**Coal Demand to Supply Ratio** (Dmnl) = Total Coal Demand/Potential Coal Production **Description:** *Coal Demand to Supply Ratio.*
Energy Coal	C	**Coal Desired Gross Margin** (Dmnl) = 0.2 **Description:** *Desired Gross Margin per unit coal resources.* **Used by:** • Indicated Coal Price - Indicated coal price accounting for exploration and production cost and gross margin.
Energy Coal	C	**Coal Discovery Technology Development Time** (Year) = 6 **Description:** *Average time required to turn investments into concrete coal discovery developments.*

		Used by: • Increase in Ratio of Coal Fraction Discoverable to Undiscoverable - Increase in Ratio of Coal Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Coal	F,A	**Coal Exploration** (Mtoe/Year) = MAX(Coal Exploration Rate,0) **Description:** *Coal resources discovery rate.* **Used by:** • Identified Coal Resources - Coal Resources discovered thanks to developments in exploration technology. • Desired Investment in Coal Exploration - Desired amount of resources that need to be invested in order to secure desired coal exploration. • Coal Cost - Cost of unit coal resources as a sum of unit exploration and production costs. • Undiscovered Coal Resources - Existing Coal Resources but not discovered yet.
Energy Coal	A	**Coal Exploration Rate** (Mtoe/Year) = MIN(Desired Coal Exploration Rate,Potential Coal Exploration) **Description:** *Coal Exploration Rate accounting for potential and desired coal exploration rates.* **Used by:** • Coal Exploration - Coal resources discovery rate.
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)) **Description:** *Percentage of coal resources that can be still explored due to current state of discovery technology.* **Used by:** • Total Coal Discoverable Resources - Total Coal Discoverable Resources as a percentage of Total Coal Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments. • Fraction Invested in Coal Discovery Technology - Fraction of investments in coal technology dedicated to discovery technology. • Coal Technology - Factor productivity in Coal energy sector.
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)) **Description:** *Percentage of coal resources that can be produced due to current state of recovery technology.* **Used by:** • Identified Coal Resources - Coal Resources discovered thanks to developments in exploration technology. • Total Coal Recoverable Resource Remaining - Total Coal Recoverable Resources Remaining as a percentage of Cumulative Additions to Coal Production. It excludes already produced resources. The percentage is determined by production technology developments. • Coal Technology - Factor productivity in Coal energy sector.
Energy Coal	A	**Coal Gross Margin** (Dmnl) = (Coal Price-Coal Cost)/Coal Cost **Description:** *Actual coal gross margin.*
Energy Coal	A	**Coal Price** ($/Mtoe) = Indicated Coal Price*Effect of Coal Demand and Supply on Price **Description:** *Actual coal price accounting for indicated coal price and effect of demand and supply.* **Used by:** • Coal Price per Ton - Actual Coal Price per Ton. • Coal Gross Margin - Actual coal gross margin. • Coal Revenue - Total revenue in coal market. • Coal Price toe - Actual coal price in dollars per toe.

Energy Coal	A	**Coal Price per Ton** ($/Ton) = Coal Price*Mtoe per Ton **Description:** *Actual Coal Price per Ton.*
Energy Coal	A	**Coal Production** (Mtoe/Year) = Coal Production Rate **Description:** *Total coal energy production per year. Source of historical data: International Energy Agency Key World Energy Statistics 2007; BP Statistical Review of World Energy June 2008* **Used by:** • C Emission from Coal Energy - Total carbon emission from coal energy production and it use. • Change in Average Coal Production - Change in Average Coal Production. • Identified Coal Resources - Coal Resources discovered thanks to developments in exploration technology. • Coal Shortage - Difference between demand and the coal production rate. • Desired Coal Exploration Rate - Desired Coal exploration rate due to Total Coal Demand and Identified Coal Resources safety coverage. • Cumulative Coal Production - Cumulative Coal resources that has been produced. • Energy Production - Total energy production per year.
Energy Coal	A	**Coal Production Coverage** (Year) = Identified Coal Resources/Average Coal Production **Description:** *Ratio indicating coal coverage in years for discovered resources and at the current average coal production.* **Used by:** • Change in Coal Productivity of Investment - Change in Coal Productivity of Investment.
Energy Coal	A	**Coal Production Rate** (Mtoe/Year) = MIN(Total Coal Demand,Potential Coal Production) **Description:** *Total coal energy production per year due to available resources, developments in production technology and coal energy demand.* **Used by:** • Coal Production - Total coal energy production per year. Source of historical data: International Energy Agency Key World Energy Statistics 2007; BP Statistical Review of World Energy June 2008
Energy Coal	S	**Coal Productivity of Investment** (toe/$) = 0.00188537 + ∫ (Change in Coal Productivity of Investment) **Description:** *Factor indicating productivity of investments in coal production.* **Used by:** • Change in Coal Productivity of Investment - Change in Coal Productivity of Investment. • Productivity of Investment in Coal Production - Parameter indicating the amount of coal resources possible to be recovered per unit investment spent.
Energy Coal	C	**Coal Recovery Technology Development Time** (Year) = 6 **Description:** *Average time required to turn investments into concrete coal recovery developments.* **Used by:** • Increase in Ratio of Coal Fraction Recoverable to Unrecoverable - Increase in Ratio of Coal Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Coal	A	**Coal Revenue** ($/Year) = Coal Price*Average Coal Production **Description:** *Total revenue in coal market.* **Used by:** • Investment in Coal Technology - Investments in development of coal exploration and production technology.
Energy Coal	A	**Coal Shortage** (Mtoe/Year) = Total Coal Demand-Coal Production **Description:** *Difference between demand and the coal production rate.*

Energy Coal	A	**Cumulative Additions to Coal Production** (Mtoe) = Identified Coal Resources+Cumulative Coal Production **Description:** *Identified and already produced coal resources.* **Used by:** • Total Coal Discoverable Resources - Total Coal Discoverable Resources as a percentage of Total Coal Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments. • Total Coal Recoverable Resource Remaining - Total Coal Recoverable Resources Remaining as a percentage of Cumulative Additions to Coal Production. It excludes already produced resources. The percentage is determined by production technology developments. • Total Coal Resources - Total coal resources including Undiscovered Coal Resources, Identified Coal Resources and resources already produced i.e. Cumulative Coal Production.
Energy Coal	S,SI	**Cumulative Coal Production** (Mtoe) = INIT CCPN + ∫ (Coal Production) **Description:** *Cumulative Coal resources that has been produced.* **Used by:** • Identified Coal Resources - Coal Resources discovered thanks to developments in exploration technology. • Total Coal Recoverable Resource Remaining - Total Coal Recoverable Resources Remaining as a percentage of Cumulative Additions to Coal Production. It excludes already produced resources. The percentage is determined by production technology developments. • Cumulative Additions to Coal Production - Identified and already produced coal resources.
Energy Coal	A	**Desired Coal Exploration Rate** (Mtoe/Year) = MAX(0,Adjustment for Identified Coal Resource+Coal Production) **Description:** *Desired Coal exploration rate due to Total Coal Demand and Identified Coal Resources safety coverage.* **Used by:** • Desired Investment in Coal Exploration - Desired amount of resources that need to be invested in order to secure desired coal exploration. • Coal Exploration Rate - Coal Exploration Rate accounting for potential and desired coal exploration rates.
Energy Coal	A	**Desired Investment in Coal Exploration** ($/Year) = Desired Coal Exploration Rate*Unit Cost of Coal Exploration **Description:** *Desired amount of resources that need to be invested in order to secure desired coal exploration.* **Used by:** • Investment in Coal Exploration - Amount of resources dedicated to coal exploration.
Energy Coal	A	**Desired Investment in Coal Production** ($/Year) = MIN(Potential Coal Production from Resources,Total Coal Demand)/Productivity of Investment in Coal Production*toe per Mtoe **Description:** *Desired Investment in Coal Production due to Total Coal Demand and Productivity of Investment in Coal Production.* **Used by:** • Investment in Coal Production - Amount of resources dedicated to 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*toe per Mtoe **Description:** *Desired Investment in Oil Production due to Total Oil Demand and Productivity of Investment in Oil Production.* **Used by:** • Investment in Oil Production - Amount of resources dedicated to 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 **Description:** *Effect of Coal Demand and Supply ratio on actual coal price.* **Used by:**

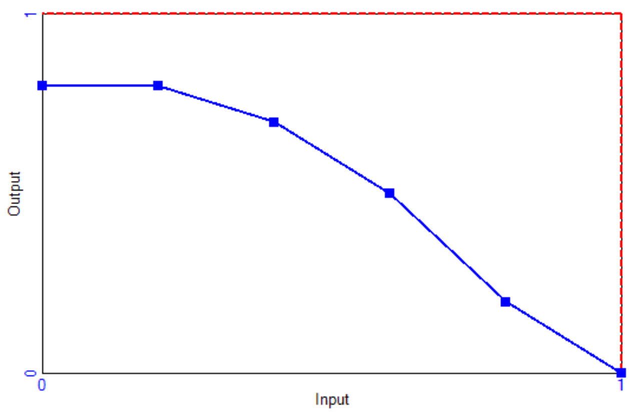
		• Coal Price - Actual coal price accounting for indicated coal price and effect of demand and supply.
Energy Coal	A	**Effect of Technology on Coal Discoveries** (Dmnl) = Total Coal Discoverable Resources/INIT UCRN **Description:** *Impact of technology development on coal exploration taking into account remaining undiscovered coal resources (the less remaining undiscovered coal resources the more expensive it is to discover them).* **Used by:** • Productivity of Investment in Coal Exploration - Parameter indicating the amount of coal resources possible to be explored per unit investment spent.
Energy Coal	S	**Effective Investment in Coal Exploration** ($/Year) = 1.01518e+011 + ∫ (Change in Effective Investment in Coal Exploration) **Description:** *Effective investments dedicated for coal resources exploration.* **Used by:** • Potential Coal Exploration - Potential Coal exploration due to available investments in coal resources discovery. • Change in Effective Investment in Coal Exploration - Change in Effective Investment in Coal Exploration.
Energy Coal	S	**Effective Investment in Coal Production** ($/Year) = 1.01521e+010 + ∫ (Change in Effective Investment in Coal Production) **Description:** *Effective investments dedicated for coal resources production.* **Used by:** • Potential Coal Production from Investment - Potential Coal Production due to available investments in coal resources recovery. • Change in Effective Investment in Coal Production - Change in Effective Investment in Coal Production.
Energy Coal	C	**Effectiveness of Investment in Coal Discovery Technology** (1/$) = 1.62e-011 **Description:** *Effectiveness of resources dedicated to coal discovery technology development.* **Used by:** • Increase in Ratio of Coal Fraction Discoverable to Undiscoverable - Increase in Ratio of Coal Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Coal	C	**Effectiveness of Investment in Coal Recovery Technology** (1/$) = 1.3e-012 **Description:** *Effectiveness of resources dedicated to coal recovery technology development.* **Used by:** • Increase in Ratio of Coal Fraction Recoverable to Unrecoverable - Increase in Ratio of Coal Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Coal	A	**Fraction Invested in Coal Discovery Technology** (Dmnl) = Table for FICDT(Coal Fraction Discoverable) **Description:** *Fraction of investments in coal technology dedicated to discovery technology.* **Used by:** • Investment in Coal Recovery Technology - Total investments in coal production technology. • Investment in Coal Discovery Technology - Total investments in coal exploration technology.
Energy Coal	C	**Fraction of Coal Revenues Invested in Technology** (Dmnl) = 0.04 **Description:** *Percentage of total coal sector revenue dedicated to exploration and production technology development.* **Used by:** • Investment in Coal Technology - Investments in development of coal exploration and production technology.
Energy Coal	S	**Identified Coal Resources** (Mtoe) = **Description:** *Coal Resources discovered thanks to developments in exploration technology.* **Used by:** • Coal Production Coverage - Ratio indicating coal coverage in years for discovered

		resources and at the current average coal production. • Required Identified Coal Resources - The desired Identified Coal Resources level sought by the coal sector. • Cumulative Additions to Coal Production - Identified and already produced coal resources. • Adjustment for Identified Coal Resource - Adjustment of Identified Coal Resource to the desired level over a specified adjustment time.
Energy Coal	C	**Identified Coal Resources Adjustment Time** (Year) = 15 **Description:** *Time to adjust Identified Oil Coal Resource to the desired level.* **Used by:** • Adjustment for Identified Coal Resource - Adjustment of Identified Coal Resource to the desired level over a specified adjustment time.
Energy Coal	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) **Description:** *Increase in Ratio of Coal Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.* **Used by:** • Ratio of Coal Fraction Discoverable to Undiscoverable - Ratio of Coal Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.
Energy Coal	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) **Description:** *Increase in Ratio of Coal Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.* **Used by:** • Ratio of Coal Fraction Recoverable to Unrecoverable - Ratio of Coal Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.
Energy Coal	A	**Indicated Coal Price** ($/Mtoe) = Coal Cost*(1+Coal Desired Gross Margin) **Description:** *Indicated coal price accounting for exploration and production cost and gross margin.* **Used by:** • Coal Price - Actual coal price accounting for indicated coal price and effect of demand and supply.
Energy Coal	C	**INIT CCPN** (Mtoe) = 37630 **Description:** *Cumulative Coal resources for 1900.* **Used by:** • Cumulative Coal Production - Cumulative Coal resources that has been produced.
Energy Coal	C	**INIT RCDU** (Dmnl) = 0 **Description:** *Initial Ratio of Coal Fraction Discoverable to Undiscoverable.* **Used by:** • Ratio of Coal Fraction Discoverable to Undiscoverable - Ratio of Coal Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.
Energy Coal	C	**INIT RCRU** (Dmnl) = 0 **Description:** *Initial Ratio of Coal Fraction Recoverable to Unrecoverable.* **Used by:** • Ratio of Coal Fraction Recoverable to Unrecoverable - Ratio of Coal Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.
Energy Coal	C	**INIT UCRN** (Mtoe) = 400000 **Description:** *Initial amount of Undiscovered Coal Resources.*

		Used by: • Effect of Technology on Coal Discoveries - Impact of technology development on coal exploration taking into account remaining undiscovered coal resources (the less remaining undiscovered coal resources the more expensive it is to discover them). • Undiscovered Coal Resources - Existing Coal Resources but not discovered yet.
Energy Coal	A	**Investment in Coal Discovery Technology** ($/Year) = Investment in Coal Technology*Fraction Invested in Coal Discovery Technology **Description:** *Total investments in coal exploration technology.* **Used by:** • Increase in Ratio of Coal Fraction Discoverable to Undiscoverable - Increase in Ratio of Coal Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Coal	A	**Investment in Coal Exploration** ($/Year) = Desired Investment in Coal Exploration **Description:** *Amount of resources dedicated to coal exploration.* **Used by:** • Change in Effective Investment in Coal Exploration - Change in Effective Investment in Coal Exploration. • Net Energy Capital Change - Capital change from energy sector.
Energy Coal	C	**Investment in Coal Exploration Delay** (Year) = 5 **Description:** *Time delay to make investments in coal exploration effective.* **Used by:** • Change in Effective Investment in Coal Exploration - Change in Effective Investment in Coal Exploration.
Energy Coal	A	**Investment in Coal Production** ($/Year) = Desired Investment in Coal Production **Description:** *Amount of resources dedicated to coal production.* **Used by:** • Change in Effective Investment in Coal Production - Change in Effective Investment in Coal Production. • Net Energy Capital Change - Capital change from energy sector.
Energy Coal	C	**Investment in Coal Production Delay** (Year) = 5 **Description:** *Time delay to make investments in coal production effective.* **Used by:** • Change in Effective Investment in Coal Production - Change in Effective Investment in Coal Production.
Energy Coal	A	**Investment in Coal Recovery Technology** ($/Year) = Investment in Coal Technology*(1-Fraction Invested in Coal Discovery Technology) **Description:** *Total investments in coal production technology.* **Used by:** • Increase in Ratio of Coal Fraction Recoverable to Unrecoverable - Increase in Ratio of Coal Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Coal	A	**Investment in Coal Technology** ($/Year) = Fraction of Coal Revenues Invested in Technology*Coal Revenue **Description:** *Investments in development of coal exploration and production technology.* **Used by:** • Investment in Coal Recovery Technology - Total investments in coal production technology. • Investment in Coal Discovery Technology - Total investments in coal exploration technology. • Net Energy Capital Change - Capital change from energy sector.
Energy Coal	C	**Max Unit Cost of Coal Exploration** ($/Mtoe) = 1e+009 **Description:** *Upper level limit for unit cost of coal exploration.*
Energy Coal	C	**MAXCFD** (Dmnl)

		= 1 **Description:** *Maximal possible percentage of coal resources to be discovered.* **Used by:** • Coal Fraction Discoverable - Percentage of coal resources that can be still explored due to current state of discovery technology. • Coal Technology - Factor productivity in Coal energy sector.
Energy Coal	C	**MAXCFR** (Dmnl) = 1 **Description:** *Maximal possible percentage of coal resources to be recovered.* **Used by:** • Coal Fraction Recoverable - Percentage of coal resources that can be produced due to current state of recovery technology. • Coal Technology - Factor productivity in Coal energy sector.
Energy Coal	C	**MINCFD** (Dmnl) = 0.5 **Description:** *Initial and minimal possible percentage of coal resources to be discovered.* **Used by:** • Coal Fraction Discoverable - Percentage of coal resources that can be still explored due to current state of discovery technology.
Energy Coal	C	**MINCFR** (Dmnl) = 0.15 **Description:** *Initial and minimal possible percentage of coal resources to be recovered.* **Used by:** • Coal Fraction Recoverable - Percentage of coal resources that can be produced due to current state of recovery technology.
Energy Coal	SI,C	**Normal Coal Production Ratio** (Year) = 20 **Description:** *Safety stock coverage as a number of years of the total coal demand the coal sector would like to maintain in identified coal resources. It secures the market against possibility of unforeseen variations in demand. It is also a stimulus for coal exploration.* **Used by:** • Identified Coal Resources - Coal Resources discovered thanks to developments in exploration technology. • Required Identified Coal Resources - The desired Identified Coal Resources level sought by the coal sector. • Potential Coal Production from Resources - Potential Coal Production rate due to Total Coal Recoverable Resource Remaining adjusted by coal production safety coverage.
Energy Coal	A	**Potential Coal Exploration** (Mtoe/Year) = Effective Investment in Coal Exploration*Productivity of Investment in Coal Exploration/toe per Mtoe **Description:** *Potential Coal exploration due to available investments in coal resources discovery.* **Used by:** • Coal Exploration Rate - Coal Exploration Rate accounting for potential and desired coal exploration rates.
Energy Coal	A	**Potential Coal Production** (Mtoe/Year) = MIN(Potential Coal Production from Investment,Potential Coal Production from Resources) **Description:** *Potential Coal Production due to available investments in coal resources recovery and recovery technology.* **Used by:** • Effect of Coal Demand and Supply on Price - Effect of Coal Demand and Supply ratio on actual coal price. • Coal Production Rate - Total coal energy production per year due to available resources, developments in production technology and coal energy demand. • Coal Demand to Supply Ratio - Coal Demand to Supply Ratio.
Energy Coal	A	**Potential Coal Production from Investment** (Mtoe/Year) = Productivity of Investment in Coal Production*Effective Investment in Coal Production/toe per Mtoe **Description:** *Potential Coal Production due to available investments in coal resources*

		recovery. **Used by:** • Potential Coal Production - Potential Coal Production due to available investments in coal resources recovery and recovery technology.
Energy Coal	A	**Potential Coal Production from Resources** (Mtoe/Year) = Total Coal Recoverable Resource Remaining/Normal Coal Production Ratio **Description:** *Potential Coal Production rate due to Total Coal Recoverable Resource Remaining adjusted by coal production safety coverage.* **Used by:** • Desired Investment in Coal Production - Desired Investment in Coal Production due to Total Coal Demand and Productivity of Investment in Coal Production. • Potential Coal Production - Potential Coal Production due to available investments in coal resources recovery and recovery technology.
Energy Coal	C	**Price Elasticity of Demand Gas** (Dmnl) = 0.54 **Description:** *Gas energy price elasticity of demand.* **Used by:** • Effect of Price on Market Share Gas - Effect of gas energy price competitiveness on market share.
Energy Coal	A	**Productivity of Investment in Coal Exploration** (toe/$) = MAX(0,Relative Productivity of Investment in Coal Exploration*Effect of Technology on Coal Discoveries) **Description:** *Parameter indicating the amount of coal resources possible to be explored per unit investment spent.* **Used by:** • Potential Coal Exploration - Potential Coal exploration due to available investments in coal resources discovery. • Change in Coal Productivity of Investment - Change in Coal Productivity of Investment.
Energy Coal	A	**Productivity of Investment in Coal Production** (toe/$) = Relative Productivity of Investment in Coal Production Compared to Exploration*Coal Productivity of Investment **Description:** *Parameter indicating the amount of coal resources possible to be recovered per unit investment spent.* **Used by:** • Unit Cost of Coal Production - Unit cost of coal production. ZIDZ(1, Productivity of Investment in Coal Production/Million toe per Mtoe) • Potential Coal Production from Investment - Potential Coal Production due to available investments in coal resources recovery. • Desired Investment in Coal Production - Desired Investment in Coal Production due to Total Coal Demand and Productivity of Investment in Coal Production.
Energy Coal	S	**Ratio of Coal Fraction Discoverable to Undiscoverable** (Dmnl) = INIT RCDU + ∫ (Increase in Ratio of Coal Fraction Discoverable to Undiscoverable) **Description:** *Ratio of Coal Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.* **Used by:** • Coal Fraction Discoverable - Percentage of coal resources that can be still explored due to current state of discovery technology.
Energy Coal	S	**Ratio of Coal Fraction Recoverable to Unrecoverable** (Dmnl) = INIT RCRU + ∫ (Increase in Ratio of Coal Fraction Recoverable to Unrecoverable) **Description:** *Ratio of Coal Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.* **Used by:** • Coal Fraction Recoverable - Percentage of coal resources that can be produced due to current state of recovery technology.
Energy Coal	C	**Relative Productivity of Investment in Coal Exploration** (toe/$) = 0.098 **Description:** *Relative Productivity of Investment in Coal Exploration without taking into account remaining undiscovered coal resources and advances in exploration technologies.* **Used by:**

		• [Productivity of Investment in Coal Exploration](#) - Parameter indicating the amount of coal resources possible to be explored per unit investment spent.
Energy Coal	C	**Relative Productivity of Investment in Coal Production Compared to Exploration** (Dmnl) = 10 **Description:** *Relative Productivity of Investment in Coal Production as a multiplier of Productivity of Investment in Coal Exploration.* **Used by:** • Productivity of Investment in Coal Production - Parameter indicating the amount of coal resources possible to be recovered per unit investment spent.
Energy Coal	A	**Required Identified Coal Resources** (Mtoe) = (Identified Coal Resources/Total Coal Recoverable Resource Remaining)*(Normal Coal Production Ratio*Total Coal Demand) **Description:** *The desired Identified Coal Resources level sought by the coal sector.* **Used by:** • Adjustment for Identified Coal Resource - Adjustment of Identified Coal Resource to the desired level over a specified adjustment time.
Energy Coal	C	**Sensitivity of Coal Price to Supply and Demand** (Dmnl) = 2 **Description:** *Sensitivity of Coal Price to Supply and Demand ratio.* **Used by:** • Effect of Coal Demand and Supply on Price - Effect of Coal Demand and Supply ratio on actual coal price.
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) **Description:** *Table determining order by which technology investments are dedicated to exploration and production technologies. For small Coal Fraction Discoverable, in order to make sufficient resources available to be produced, more investments are directed to exploration technologies. Once the Coal Fraction Discoverable increases the investments are redirected to production technologies.* **Used by:** • Fraction Invested in Coal Discovery Technology - Fraction of investments in coal technology dedicated to discovery technology. 
Energy Coal	C	**Time to Average Coal Production** (Year) = 1 **Description:** *Time to average total coal production per year.* **Used by:** • Change in Average Coal Production - Change in Average Coal Production.
Energy Coal	SI,A	**Total Coal Demand** (Mtoe/Year) = Energy Demand*Market Share Coal **Description:** *Total demand for coal resources.* **Used by:** • Desired Investment in Coal Production - Desired Investment in Coal Production due to Total Coal Demand and Productivity of Investment in Coal Production. • Identified Coal Resources - Coal Resources discovered thanks to developments in exploration technology.

		• Effect of Coal Demand and Supply on Price - Effect of Coal Demand and Supply ratio on actual coal price. • Coal Shortage - Difference between demand and the coal production rate. • Coal Production Rate - Total coal energy production per year due to available resources, developments in production technology and coal energy demand. • Required Identified Coal Resources - The desired Identified Coal Resources level sought by the coal sector. • Coal Demand to Supply Ratio - Coal Demand to Supply Ratio.
Energy Coal	A	**Total Coal Discoverable Resources** (Mtoe) = Total Coal Resources*Coal Fraction Discoverable-Cumulative Additions to Coal Production **Description:** *Total Coal Discoverable Resources as a percentage of Total Coal Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.* **Used by:** • Effect of Technology on Coal Discoveries - Impact of technology development on coal exploration taking into account remaining undiscovered coal resources (the less remaining undiscovered coal resources the more expensive it is to discover them).
Energy Coal	A	**Total Coal Recoverable Resource Remaining** (Mtoe) = Cumulative Additions to Coal Production*Coal Fraction Recoverable-Cumulative Coal Production **Description:** *Total Coal Recoverable Resources Remaining as a percentage of Cumulative Additions to Coal Production. It excludes already produced resources. The percentage is determined by production technology developments.* **Used by:** • Required Identified Coal Resources - The desired Identified Coal Resources level sought by the coal sector. • Potential Coal Production from Resources - Potential Coal Production rate due to Total Coal Recoverable Resource Remaining adjusted by coal production safety coverage.
Energy Coal	A	**Total Coal Resources** (Mtoe) = Undiscovered Coal Resources+Cumulative Additions to Coal Production **Description:** *Total coal resources including Undiscovered Coal Resources, Identified Coal Resources and resources already produced i.e. Cumulative Coal Production.* **Used by:** • Total Coal Discoverable Resources - Total Coal Discoverable Resources as a percentage of Total Coal Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.
Energy Coal	S	**Undiscovered Coal Resources** (Mtoe) = INIT UCRN + ∫ (-Coal Exploration) **Description:** *Existing Coal Resources but not discovered yet.* **Used by:** • Total Coal Resources - Total coal resources including Undiscovered Coal Resources, Identified Coal Resources and resources already produced i.e. Cumulative Coal Production.
Energy Coal	A	**Unit Cost of Coal Production** ($/Mtoe) = 1/Productivity of Investment in Coal Production*toe per Mtoe **Description:** *Unit cost of coal production. ZIDZ(1, Productivity of Investment in Coal Production/Million toe per Mtoe)* **Used by:** • Coal Cost - Cost of unit coal resources as a sum of unit exploration and production costs.
Energy Gas	A	**Adjustment for Identified Gas Resource** (Mtoe/Year) = (Required Identified Gas Resources-Identified Gas Resources)/Identified Gas Resources Adjustment Time **Description:** *Adjustment of Identified Gas Resource to the desired level over a specified adjustment time.* **Used by:** • Desired Gas Exploration Rate - Desired Gas exploration rate due to Total Gas Demand and Identified Gas Resources safety coverage.
Energy Gas	S	**Average Gas Production** (Mtoe/Year)

		= 1.87028 + ∫ (Change in Average Gas Production) **Description:** *Average total gas production per year.* **Used by:** • Change in Average Gas Production - Change in Average Gas Production. • Gas Revenue - Total revenue in gas market. • Gas Production Coverage - Ratio indicating gas coverage in years for discovered resources and at the current average gas production.
Energy Gas	A	**Change in Average Gas Production** (Mtoe/(Year*Year)) = (Gas Production-Average Gas Production)/Time to Average Gas Production **Description:** *Change in Average Gas Production.* **Used by:** • Average Gas Production - Average total gas production per year.
Energy Gas	A	**Change in Effective Investment in Gas Exploration** ($/(Year*Year)) = (Investment in Gas Exploration-Effective Investment in Gas Exploration)/Investment in Gas Exploration Delay **Description:** *Change in Effective Investment in Gas Exploration.* **Used by:** • Effective Investment in Gas Exploration - Effective investments dedicated for gas resources exploration.
Energy Gas	A	**Change in Effective Investment in Gas Production** ($/(Year*Year)) = (Investment in Gas Production-Effective Investment in Gas Production)/Investment in Gas Production Delay **Description:** *Change in Effective Investment in Gas Production.* **Used by:** • Effective Investment in Gas Production - Effective investments dedicated for gas resources production.
Energy Gas	A	**Change in Gas Productivity of Investment** (toe/(Year*$)) = (Productivity of Investment in Gas Exploration-Gas Productivity of Investment)/Gas Production Coverage **Description:** *Change in Gas Productivity of Investment.* **Used by:** • Gas Productivity of Investment - Factor indicating productivity of investments in gas production.
Energy Gas	A	**Cumulative Additions to Gas Production** (Mtoe) = Identified Gas Resources+Cumulative Gas Production **Description:** *Identified and already produced gas resources.* **Used by:** • Total Gas Recoverable Resource Remaining - Total Gas Recoverable Resources Remaining as a percentage of Cumulative Additions to Gas Production. It excludes already produced resources. The percentage is determined by production technology developments. • Total Gas Resources - Total gas resources including Undiscovered Gas Resources, Identified Gas Resources and resources already produced i.e. Cumulative Gas Production. • Total Gas Discoverable Resources - Total Gas Discoverable Resources as a percentage of Total Gas Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.
Energy Gas	S,SI	**Cumulative Gas Production** (Mtoe) = INIT CGPN + ∫ (Gas Production) **Description:** *Cumulative Gas resources that has been produced.* **Used by:** • Identified Gas Resources - Gas Resources discovered thanks to developments in exploration technology. • Total Gas Recoverable Resource Remaining - Total Gas Recoverable Resources Remaining as a percentage of Cumulative Additions to Gas Production. It excludes already produced resources. The percentage is determined by production technology developments. • Cumulative Additions to Gas Production - Identified and already produced gas resources.

Energy Gas	A	**Desired Gas Exploration Rate** (Mtoe/Year) = MAX(0,Adjustment for Identified Gas Resource+Gas Production) **Description:** *Desired Gas exploration rate due to Total Gas Demand and Identified Gas Resources safety coverage.* **Used by:** • Desired Investment in Gas Exploration - Desired amount of resources that need to be invested in order to secure desired gas exploration. • Gas Exploration Rate - Gas Exploration Rate accounting for potential and desired gas exploration rates.
Energy Gas	C	**Desired Gas Gross Margin** (Dmnl) = 0.2 **Description:** *Desired Gross Margin per unit gas resources.* **Used by:** • Indicated Gas Price - Indicated gas price accounting for exploration and production cost and gross margin.
Energy Gas	A	**Desired Investment in Gas Exploration** ($/Year) = Desired Gas Exploration Rate*Unit Cost of Gas Exploration **Description:** *Desired amount of resources that need to be invested in order to secure desired gas exploration.* **Used by:** • Investment in Gas Exploration - Amount of resources dedicated to gas exploration.
Energy Gas	A	**Desired Investment in Gas Production** ($/Year) = MIN(Potential Gas Production from Resources,Total Gas Demand)/Productivity of Investment in Gas Production*toe per Mtoe **Description:** *Desired Investment in Gas Production due to Total Gas Demand and Productivity of Investment in Gas Production.* **Used by:** • Investment in Gas Production - Amount of resources dedicated to 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 **Description:** *Effect of Gas Demand and Supply ratio on actual gas price.* **Used by:** • Gas Price - Actual gas price accounting for indicated gas price and effect of demand and supply.
Energy Gas	A	**Effect of Technology on Gas Discoveries** (Dmnl) = Total Gas Discoverable Resources/INIT UGRN **Description:** *Impact of technology development on gas exploration taking into account remaining undiscovered gas resources (the less remaining undiscovered gas resources the more expensive it is to discover them).* **Used by:** • Productivity of Investment in Gas Exploration - Parameter indicating the amount of gas resources possible to be explored per unit investment spent.
Energy Gas	S	**Effective Investment in Gas Exploration** ($/Year) = 9.08164e+007 + ∫ (Change in Effective Investment in Gas Exploration) **Description:** *Effective investments dedicated for gas resources exploration.* **Used by:** • Potential Gas Exploration - Potential Gas exploration due to available investments in gas resources discovery. • Change in Effective Investment in Gas Exploration - Change in Effective Investment in Gas Exploration.
Energy Gas	S	**Effective Investment in Gas Production** ($/Year) = 9.08165e+006 + ∫ (Change in Effective Investment in Gas Production) **Description:** *Effective investments dedicated for gas resources production.* **Used by:** • Potential Gas Production from Investment - Potential Gas Production due to available investments in gas resources recovery. • Change in Effective Investment in Gas Production - Change in Effective Investment in Gas Production.

Energy Gas	C	**Effectiveness of Investment in Gas Discovery Technology** (1/$) = 1.86e-009 **Description:** *Effectiveness of resources dedicated to gas discovery technology development.* **Used by:** • Increase in Ratio of Gas Fraction Discoverable to Undiscoverable - Increase in Ratio of Gas Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Gas	C	**Effectiveness of Investment in Gas Recovery Technology** (1/$) = 3e-011 **Description:** *Effectiveness of resources dedicated to gas recovery technology development.* **Used by:** • Increase in Ratio of Gas Fraction Recoverable to Unrecoverable - Increase in Ratio of Gas Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Gas	A	**Fraction Invested in Gas Discovery Technology** (Dmnl) = Table for FIGDT(Gas Fraction Discoverable) **Description:** *Fraction of investments in gas technology dedicated to discovery technology.* **Used by:** • Investment in Gas Discovery Technology - Total investments in gas exploration technology. • Investment in Gas Recovery Technology - Total investments in gas production technology.
Energy Gas	C	**Fraction of Gas Revenues Invested in Technology** (Dmnl) = 0.04 **Description:** *Percentage of total gas sector revenue dedicated to exploration and production technology development.* **Used by:** • Investment in Gas Technology - Investments in development of gas exploration and production technology.
Energy Gas	A	**Gas Cost** ($/Mtoe) = Unit Cost of Gas Exploration+Unit Cost of Gas Production **Description:** *Cost of unit gas resources as a sum of unit exploration and production costs.* **Used by:** • Indicated Gas Price - Indicated gas price accounting for exploration and production cost and gross margin. • Gas Gross Margin - Actual gas gross margin.
Energy Gas	A	**Gas Demand to Supply Ratio** (Dmnl) = Total Gas Demand/Potential Gas Production **Description:** *Gas Demand to Supply Ratio.*
Energy Gas	C	**Gas Discovery Technology Development Time** (Year) = 6 **Description:** *Average time required to turn investments into concrete gas discovery developments.* **Used by:** • Increase in Ratio of Gas Fraction Discoverable to Undiscoverable - Increase in Ratio of Gas Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Gas	F,A	**Gas Exploration** (Mtoe/Year) = MAX(0,Gas Exploration Rate) **Description:** *Gas resources discovery rate.* **Used by:** • Identified Gas Resources - Gas Resources discovered thanks to developments in exploration technology. • Desired Investment in Gas Exploration - Desired amount of resources that need to be invested in order to secure desired gas exploration. • Undiscovered Gas Resources - Existing Gas Resources but not discovered yet. • Gas Cost - Cost of unit gas resources as a sum of unit exploration and production costs.
Energy Gas	A	**Gas Exploration Rate** (Mtoe/Year)

		= MIN(Desired Gas Exploration Rate,Potential Gas Exploration) **Description:** *Gas Exploration Rate accounting for potential and desired gas exploration rates.* **Used by:** • Gas Exploration - Gas resources discovery rate.
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)) **Description:** *Percentage of gas resources that can be still explored due to current state of discovery technology.* **Used by:** • Gas Technology - Factor productivity in Gas energy sector. • Total Gas Discoverable Resources - Total Gas Discoverable Resources as a percentage of Total Gas Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments. • Fraction Invested in Gas Discovery Technology - Fraction of investments in gas technology dedicated to discovery technology.
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)) **Description:** *Percentage of gas resources that can be produced due to current state of recovery technology.* **Used by:** • Gas Technology - Factor productivity in Gas energy sector. • Identified Gas Resources - Gas Resources discovered thanks to developments in exploration technology. • Total Gas Recoverable Resource Remaining - Total Gas Recoverable Resources Remaining as a percentage of Cumulative Additions to Gas Production. It excludes already produced resources. The percentage is determined by production technology developments.
Energy Gas	A	**Gas Gross Margin** (Dmnl) = (Gas Price-Gas Cost)/Gas Cost **Description:** *Actual gas gross margin.*
Energy Gas	A	**Gas Price** ($/Mtoe) = Indicated Gas Price*Effect of Gas Demand and Supply on Price **Description:** *Actual gas price accounting for indicated gas price and effect of demand and supply.* **Used by:** • Gas Price toe - Actual gas price in dollars per toe. • Gas Price per MBtu - Actual Gas Price per Barrel. • Gas Revenue - Total revenue in gas market. • Gas Gross Margin - Actual gas gross margin.
Energy Gas	A	**Gas Price per MBtu** ($/MBtu) = Gas Price*Mtoe per Btu **Description:** *Actual Gas Price per Barrel.*
Energy Gas	A	**Gas Production** (Mtoe/Year) = Gas Production Rate **Description:** *Total gas energy production per year. Source of historical data: International Energy Agency Key World Energy Statistics 2007; BP Statistical Review of World Energy June 2008* **Used by:** • C Emission from Gas Energy - Total carbon emission from gas energy production and it use. • Energy Production - Total energy production per year. • Change in Average Gas Production - Change in Average Gas Production. • Identified Gas Resources - Gas Resources discovered thanks to developments in exploration technology. • Gas Shortage - Difference between demand and the gas production rate. • Cumulative Gas Production - Cumulative Gas resources that has been produced.

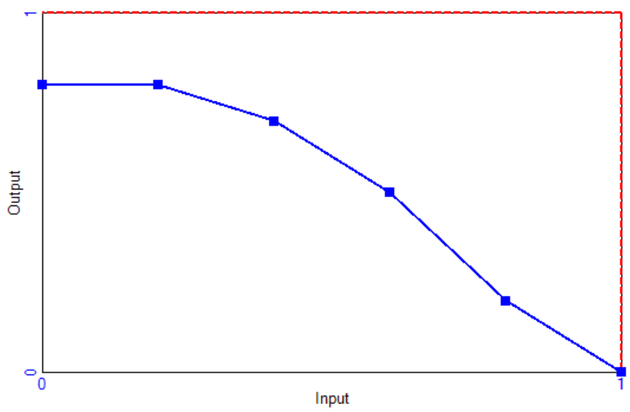
		• Desired Gas Exploration Rate - Desired Gas exploration rate due to Total Gas Demand and Identified Gas Resources safety coverage.
Energy Gas	A	**Gas Production Coverage** (Year) = Identified Gas Resources/Average Gas Production **Description:** *Ratio indicating gas coverage in years for discovered resources and at the current average gas production.* **Used by:** • Change in Gas Productivity of Investment - Change in Gas Productivity of Investment.
Energy Gas	A	**Gas Production Rate** (Mtoe/Year) = MIN(Total Gas Demand,Potential Gas Production) **Description:** *Total gas energy production per year due to available resources, developments in production technology and gas energy demand.* **Used by:** • Gas Production - Total gas energy production per year. Source of historical data: International Energy Agency Key World Energy Statistics 2007; BP Statistical Review of World Energy June 2008
Energy Gas	S	**Gas Productivity of Investment** (toe/$) = 0.0205941 + ∫ (Change in Gas Productivity of Investment) **Description:** *Factor indicating productivity of investments in gas production.* **Used by:** • Change in Gas Productivity of Investment - Change in Gas Productivity of Investment. • Productivity of Investment in Gas Production - Parameter indicating the amount of gas resources possible to be recovered per unit investment spent.
Energy Gas	C	**Gas Recovery Technology Development Time** (Year) = 6 **Description:** *Average time required to turn investments into concrete gas recovery developments.* **Used by:** • Increase in Ratio of Gas Fraction Recoverable to Unrecoverable - Increase in Ratio of Gas Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Gas	A	**Gas Revenue** ($/Year) = Gas Price*Average Gas Production **Description:** *Total revenue in gas market.* **Used by:** • Investment in Gas Technology - Investments in development of gas exploration and production technology.
Energy Gas	A	**Gas Shortage** (Mtoe/Year) = Total Gas Demand-Gas Production **Description:** *Difference between demand and the gas production rate.*
Energy Gas	S	**Identified Gas Resources** (Mtoe) = **Description:** *Gas Resources discovered thanks to developments in exploration technology.* **Used by:** • Adjustment for Identified Gas Resource - Adjustment of Identified Gas Resource to the desired level over a specified adjustment time. • Required Identified Gas Resources - The desired Identified Gas Resources level sought by the gas sector. • Cumulative Additions to Gas Production - Identified and already produced gas resources. • Gas Production Coverage - Ratio indicating gas coverage in years for discovered resources and at the current average gas production.
Energy Gas	C	**Identified Gas Resources Adjustment Time** (Year) = 5 **Description:** *Time to adjust Identified Gas Resource to the desired level.* **Used by:** • Adjustment for Identified Gas Resource - Adjustment of Identified Gas Resource to

		the desired level over a specified adjustment time.
Energy Gas	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) **Description:** *Increase in Ratio of Gas Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.* **Used by:** • Ratio of Gas Fraction Discoverable to Undiscoverable - Ratio of Gas Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.
Energy Gas	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) **Description:** *Increase in Ratio of Gas Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.* **Used by:** • Ratio of Gas Fraction Recoverable to Unrecoverable - Ratio of Gas Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.
Energy Gas	A	**Indicated Gas Price** ($/Mtoe) = Gas Cost*(1+Desired Gas Gross Margin) **Description:** *Indicated gas price accounting for exploration and production cost and gross margin.* **Used by:** • Gas Price - Actual gas price accounting for indicated gas price and effect of demand and supply.
Energy Gas	C	**INIT CGPN** (Mtoe) = 0 **Description:** *Cumulative Oil resources for 1900.* **Used by:** • Cumulative Gas Production - Cumulative Gas resources that has been produced.
Energy Gas	C	**INIT RGDU** (Dmnl) = 0 **Description:** *Initial Ratio of Gas Fraction Discoverable to Undiscoverable.* **Used by:** • Ratio of Gas Fraction Discoverable to Undiscoverable - Ratio of Gas Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.
Energy Gas	C	**INIT RGRU** (Dmnl) = 0 **Description:** *Initial Ratio of Gas Fraction Recoverable to Unrecoverable.* **Used by:** • Ratio of Gas Fraction Recoverable to Unrecoverable - Ratio of Gas Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.
Energy Gas	C	**INIT UGRN** (Mtoe) = 325000 **Description:** *Initial amount of Undiscovered Gas Resources.* **Used by:** • Effect of Technology on Gas Discoveries - Impact of technology development on gas exploration taking into account remaining undiscovered gas resources (the less remaining undiscovered gas resources the more expensive it is to discover them). • Undiscovered Gas Resources - Existing Gas Resources but not discovered yet.
Energy Gas	A	**Investment in Gas Discovery Technology** ($/Year) = Investment in Gas Technology*Fraction Invested in Gas Discovery Technology **Description:** *Total investments in gas exploration technology.* **Used by:** • Increase in Ratio of Gas Fraction Discoverable to Undiscoverable - Increase in Ratio of Gas Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.

Energy Gas	A	**Investment in Gas Exploration** ($/Year) = Desired Investment in Gas Exploration **Description:** *Amount of resources dedicated to gas exploration.* **Used by:** • Net Energy Capital Change - Capital change from energy sector. • Change in Effective Investment in Gas Exploration - Change in Effective Investment in Gas Exploration.
Energy Gas	C	**Investment in Gas Exploration Delay** (Year) = 5 **Description:** *Time delay to make investments in gas exploration effective.* **Used by:** • Change in Effective Investment in Gas Exploration - Change in Effective Investment in Gas Exploration.
Energy Gas	A	**Investment in Gas Production** ($/Year) = Desired Investment in Gas Production **Description:** *Amount of resources dedicated to gas production.* **Used by:** • Net Energy Capital Change - Capital change from energy sector. • Change in Effective Investment in Gas Production - Change in Effective Investment in Gas Production.
Energy Gas	C	**Investment in Gas Production Delay** (Year) = 5 **Description:** *Time delay to make investments in gas production effective.* **Used by:** • Change in Effective Investment in Gas Production - Change in Effective Investment in Gas Production.
Energy Gas	A	**Investment in Gas Recovery Technology** ($/Year) = Investment in Gas Technology*(1-Fraction Invested in Gas Discovery Technology) **Description:** *Total investments in gas production technology.* **Used by:** • Increase in Ratio of Gas Fraction Recoverable to Unrecoverable - Increase in Ratio of Gas Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Gas	A	**Investment in Gas Technology** ($/Year) = Fraction of Gas Revenues Invested in Technology*Gas Revenue **Description:** *Investments in development of gas exploration and production technology.* **Used by:** • Net Energy Capital Change - Capital change from energy sector. • Investment in Gas Discovery Technology - Total investments in gas exploration technology. • Investment in Gas Recovery Technology - Total investments in gas production technology.
Energy Gas	C	**Max Unit Cost of Gas Exploration** ($/Mtoe) = 1e+009 **Description:** *Upper level limit for unit cost of gas exploration.*
Energy Gas	C	**MAXGFD** (Dmnl) = 1 **Description:** *Maximal possible percentage of gas resources to be discovered.* **Used by:** • Gas Technology - Factor productivity in Gas energy sector. • Gas Fraction Discoverable - Percentage of gas resources that can be still explored due to current state of discovery technology.
Energy Gas	C	**MAXGFR** (Dmnl) = 1 **Description:** *Maximal possible percentage of gas resources to be recovered.* **Used by:** • Gas Technology - Factor productivity in Gas energy sector. • Gas Fraction Recoverable - Percentage of gas resources that can be produced due

		to current state of recovery technology.
Energy Gas	C	**MINGFD** (Dmnl) = 0.02 **Description:** *Initial and minimal possible percentage of gas resources to be discovered.* **Used by:** • Gas Fraction Discoverable - Percentage of gas resources that can be still explored due to current state of discovery technology.
Energy Gas	C	**MINGFR** (Dmnl) = 0.008 **Description:** *Initial and minimal possible percentage of gas resources to be recovered.* **Used by:** • Gas Fraction Recoverable - Percentage of gas resources that can be produced due to current state of recovery technology.
Energy Gas	C	**Mtoe per Btu** (Mtoe/MBtu) = 2.5e-008 **Description:** *Coefficient to convert million tons of oil equivalent unit (Mtoe) into British thermal unit (Btu).* **Used by:** • Gas Price per MBtu - Actual Gas Price per Barrel.
Energy Gas	SI,C	**Normal Gas Production Ratio** (Year) = 5 **Description:** *Safety stock coverage as a number of years of the total gas demand the gas sector would like to maintain in identified gas resources. It secures the market against possibility of unforeseen variations in demand. It is also a stimulus for gas exploration.* **Used by:** • Identified Gas Resources - Gas Resources discovered thanks to developments in exploration technology. • Required Identified Gas Resources - The desired Identified Gas Resources level sought by the gas sector. • Potential Gas Production from Resources - Potential Gas Production rate due to Total Oil Recoverable Resource Remaining adjusted by oil production safety coverage.
Energy Gas	A	**Potential Gas Exploration** (Mtoe/Year) = Effective Investment in Gas Exploration*Productivity of Investment in Gas Exploration/toe per Mtoe **Description:** *Potential Gas exploration due to available investments in gas resources discovery.* **Used by:** • Gas Exploration Rate - Gas Exploration Rate accounting for potential and desired gas exploration rates.
Energy Gas	A	**Potential Gas Production** (Mtoe/Year) = MIN(Potential Gas Production from Investment,Potential Gas Production from Resources) **Description:** *Potential Gas Production due to available investments in gas resources recovery and recovery technology.* **Used by:** • Effect of Gas Demand and Supply on Price - Effect of Gas Demand and Supply ratio on actual gas price. • Gas Demand to Supply Ratio - Gas Demand to Supply Ratio. • Gas Production Rate - Total gas energy production per year due to available resources, developments in production technology and gas energy demand.
Energy Gas	A	**Potential Gas Production from Investment** (Mtoe/Year) = Productivity of Investment in Gas Production*Effective Investment in Gas Production/toe per Mtoe **Description:** *Potential Gas Production due to available investments in gas resources recovery.* **Used by:** • Potential Gas Production - Potential Gas Production due to available investments in gas resources recovery and recovery technology.
Energy Gas	A	**Potential Gas Production from Resources** (Mtoe/Year) = Total Gas Recoverable Resource Remaining/Normal Gas Production Ratio

		Description: *Potential Gas Production rate due to Total Oil Recoverable Resource Remaining adjusted by oil production safety coverage.* **Used by:** • Desired Investment in Gas Production - Desired Investment in Gas Production due to Total Gas Demand and Productivity of Investment in Gas Production. • Potential Gas Production - Potential Gas Production due to available investments in gas resources recovery and recovery technology.
Energy Gas	A	**Productivity of Investment in Gas Exploration** (toe/$) = MAX(0,Relative Productivity of Investment in Gas Exploration*Effect of Technology on Gas Discoveries) **Description:** *Parameter indicating the amount of gas resources possible to be explored per unit investment spent.* **Used by:** • Potential Gas Exploration - Potential Gas exploration due to available investments in gas resources discovery. • Change in Gas Productivity of Investment - Change in Gas Productivity of Investment.
Energy Gas	A	**Productivity of Investment in Gas Production** (toe/$) = Relative Productivity of Investment in Gas Production to Exploration*Gas Productivity of Investment **Description:** *Parameter indicating the amount of gas resources possible to be recovered per unit investment spent.* **Used by:** • Unit Cost of Gas Production - Unit cost of gas production. • Desired Investment in Gas Production - Desired Investment in Gas Production due to Total Gas Demand and Productivity of Investment in Gas Production. • Potential Gas Production from Investment - Potential Gas Production due to available investments in gas resources recovery.
Energy Gas	S	**Ratio of Gas Fraction Discoverable to Undiscoverable** (Dmnl) = INIT RGDU + ∫ (Increase in Ratio of Gas Fraction Discoverable to Undiscoverable) **Description:** *Ratio of Gas Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.* **Used by:** • Gas Fraction Discoverable - Percentage of gas resources that can be still explored due to current state of discovery technology.
Energy Gas	S	**Ratio of Gas Fraction Recoverable to Unrecoverable** (Dmnl) = INIT RGRU + ∫ (Increase in Ratio of Gas Fraction Recoverable to Unrecoverable) **Description:** *Ratio of Gas Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.* **Used by:** • Gas Fraction Recoverable - Percentage of gas resources that can be produced due to current state of recovery technology.
Energy Gas	C	**Relative Productivity of Investment in Gas Exploration** (toe/$) = 1.25 **Description:** *Relative Productivity of Investment in Gas Exploration without taking into account remaining undiscovered gas resources and advances in exploration technologies.* **Used by:** • Productivity of Investment in Gas Exploration - Parameter indicating the amount of gas resources possible to be explored per unit investment spent.
Energy Gas	C	**Relative Productivity of Investment in Gas Production to Exploration** (Dmnl) = 10 **Description:** *Relative Productivity of Investment in Gas Production as a multiplier of Productivity of Investment in Gas Exploration.* **Used by:** • Productivity of Investment in Gas Production - Parameter indicating the amount of gas resources possible to be recovered per unit investment spent.
Energy Gas	A	**Required Identified Gas Resources** (Mtoe) = (Identified Gas Resources/Total Gas Recoverable Resource Remaining)*(Normal Gas Production Ratio*Total Gas Demand) **Description:** *The desired Identified Gas Resources level sought by the gas sector.*

		Used by: • Adjustment for Identified Gas Resource - Adjustment of Identified Gas Resource to the desired level over a specified adjustment time.
Energy Gas	C	**Sensitivity of Gas Price to Supply and Demand** (Dmnl) = 2 **Description:** *Sensitivity of Gas Price to Supply and Demand ratio.* **Used by:** • Effect of Gas Demand and Supply on Price - Effect of Gas Demand and Supply ratio on actual gas price.
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) **Description:** *Table determining order by which technology investments are dedicated to gas exploration and production technologies. For small Gas Fraction Discoverable, in order to make sufficient resources available to be produced, more investments are directed to exploration technologies. Once the Gas Fraction Discoverable increases the investments are redirected to production technologies.* **Used by:** • Fraction Invested in Gas Discovery Technology - Fraction of investments in gas technology dedicated to discovery technology. 
Energy Gas	C	**Time to Average Gas Production** (Year) = 1 **Description:** *Time to average total gas production per year.* **Used by:** • Change in Average Gas Production - Change in Average Gas Production.
Energy Gas	SI,A	**Total Gas Demand** (Mtoe/Year) = Energy Demand*Market Share Gas **Description:** *Total demand for gas resources.* **Used by:** • Desired Investment in Gas Production - Desired Investment in Gas Production due to Total Gas Demand and Productivity of Investment in Gas Production. • Identified Gas Resources - Gas Resources discovered thanks to developments in exploration technology. • Effect of Gas Demand and Supply on Price - Effect of Gas Demand and Supply ratio on actual gas price. • Required Identified Gas Resources - The desired Identified Gas Resources level sought by the gas sector. • Gas Shortage - Difference between demand and the gas production rate. • Gas Demand to Supply Ratio - Gas Demand to Supply Ratio. • Gas Production Rate - Total gas energy production per year due to available resources, developments in production technology and gas energy demand.
Energy Gas	A	**Total Gas Discoverable Resources** (Mtoe) = Total Gas Resources*Gas Fraction Discoverable-Cumulative Additions to Gas Production **Description:** *Total Gas Discoverable Resources as a percentage of Total Gas Resources. It excludes identified and already produced resources. The percentage is determined by*

		exploration technology developments. **Used by:** • Effect of Technology on Gas Discoveries - Impact of technology development on gas exploration taking into account remaining undiscovered gas resources (the less remaining undiscovered gas resources the more expensive it is to discover them).
Energy Gas	A	**Total Gas Recoverable Resource Remaining** (Mtoe) = Cumulative Additions to Gas Production*Gas Fraction Recoverable-Cumulative Gas Production **Description:** *Total Gas Recoverable Resources Remaining as a percentage of Cumulative Additions to Gas Production. It excludes already produced resources. The percentage is determined by production technology developments.* **Used by:** • Required Identified Gas Resources - The desired Identified Gas Resources level sought by the gas sector. • Potential Gas Production from Resources - Potential Gas Production rate due to Total Oil Recoverable Resource Remaining adjusted by oil production safety coverage.
Energy Gas	A	**Total Gas Resources** (Mtoe) = Undiscovered Gas Resources+Cumulative Additions to Gas Production **Description:** *Total gas resources including Undiscovered Gas Resources, Identified Gas Resources and resources already produced i.e. Cumulative Gas Production.* **Used by:** • Total Gas Discoverable Resources - Total Gas Discoverable Resources as a percentage of Total Gas Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.
Energy Gas	S	**Undiscovered Gas Resources** (Mtoe) = INIT UGRN + ∫ (-Gas Exploration) **Description:** *Existing Gas Resources but not discovered yet.* **Used by:** • Total Gas Resources - Total gas resources including Undiscovered Gas Resources, Identified Gas Resources and resources already produced i.e. Cumulative Gas Production.
Energy Gas	A	**Unit Cost of Gas Production** ($/Mtoe) = 1/Productivity of Investment in Gas Production*toe per Mtoe **Description:** *Unit cost of gas production.* **Used by:** • Gas Cost - Cost of unit gas resources as a sum of unit exploration and production costs.
Energy Oil	A	**Adjustment for Identified Oil Resource** (Mtoe/Year) = (Required Identified Oil Resources-Identified Oil Resources)/Identified Oil Resources Adjustment Time **Description:** *Adjustment of Identified Oil Resource to the desired level over a specified adjustment time.* **Used by:** • Desired Oil Exploration Rate - Desired Oil exploration rate due to Total Oil Demand and Identified Oil Resources safety coverage.
Energy Oil	S	**Average Oil Production** (Mtoe/Year) = 6.537 + ∫ (Change in Average Oil Production) **Description:** *Average total oil production per year.* **Used by:** • Change in Average Oil Production - Change in Average Oil Production. • Oil Production Coverage - Ratio indicating oil coverage in years for discovered resources and at the current average oil production. • Oil Revenue - Total revenue in oil market.
Energy Oil	A	**Change in Average Oil Production** (Mtoe/(Year*Year)) = (Oil Production-Average Oil Production)/Time to Average Oil Production **Description:** *Change in Average Oil Production.* **Used by:** • Average Oil Production - Average total oil production per year.
Energy Oil	A	**Change in Effective Investment in Oil Exploration** ($/(Year*Year))

		= (Investment in Oil Exploration-Effective Investment in Oil Exploration)/Investment in Oil Exploration Delay **Description:** *Change in Effective Investment in Oil Exploration.* **Used by:** • Effective Investment in Oil Exploration - Effective investments dedicated for oil resources exploration.
Energy Oil	A	**Change in Effective Investment in Oil Production** ($/(Year*Year)) = (Investment in Oil Production-Effective Investment in Oil Production)/Investment in Oil Production Delay **Description:** *Change in Effective Investment in Oil Production.* **Used by:** • Effective Investment in Oil Production - Effective investments dedicated for oil resources production.
Energy Oil	A	**Change in Oil Productivity of Investment** (toe/(Year*$)) = (Productivity of Investment in Oil Exploration-Oil Productivity of Investment)/Oil Production Coverage **Description:** *Change in Oil Productivity of Investment.* **Used by:** • Oil Productivity of Investment - Factor indicating productivity of investments in oil production.
Energy Oil	A	**Cumulative Additions to Oil Production** (Mtoe) = Identified Oil Resources+Cumulative Oil Production **Description:** *Identified and already produced resources.* **Used by:** • Total Oil Recoverable Resource Remaining - Total Oil Recoverable Resources Remaining as a percentage of Cumulative Additions to Oil Production. It already produced resources. The percentage is determined by production technology developments. • Total Oil Resources - Total oil resources including Undiscovered Oil Resources, Identified Oil Resources and resources already produced i.e. Cumulative Oil Production. • Total Oil Discoverable Resources - Total Oil Discoverable Resources as a percentage of Total Oil Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.
Energy Oil	S,SI	**Cumulative Oil Production** (Mtoe) = INIT COPN + ∫ (Oil Production) **Description:** *Cumulative Oil Resources that has been produced.* **Used by:** • Identified Oil Resources - Oil Resources discovered thanks to developments in exploration technology. • Total Oil Recoverable Resource Remaining - Total Oil Recoverable Resources Remaining as a percentage of Cumulative Additions to Oil Production. It already produced resources. The percentage is determined by production technology developments. • Cumulative Additions to Oil Production - Identified and already produced resources.
Energy Oil	A	**Desired Investment in Oil Exploration** ($/Year) = Desired Oil Exploration Rate*Unit Cost of Oil Exploration **Description:** *Desired amount of resources that need to be invested in order to secure desired oil exploration.* **Used by:** • Investment in Oil Exploration - Amount of resources dedicated to oil exploration.
Energy Oil	A	**Desired Oil Exploration Rate** (Mtoe/Year) = MAX(0,Adjustment for Identified Oil Resource+Oil Production) **Description:** *Desired Oil exploration rate due to Total Oil Demand and Identified Oil Resources safety coverage.* **Used by:** • Desired Investment in Oil Exploration - Desired amount of resources that need to be invested in order to secure desired oil exploration. • Oil Exploration Rate - Oil Exploration Rate accounting for potential and desired oil exploration rates.

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 **Description:** *Effect of Oil Demand and Supply ratio on actual oil price.* **Used by:** • Oil Price - Actual oil price accounting for indicated oil price and effect of demand and supply.
Energy Oil	A	**Effect of Technology on Oil Discoveries** (Dmnl) = Total Oil Discoverable Resources/INIT UORN **Description:** *Impact of technology development on oil exploration taking into account remaining undiscovered oil resources (the less remaining undiscovered oil resources the more expensive it to discover them).* **Used by:** • Productivity of Investment in Oil Exploration - Parameter indicating the amount of oil resources possible to be explored per unit investment spent.
Energy Oil	S	**Effective Investment in Oil Exploration** ($/Year) = 1.25068e+009 + ∫ (Change in Effective Investment in Oil Exploration) **Description:** *Effective investments dedicated for oil resources exploration.* **Used by:** • Potential Oil Exploration - Potential Oil exploration due to available investments in oil resources discovery. • Change in Effective Investment in Oil Exploration - Change in Effective Investment in Oil Exploration.
Energy Oil	S	**Effective Investment in Oil Production** ($/Year) = 1.25068e+008 + ∫ (Change in Effective Investment in Oil Production) **Description:** *Effective investments dedicated for oil resources production.* **Used by:** • Potential Oil Production from Investment - Potential Oil Production due to available investments in oil resources recovery. • Change in Effective Investment in Oil Production - Change in Effective Investment in Oil Production.
Energy Oil	C	**Effectiveness of Investment in Oil Discovery Technology** (1/$) = 4.48e-009 **Description:** *Effectiveness of resources dedicated to oil discovery technology development.* **Used by:** • Increase in Ratio of Oil Fraction Discoverable to Undiscoverable - Increase in Ratio of Oil Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Oil	C	**Effectiveness of Investment in Oil Recovery Technology** (1/$) = 2.8e-011 **Description:** *Effectiveness of resources dedicated to recovery technology development.* **Used by:** • Increase in Ratio of Oil Fraction Recoverable to Unrecoverable - Increase in Ratio of Oil Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Oil	A	**Fraction Invested in Oil Discovery Technology** (Dmnl) = Table for FIODT(Oil Fraction Discoverable) **Description:** *Fraction of investments in oil technology dedicated to discovery technology.* **Used by:** • Investment in Oil Discovery Technology - Total investments in oil exploration technology. • Investment in Oil Recovery Technology - Total investments in oil production technology.
Energy Oil	C	**Fraction of Oil Revenues Invested in Technology** (Dmnl) = 0.04 **Description:** *Percentage of total oil sector revenue dedicated to exploration and production technology development.* **Used by:** • Investment in Oil Technology - Investments in development of exploration and production technology.

Energy Oil	S	**Identified Oil Resources** (Mtoe) = **Description:** *Oil Resources discovered thanks to developments in exploration technology.* **Used by:** • Adjustment for Identified Oil Resource - Adjustment of Identified Oil Resource to the desired level over a specified adjustment time. • Cumulative Additions to Oil Production - Identified and already produced resources. • Required Identified Oil Resources - The desired Identified Oil Resources level sought by the oil sector. • Oil Production Coverage - Ratio indicating oil coverage in years for discovered resources and at the current average oil production.
Energy Oil	C	**Identified Oil Resources Adjustment Time** (Year) = 5 **Description:** *Time to adjust Identified Oil Resource to the desired level.* **Used by:** • Adjustment for Identified Oil Resource - Adjustment of Identified Oil Resource to the desired level over a specified adjustment time.
Energy Oil	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) **Description:** *Increase in Ratio of Oil Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.* **Used by:** • Ratio of Oil Fraction Discoverable to Undiscoverable - Ratio of Oil Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.
Energy Oil	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) **Description:** *Increase in Ratio of Oil Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.* **Used by:** • Ratio of Oil Fraction Recoverable to Unrecoverable - Ratio of Oil Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.
Energy Oil	A	**Indicated Oil Price** ($/Mtoe) = Oil Cost*(1+Oil Desired Gross Margin) **Description:** *Indicated oil price accounting for exploration and production cost and gross margin.* **Used by:** • Oil Price - Actual oil price accounting for indicated oil price and effect of demand and supply.
Energy Oil	C	**INIT COPN** (Mtoe) = 0 **Description:** *Cumulative Oil Resources for 1900.* **Used by:** • Cumulative Oil Production - Cumulative Oil Resources that has been produced.
Energy Oil	C	**INIT RODU** (Dmnl) = 0 **Description:** *Initial Ratio of Oil Fraction Discoverable to Undiscoverable.* **Used by:** • Ratio of Oil Fraction Discoverable to Undiscoverable - Ratio of Oil Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.
Energy Oil	C	**INIT RORU** (Dmnl) = 0 **Description:** *Initial Ratio of Oil Fraction Recoverable to Unrecoverable.* **Used by:** • Ratio of Oil Fraction Recoverable to Unrecoverable - Ratio of Oil Fraction Recoverable to Unrecoverable increased due to investments in recovery technology

		and their productivity.
Energy Oil	C	**INIT UORN** (Mtoe) = 375000 **Description:** *Initial amount of Undiscovered Oil Resources.* **Used by:** • Effect of Technology on Oil Discoveries - Impact of technology development on oil exploration taking into account remaining undiscovered oil resources (the less remaining undiscovered oil resources the more expensive it to discover them). • Undiscovered Oil Resources - Existing Oil Resources but not discovered yet.
Energy Oil	A	**Investment in Oil Discovery Technology** ($/Year) = Investment in Oil Technology*Fraction Invested in Oil Discovery Technology **Description:** *Total investments in oil exploration technology.* **Used by:** • Increase in Ratio of Oil Fraction Discoverable to Undiscoverable - Increase in Ratio of Oil Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Oil	A	**Investment in Oil Exploration** ($/Year) = Desired Investment in Oil Exploration **Description:** *Amount of resources dedicated to oil exploration.* **Used by:** • Net Energy Capital Change - Capital change from energy sector. • Change in Effective Investment in Oil Exploration - Change in Effective Investment in Oil Exploration.
Energy Oil	C	**Investment in Oil Exploration Delay** (Year) = 5 **Description:** *Time delay to make investments in oil exploration effective.* **Used by:** • Change in Effective Investment in Oil Exploration - Change in Effective Investment in Oil Exploration.
Energy Oil	A	**Investment in Oil Production** ($/Year) = Desired Investment in Oil Production **Description:** *Amount of resources dedicated to oil production.* **Used by:** • Net Energy Capital Change - Capital change from energy sector. • Change in Effective Investment in Oil Production - Change in Effective Investment in Oil Production.
Energy Oil	C	**Investment in Oil Production Delay** (Year) = 5 **Description:** *Time delay to make investments in oil production effective.* **Used by:** • Change in Effective Investment in Oil Production - Change in Effective Investment in Oil Production.
Energy Oil	A	**Investment in Oil Recovery Technology** ($/Year) = Investment in Oil Technology*(1-Fraction Invested in Oil Discovery Technology) **Description:** *Total investments in oil production technology.* **Used by:** • Increase in Ratio of Oil Fraction Recoverable to Unrecoverable - Increase in Ratio of Oil Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Oil	A	**Investment in Oil Technology** ($/Year) = Fraction of Oil Revenues Invested in Technology*Oil Revenue **Description:** *Investments in development of exploration and production technology.* **Used by:** • Net Energy Capital Change - Capital change from energy sector. • Investment in Oil Discovery Technology - Total investments in oil exploration technology. • Investment in Oil Recovery Technology - Total investments in oil production technology.

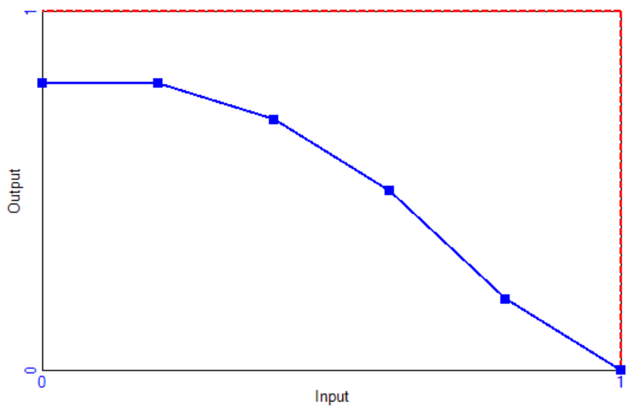
Energy Oil	C	**Max Unit Cost of Oil Exploration** ($/Mtoe) = 1e+009 **Description:** *Upper level limit for unit cost of oil exploration.*
Energy Oil	C	**MAXOFD** (Dmnl) = 1 **Description:** *Maximal possible percentage of oil resources to be discovered.* **Used by:** • Oil Technology - Factor productivity in Oil energy sector. • Oil Fraction Discoverable - Percentage of oil resources that can be still explored due to current state of discovery technology.
Energy Oil	C	**MAXOFR** (Dmnl) = 1 **Description:** *Maximal possible percentage of oil resources to be recovered.* **Used by:** • Oil Technology - Factor productivity in Oil energy sector. • Oil Fraction Recoverable - Percentage of oil resources that can be produced due to current state of recovery technology.
Energy Oil	C	**MINOFD** (Dmnl) = 0.02 **Description:** *Initial and minimal possible percentage of oil resources to be discovered.* **Used by:** • Oil Fraction Discoverable - Percentage of oil resources that can be still explored due to current state of discovery technology.
Energy Oil	C	**MINOFR** (Dmnl) = 0.1 **Description:** *Initial and minimal possible percentage of oil resources to be recovered.* **Used by:** • Oil Fraction Recoverable - Percentage of oil resources that can be produced due to current state of recovery technology.
Energy Oil	C	**Mtoe per Barrel** (Mtoe/Barrel) = 1.364e-007 **Description:** *Coefficient to convert million tons of oil equivalent unit (Mtoe) into barrels.* **Used by:** • Oil Price per Barrel - Actual Oil Price per Barrel.
Energy Oil	SI,C	**Normal Oil Production Ratio** (Year) = 5 **Description:** *Safety stock coverage as a number of years of the total oil demand the oil sector would like to maintain in identified oil resources. It secures the market against possibility of unforeseen variations in demand. It is also a stimulus for oil exploration.* **Used by:** • Identified Oil Resources - Oil Resources discovered thanks to developments in exploration technology. • Required Identified Oil Resources - The desired Identified Oil Resources level sought by the oil sector. • Potential Oil Production from Resources - Desired Oil Production rate due to Total Oil Recoverable Resource Remaining adjusted by oil production safety coverage.
Energy Oil	A	**Oil Cost** ($/Mtoe) = Unit Cost of Oil Exploration+Unit Cost of Oil Production **Description:** *Cont of unit oil resources as a sum of unit exploration and production costs.* **Used by:** • Indicated Oil Price - Indicated oil price accounting for exploration and production cost and gross margin. • Oil Gross Margin - Actual oil gross margin.
Energy Oil	A	**Oil Demand to Supply Ratio** (Dmnl) = Total Oil Demand/Potential Oil Production **Description:** *Oil Demand to Supply Ratio.*
Energy Oil	C	**Oil Desired Gross Margin** (Dmnl) = 0.2 **Description:** *Desired Gross Margin per unit oil resources.*

		Used by: • Indicated Oil Price - Indicated oil price accounting for exploration and production cost and gross margin.
Energy Oil	C	**Oil Discovery Technology Development Time** (Year) = 6 **Description:** *Average time required to turn investments into concrete oil discovery developments.* **Used by:** • Increase in Ratio of Oil Fraction Discoverable to Undiscoverable - Increase in Ratio of Oil Fraction Discoverable to Undiscoverable due to investments in discovery technology and their productivity.
Energy Oil	F,A	**Oil Exploration** (Mtoe/Year) = MAX(0,Oil Exploration Rate) **Description:** *Oil resources discovery rate.* **Used by:** • Identified Oil Resources - Oil Resources discovered thanks to developments in exploration technology. • Oil Cost - Cont of unit oil resources as a sum of unit exploration and production costs. • Desired Investment in Oil Exploration - Desired amount of resources that need to be invested in order to secure desired oil exploration. • Undiscovered Oil Resources - Existing Oil Resources but not discovered yet.
Energy Oil	A	**Oil Exploration Rate** (Mtoe/Year) = MIN(Desired Oil Exploration Rate,Potential Oil Exploration) **Description:** *Oil Exploration Rate accounting for potential and desired oil exploration rates.* **Used by:** • Oil Exploration - Oil resources discovery rate.
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)) **Description:** *Percentage of oil resources that can be still explored due to current state of discovery technology.* **Used by:** • Oil Technology - Factor productivity in Oil energy sector. • Total Oil Discoverable Resources - Total Oil Discoverable Resources as a percentage of Total Oil Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments. • Fraction Invested in Oil Discovery Technology - Fraction of investments in oil technology dedicated to discovery technology.
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)) **Description:** *Percentage of oil resources that can be produced due to current state of recovery technology.* **Used by:** • Oil Technology - Factor productivity in Oil energy sector. • Identified Oil Resources - Oil Resources discovered thanks to developments in exploration technology. • Total Oil Recoverable Resource Remaining - Total Oil Recoverable Resources Remaining as a percentage of Cumulative Additions to Oil Production. It already produced resources. The percentage is determined by production technology developments.
Energy Oil	A	**Oil Gross Margin** (Dmnl) = (Oil Price-Oil Cost)/Oil Cost **Description:** *Actual oil gross margin.*
Energy Oil	A	**Oil Price** ($/Mtoe) = Indicated Oil Price*Effect of Oil Demand and Supply on Price **Description:** *Actual oil price accounting for indicated oil price and effect of demand and supply.*

		Used by: • Oil Price toe - Actual oil price in dollars per toe. • Oil Price per Barrel - Actual Oil Price per Barrel. • Oil Gross Margin - Actual oil gross margin. • Oil Revenue - Total revenue in oil market.
Energy Oil	A	**Oil Price per Barrel** ($/Barrel) = Oil Price*Mtoe per Barrel **Description:** *Actual Oil Price per Barrel.*
Energy Oil	A	**Oil Production** (Mtoe/Year) = Oil Production Rate **Description:** *Total oil energy production per year. Source of historical data: International Energy Agency Key World Energy Statistics 2007; BP Statistical Review of World Energy June 2008* **Used by:** • C Emission from Oil Energy - Total carbon emission from oil production and it use. • Energy Production - Total energy production per year. • Change in Average Oil Production - Change in Average Oil Production. • Identified Oil Resources - Oil Resources discovered thanks to developments in exploration technology. • Cumulative Oil Production - Cumulative Oil Resources that has been produced. • Desired Oil Exploration Rate - Desired Oil exploration rate due to Total Oil Demand and Identified Oil Resources safety coverage. • Oil Shortage - Difference between demand and the oil production rate.
Energy Oil	A	**Oil Production Coverage** (Year) = Identified Oil Resources/Average Oil Production **Description:** *Ratio indicating oil coverage in years for discovered resources and at the current average oil production.* **Used by:** • Change in Oil Productivity of Investment - Change in Oil Productivity of Investment.
Energy Oil	A	**Oil Production Rate** (Mtoe/Year) = MIN(Total Oil Demand,Potential Oil Production) **Description:** *Total oil energy production per year due to available resources, developments in production technology and oil energy demand.* **Used by:** • Oil Production - Total oil energy production per year. Source of historical data: International Energy Agency Key World Energy Statistics 2007; BP Statistical Review of World Energy June 2008
Energy Oil	S	**Oil Productivity of Investment** (toe/$) = 0.0052 + ∫ (Change in Oil Productivity of Investment) **Description:** *Factor indicating productivity of investments in oil production.* **Used by:** • Productivity of Investment in Oil Production - Parameter indicating the amount of oil resources possible to be recovered per unit investment spent. • Change in Oil Productivity of Investment - Change in Oil Productivity of Investment.
Energy Oil	C	**Oil Recovery Technology Development Time** (Year) = 6 **Description:** *Average time required to turn investments into concrete oil recovery developments.* **Used by:** • Increase in Ratio of Oil Fraction Recoverable to Unrecoverable - Increase in Ratio of Oil Fraction Recoverable to Unrecoverable due to investments in recovery technology and their productivity.
Energy Oil	A	**Oil Revenue** ($/Year) = Oil Price*Average Oil Production **Description:** *Total revenue in oil market.* **Used by:** • Investment in Oil Technology - Investments in development of exploration and production technology.

Energy Oil	A	**Oil Shortage** (Mtoe/Year) = Total Oil Demand-Oil Production **Description:** *Difference between demand and the oil production rate.*
Energy Oil	A	**Potential Oil Exploration** (Mtoe/Year) = Effective Investment in Oil Exploration*Productivity of Investment in Oil Exploration/toe per Mtoe **Description:** *Potential Oil exploration due to available investments in oil resources discovery.* **Used by:** • Oil Exploration Rate - Oil Exploration Rate accounting for potential and desired oil exploration rates.
Energy Oil	A	**Potential Oil Production** (Mtoe/Year) = MIN(Potential Oil Production from Investment,Potential Oil Production from Resources) **Description:** *Potential Oil Production due to available investments in oil resources recovery and recovery technology.* **Used by:** • Effect of Oil Demand and Supply on Price - Effect of Oil Demand and Supply ratio on actual oil price. • Oil Demand to Supply Ratio - Oil Demand to Supply Ratio. • Oil Production Rate - Total oil energy production per year due to available resources, developments in production technology and oil energy demand.
Energy Oil	A	**Potential Oil Production from Investment** (Mtoe/Year) = Productivity of Investment in Oil Production*Effective Investment in Oil Production/toe per Mtoe **Description:** *Potential Oil Production due to available investments in oil resources recovery.* **Used by:** • Potential Oil Production - Potential Oil Production due to available investments in oil resources recovery and recovery technology.
Energy Oil	A	**Potential Oil Production from Resources** (Mtoe/Year) = Total Oil Recoverable Resource Remaining/Normal Oil Production Ratio **Description:** *Desired Oil Production rate due to Total Oil Recoverable Resource Remaining adjusted by oil production safety coverage.* **Used by:** • Desired Investment in Oil Production - Desired Investment in Oil Production due to Total Oil Demand and Productivity of Investment in Oil Production. • Potential Oil Production - Potential Oil Production due to available investments in oil resources recovery and recovery technology.
Energy Oil	A	**Productivity of Investment in Oil Exploration** (toe/$) = MAX(0,Relative Productivity of Investment in Oil Exploration*Effect of Technology on Oil Discoveries) **Description:** *Parameter indicating the amount of oil resources possible to be explored per unit investment spent.* **Used by:** • Potential Oil Exploration - Potential Oil exploration due to available investments in oil resources discovery. • Change in Oil Productivity of Investment - Change in Oil Productivity of Investment.
Energy Oil	A	**Productivity of Investment in Oil Production** (toe/$) = Relative Productivity of Investment in Oil Production Compared to Exploration*Oil Productivity of Investment **Description:** *Parameter indicating the amount of oil resources possible to be recovered per unit investment spent.* **Used by:** • Desired Investment in Oil Production - Desired Investment in Oil Production due to Total Oil Demand and Productivity of Investment in Oil Production. • Unit Cost of Oil Production - Unit cost of oil production. • Potential Oil Production from Investment - Potential Oil Production due to available investments in oil resources recovery.
Energy Oil	S	**Ratio of Oil Fraction Discoverable to Undiscoverable** (Dmnl) = INIT RODU + ∫ (Increase in Ratio of Oil Fraction Discoverable to Undiscoverable) **Description:** *Ratio of Oil Fraction Discoverable to Undiscoverable increased due to investments in discovery technology and their productivity.*

		Used by: • Oil Fraction Discoverable - Percentage of oil resources that can be still explored due to current state of discovery technology.
Energy Oil	S	**Ratio of Oil Fraction Recoverable to Unrecoverable** (Dmnl) = INIT RORU + ∫ (Increase in Ratio of Oil Fraction Recoverable to Unrecoverable) **Description:** *Ratio of Oil Fraction Recoverable to Unrecoverable increased due to investments in recovery technology and their productivity.* **Used by:** • Oil Fraction Recoverable - Percentage of oil resources that can be produced due to current state of recovery technology.
Energy Oil	C	**Relative Productivity of Investment in Oil Exploration** (toe/$) = 1 **Description:** *Relative Productivity of Investment in Oil Exploration without taking into account remaining undiscovered oil resources and advances in exploration technologies.* **Used by:** • Productivity of Investment in Oil Exploration - Parameter indicating the amount of oil resources possible to be explored per unit investment spent.
Energy Oil	C	**Relative Productivity of Investment in Oil Production Compared to Exploration** (Dmnl) = 10 **Description:** *Relative Productivity of Investment in Oil Production as a multiplier of Productivity of Investment in Oil Exploration.* **Used by:** • Productivity of Investment in Oil Production - Parameter indicating the amount of oil resources possible to be recovered per unit investment spent.
Energy Oil	A	**Required Identified Oil Resources** (Mtoe) = (Identified Oil Resources/Total Oil Recoverable Resource Remaining)*(Normal Oil Production Ratio*Total Oil Demand) **Description:** *The desired Identified Oil Resources level sought by the oil sector.* **Used by:** • Adjustment for Identified Oil Resource - Adjustment of Identified Oil Resource to the desired level over a specified adjustment time.
Energy Oil	C	**Sensitivity of Oil Price to Supply and Demand** (Dmnl) = 2 **Description:** *Sensitivity of Oil Price to Supply and Demand ratio.* **Used by:** • Effect of Oil Demand and Supply on Price - Effect of Oil Demand and Supply ratio on actual oil price.
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) **Description:** *Table determining order by which technology investments are dedicated to exploration and production technologies. For small Oil Fraction Discoverable, in order to make sufficient resources available to be produced, more investments are directed to exploration technologies. Once the Oil Fraction Discoverable increases the investments are redirected to production technologies.* **Used by:** • Fraction Invested in Oil Discovery Technology - Fraction of investments in oil technology dedicated to discovery technology.

		
Energy Oil	C	**Time to Average Oil Production** (Year) = 1 **Description:** *Time to average total oil production per year.* **Used by:** • Change in Average Oil Production - Change in Average Oil Production.
Energy Oil	C	**toe per Mtoe** (toe/Mtoe) = 1e+006 **Description:** *Conversion from Mtoe to toe.* **Used by:** • Unit Cost of Coal Production - Unit cost of coal production. ZIDZ(1, Productivity of Investment in Coal Production/Million toe per Mtoe) • Potential Coal Production from Investment - Potential Coal Production due to available investments in coal resources recovery. • Potential Coal Exploration - Potential Coal exploration due to available investments in coal resources discovery. • Desired Investment in Coal Production - Desired Investment in Coal Production due to Total Coal Demand and Productivity of Investment in Coal Production. • Desired Investment in Oil Production - Desired Investment in Oil Production due to Total Oil Demand and Productivity of Investment in Oil Production. • Wind Price toe - Actual wind energy price in dollars per toe. • Biomass Price toe - Actual biomass energy price in dollars per toe. • Coal Price toe - Actual coal price in dollars per toe. • Gas Price toe - Actual gas price in dollars per toe. • Oil Price toe - Actual oil price in dollars per toe. • Solar Price toe - Actual solar energy price in dollars per toe. • Unit Cost of Gas Production - Unit cost of gas production. • Potential Gas Exploration - Potential Gas exploration due to available investments in gas resources discovery. • Desired Investment in Gas Production - Desired Investment in Gas Production due to Total Gas Demand and Productivity of Investment in Gas Production. • Potential Gas Production from Investment - Potential Gas Production due to available investments in gas resources recovery. • Unit Cost of Oil Production - Unit cost of oil production. • Potential Oil Exploration - Potential Oil exploration due to available investments in oil resources discovery. • Potential Oil Production from Investment - Potential Oil Production due to available investments in oil resources recovery.
Energy Oil	SI,A	**Total Oil Demand** (Mtoe/Year) = Energy Demand*Market Share Oil **Description:** *Total demand for oil resources.* **Used by:** • Desired Investment in Oil Production - Desired Investment in Oil Production due to

		Total Oil Demand and Productivity of Investment in Oil Production. • Identified Oil Resources - Oil Resources discovered thanks to developments in exploration technology. • Effect of Oil Demand and Supply on Price - Effect of Oil Demand and Supply ratio on actual oil price. • Oil Demand to Supply Ratio - Oil Demand to Supply Ratio. • Required Identified Oil Resources - The desired Identified Oil Resources level sought by the oil sector. • Oil Production Rate - Total oil energy production per year due to available resources, developments in production technology and oil energy demand. • Oil Shortage - Difference between demand and the oil production rate.
Energy Oil	A	**Total Oil Discoverable Resources** (Mtoe) = Total Oil Resources*Oil Fraction Discoverable-Cumulative Additions to Oil Production **Description:** *Total Oil Discoverable Resources as a percentage of Total Oil Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.* **Used by:** • Effect of Technology on Oil Discoveries - Impact of technology development on oil exploration taking into account remaining undiscovered oil resources (the less remaining undiscovered oil resources the more expensive it to discover them).
Energy Oil	A	**Total Oil Recoverable Resource Remaining** (Mtoe) = Cumulative Additions to Oil Production*Oil Fraction Recoverable-Cumulative Oil Production **Description:** *Total Oil Recoverable Resources Remaining as a percentage of Cumulative Additions to Oil Production. It already produced resources. The percentage is determined by production technology developments.* **Used by:** • Required Identified Oil Resources - The desired Identified Oil Resources level sought by the oil sector. • Potential Oil Production from Resources - Desired Oil Production rate due to Total Oil Recoverable Resource Remaining adjusted by oil production safety coverage.
Energy Oil	A	**Total Oil Resources** (Mtoe) = Undiscovered Oil Resources+Cumulative Additions to Oil Production **Description:** *Total oil resources including Undiscovered Oil Resources, Identified Oil Resources and resources already produced i.e. Cumulative Oil Production.* **Used by:** • Total Oil Discoverable Resources - Total Oil Discoverable Resources as a percentage of Total Oil Resources. It excludes identified and already produced resources. The percentage is determined by exploration technology developments.
Energy Oil	S	**Undiscovered Oil Resources** (Mtoe) = INIT UORN + ∫ (-Oil Exploration) **Description:** *Existing Oil Resources but not discovered yet.* **Used by:** • Total Oil Resources - Total oil resources including Undiscovered Oil Resources, Identified Oil Resources and resources already produced i.e. Cumulative Oil Production.
Energy Oil	A	**Unit Cost of Oil Production** ($/Mtoe) = 1/Productivity of Investment in Oil Production*toe per Mtoe **Description:** *Unit cost of oil production.* **Used by:** • Oil Cost - Cont of unit oil resources as a sum of unit exploration and production costs.
Energy Solar	A	**Cost of Solar Energy** ($/Mtoe) = Unit Cost of Solar Capacity Installation+Unit Cost of Solar Energy Production **Description:** *Cost of solar energy production assuming an impact of learning curve.* **Used by:** • Indicated Solar Energy Price - Indicated solar energy price accounting for unit cost and gross margin.
Energy Solar	S	**Cumulative Solar Energy Produced** (Mtoe) = 0 + ∫ (Solar Energy Production)

		Description: *Cumulative solar energy that has been produced.*
Energy Solar	C	**Desired Solar Energy Gross Margin** (Dmnl) = 0.2 **Description:** *Desired Gross Margin per unit of solar energy.* **Used by:** • Indicated Solar Energy Price - Indicated solar energy price accounting for unit cost and gross margin.
Energy Solar	A	**Desired Solar Installed Capacity** (m*m) = Total Solar Demand/Efficiency of Solar Installed Capacity **Description:** *Desired Solar Installed Capacity accounting for Total Solar Demand and Efficiency of Solar Installed Capacity.* **Used by:** • Solar Infrastructure Adjustment - Adjustment of Solar Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
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 **Description:** *Effect of Solar Demand and Supply ratio on actual solar energy price.* **Used by:** • Solar Energy Price - Actual solar energy price accounting for indicated solar energy price and effect of demand and supply.
Energy Solar	C	**Effectiveness of Investment in Solar Energy Technology** (1/$) = 1e-009 **Description:** *Effectivenes of resources dedicated to solar conversion efficiency technology development.* **Used by:** • Increase in Solar Energy Technology Ratio - Increase in Solar Energy Technology Ratio due to investments in solar conversion efficiency technology and their productivity.
Energy Solar	C	**Effectiveness of Investment in Solar Installation Technology** (1/$) = 1e-010 **Description:** *Effectiveness of resources dedicated to solar energy capacity efficiency technology development.* **Used by:** • Increase in Solar Installation Technology Ratio - Increase in Solar Installation Technology Ratio due to investments in solar energy installation capacity.
Energy Solar	A	**Efficiency of Solar Installed Capacity** (Mtoe/(Year*m*m)) = Possible Solar Energy Production/Solar Installed Capacity **Description:** *Total production efficiency of Solar Installed Capacity for given weather conditions and technology developments.* **Used by:** • Investment in Solar Capacity - Amount of resources dedicated to solar energy capacity development. • Desired Solar Installed Capacity - Desired Solar Installed Capacity accounting for Total Solar Demand and Efficiency of Solar Installed Capacity.
Energy Solar	C	**Fraction for Solar Learning Curve Strength** (1) = 0.2 **Description:** *Fraction for Solar Learning Curve Strength indicating by what percentage the solar energy cost will drop for each doubling of solar installed capacity.* **Used by:** • Solar Learning Curve Strength - Strength of learning curve with which the solar energy costs are influenced.
Energy Solar	A	**Fraction Invested in Solar Energy Installation** (Dmnl) = Table for FISEI(Solar Installation Efficiency) **Description:** *Fraction of investments in solar energy technology dedicated to capacity.* **Used by:** • Investment in Solar Energy Efficiency - Total investments in solar conversion efficiency technology. • Investment in Solar Energy Installation - Total investments in solar energy capacity.

Energy Solar	A	**Fraction of Revenue Invested in Solar Technology** (Dmnl) = RAMP(Solar Investment Fraction Slope, Solar Investment Fraction Start , Solar Investment Fraction Finish) **Description:** *Parameter to take into account historical increase of the solar energy significance and over time greater resources dedicated to the technology development.* **Used by:** • Investment in Solar Energy Technology - Investments in development of solar conversion efficiency technology and production capability.
Energy Solar	A	**Impact of Learning on Solar Unit Cost of Technology PC** (1) = (Solar Installed Capacity/INIT SIC)^Solar Learning Curve Strength **Description:** *Impact of learning curve on solar energy cost.* **Used by:** • Unit Cost of Solar Capacity Installation - Unit Cost of Solar Capacity Installation. Determined by Productivity of Investment in Solar Capacity Installation.
Energy Solar	A	**Impact of Space on Capacity Installation** (Dmnl) = MAX(0,(1-Solar Installed Capacity/Solar Available Area)) **Description:** *Ratio of currently installed solar capacity to total possible.* **Used by:** • Productivity of Investment in Solar Capacity Installation - Productivity of solar capacity installation taking into account the level of available capacities and technology development state.
Energy Solar	A	**Increase in Solar Energy Technology Ratio** (1/Year) = DELAY3(Investment in Solar Energy Efficiency*Effectiveness of Investment in Solar Energy Technology, Solar Energy Technology Development Time) **Description:** *Increase in Solar Energy Technology Ratio due to investments in solar conversion efficiency technology and their productivity.* **Used by:** • Solar Energy Technology Ratio - Solar Energy Technology Ratio increased due to investments in solar conversion efficiency.
Energy Solar	A	**Increase in Solar Installation Technology Ratio** (1/Year) = DELAY3(Investment in Solar Energy Installation*Effectiveness of Investment in Solar Installation Technology, Solar Installation Technology Development Time) **Description:** *Increase in Solar Installation Technology Ratio due to investments in solar energy installation capacity.* **Used by:** • Solar Installation Technology Ratio - Solar Installation Technology Ratio increased due to investments in solar energy capacity installation efficiency.
Energy Solar	A	**Indicated Solar Energy Price** ($/Mtoe) = Cost of Solar Energy*(1+Desired Solar Energy Gross Margin) **Description:** *Indicated solar energy price accounting for unit cost and gross margin.* **Used by:** • Solar Energy Price - Actual solar energy price accounting for indicated solar energy price and effect of demand and supply.
Energy Solar	C	**INIT SETRN** (Dmnl) = 0 **Description:** *Initial Solar Energy Technology Ratio.* **Used by:** • Solar Energy Technology Ratio - Solar Energy Technology Ratio increased due to investments in solar conversion efficiency.
Energy Solar	C	**INIT SIC** (m*m) = 400 **Description:** *Initial installed capacity to transform sun radiation into energy.* **Used by:** • Impact of Learning on Solar Unit Cost of Technology PC - Impact of learning curve on solar energy cost. • Solar Installed Capacity - Installed capacity to transform solar radiation into energy.
Energy Solar	C	**INIT SITRN** (Dmnl) = 0 **Description:** *Initial Solar Installation Technology Ratio.* **Used by:**

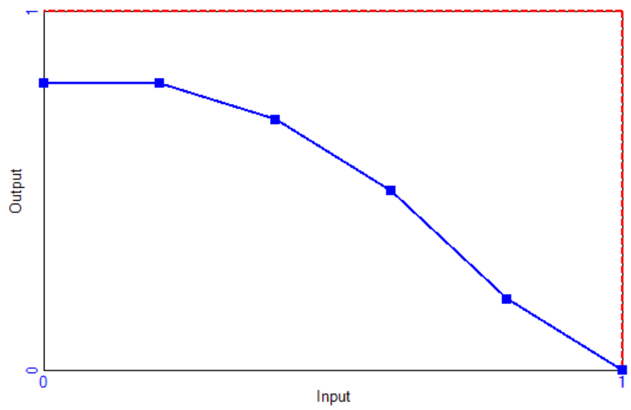
		• Solar Installation Technology Ratio - Solar Installation Technology Ratio increased due to investments in solar energy capacity installation efficiency.
Energy Solar	C	**INIT Unit Cost of Solar Capacity Installation** ($/Mtoe) = 2e+009 **Description:** *Initial unit cost per unit solar capacity installation.* **Used by:** • Unit Cost of Solar Capacity Installation - Unit Cost of Solar Capacity Installation. Determined by Productivity of Investment in Solar Capacity Installation.
Energy Solar	F,A	**Installation of Solar Capacity Rate** (m*m/Year) = Productivity of Investment in Solar Capacity Installation*Solar Infrastructure Adjustment **Description:** *Rate of new solar capacity installation.* **Used by:** • Investment in Solar Capacity - Amount of resources dedicated to solar energy capacity development. • Solar Installed Capacity - Installed capacity to transform solar radiation into energy.
Energy Solar	A	**Investment in Solar Capacity** ($/Year) = Installation of Solar Capacity Rate*Unit Cost of Solar Capacity Installation*Efficiency of Solar Installed Capacity*Solar Capacity Aging Time **Description:** *Amount of resources dedicated to solar energy capacity development.* **Used by:** • Net Energy Capital Change - Capital change from energy sector.
Energy Solar	A	**Investment in Solar Energy Efficiency** ($/Year) = Investment in Solar Energy Technology*(1-Fraction Invested in Solar Energy Installation) **Description:** *Total investments in solar conversion efficiency technology.* **Used by:** • Increase in Solar Energy Technology Ratio - Increase in Solar Energy Technology Ratio due to investments in solar conversion efficiency technology and their productivity.
Energy Solar	A	**Investment in Solar Energy Installation** ($/Year) = Investment in Solar Energy Technology*Fraction Invested in Solar Energy Installation **Description:** *Total investments in solar energy capacity.* **Used by:** • Increase in Solar Installation Technology Ratio - Increase in Solar Installation Technology Ratio due to investments in solar energy installation capacity.
Energy Solar	A	**Investment in Solar Energy Technology** ($/Year) = Fraction of Revenue Invested in Solar Technology*Solar Energy Revenue **Description:** *Investments in development of solar conversion efficiency technology and production capability.* **Used by:** • Investment in Solar Energy Efficiency - Total investments in solar conversion efficiency technology. • Investment in Solar Energy Installation - Total investments in solar energy capacity. • Net Energy Capital Change - Capital change from energy sector.
Energy Solar	A	**Max Power Point** (W) = Solar Conversion Efficiency*Standard Test Conditions*Solar Installed Capacity **Description:** *Max Power Point measured at Standard Test Conditions for installed solar energy production capacity and current solar conversion efficiency.* **Used by:** • Max Power Point GW - Solar Max Power Point measured in GW.
Energy Solar	A	**Max Power Point GW** (GW) = Max Power Point/W into GW **Description:** *Solar Max Power Point measured in GW.*
Energy Solar	C	**MAXSCE** (Dmnl) = 0.4 **Description:** *Maximal efficiency of solar radiation conversion.* **Used by:** • Solar Conversion Efficiency - Parameter indicating efficiency of solar radiation conversion at the current state of technical developments.

		• Solar Technology - Factor productivity in Solar energy sector.
Energy Solar	C	**MAXSIE** (Dmnl) = 1 **Description:** *Maximal value of Solar Installation Efficiency factor.* **Used by:** • Solar Installation Efficiency - Parameter indicating solar energy capacity installation efficiency at the current state of technical developments. • Solar Technology - Factor productivity in Solar energy sector.
Energy Solar	C	**MINSCE** (Dmnl) = 0.13 **Description:** *Minimal and initial efficiency of solar radiation conversion.* **Used by:** • Solar Conversion Efficiency - Parameter indicating efficiency of solar radiation conversion at the current state of technical developments.
Energy Solar	C	**MINSIE** (Dmnl) = 0.01 **Description:** *Minimal and initial value of Solar Installation Efficiency factor.* **Used by:** • Solar Installation Efficiency - Parameter indicating solar energy capacity installation efficiency at the current state of technical developments.
Energy Solar	A	**Possible Solar Energy Production** (Mtoe/Year) = Sun Radiation*Solar Installed Capacity*Time FL*Solar Conversion Efficiency*kWh into Mtoe **Description:** *Potential solar energy production per year due to available production capability, weather conditions and technical developments.* **Used by:** • Solar Energy Production Rate - Total solar energy production per year accounting for demand and potential production due to available production capability and technical developments. • Effect of Solar Energy Demand and Supply on Price - Effect of Solar Demand and Supply ratio on actual solar energy price. • Solar Energy Demand to Supply Ratio - Solar Energy Demand to Supply Ratio. • Efficiency of Solar Installed Capacity - Total production efficiency of Solar Installed Capacity for given weather conditions and technology developments.
Energy Solar	A	**Production to Installation Ratio** (Mtoe/(m*m*Year)) = Solar Energy Production/Solar Installed Capacity **Description:** *Ratio of solar energy production to available production capacity.* **Used by:** • Unit Cost of Solar Energy Production - Unit cost of solar capacity installation per energy unit.
Energy Solar	A	**Productivity of Investment in Solar Capacity Installation** (Dmnl) = Impact of Space on Capacity Installation*Solar Installation Efficiency **Description:** *Productivity of solar capacity installation taking into account the level of available capacities and technology development state.* **Used by:** • Installation of Solar Capacity Rate - Rate of new solar capacity installation.
Energy Solar	C	**Reference Cost of Solar Energy Production** ($/((m*m)*Year)) = 40 **Description:** *Reference cost of unit solar energy production per year.* **Used by:** • Unit Cost of Solar Energy Production - Unit cost of solar capacity installation per energy unit.
Energy Solar	C	**Sensitivity of Solar Energy Price to Supply and Demand** (Dmnl) = 0 **Description:** *Sensitivity of Solar Energy Price to Supply and Demand ratio.* **Used by:** • Effect of Solar Energy Demand and Supply on Price - Effect of Solar Demand and Supply ratio on actual solar energy price.
Energy Solar	C	**Solar Available Area** (m*m) = 5e+011

		Description: *Total area available for solar energy production capacities.* **Used by:** • Impact of Space on Capacity Installation - Ratio of currently installed solar capacity to total possible.
Energy Solar	A	**Solar Capacity Aging Rate** (m*m/Year) = Solar Installed Capacity/Solar Capacity Aging Time **Description:** *Aging rate of solar energy production capacities.* **Used by:** • Solar Infrastructure Adjustment - Adjustment of Solar Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process. • Solar Installed Capacity - Installed capacity to transform solar radiation into energy.
Energy Solar	A	**Solar Conversion Efficiency** (1) = MINSCE+(MAXSCE-MINSCE)*(Solar Energy Technology Ratio/(Solar Energy Technology Ratio+1)) **Description:** *Parameter indicating efficiency of solar radiation conversion at the current state of technical developments.* **Used by:** • Max Power Point - Max Power Point measured at Standard Test Conditions for installed solar energy production capacity and current solar conversion efficiency. • Possible Solar Energy Production - Potential solar energy production per year due to available production capability, weather conditions and technical developments. • Solar Technology - Factor productivity in Solar energy sector.
Energy Solar	A	**Solar Energy Demand to Supply Ratio** (Dmnl) = Total Solar Demand/Possible Solar Energy Production **Description:** *Solar Energy Demand to Supply Ratio.*
Energy Solar	A	**Solar Energy Price** ($/Mtoe) = Indicated Solar Energy Price*Effect of Solar Energy Demand and Supply on Price **Description:** *Actual solar energy price accounting for indicated solar energy price and effect of demand and supply.* **Used by:** • Solar Energy Price per kWh - Actual solar energy price accounting for indicated solar energy price and effect of demand and supply measured in dollars per kWh. • Solar Energy Revenue - Total revenue in solar energy market. • Solar Price toe - Actual solar energy price in dollars per toe.
Energy Solar	A	**Solar Energy Price per kWh** ($/(kW*Hour)) = Solar Energy Price*kWh into Mtoe **Description:** *Actual solar energy price accounting for indicated solar energy price and effect of demand and supply measured in dollars per kWh.*
Energy Solar	A	**Solar Energy Production** (Mtoe/Year) = Solar Energy Production Rate **Description:** *Total solar energy production per year.* **Used by:** • C Emission from Solar Energy - Total carbon emission from solar energy production and it use. • Production to Installation Ratio - Ratio of solar energy production to available production capacity. • Cumulative Solar Energy Produced - Cumulative solar energy that has been produced. • Solar Energy Revenue - Total revenue in solar energy market. • Energy Production - Total energy production per year.
Energy Solar	A	**Solar Energy Production Rate** (Mtoe/Year) = MIN(Possible Solar Energy Production,Total Solar Demand) **Description:** *Total solar energy production per year accounting for demand and potential production due to available production capability and technical developments.* **Used by:** • Solar Energy Production - Total solar energy production per year.
Energy Solar	A	**Solar Energy Revenue** ($/Year)

		= Solar Energy Production*Solar Energy Price **Description:** *Total revenue in solar energy market.* **Used by:** • Investment in Solar Energy Technology - Investments in development of solar conversion efficiency technology and production capability.
Energy Solar	C	**Solar Energy Technology Development Time** (Year) = 50 **Description:** *Average time required to turn investments into concrete solar conversion efficiency technology developments. Since the simulation starts in 1900 it is a significant time.* **Used by:** • Increase in Solar Energy Technology Ratio - Increase in Solar Energy Technology Ratio due to investments in solar conversion efficiency technology and their productivity.
Energy Solar	S	**Solar Energy Technology Ratio** (Dmnl) = INIT SETRN + ∫ (Increase in Solar Energy Technology Ratio) **Description:** *Solar Energy Technology Ratio increased due to investments in solar conversion efficiency.* **Used by:** • Solar Conversion Efficiency - Parameter indicating efficiency of solar radiation conversion at the current state of technical developments.
Energy Solar	C	**Solar Final Investment** (Dmnl) = 0.03 **Description:** *Eventual average level of investments in solar energy technology.* **Used by:** • Solar Investment Fraction Slope - Intensity of increase in investments in solar energy technology.
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 **Description:** *Adjustment of Solar Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.* **Used by:** • Installation of Solar Capacity Rate - Rate of new solar capacity installation.
Energy Solar	C	**Solar Initial Investment** (Dmnl) = 0 **Description:** *Initial level of fractional investments in solar energy technology.* **Used by:** • Solar Investment Fraction Slope - Intensity of increase in investments in solar energy technology.
Energy Solar	A	**Solar Installation Efficiency** (1) = MINSIE+(MAXSIE-MINSIE)*(Solar Installation Technology Ratio/(Solar Installation Technology Ratio+1)) **Description:** *Parameter indicating solar energy capacity installation efficiency at the current state of technical developments.* **Used by:** • Productivity of Investment in Solar Capacity Installation - Productivity of solar capacity installation taking into account the level of available capacities and technology development state. • Fraction Invested in Solar Energy Installation - Fraction of investments in solar energy technology dedicated to capacity. • Solar Technology - Factor productivity in Solar energy sector.
Energy Solar	C	**Solar Installation Technology Development Time** (Year) = 100 **Description:** *Average time required to turn investments into concrete solar energy production capacity. Since the simulation starts in 1900 it is a significant time.* **Used by:** • Increase in Solar Installation Technology Ratio - Increase in Solar Installation Technology Ratio due to investments in solar energy installation capacity.
Energy Solar	S	**Solar Installation Technology Ratio** (Dmnl) = INIT SITRN + ∫ (Increase in Solar Installation Technology Ratio)

		Description: *Solar Installation Technology Ratio increased due to investments in solar energy capacity installation efficiency.* **Used by:** • Solar Installation Efficiency - Parameter indicating solar energy capacity installation efficiency at the current state of technical developments.
Energy Solar	S	**Solar Installed Capacity** (m*m) = INIT SIC + ∫ (Installation of Solar Capacity Rate-Solar Capacity Aging Rate) **Description:** *Installed capacity to transform solar radiation into energy.* **Used by:** • Solar Infrastructure Adjustment - Adjustment of Solar Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process. • Impact of Space on Capacity Installation - Ratio of currently installed solar capacity to total possible. • Production to Installation Ratio - Ratio of solar energy production to available production capacity. • Impact of Learning on Solar Unit Cost of Technology PC - Impact of learning curve on solar energy cost. • Max Power Point - Max Power Point measured at Standard Test Conditions for installed solar energy production capacity and current solar conversion efficiency. • Possible Solar Energy Production - Potential solar energy production per year due to available production capability, weather conditions and technical developments. • Efficiency of Solar Installed Capacity - Total production efficiency of Solar Installed Capacity for given weather conditions and technology developments. • Solar Capacity Aging Rate - Aging rate of solar energy production capacities.
Energy Solar	I	**Solar Investment Fraction Finish** (Year) = INITIAL TIME+Ramp Investment Period **Description:** *End of fractional investments in solar energy technology.* **Used by:** • Fraction of Revenue Invested in Solar Technology - Parameter to take into account historical increase of the solar energy significance and over time greater resources dedicated to the technology development.
Energy Solar	A	**Solar Investment Fraction Slope** (1/Year) = ABS(Solar Final Investment-Solar Initial Investment)/Ramp Investment Period **Description:** *Intensity of increase in investments in solar energy technology.* **Used by:** • Fraction of Revenue Invested in Solar Technology - Parameter to take into account historical increase of the solar energy significance and over time greater resources dedicated to the technology development.
Energy Solar	I	**Solar Investment Fraction Start** (Year) = INITIAL TIME **Description:** *Start of investments in solar energy technology.* **Used by:** • Fraction of Revenue Invested in Solar Technology - Parameter to take into account historical increase of the solar energy significance and over time greater resources dedicated to the technology development.
Energy Solar	A	**Solar Learning Curve Strength** (1) = LN(1 - Fraction for Solar Learning Curve Strength)/LN(2) **Description:** *Strength of learning curve with which the solar energy costs are influenced.* **Used by:** • Impact of Learning on Solar Unit Cost of Technology PC - Impact of learning curve on solar energy cost.
Energy Solar	C	**Standard Test Conditions** (W/(m*m)) = 1000 **Description:** *Standard Test Conditions assuming irradiance of 1000 W/(m*m) to calculate Max Power Point.* **Used by:** • Max Power Point - Max Power Point measured at Standard Test Conditions for installed solar energy production capacity and current solar conversion efficiency.

Energy Solar	C	**Sun Radiation** (kW/(m*m)) = 0.5 **Description:** *Average sun radiation in kW per sqr meter.* **Used by:** • Possible Solar Energy Production - Potential solar energy production per year due to available production capability, weather conditions and technical developments.
Energy Solar	L	**Table for FISEI** (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) **Description:** *Table determining order by which technology investments are dedicated to energy and installation efficiency. For small Solar Installation Efficiency, in order to secure sufficient production capacity, more investments are directed to infrastructure. Once the Solar Installation Efficiency increases the investments are redirected to solar conversion efficiency technologies.* **Used by:** • Fraction Invested in Solar Energy Installation - Fraction of investments in solar energy technology dedicated to capacity. 
Energy Solar	A	**Time FL** (Hour/Year) = Weather Factor*Hours per Year **Description:** *Average time of sun availability.* **Used by:** • Possible Solar Energy Production - Potential solar energy production per year due to available production capability, weather conditions and technical developments.
Energy Solar	C	**Time to Adjust Solar Infrastructure** (Year) = 5 **Description:** *Time to adjust Solar Infrastructure to the desired level.* **Used by:** • Solar Infrastructure Adjustment - Adjustment of Solar Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Solar	A	**Total Solar Demand** (Mtoe/Year) = Energy Demand*Market Share Solar **Description:** *Total demand for solar energy.* **Used by:** • Total Solar Demand GW - Total demand for solar energy measured in GW. • Solar Energy Production Rate - Total solar energy production per year accounting for demand and potential production due to available production capability and technical developments. • Effect of Solar Energy Demand and Supply on Price - Effect of Solar Demand and Supply ratio on actual solar energy price. • Solar Energy Demand to Supply Ratio - Solar Energy Demand to Supply Ratio. • Desired Solar Installed Capacity - Desired Solar Installed Capacity accounting for Total Solar Demand and Efficiency of Solar Installed Capacity.
Energy Solar	A	**Total Solar Demand GW** (GW/Year) = Total Solar Demand/kWh into Mtoe peak hour/kW into GW

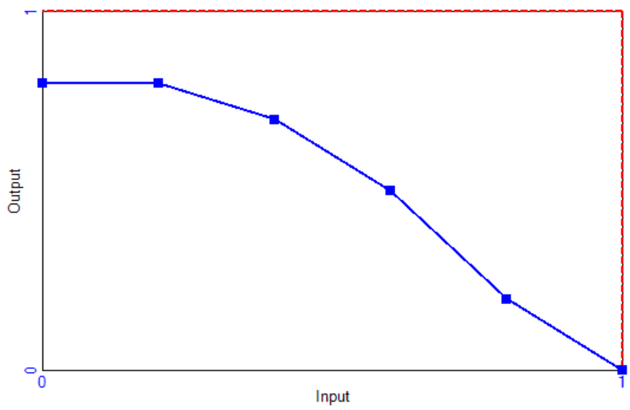
		Description: *Total demand for solar energy measured in GW.*
Energy Solar	A	**Unit Cost of Solar Capacity Installation** ($/Mtoe) = INIT Unit Cost of Solar Capacity Installation*Impact of Learning on Solar Unit Cost of Technology PC **Description:** *Unit Cost of Solar Capacity Installation. Determined by Productivity of Investment in Solar Capacity Installation.* **Used by:** • Investment in Solar Capacity - Amount of resources dedicated to solar energy capacity development. • Cost of Solar Energy - Cost of solar energy production assuming an impact of learning curve.
Energy Solar	A	**Unit Cost of Solar Energy Production** ($/Mtoe) = Reference Cost of Solar Energy Production/Production to Installation Ratio **Description:** *Unit cost of solar capacity installation per energy unit.* **Used by:** • Cost of Solar Energy - Cost of solar energy production assuming an impact of learning curve.
Energy Solar	C	**Weather Factor** (Dmnl) = 0.1 **Description:** *Percentage of total hours per year when solar energy can be produced.* **Used by:** • Time FL - Average time of sun availability.
Energy Wind	C	**Average Capacity per SqMeter** (kW/(m*m)) = 0.009 **Description:** *Average wind energy production from one sqr meter of wind installed capacity.* **Used by:** • Potential Wind Energy Production - Potential solar energy production per year due to available production capability and technical developments. • Max Wind Power Point - Max Power Point measured at Standard Test Conditions for installed wind energy production capacity and current wind conversion efficiency.
Energy Wind	A	**Cost of Wind Energy** ($/Mtoe) = Unit Cost of Wind Capacity Installation+Unit Cost of Wind Energy Production **Description:** *Cost of wind energy production assuming an impact of learning curve.* **Used by:** • Indicated Wind Energy Price - Indicated wind energy price accounting for unit cost and gross margin.
Energy Wind	S	**Cumulative Wind Energy Produced** (Mtoe) = 0 + ∫ (Wind Energy Production) **Description:** *Cumulative wind energy that has been produced.*
Energy Wind	C	**Desired Wind Energy Gross Margin** (Dmnl) = 0.2 **Description:** *Desired Gross Margin per unit of wind energy.* **Used by:** • Indicated Wind Energy Price - Indicated wind energy price accounting for unit cost and gross margin.
Energy Wind	A	**Desired Wind Installed Capacity** (m*m) = Total Wind Demand/Efficiency of Wind Installed Capacity **Description:** *Desired Wind Installed Capacity accounting for Total Wind Demand and Efficiency of Wind Installed Capacity.* **Used by:** • Wind Infrastructure Adjustment - Adjustment of Wind Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Wind	A	**Effect of Wind Energy Demand and Supply on Price** (Dmnl) = (Total Wind Demand/Potential Wind Energy Production)^Sensitivity of Wind Energy Price to Supply and Demand **Description:** *Effect of Wind Demand and Supply ratio on actual wind energy price.* **Used by:** • Wind Energy Price - Actual wind energy price accounting for indicated wind energy

		price and effect of demand and supply.
Energy Wind	C	**Effectiveness of Investment in Wind Energy Technology** (1/$) = 1e-009 **Description:** *Effectivenes of resources dedicated to wind conversion efficiency technology development.* **Used by:** • Increase in Wind Energy Technology Ratio - Increase in Wind Energy Technology Ratio due to investments in wind conversion efficiency technology and their productivity.
Energy Wind	C	**Effectiveness of Investment in Wind Installation Technology** (1/$) = 1e-010 **Description:** *Effectiveness of resources dedicated to wind energy capacity efficiency technology development.* **Used by:** • Increase in Wind Installation Technology Ratio - Increase in Wind Installation Technology Ratio due to investments in wind energy installation capacity.
Energy Wind	A	**Efficiency of Wind Installed Capacity** (Mtoe/(Year*m*m)) = ZIDZ(Potential Wind Energy Production,Wind Installed Capacity) **Description:** *Total production efficiency of Wind Installed Capacity for given technology developments.* **Used by:** • Investment in Wind Capacity - Amount of resources dedicated to wind energy capacity development. • Desired Wind Installed Capacity - Desired Wind Installed Capacity accounting for Total Wind Demand and Efficiency of Wind Installed Capacity.
Energy Wind	C	**Fraction for Wind Learning Curve Strength** (1) = 0.2 **Description:** *Fraction for Wind Learning Curve Strength indicating by what percentage the wind energy cost will drop for each doubling of wind installed capacity.* **Used by:** • Wind Learning Curve Strength - Strength of learning curve with which the wind energy costs are influenced.
Energy Wind	A	**Fraction Invested in Wind Energy Installation** (Dmnl) = Table for FIWEI(Wind Installation Efficiency) **Description:** *Fraction of investments in wind energy technology dedicated to capacity.* **Used by:** • Investment in Wind Energy Efficiency - Total investments in wind conversion efficiency technology. • Investment in Wind Energy Installation - Total investments in wind energy capacity.
Energy Wind	A	**Fraction of Revenue Invested in Wind Technology** (Dmnl) = RAMP(Wind Investment Fraction Slope, Wind Investment Fraction Start , Wind Investment Fraction Finish) **Description:** *Parameter to take into account historical increase of the wind energy significance and over time greater resources dedicated to the technology development.* **Used by:** • Investment in Wind Energy Technology - Investments in development of wind conversion efficiency technology and production capability.
Energy Wind	A	**Impact of Learning on Wind Unit Cost of Technology** (1) = (Wind Installed Capacity/INIT WIC)^Wind Learning Curve Strength **Description:** *Impact of learning curve on wind energy cost.* **Used by:** • Unit Cost of Wind Capacity Installation - Unit Cost of Wind Capacity Installation. Determined by Productivity of Investment in Wind Capacity Installation.
Energy Wind	A	**Impact of Space on Wind Capacity Installation** (1) = MAX(0,(1-Wind Installed Capacity/Wind Available Area)) **Description:** *Ratio of currently installed wind capacity to total possible.* **Used by:** • Productivity of Investment in Wind Capacity Installation - Productivity of wind capacity installation taking into account the level of remaining possible capacities and technology development state.

Energy Wind	A	**Increase in Wind Energy Technology Ratio** (1/Year) = DELAY3(Investment in Wind Energy Efficiency*Effectiveness of Investment in Wind Energy Technology, Wind Energy Technology Development Time) **Description:** *Increase in Wind Energy Technology Ratio due to investments in wind conversion efficiency technology and their productivity.* **Used by:** • Wind Energy Technology Ratio - Wind Energy Technology Ratio increased due to investments in wind conversion efficiency.
Energy Wind	A	**Increase in Wind Installation Technology Ratio** (1/Year) = DELAY3(Investment in Wind Energy Installation*Effectiveness of Investment in Wind Installation Technology, Wind Installation Technology Development Time) **Description:** *Increase in Wind Installation Technology Ratio due to investments in wind energy installation capacity.* **Used by:** • Wind Installation Technology Ratio - Wind Installation Technology Ratio increased due to investments in wind energy capacity installation efficiency.
Energy Wind	A	**Indicated Wind Energy Price** ($/Mtoe) = Cost of Wind Energy*(1+Desired Wind Energy Gross Margin) **Description:** *Indicated wind energy price accounting for unit cost and gross margin.* **Used by:** • Wind Energy Price - Actual wind energy price accounting for indicated wind energy price and effect of demand and supply.
Energy Wind	C	**INIT Unit Cost of Wind Capacity Installation** ($/Mtoe) = 2e+009 **Description:** *Initial unit cost per unit wind capacity installation.* **Used by:** • Unit Cost of Wind Capacity Installation - Unit Cost of Wind Capacity Installation. Determined by Productivity of Investment in Wind Capacity Installation.
Energy Wind	C	**INIT WETRN** (Dmnl) = 0 **Description:** *Initial Wind Energy Technology Ratio.* **Used by:** • Wind Energy Technology Ratio - Wind Energy Technology Ratio increased due to investments in wind conversion efficiency.
Energy Wind	C	**INIT WIC** (m*m) = 4000 **Description:** *Initial installed capacity to transform wind into energy.* **Used by:** • Impact of Learning on Wind Unit Cost of Technology - Impact of learning curve on wind energy cost. • Wind Installed Capacity - Installed capacity to transform wind into energy.
Energy Wind	C	**INIT WITRN** (Dmnl) = 0 **Description:** *Initial Wind Installation Technology Ratio.* **Used by:** • Wind Installation Technology Ratio - Wind Installation Technology Ratio increased due to investments in wind energy capacity installation efficiency.
Energy Wind	F,A	**Installation of Wind Capacity Rate** (m*m/Year) = Productivity of Investment in Wind Capacity Installation*Wind Infrastructure Adjustment **Description:** *Rate of new wind capacity installation.* **Used by:** • Investment in Wind Capacity - Amount of resources dedicated to wind energy capacity development. • Wind Installed Capacity - Installed capacity to transform wind into energy.
Energy Wind	A	**Investment in Wind Capacity** ($/Year) = Installation of Wind Capacity Rate*Unit Cost of Wind Capacity Installation*Efficiency of Wind Installed Capacity*Wind Aging Time **Description:** *Amount of resources dedicated to wind energy capacity development.* **Used by:**

		• Net Energy Capital Change - Capital change from energy sector.
Energy Wind	A	**Investment in Wind Energy Efficiency** ($/Year) = Investment in Wind Energy Technology*(1-Fraction Invested in Wind Energy Installation) **Description:** *Total investments in wind conversion efficiency technology.* **Used by:** • Increase in Wind Energy Technology Ratio - Increase in Wind Energy Technology Ratio due to investments in wind conversion efficiency technology and their productivity.
Energy Wind	A	**Investment in Wind Energy Installation** ($/Year) = Investment in Wind Energy Technology*Fraction Invested in Wind Energy Installation **Description:** *Total investments in wind energy capacity.* **Used by:** • Increase in Wind Installation Technology Ratio - Increase in Wind Installation Technology Ratio due to investments in wind energy installation capacity.
Energy Wind	A	**Investment in Wind Energy Technology** ($/Year) = Fraction of Revenue Invested in Wind Technology*Wind Energy Revenue **Description:** *Investments in development of wind conversion efficiency technology and production capability.* **Used by:** • Investment in Wind Energy Efficiency - Total investments in wind conversion efficiency technology. • Investment in Wind Energy Installation - Total investments in wind energy capacity. • Net Energy Capital Change - Capital change from energy sector.
Energy Wind	A	**Max Wind Power Point** (kW) = Wind Installed Capacity*Average Capacity per SqMeter*Wind Capacity Factor **Description:** *Max Power Point measured at Standard Test Conditions for installed wind energy production capacity and current wind conversion efficiency.* **Used by:** • Max Wind Power Point TW - Wind Max Power Point measured in TW. • Max Wind Power Point GW - Wind Max Power Point measured in GW.
Energy Wind	A	**Max Wind Power Point GW** (GW) = Max Wind Power Point/kW into GW **Description:** *Wind Max Power Point measured in GW.*
Energy Wind	A	**Max Wind Power Point TW** (TW) = Max Wind Power Point/kW into TW **Description:** *Wind Max Power Point measured in TW.*
Energy Wind	C	**MAXWCF** (Dmnl) = 0.5 **Description:** *Maximal wind capacity factor.* **Used by:** • Wind Capacity Factor - Parameter indicating what fraction of average wind capacity per sqr meter it is possible to realize with the current state of technical developments. • Wind Technology - Factor productivity in Wind energy sector.
Energy Wind	C	**MAXWIE** (Dmnl) = 1 **Description:** *Maximal value of Wind Installation Efficiency factor.* **Used by:** • Wind Installation Efficiency - Parameter indicating wind energy capacity installation efficiency at the current state of technical developments. • Wind Technology - Factor productivity in Wind energy sector.
Energy Wind	C	**MINWCF** (Dmnl) = 0.2 **Description:** *Minimal and initial wind capacity factor.* **Used by:** • Wind Capacity Factor - Parameter indicating what fraction of average wind capacity per sqr meter it is possible to realize with the current state of technical developments.
Energy Wind	C	**MINWIE** (Dmnl) = 0.01

		Description: *Minimal and initial value of Wind Installation Efficiency factor.* **Used by:** • Wind Installation Efficiency - Parameter indicating wind energy capacity installation efficiency at the current state of technical developments.
Energy Wind	A	**Potential Wind Energy Production** (Mtoe/Year) = Wind Installed Capacity*Average Capacity per SqMeter*Wind Capacity Factor*Hours per Year*kWh into Mtoe **Description:** *Potential solar energy production per year due to available production capability and technical developments.* **Used by:** • Effect of Wind Energy Demand and Supply on Price - Effect of Wind Demand and Supply ratio on actual wind energy price. • Wind Energy Demand to Supply Ratio - Wind Energy Demand to Supply Ratio. • Efficiency of Wind Installed Capacity - Total production efficiency of Wind Installed Capacity for given technology developments. • Wind Energy Production Rate - Total wind energy production per year accounting for demand and potential production due to available production capability and technical developments.
Energy Wind	A	**Productivity of Investment in Wind Capacity Installation** (Dmnl) = Impact of Space on Wind Capacity Installation*Wind Installation Efficiency **Description:** *Productivity of wind capacity installation taking into account the level of remaining possible capacities and technology development state.* **Used by:** • Installation of Wind Capacity Rate - Rate of new wind capacity installation.
Energy Wind	C	**Reference Cost of Wind Energy Production** ($/((m*m)*Year)) = 12 **Description:** *Reference cost of unit wind energy production per year.* **Used by:** • Unit Cost of Wind Energy Production - Unit cost of wind capacity installation per energy unit.
Energy Wind	C	**Sensitivity of Wind Energy Price to Supply and Demand** (Dmnl) = 0 **Description:** *Sensitivity of Wind Energy Price to Supply and Demand ratio.* **Used by:** • Effect of Wind Energy Demand and Supply on Price - Effect of Wind Demand and Supply ratio on actual wind energy price.
Energy Wind	C	**Solar Capacity Aging Time** (Year) = 20 **Description:** *Average solar energy production capacity aging time.* **Used by:** • Investment in Solar Capacity - Amount of resources dedicated to solar energy capacity development. • Solar Capacity Aging Rate - Aging rate of solar energy production capacities.
Energy Wind	L	**Table for FIWEI** (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) **Description:** *Table determining order by which technology investments are dedicated to energy and installation efficiency. For small Wind Installation Efficiency, in order to secure sufficient production capacity, more investments are directed to infrastructure. Once the Wind Installation Efficiency increases the investments are redirected to solar conversion efficiency technologies.* **Used by:** • Fraction Invested in Wind Energy Installation - Fraction of investments in wind energy technology dedicated to capacity.

		
Energy Wind	C	**Time to Adjust Wind Infrastructure** (Year) = 5 **Description:** *Time to adjust Wind Infrastructure to the desired level.* **Used by:** • Wind Infrastructure Adjustment - Adjustment of Wind Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Wind	A	**Total Wind Demand** (Mtoe/Year) = Energy Demand*Market Share Wind **Description:** *Total demand for wind energy.* **Used by:** • Effect of Wind Energy Demand and Supply on Price - Effect of Wind Demand and Supply ratio on actual wind energy price. • Wind Energy Demand to Supply Ratio - Wind Energy Demand to Supply Ratio. • Total Wind Demand GW - Total demand for wind energy measured in GW. • Desired Wind Installed Capacity - Desired Wind Installed Capacity accounting for Total Wind Demand and Efficiency of Wind Installed Capacity. • Wind Energy Production Rate - Total wind energy production per year accounting for demand and potential production due to available production capability and technical developments.
Energy Wind	A	**Total Wind Demand GW** (GW/Year) = Total Wind Demand/kWh into Mtoe peak hour/kW into GW **Description:** *Total demand for wind energy measured in GW.*
Energy Wind	A	**Unit Cost of Wind Capacity Installation** ($/Mtoe) = INIT Unit Cost of Wind Capacity Installation*Impact of Learning on Wind Unit Cost of Technology **Description:** *Unit Cost of Wind Capacity Installation. Determined by Productivity of Investment in Wind Capacity Installation.* **Used by:** • Investment in Wind Capacity - Amount of resources dedicated to wind energy capacity development. • Cost of Wind Energy - Cost of wind energy production assuming an impact of learning curve.
Energy Wind	A	**Unit Cost of Wind Energy Production** ($/Mtoe) = Reference Cost of Wind Energy Production/Wind Production to Installation Ratio **Description:** *Unit cost of wind capacity installation per energy unit.* **Used by:** • Cost of Wind Energy - Cost of wind energy production assuming an impact of learning curve.
Energy Wind	C	**Wind Aging Time** (Year) = 20 **Description:** *Average wind energy production capacity aging time.* **Used by:** • Investment in Wind Capacity - Amount of resources dedicated to wind energy capacity development.

		• Wind Capacity Aging Rate - Aging rate of wind energy production capacities.
Energy Wind	C	**Wind Available Area** (m*m) = 8e+012 **Description:** *Total area available for wind energy production capacities.* **Used by:** • Impact of Space on Wind Capacity Installation - Ratio of currently installed wind capacity to total possible.
Energy Wind	A	**Wind Capacity Aging Rate** (m*m/Year) = Wind Installed Capacity/Wind Aging Time **Description:** *Aging rate of wind energy production capacities.* **Used by:** • Wind Installed Capacity - Installed capacity to transform wind into energy. • Wind Infrastructure Adjustment - Adjustment of Wind Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Wind	A	**Wind Capacity Factor** (1) = MINWCF+(MAXWCF-MINWCF)*(Wind Energy Technology Ratio/(Wind Energy Technology Ratio+1)) **Description:** *Parameter indicating what fraction of average wind capacity per sqr meter it is possible to realize with the current state of technical developments.* **Used by:** • Potential Wind Energy Production - Potential solar energy production per year due to available production capability and technical developments. • Max Wind Power Point - Max Power Point measured at Standard Test Conditions for installed wind energy production capacity and current wind conversion efficiency. • Wind Technology - Factor productivity in Wind energy sector.
Energy Wind	A	**Wind Energy Demand to Supply Ratio** (Dmnl) = Total Wind Demand/Potential Wind Energy Production **Description:** *Wind Energy Demand to Supply Ratio.*
Energy Wind	A	**Wind Energy Price** ($/Mtoe) = Indicated Wind Energy Price*Effect of Wind Energy Demand and Supply on Price **Description:** *Actual wind energy price accounting for indicated wind energy price and effect of demand and supply.* **Used by:** • Wind Energy Price per kWh - Actual wind energy price accounting for indicated wind energy price and effect of demand and supply measured in dollars per kWh. • Wind Energy Revenue - Total revenue in wind energy market. • Wind Price toe - Actual wind energy price in dollars per toe.
Energy Wind	A	**Wind Energy Price per kWh** ($/(kW*Hour)) = Wind Energy Price*kWh into Mtoe **Description:** *Actual wind energy price accounting for indicated wind energy price and effect of demand and supply measured in dollars per kWh.*
Energy Wind	A	**Wind Energy Production** (Mtoe/Year) = Wind Energy Production Rate **Description:** *Total wind energy production per year.* **Used by:** • C Emission from Wind Energy - Total carbon emission from wind energy production and it use. • Wind Production to Installation Ratio - Ratio of wind energy production to available production capacity. • Cumulative Wind Energy Produced - Cumulative wind energy that has been produced. • Wind Energy Revenue - Total revenue in wind energy market. • Energy Production - Total energy production per year.
Energy Wind	A	**Wind Energy Production Rate** (Mtoe/Year) = MIN(Potential Wind Energy Production,Total Wind Demand) **Description:** *Total wind energy production per year accounting for demand and potential production due to available production capability and technical developments.*

		Used by: • Wind Energy Production - Total wind energy production per year.
Energy Wind	A	**Wind Energy Revenue** ($/Year) = Wind Energy Production*Wind Energy Price **Description:** *Total revenue in wind energy market.* **Used by:** • Investment in Wind Energy Technology - Investments in development of wind conversion efficiency technology and production capability.
Energy Wind	C	**Wind Energy Technology Development Time** (Year) = 50 **Description:** *Average time required to turn investments into concrete wind conversion efficiency technology developments. Since the simulation starts in 1900 it is a significant time.* **Used by:** • Increase in Wind Energy Technology Ratio - Increase in Wind Energy Technology Ratio due to investments in wind conversion efficiency technology and their productivity.
Energy Wind	S	**Wind Energy Technology Ratio** (Dmnl) = INIT WETRN + ∫ (Increase in Wind Energy Technology Ratio) **Description:** *Wind Energy Technology Ratio increased due to investments in wind conversion efficiency.* **Used by:** • Wind Capacity Factor - Parameter indicating what fraction of average wind capacity per sqr meter it is possible to realize with the current state of technical developments.
Energy Wind	C	**Wind Final Investment** (Dmnl) = 0.03 **Description:** *Eventual average level of investments in wind energy technology.* **Used by:** • Wind Investment Fraction Slope - Intensity of increase in investments in wind energy technology.
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 **Description:** *Adjustment of Wind Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.* **Used by:** • Installation of Wind Capacity Rate - Rate of new wind capacity installation.
Energy Wind	C	**Wind Initial Investment** (Dmnl) = 0 **Description:** *Initial level of fractional investments in wind energy technology.* **Used by:** • Wind Investment Fraction Slope - Intensity of increase in investments in wind energy technology.
Energy Wind	A	**Wind Installation Efficiency** (1) = MINWIE+(MAXWIE-MINWIE)*(Wind Installation Technology Ratio/(Wind Installation Technology Ratio+1)) **Description:** *Parameter indicating wind energy capacity installation efficiency at the current state of technical developments.* **Used by:** • Productivity of Investment in Wind Capacity Installation - Productivity of wind capacity installation taking into account the level of remaining possible capacities and technology development state. • Fraction Invested in Wind Energy Installation - Fraction of investments in wind energy technology dedicated to capacity. • Wind Technology - Factor productivity in Wind energy sector.
Energy Wind	C	**Wind Installation Technology Development Time** (Year) = 100 **Description:** *Average time required to turn investments into concrete wind energy production capacity. Since the simulation starts in 1900 it is a significant time.* **Used by:** • Increase in Wind Installation Technology Ratio - Increase in Wind Installation

		Technology Ratio due to investments in wind energy installation capacity.
Energy Wind	S	**Wind Installation Technology Ratio** (Dmnl) = INIT WITRN + ∫ (Increase in Wind Installation Technology Ratio) **Description:** *Wind Installation Technology Ratio increased due to investments in wind energy capacity installation efficiency.* **Used by:** • Wind Installation Efficiency - Parameter indicating wind energy capacity installation efficiency at the current state of technical developments.
Energy Wind	S	**Wind Installed Capacity** (m*m) = INIT WIC + ∫ (Installation of Wind Capacity Rate-Wind Capacity Aging Rate) **Description:** *Installed capacity to transform wind into energy.* **Used by:** • Impact of Space on Wind Capacity Installation - Ratio of currently installed wind capacity to total possible. • Wind Production to Installation Ratio - Ratio of wind energy production to available production capacity. • Potential Wind Energy Production - Potential solar energy production per year due to available production capability and technical developments. • Max Wind Power Point - Max Power Point measured at Standard Test Conditions for installed wind energy production capacity and current wind conversion efficiency. • Efficiency of Wind Installed Capacity - Total production efficiency of Wind Installed Capacity for given technology developments. • Impact of Learning on Wind Unit Cost of Technology - Impact of learning curve on wind energy cost. • Wind Capacity Aging Rate - Aging rate of wind energy production capacities. • Wind Infrastructure Adjustment - Adjustment of Wind Infrastructure to the desired level over a specified adjustment time and accounting for constant infrastructure decrease due to aging process.
Energy Wind	I	**Wind Investment Fraction Finish** (Year) = INITIAL TIME+Ramp Investment Period **Description:** *End of fractional investments in wind energy technology.* **Used by:** • Fraction of Revenue Invested in Wind Technology - Parameter to take into account historical increase of the wind energy significance and over time greater resources dedicated to the technology development.
Energy Wind	A	**Wind Investment Fraction Slope** (1/Year) = ABS(Wind Final Investment-Wind Initial Investment)/Ramp Investment Period **Description:** *Intensity of increase in investments in wind energy technology.* **Used by:** • Fraction of Revenue Invested in Wind Technology - Parameter to take into account historical increase of the wind energy significance and over time greater resources dedicated to the technology development.
Energy Wind	I	**Wind Investment Fraction Start** (Year) = INITIAL TIME **Description:** *Start of investments in wind energy technology.* **Used by:** • Fraction of Revenue Invested in Wind Technology - Parameter to take into account historical increase of the wind energy significance and over time greater resources dedicated to the technology development.
Energy Wind	A	**Wind Learning Curve Strength** (1) = LN(1 - Fraction for Wind Learning Curve Strength)/LN(2) **Description:** *Strength of learning curve with which the wind energy costs are influenced.* **Used by:** • Impact of Learning on Wind Unit Cost of Technology - Impact of learning curve on wind energy cost.
Energy Wind	A	**Wind Production to Installation Ratio** (Mtoe/(m*m*Year)) = Wind Energy Production/Wind Installed Capacity **Description:** *Ratio of wind energy production to available production capacity.* **Used by:**

		• Unit Cost of Wind Energy Production - Unit cost of wind capacity installation per energy unit.
Indexes	C	**Cropland Ecosystem Value** ($/ha) = 90 **Description:** *Ecosystem value of unit area of cropland.* **Used by:** • Total Change in Cropland Ecosystem Value - Total ecosystem value of cropland.
Indexes	S	**Education index** (Dmnl) = INIT Educational Attainment + ∫ (Net Change in Educational Attainment) **Description:** *Educational Attainment calculated according to UNDP Human Development Report 2011. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/* **Used by:** • Human Development Index - Human Development Index as an average of three indexes of achievement. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/ • Educational Attainment Ratio - Ratio of Educational Attainment. • Net Change in Educational Attainment - Net Change in Educational Attainment. • Impact of Educational on Fertility - A nonlinear function representing the impact of population educational on fertility. With increasing education the fertility decreases.
Indexes	A	**Educational Attainment Change Rate** (1/Year) = RAMP(Educational Attainment Change Rate Slope, Educational Attainment Change Rate Start, Educational Attainment Change Rate Finish) **Description:** *Educational Attainment Change Rate.* **Used by:** • Educational Attainment Ratio - Ratio of Educational Attainment.
Indexes	I	**Educational Attainment Change Rate Finish** (Year) = INITIAL TIME+Ramp Educational Attainment Investment Period **Description:** *End of fractional investments in Educational Attainment.* **Used by:** • Educational Attainment Change Rate - Educational Attainment Change Rate.
Indexes	A	**Educational Attainment Change Rate Slope** (1/(Year*Year)) = ABS(Final Educational Attainment Change Rate-Initial Educational Attainment Change Rate)/Ramp Educational Attainment Investment Period **Description:** *Intensity of Educational Attainment Change Rate.* **Used by:** • Educational Attainment Change Rate - Educational Attainment Change Rate.
Indexes	I	**Educational Attainment Change Rate Start** (Year) = INITIAL TIME **Description:** *Start of increased investments in Educational Attainment.* **Used by:** • Educational Attainment Change Rate - Educational Attainment Change Rate.
Indexes	A	**Educational Attainment Ratio** (1/Year) = Educational Attainment Change Rate*(1-Education index/Max Educational Attainment) **Description:** *Ratio of Educational Attainment.* **Used by:** • Net Change in Educational Attainment - Net Change in Educational Attainment.
Indexes	C	**Final Educational Attainment Change Rate** (1/Year) = 0.028 **Description:** *Final Educational Attainment Change Rate* **Used by:** • Educational Attainment Change Rate Slope - Intensity of Educational Attainment Change Rate.
Indexes	C	**Forest Ecosystem Value** ($/ha) = 700 **Description:** *Ecosystem value of unit area of forest.* **Used by:** • Total Change in Forest Ecosystem Value - Total ecosystem value of forest.
Indexes	A	**Health index** (Dmnl)

		= (Life Expectancy-Min Life Expectancy)/(Max Life Expectancy-Min Life Expectancy) **Description:** *Index of achievement in Life Expectancy. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/* **Used by:** • Human Development Index - Human Development Index as an average of three indexes of achievement. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	A	**Human Development Index** (Dmnl) = (Health index^(1/3))*(Income index^(1/3))*(Education index^(1/3)) **Description:** *Human Development Index as an average of three indexes of achievement. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/*
Indexes	A	**Income index** (Dmnl) = (LN(GWP per Capita/Reference GWP per Capita for Income Index)-LN(Min GWP per Capita/Reference GWP per Capita for Income Index))/(LN(Max GWP per Capita/Reference GWP per Capita for Income Index)-LN(Min GWP per Capita/Reference GWP per Capita for Income Index)) **Description:** *Index of achievement in GWP per Capita. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/* **Used by:** • Human Development Index - Human Development Index as an average of three indexes of achievement. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**INIT Educational Attainment** (Dmnl) = 0.29 **Description:** *Assumed initial value of Educational Attainment.* **Used by:** • Education index - Educational Attainment calculated according to UNDP Human Development Report 2011. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**Initial Educational Attainment Change Rate** (1/Year) = 0 **Description:** *Initial Educational Attainment Change Rate* **Used by:** • Educational Attainment Change Rate Slope - Intensity of Educational Attainment Change Rate.
Indexes	C	**Max Educational Attainment** (Dmnl) = 1 **Description:** *Assumed reference Educational Attainment.* **Used by:** • Educational Attainment Ratio - Ratio of Educational Attainment.
Indexes	C	**Max GWP per Capita** ($/(Year*Person)) = 107721 **Description:** *Maximal reference Gross World Product per Capita.* **Used by:** • Income index - Index of achievement in GWP per Capita. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**Max Life Expectancy** (Year) = 83.4 **Description:** *Maximal reference Life Expectancy.* **Used by:** • Health index - Index of achievement in Life Expectancy. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**Min GWP per Capita** ($/(Year*Person)) = 100 **Description:** *Minimal reference Gross World Product per Capita.* **Used by:** • Income index - Index of achievement in GWP per Capita. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**Min Life Expectancy** (Year) = 20 **Description:** *Minimal reference Life Expectancy.*

		Used by: • Health index - Index of achievement in Life Expectancy. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	A	**Net Change in Educational Attainment** (1/Year) = DELAY3(Education index*Educational Attainment Ratio,Time to Adjust Educational Attainment) **Description:** *Net Change in Educational Attainment.* **Used by:** • Education index - Educational Attainment calculated according to UNDP Human Development Report 2011. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**Other Land Ecosystem Value** ($/ha) = 230 **Description:** *Ecosystem value of unit area of other land.* **Used by:** • Total Change in Other Land Ecosystem Value - Total ecosystem value of other land.
Indexes	C	**Ramp Educational Attainment Investment Period** (Year) = 100 **Description:** *Period of increasing investments in Educational Attainment.* **Used by:** • Educational Attainment Change Rate Slope - Intensity of Educational Attainment Change Rate. • Educational Attainment Change Rate Finish - End of fractional investments in Educational Attainment.
Indexes	C	**Reference GWP per Capita for Income Index** ($/(Year*Person)) = 1 **Description:** *Auxilary variable to eliminate units and make the Income index dimensionless.* **Used by:** • Income index - Index of achievement in GWP per Capita. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/
Indexes	C	**Time to Adjust Educational Attainment** (Year) = 10 **Description:** *Time to Adjust Educational Attainment.* **Used by:** • Net Change in Educational Attainment - Net Change in Educational Attainment.
Indexes	A	**Total Change in Cropland Ecosystem Value** ($) = (Agricultural Land-INIT Agricultural Land)*Cropland Ecosystem Value*Sqr m to ha **Description:** *Total ecosystem value of cropland.* **Used by:** • Total Change in Ecosystem Value - Total ecosystem value of all considered areas - forest, cropland and other land like woodland and grassland.
Indexes	A	**Total Change in Ecosystem Value** ($) = Total Change in Forest Ecosystem Value+Total Change in Cropland Ecosystem Value+Total Change in Other Land Ecosystem Value **Description:** *Total ecosystem value of all considered areas - forest, cropland and other land like woodland and grassland.*
Indexes	A	**Total Change in Forest Ecosystem Value** ($) = (Forest Land-INIT Forest Land)*Sqr m to ha*Forest Ecosystem Value **Description:** *Total ecosystem value of forest.* **Used by:** • Total Change in Ecosystem Value - Total ecosystem value of all considered areas - forest, cropland and other land like woodland and grassland.
Indexes	A	**Total Change in Other Land Ecosystem Value** ($) = (Other Land-INIT Other Land)*Sqr m to ha*Other Land Ecosystem Value **Description:** *Total ecosystem value of other land.* **Used by:** • Total Change in Ecosystem Value - Total ecosystem value of all considered areas - forest, cropland and other land like woodland and grassland.
Land	A	**Actual Forest Land Harvested** (ha)

		= (Forest Biomass Production/(1-Biomass Production Processing Loss))/Forest Land Energy Yield **Description:** *Forest biomass production expressed in terms of forest land harvested excluding forest biomass production processing loss.* **Used by:** • Forest Biomass Production Land Ratio - Ratio of forest land area being used for biomass production.
Land	S	**Agricultural Land** (m*m) = INIT Agricultural Land + ∫ (Forest Agriculture Allocation Rate-Agriculture Other Land Allocation Rate-Agriculture Urban Industrial Land Allocation Rate) **Description:** *Total Agriculture Land.* **Used by:** • Impact of Agricultural Land Changes on Biodiversity - Nonlinear function representing impact of agricultural land use change on species carrying capacity. • Total Change in Cropland Ecosystem Value - Total ecosystem value of cropland. • Irrigated Agriculture Land - Area of agricultural land on which the supply of water is only due to irrigation. Source of Historical Data: Gleick,P.H., et al. The World's Water Volume 7: The Biennial Report on Freshwater Resources. Washington: Island Press, 2012. • Rainfed Agriculture Land - Area of agricultural land on which the supply of water is only due to rain. • Agricultural Land Change - Ratio of agricultural land area change compared to its initial area in year 1900. • Fertilizer Consumption - Total consumption of fertilizers. Source of historical data: http://faostat.fao.org • Permanent meadows and pastures ha - Area of permanent meadows and pastures land. • FAO Agricultural area ha - Historical data and projection of total agriculture land change accoring to FAO. Source of historical data: http://faostat.fao.org • Permanent crops ha - Area of permanent crops land. • Agriculture Land ha - Total Agriculture Land in ha. • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land. • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land. • Arable Land ha - Area of arable land. • Total Land - Total considered land. • Agriculture Urban Industrial Land Allocation Rate - Transformation process of Agriculture Land into Urban and Industrial Land.
Land	A	**Agricultural Land Available** (ha) = Crops Potential Agriculture Land+Animal Food Potential Agriculture Land **Description:** *Total area of agricultural land available for production of crops and animal food.* **Used by:** • Ratio of Agricultural Land Available to Needed - Ratio of agricultural land available to needed indicating shortage of land available for agricultural production. • Difference of Agricultural Land Available to Needed - Difference between agricultural land available and needed.
Land	A	**Agricultural Land Needed** (ha) = Food Crops Land Needed+Energy Crops Land Needed+Animal Food Land Needed **Description:** *Total area of required land to meed demand for food crops, energy crops and animal food.* **Used by:** • Ratio of Agricultural Land Available to Needed - Ratio of agricultural land available to needed indicating shortage of land available for agricultural production. • Difference of Agricultural Land Available to Needed - Difference between agricultural land available and needed.
Land	A	**Agriculture Land Energy Yield** (Biomass ton/(Year*ha)) = Nominal Energy Agriculture Land Productivity*Cropland Land Fertility

		Description: *Yield from a unit energy crops land area.* **Used by:** • Energy Crops Land Needed - Land area dedicated to energy crops production. • Energy Crops Production - Total energy biomass production from energy crops.
Land	A	**Agriculture Land ha** (ha) = Agricultural Land*Sqr m to ha **Description:** *Total Agriculture Land in ha.*
Land	A	**Agriculture Other Change** (Dmnl) = -Effect of Food Purpose Agriculture Land Shortage on Other to Agriculture Land Expansion **Description:** *Parameter indicating a need for change in land use and transformation between Agriculture and Other Land. Sign plus indicate transformation from agricultural to other land. Sign minus indicate transformation from other to agricultural land.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land.
Land	F,A	**Agriculture Other Land Allocation Rate** (m*m/Year) = MAX(0, Agriculture Other Change*(Agricultural Land-Agriculture Protected Land)/Agriculture to Other Land Allocation Time)+MIN(0,ProNature*ProNaturePlus*Agriculture Other Change*(Other Land-Other Protected Land)/Other to Agriculture Land Allocation Time) **Description:** *Process of transformation between Agriculture and Other Land.* **Used by:** • Agricultural Land - Total Agriculture Land. • Other Land - Land not classified as Agricultural area, Forest area or Urban and Industrial Land.
Land	C	**Agriculture Protected Land** (m*m) = 1.46683e+013 **Description:** *Area of Agriculture Land not transformable into other kind of lands.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land. • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land. • Agriculture Urban Industrial Land Allocation Rate - Transformation process of Agriculture Land into Urban and Industrial Land.
Land	C	**Agriculture to Forest Land Allocation Time** (Year) = 150 **Description:** *Average time which natural transformation of Agriculture to Forest Land would take.* **Used by:** • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land.
Land	C	**Agriculture to Other Land Allocation Time** (Year) = 20 **Description:** *Average time which natural transformation of Agriculture to Other Land would take.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land.
Land	C	**Agriculture to Urban Land Allocation Time** (Year) = 5 **Description:** *Average time which natural transformation of Agriculture to Urban and Industrial Land would take.* **Used by:** • Agriculture Urban Industrial Land Allocation Rate - Transformation process of Agriculture Land into Urban and Industrial Land.
Land	A	**Agriculture Urban Change** (Dmnl) = Effect of Urban and Industrial Land Shortage on the Land Expansion **Description:** *Parameter indicating a need for change in land use and transformation of Agriculture Land into Urban and Industrial Land.* **Used by:**

		• Agriculture Urban Industrial Land Allocation Rate - Transformation process of Agriculture Land into Urban and Industrial Land.
Land	F,A	**Agriculture Urban Industrial Land Allocation Rate** (m*m/Year) = MAX(0, Agriculture Urban Change*(Agricultural Land-Agriculture Protected Land)/Agriculture to Urban Land Allocation Time) **Description:** *Transformation process of Agriculture Land into Urban and Industrial Land.* **Used by:** • Agricultural Land - Total Agriculture Land. • Urban and Industrial Land m - Total Urban and Industrial Land.
Land	A	**Animal Calories Baseline** (kcal/(Person*Day)) = Animal Food supply kcal capita day **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Animal Calories BioenergyPlus** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Animal Calories Consumption Decrease Factor** (1/Year) = 0.007 **Description:** *Factor of change in animal food calories demand due to diet shift.* **Used by:** • Decrease to Change to 2010 Demand Animal Calories - Change in animal food calories demand due to diet shift.
Land	A	**Animal Calories Dietshift** (kcal/(Person*Day)) = Animal Food supply kcal capita day **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Animal Calories ProNature** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Animal Calories ProNaturePlus** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Animal Food Land** (ha) = Animal Food Potential Agriculture Land **Description:** *Land area dedicated to animal and food for animal production.* **Used by:** • Animal Food Production - Total animal food production due to animal food land availability and animal food land yield. • Ratio of Animal Food Land Needed to Available - Ratio of animal food land needed to available.
Land	A	**Animal Food Land Fertility** (Dmnl) = Normal Animal Food Land Fertility*Effect of Climate Change on Animal Food Land Fertility*Effect of Management Practices on Animal Food Land Fertility*Effect of Pollution on Animal Food Land Fertility *Effect of Water Withdrawal on Animal Food Land Fertility*Effect of Input Neutral Technology Change on Agricultural Land Fertility **Description:** *Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.* **Used by:** • Animal Food Land Yield - Yield from a unit animal food land area.
Land	A	**Animal Food Land Needed** (ha) = Animal Food Production Needed/Animal Food Land Yield **Description:** *Land area required for animal food production due to food demand.* **Used by:** • Crops vs Animal Food Land Needed - Ratio of land needed for vegetal versus land needed for animal food. Used as one of drivers for land use change. • Animal Food Production - Total animal food production due to animal food land availability and animal food land yield. • Agricultural Land Needed - Total area of required land to meed demand for food crops, energy crops and animal food. • Ratio of Animal Food Land Needed to Available - Ratio of animal food land needed to available.

Land	A	**Animal Food Land Yield** (kcal/(ha*Year)) = Nominal Animal Food Land Yield*Animal Food Land Fertility **Description:** *Yield from a unit animal food land area.* **Used by:** • Animal Food Production - Total animal food production due to animal food land availability and animal food land yield. • Animal Food Yield - Calculated historical data and projection of animal food land yield according to FAO. Source of historical data: http://faostat.fao.org • Animal Food Land Needed - Land area required for animal food production due to food demand.
Land	A	**Animal Food Potential Agriculture Land** (ha) = Permanent meadows and pastures ha+(Arable Land ha+Permanent crops ha)*(1-Vegetal vs Animal Food Dedicated Land) **Description:** *Land area dedicated to animal and food for animal production.* **Used by:** • Agricultural Land Available - Total area of agricultural land available for production of crops and animal food. • Animal Food Land - Land area dedicated to animal and food for animal production. • Land for Animal Food - Calculated historical data and projection for land for animal food according to FAO. Source of historical data: http://faostat.fao.org
Land	A	**Animal Food Production** (kcal/Year) = MIN(Animal Food Land,Animal Food Land Needed)*Animal Food Land Yield **Description:** *Total animal food production due to animal food land availability and animal food land yield.* **Used by:** • Animal Food supply kcal capita day - Average amount of animal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org • Animal Food supply quantity tonnes - Average amount of animal food measured in tons available each year. Source of historical data: http://faostat.fao.org • Calories Consumption per Capita per Day - The average amount of food calories each person consumes per day.
Land	A	**Animal Food Production Needed** (kcal/Year) = SCEN Demand Animal Calor Consum per Capita per Day*Population*Days in Year **Description:** *Total demand for animal food accounting for total population and annual food requirements per capita.* **Used by:** • Animal Food Land Needed - Land area required for animal food production due to food demand.
Land	A	**Animal Food supply kcal capita day** (kcal/(Person*Day)) = Animal Food Production/Population/Days in Year **Description:** *Average amount of animal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org* **Used by:** • Calories Consumption GLOBIOM kcal cap day - Total average amount of food measured in calories available for each person per day. Source of projection data: GLOBIOM model, IIASA. • Animal Calories Dietshift - WWF Scenario variable. Further development required. • Animal Calories Baseline - WWF Scenario variable. Further development required.
Land	A	**Animal Food supply quantity tonnes** (Ton/Year) = Animal Food Production/Average Animal Calories per Ton **Description:** *Average amount of animal food measured in tons available each year. Source of historical data: http://faostat.fao.org*
Land	A	**Animal Food Yield** (kcal/(ha*Year)) = Animal Food Land Yield **Description:** *Calculated historical data and projection of animal food land yield according to FAO. Source of historical data: http://faostat.fao.org*
Land	A	**Arable Land ha** (ha) = Agricultural Land*Sqr m to ha*Arable Percentage of Agriculture Land

		Description: *Area of arable land.* **Used by:** • Cropland Baseline - WWF Scenario variable. Further development required. • Cropland Dietshift - WWF Scenario variable. Further development required. • Animal Food Potential Agriculture Land - Land area dedicated to animal and food for animal production. • Cropland GLOBIOM ha - Projection of cropland change according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA. • FAO Arable land ha - Historical data and projection of arable land change accoring to FAO. Source of historical data: http://faostat.fao.org • Crops Potential Agriculture Land - Land area dedicated to crops production.
Land	C	**Arable Percentage of Agriculture Land** (Dmnl) = 0.287 **Description:** *Percentage of agricultural land constituting the arable land.* **Used by:** • Arable Land ha - Area of arable land.
Land	C	**Average Animal Calories per Ton** (kcal/Ton) = 1e+006 **Description:** *Conversion from animal tons to calories.* **Used by:** • Animal Food supply quantity tonnes - Average amount of animal food measured in tons available each year. Source of historical data: http://faostat.fao.org
Land	C	**Biomass Production Processing Loss** (Dmnl) = 0.1 **Description:** *Average percentage of total forest biomass production lost due to processing.* **Used by:** • Potential Biomass Production - Potential Biomass Production for given area to be harvested, actual yield from ha and excluding forest biomass production processing losses. • Forest Biomass Production - Total biomass production from forest. • Forest Land Needed to be Harvested - Total area of Forest needed for biomass production purposes accounting for total demand for forest biomass, average forest land yield and average losses in forest biomass production process. • Actual Forest Land Harvested - Forest biomass production expressed in terms of forest land harvested excluding forest biomass production processing loss.
Land	A	**Calories Consumption GLOBIOM kcal cap day** (kcal/Person/Day) = Animal Food supply kcal capita day+Vegetal Food supply kcal capita day **Description:** *Total average amount of food measured in calories available for each person per day. Source of projection data: GLOBIOM model, IIASA.* **Used by:** • Total Calories Dietshift - WWF Scenario variable. Further development required. • Total Calories Baseline - WWF Scenario variable. Further development required.
Land	F,A	**Change to 2010 Demand Animal Calories** (kcal/(Person*Day*Year)) = PULSE(2010,1)*Demand Animal Calories Consumption per Capita per Day/Change to 2010 Demand Animal Calories Adjustment Time **Description:** *Variable capturing the level of animal calories demand per capita per day in year 2010.* **Used by:** • Starting in 2010 Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person as of year 2010.
Land	C	**Change to 2010 Demand Animal Calories Adjustment Time** (Year) = 1 **Description:** *Period of time over which the level of animal calories demand per capita per day in year 2010 is captured.* **Used by:** • Change to 2010 Demand Animal Calories - Variable capturing the level of animal calories demand per capita per day in year 2010.
Land	A	**Change to Demand Vegetal Calories** (1/Year)

		= IF THEN ELSE(Time<2010,0,Increase to Demand Vegetal Calories*Vegetal Calories Consumption Increase Factor) **Description:** *Change to increase in vegetal food demand.* **Used by:** • Increase to Demand Vegetal Calories - Increase in daily demand of vegetal food calories.
Land	C	**Climate Impact on Agriculture Land Fertility Nonlinearity** (Dmnl) = 2 **Description:** *Elasticity of climate impact on cropland fertility.* **Used by:** • Effect of Climate Change on Agriculture Land Fertility - Impact of climate change risk on cropland fertility.
Land	C	**Climate Impact on Agriculture Land Fertility Reference Temperature** (DegreesC) = 3 **Description:** *Reference temperature against which the average temerature is compared in calculation of impact of climate change on cropland fertility.* **Used by:** • Effect of Climate Change on Agriculture Land Fertility - Impact of climate change risk on cropland fertility.
Land	C	**Climate Impact on Agriculture Land Fertility Scale** (Dmnl) = 0.013 **Description:** *Increment of climate impact on cropland fertility.* **Used by:** • Effect of Climate Change on Agriculture Land Fertility - Impact of climate change risk on cropland fertility.
Land	C	**Climate Impact on Animal Food Land Fertility Nonlinearity** (Dmnl) = 2 **Description:** *Elasticity of climate impact on animal food land fertility.* **Used by:** • Effect of Climate Change on Animal Food Land Fertility - Impact of climate change risk on land fertility related to animal food.
Land	C	**Climate Impact on Animal Food Land Fertility Reference Temperature** (DegreesC) = 3 **Description:** *Reference temperature against which the avaerage temerature is compared in calculation of impact of climate change on animal food land fertility.* **Used by:** • Effect of Climate Change on Animal Food Land Fertility - Impact of climate change risk on land fertility related to animal food.
Land	C	**Climate Impact on Animal Food Land Fertility Scale** (Dmnl) = 0.013 **Description:** *Increment of climate impact on animal food land fertility.* **Used by:** • Effect of Climate Change on Animal Food Land Fertility - Impact of climate change risk on land fertility related to animal food.
Land	C	**Climate Impact on Forest Land Fertility Nonlinearity** (Dmnl) = 2 **Description:** *Elasticity of climate impact on forest land fertility.* **Used by:** • Effect of Climate Change on Forest Land Fertility - Impact of climate change risk on forest land fertility.
Land	C	**Climate Impact on Forest Land Fertility Reference Temperature** (DegreesC) = 3 **Description:** *Reference temperature against which the average temerature is compared in calculation of impact of climate change on forest land fertility.* **Used by:** • Effect of Climate Change on Forest Land Fertility - Impact of climate change risk on forest land fertility.
Land	C	**Climate Impact on Forest Land Fertility Scale** (Dmnl) = 0.013 **Description:** *Increment of climate impact on forest land fertility.*

		Used by: • Effect of Climate Change on Forest Land Fertility - Impact of climate change risk on forest land fertility.
Land	A	**Cropland Baseline** (ha) = Arable Land ha **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Cropland BioenergyPlus** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Cropland Dietshift** (ha) = Arable Land ha **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Cropland GLOBIOM ha** (ha) = Arable Land ha **Description:** *Projection of cropland change according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.*
Land	A	**Cropland Land Fertility** (Dmnl) = (1-SCENARIO Do Nothing)*(Normal Cropland Fertility*Effect of Climate Change on Agriculture Land Fertility*Effect of Management Practices on Agriculture Land Fertility *Effect of Water Withdrawal on Agriculture Land Fertility*Effect of Input Neutral Technology Change on Agricultural Land Fertility *Effect of Pollution on Agriculture Land Fertility)+SCENARIO Do Nothing*(IF THEN ELSE (Time>2010, SCENARIO Do Nothing Cropland Land Fertility , (Normal Cropland Fertility*Effect of Climate Change on Agriculture Land Fertility* Effect of Management Practices on Agriculture Land Fertility *Effect of Water Withdrawal on Agriculture Land Fertility*Effect of Input Neutral Technology Change on Agricultural Land Fertility *Effect of Pollution on Agriculture Land Fertility))) **Description:** *Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900.* **Used by:** • Food Crops Land Yield - Yield from a unit food crops land area. • Agriculture Land Energy Yield - Yield from a unit energy crops land area.
Land	C	**Cropland ProNature** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Cropland ProNaturePlus** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Crops Potential Agriculture Land** (ha) = (Arable Land ha+Permanent crops ha)*Vegetal vs Animal Food Dedicated Land **Description:** *Land area dedicated to crops production.* **Used by:** • Agriculture Biomass Production Land Ratio - Ratio of agricultural land area being used for crops biomass production. • Agricultural Land Available - Total area of agricultural land available for production of crops and animal food. • Food Crops Land - Land area dedicated to crops production decreased by the area dedicated to energy crops production.
Land	A	**Crops Production Needed** (kcal/Year) = SCEN Demand Vegetal Calor Consum per Capita per Day*Population*Days in Year **Description:** *Total demand for vegetal food accounting for total population and annual food requirements per capita.* **Used by:** • Food Crops Land Needed - Land area required for food crops production due to food demand.
Land	A	**Crops vs Animal Food Land Needed** (Dmnl) = ZIDZ(Food Crops Land Needed,Animal Food Land Needed) **Description:** *Ratio of land needed for vegetal versus land needed for animal food. Used as one of drivers for land use change.* **Used by:** • Vegetal vs Animal Food Dedicated Land - Dynamic parameter responsible for

		allocation of land between crops and animal food production land in response to specific land demand.
Land	A	**Current to Max Fertilization Intensity** (Dmnl) = Fertilization Intensity Ratio*(1-Fertilization Intensity/Max Fertilization Intensity) **Description:** *Gap between maximal and current intencity of fertilization practices.* **Used by:** • Fertilization Intensity Change - Change in intencity of fertilization practices per ha per year.
Land	A	**Current to Max Forest Protected Land** (1/Year) = Forest Protected Land Change Ratio*(1-Forest Protected Land/Max Forest Protected Land) **Description:** *Gap being closed between current and max forest protected land.* **Used by:** • Forest Protected Land Change - Changes in area of forest land indicated as protected.
Land	C	**Days in Year** (Days/Year) = 365 **Description:** *The number of days per year.* **Used by:** • Animal Food Production Needed - Total demand for animal food accounting for total population and annual food requirements per capita. • Vegetal Food supply kcal capita day - Average amount of vegetal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org • Animal Food supply kcal capita day - Average amount of animal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org • Crops Production Needed - Total demand for vegetal food accounting for total population and annual food requirements per capita. • Calories Consumption per Capita per Day - The average amount of food calories each person consumes per day.
Land	A	**Decrease to Change to 2010 Demand Animal Calories** (kcal/(Person*Day*Year)) = IF THEN ELSE(Time<2010,0,Starting in 2010 Demand Animal Calories Consumption per Capita per Day*Animal Calories Consumption Decrease Factor) **Description:** *Change in animal food calories demand due to diet shift.* **Used by:** • Starting in 2010 Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person as of year 2010.
Land	A	**Deforestation** (ha) = (INIT Forest Land-Forest Land)*Sqr m to ha **Description:** *Changes in forest land area from the area in year 1900.*
Land	A	**Deforestation Time Factor** (Dmnl) = 1+Target Deforestation Time Factor+Target Delayed Deforestation Time Factor+Half Measures Deforestation Time Factor **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land.
Land	A	**Demand Animal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = Min Animal Calories Consumption per Capita per Day+(Max Animal Calories Consumption per Capita per Day-Min Animal Calories Consumption per Capita per Day)*(GWP per Capita/(GWP per Capita+Demand Animal Calories Consumption per Capita per Day Slope))-Demand Animal Calories Consumption per Capita per Day Correction **Description:** *Daily demand of animal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.* **Used by:** • Change to 2010 Demand Animal Calories - Variable capturing the level of animal calories demand per capita per day in year 2010. • SCEN Demand Animal Calor Consum per Capita per Day - Daily demand of animal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.

Land	C	**Demand Animal Calories Consumption per Capita per Day Correction** (kcal/(Person*Day)) = 180 **Description:** *Correction in demand for animal food calories for year 1900.* **Used by:** • Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	C	**Demand Animal Calories Consumption per Capita per Day Slope** ($/(Year*Person)) = 3500 **Description:** *Calibration parameter for impact of GWP on animal food calories demand.* **Used by:** • Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	A	**Demand Vegetal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = Min Vegetal Calories Consumption per Capita per Day+(Max Vegetal Calories Consumption per Capita per Day-Min Vegetal Calories Consumption per Capita per Day)*(GWP per Capita/(GWP per Capita+Demand Vegetal Calories Consumption per Capita per Day Slope)) **Description:** *Daily demand of vegetal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.* **Used by:** • SCEN Demand Vegetal Calor Consum per Capita per Day - Daily demand of vegetal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.
Land	C	**Demand Vegetal Calories Consumption per Capita per Day Slope** ($/(Year*Person)) = 3000 **Description:** *Calibration parameter for impact of GWP on vegetal food calories demand.* **Used by:** • Demand Vegetal Calories Consumption per Capita per Day - Daily demand of vegetal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	A	**Desired Production Fraction** (1) = Total Forest Biomass Demand/Potential Biomass Production **Description:** *Ratio of demand for forest biomass to potential production.* **Used by:** • Effect of Trees Aging on Yield - Parameter accounting for decreased forest biomass production from aging tress. • Effect of Trees Maturing on Yield - Parameter accounting for increased forest biomass production from mature trees.
Land	A	**Difference of Agricultural Land Available to Needed** (ha) = Agricultural Land Available-Agricultural Land Needed **Description:** *Difference between agricultural land available and needed.*
Land	A	**Effect of Biodiversity on Forest Land Fertility** (Dmnl) = Min Impact of Biodiversity on Forest Land Fertility+(Max Impact of Biodiversity on Forest Land Fertility-Min Impact of Biodiversity on Forest Land Fertility)*(Mean Species Abundance/Initial Species Abundance) **Description:** *Impact of mean species abundance on forest land fertility. Scaled between minimal and maximal impact. Relative level is the value of mean species abundance in year 1900.* **Used by:** • Forest Land Fertility - Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.
Land	A	**Effect of Climate Change on Agriculture Land Fertility** (Dmnl) = (1-Climate Impact on Agriculture Land Fertility Scale*(Temperature Change from Preindustrial/Climate Impact on Agriculture Land Fertility Reference Temperature)^Climate Impact on Agriculture Land Fertility Nonlinearity) **Description:** *Impact of climate change risk on cropland fertility.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in

		year 1900.
Land	A	**Effect of Climate Change on Animal Food Land Fertility** (Dmnl) = (1-Climate Impact on Animal Food Land Fertility Scale*(Temperature Change from Preindustrial/Climate Impact on Animal Food Land Fertility Reference Temperature)^Climate Impact on Animal Food Land Fertility Nonlinearity) **Description:** *Impact of climate change risk on land fertility related to animal food.* **Used by:** • Animal Food Land Fertility - Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.
Land	A	**Effect of Climate Change on Forest Land Fertility** (Dmnl) = (1-Climate Impact on Forest Land Fertility Scale*(Temperature Change from Preindustrial/Climate Impact on Forest Land Fertility Reference Temperature)^Climate Impact on Forest Land Fertility Nonlinearity) **Description:** *Impact of climate change risk on forest land fertility.* **Used by:** • Forest Land Fertility - Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.
Land	A	**Effect of CO2 Concentration on Forest Land Fertility** (Dmnl) = Max Effect of CO2 Concentration on Forest Land Fertility+(Min Effect of CO2 Concentration on Forest Land Fertility-Max Effect of CO2 Concentration on Forest Land Fertility)*((C Concentration Ratio-1)/((C Concentration Ratio-1)+Elasticity of CO2 Concentration on Forest Land Fertility)) **Description:** *Impact of carbon concentration on forest land fertility. Scaled between minimal and maximal impact.* **Used by:** • Forest Land Fertility - Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.
Land	A	**Effect of Food Purpose Agriculture Land Shortage on Forest to Agriculture Land Expansion** (Dmnl) = 2/(1+EXP(-Strength of Food Purpose Agriculture Land Expansion Effect*(MAX(0,Ratio of Crops Land Needed to Available+Ratio of Animal Food Land Needed to Available-2))))-1 **Description:** *Impact of food production purpose land shortage on land use and transformation from forest to agricultural land.* **Used by:** • Forest Agriculture Change - Parameter indicating a need for change in land use and transformation between Forest and Agriculture Land. Sign plus indicate transformation from forest to agricultural land. Sign minus indicate transformation from agricultural to forest land.
Land	A	**Effect of Food Purpose Agriculture Land Shortage on Other to Agriculture Land Expansion** (Dmnl) = 2/(1+EXP(-Strength of Food Purpose Agriculture Land Expansion Effect*(MAX(0,Ratio of Crops Land Needed to Available-1))))-1 **Description:** *Impact of food production purpose land shortage on land use and transformation from agricultural to other land.* **Used by:** • Agriculture Other Change - Parameter indicating a need for change in land use and transformation between Agriculture and Other Land. Sign plus indicate transformation from agricultural to other land. Sign minus indicate transformation from other to agricultural land.
Land	A	**Effect of Forest Land Shortage on Forest Land Expansion** (Dmnl) = 2/(1+EXP(-Strength of Forest Land Expansion Effect*(MAX(0,Ratio of Forest Land Needed to Available-1))))-1 **Description:** *Impact of forest land shortage on land use and transformation from other to forest.* **Used by:** • Forest Agriculture Change - Parameter indicating a need for change in land use and transformation between Forest and Agriculture Land. Sign plus indicate transformation from forest to agricultural land. Sign minus indicate transformation from agricultural to forest land. • Forest Other Change - Parameter indicating a need for change in land use and transformation between Forest and Other Land. Sign plus indicate transformation from forest to other land. Sign minus indicate transformation from other to forest land.

Land	C	**Effect of GDP on Animal Food Land Management Practices Elasticity** ((Year*Year*Person*Person)/($*$)) = 8e-009 **Description:** *Elasticity of impact of GDP on animal food land management practices.* **Used by:** • Effect of Management Practices on Animal Food Land Fertility - Impact of agricultural land management practices on land fertility related to animal food.
Land	C	**Effect of GDP on Animal Food Land Management Practices Increment** (Dmnl) = 30 **Description:** *Increment of impact of GDP on animal food land management practices.* **Used by:** • Effect of Management Practices on Animal Food Land Fertility - Impact of agricultural land management practices on land fertility related to animal food.
Land	C	**Effect of GDP on Cropland Management Practices Elasticity** ((Year*Year*Person*Person)/($*$)) = 1.5e-008 **Description:** *Elasticity of impact of GDP on cropland management practices.* **Used by:** • Effect of Management Practices on Agriculture Land Fertility - Impact of agricultural land management practices on cropland fertility.
Land	C	**Effect of GDP on Cropland Management Practices Increment** (Dmnl) = 7 **Description:** *Increment of impact of GDP on cropland management practices.* **Used by:** • Effect of Management Practices on Agriculture Land Fertility - Impact of agricultural land management practices on cropland fertility.
Land	C	**Effect of GDP on Forest Land Fertility Elasticity** ((Year*Year*Person*Person)/($*$)) = 5e-008 **Description:** *Elasticity of impact of GDP on forest land management practices.* **Used by:** • Effect of Management Practices on Forest Land Fertility - Impact of forest land management practices on forest land fertility.
Land	C	**Effect of GDP on Forest Management Practices Increment** (Dmnl) = 1.2 **Description:** *Increment of impact of GDP on forest land management practices.* **Used by:** • Effect of Management Practices on Forest Land Fertility - Impact of forest land management practices on forest land fertility.
Land	A	**Effect of Input Neutral Technology Change on Agricultural Land Fertility** (Dmnl) = Input Neutral Agriculture Technology/Reference Input Neutral TC in Agriculture **Description:** *Impact of technological advancement on agricultural land fertility.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900. • Fertilization Related Practices - Variable representing extent of technical advancement and management practices related to fertilization. • Animal Food Land Fertility - Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.
Land	A	**Effect of Input Neutral Technology Change on Forest Land Fertility** (Dmnl) = Input Neutral Forest Technology/Reference Input Neutral TC in Forest **Description:** *Impact of technological advancement on forest land fertility.* **Used by:** • Forest Land Fertility - Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.
Land	A	**Effect of Land Availability on Forest Land Expansion** (Dmnl) = IF THEN ELSE(TimeStrength of Land Availability on Forest Land Expansion Effect*(MAX(0,Ratio of Agricultural Land Available to Needed-1.1))))-1) **Description:** *Impact of agricultural land shortage on land use and transformation from forest*

		to agricultural land. **Used by:** • Forest Agriculture Change - Parameter indicating a need for change in land use and transformation between Forest and Agriculture Land. Sign plus indicate transformation from forest to agricultural land. Sign minus indicate transformation from agricultural to forest land.
Land	A	**Effect of Management Practices on Agriculture Land Fertility** (Dmnl) = 1+Effect of GDP on Cropland Management Practices Increment*(1-EXP(-Effect of GDP on Cropland Management Practices Elasticity*GWP per Capita*GWP per Capita)) **Description:** *Impact of agricultural land management practices on cropland fertility.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900. • Fertilization Related Practices - Variable representing extent of technical advancement and management practices related to fertilization.
Land	A	**Effect of Management Practices on Animal Food Land Fertility** (Dmnl) = 1+Effect of GDP on Animal Food Land Management Practices Increment*(1-EXP(-Effect of GDP on Animal Food Land Management Practices Elasticity*GWP per Capita*GWP per Capita)) **Description:** *Impact of agricultural land management practices on land fertility related to animal food.* **Used by:** • Animal Food Land Fertility - Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.
Land	A	**Effect of Management Practices on Forest Land Fertility** (Dmnl) = 1+Effect of GDP on Forest Management Practices Increment*(1-EXP(-Effect of GDP on Forest Land Fertility Elasticity*GWP per Capita*GWP per Capita)) **Description:** *Impact of forest land management practices on forest land fertility.* **Used by:** • Forest Land Fertility - Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.
Land	A	**Effect of Pollution on Agriculture Land Fertility** (Dmnl) = 1/C Concentration Ratio **Description:** *Impact of carbon concentration on cropland fertility.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900.
Land	A	**Effect of Pollution on Animal Food Land Fertility** (Dmnl) = 1/C Concentration Ratio **Description:** *Impact of carbon concentration on land fertility related to animal food.* **Used by:** • Animal Food Land Fertility - Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.
Land	A	**Effect of Trees Aging on Yield** (Dmnl) = Table for ETAY(Desired Production Fraction) **Description:** *Parameter accounting for decreased forest biomass production from aging tress.* **Used by:** • Forest Land Energy Yield - Forest Land Energy Yield accounting for reference forest biomass production and effect of trees age.
Land	A	**Effect of Trees Maturing on Yield** (Dmnl) = Table for ETMY(Desired Production Fraction) **Description:** *Parameter accounting for increased forest biomass production from mature trees.* **Used by:** • Forest Land Energy Yield - Forest Land Energy Yield accounting for reference forest biomass production and effect of trees age.

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 **Description:** *Parameter indicating a need for change in land use and transformation of Agriculture and Forest Land into Urban and Industrial Land due to land shortage for living and industrial purposes.* **Used by:** • Agriculture Urban Change - Parameter indicating a need for change in land use and transformation of Agriculture Land into Urban and Industrial Land. • Forest Urban Change - Parameter indicating a need for change in land use and transformation of Forest into Urban and Industrial Land.
Land	A	**Effect of Water Withdrawal on Agriculture Land Fertility** (Dmnl) = Agricultural Water Withdrawal Fulfillment Rate **Description:** *Impact of water availability on cropland fertility.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900.
Land	A	**Effect of Water Withdrawal on Animal Food Land Fertility** (Dmnl) = Agricultural Water Withdrawal Fulfillment Rate **Description:** *Impact of water availability on land fertility related to animal food.* **Used by:** • Animal Food Land Fertility - Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.
Land	C	**Elasticity of CO2 Concentration on Forest Land Fertility** (Dmnl) = 1 **Description:** *Elasticity of impact of carbon concentration on forest land fertility.* **Used by:** • Effect of CO2 Concentration on Forest Land Fertility - Impact of carbon concentration on forest land fertility. Scaled between minimal and maximal impact.
Land	A	**Energy Crops Land** (ha) = Energy Crops Land Needed **Description:** *Land area dedicated to energy crops production.* **Used by:** • Agriculture Biomass Production Land Ratio - Ratio of agricultural land area being used for crops biomass production. • Energy Crops Production - Total energy biomass production from energy crops.
Land	A	**Energy Crops Land Needed** (ha) = Total Crops Biomass Demand/Agriculture Land Energy Yield **Description:** *Land area dedicated to energy crops production.* **Used by:** • Agricultural Land Needed - Total area of required land to meed demand for food crops, energy crops and animal food. • Energy Crops Land - Land area dedicated to energy crops production. • Food Crops Land - Land area dedicated to crops production decreased by the area dedicated to energy crops production.
Land	A	**Energy Crops Production** (Biomass ton/Year) = Energy Crops Land*Agriculture Land Energy Yield **Description:** *Total energy biomass production from energy crops.* **Used by:** • Biomass Production - Total biomass production from forest and energy crops.
Land	A	**FAO Agricultural area ha** (ha) = Agricultural Land*Sqr m to ha **Description:** *Historical data and projection of total agriculture land change accoring to FAO. Source of historical data: http://faostat.fao.org* **Used by:** • FAO Land area ha - Total land accoring to FAO. Source of historical data: http://faostat.fao.org

Land	A	**FAO Arable land ha** (ha) = Arable Land ha **Description:** *Historical data and projection of arable land change accoring to FAO. Source of historical data: http://faostat.fao.org*
Land	A	**FAO Forest area ha** (ha) = Forest Land*Sqr m to ha **Description:** *Historical data and projection of total forest land change accoring to FAO. Source of historical data: http://faostat.fao.org* **Used by:** • FAO Land area ha - Total land accoring to FAO. Source of historical data: http://faostat.fao.org
Land	A	**FAO Land area ha** (ha) = FAO Agricultural area ha+FAO Forest area ha+FAO Other land ha+Urban and Industrial Land ha **Description:** *Total land accoring to FAO. Source of historical data: http://faostat.fao.org*
Land	A	**FAO Other land ha** (ha) = Other Land*Sqr m to ha **Description:** *Historical data and projection of other land change accoring to FAO. Source of historical data: http://faostat.fao.org* **Used by:** • FAO Land area ha - Total land accoring to FAO. Source of historical data: http://faostat.fao.org
Land	A	**FAO Permanent crops ha** (ha) = Permanent crops ha **Description:** *Historical data and projection of permanent crops land change accoring to FAO. Source of historical data: http://faostat.fao.org*
Land	A	**FAO Permanent meadows and pastures ha** (ha) = Permanent meadows and pastures ha **Description:** *Historical data and projection of permanent meadows and pastures land change accoring to FAO. Source of historical data: http://faostat.fao.org*
Land	S	**Fertilization Intensity** (TonNutrient/(ha*Year)) = INIT Fertilization Intensity + ∫ (Fertilization Intensity Change) **Description:** *Intencity of fertilization practices per ha per year.* **Used by:** • Fertilizer Consumption - Total consumption of fertilizers. Source of historical data: http://faostat.fao.org • Current to Max Fertilization Intensity - Gap between maximal and current intencity of fertilization practices. • Fertilization Intensity Change - Change in intencity of fertilization practices per ha per year.
Land	A	**Fertilization Intensity Change** (TonNutrient/(Year*Year*ha)) = Fertilization Intensity*Current to Max Fertilization Intensity/Time to Adjust Fertilization Intensity **Description:** *Change in intencity of fertilization practices per ha per year.* **Used by:** • Fertilization Intensity - Intencity of fertilization practices per ha per year.
Land	C	**Fertilization Intensity Ratio** (Dmnl) = 0.06 **Description:** *Ratio at which the gap between maximal and current intencity of fertilization practices is closed.* **Used by:** • Current to Max Fertilization Intensity - Gap between maximal and current intencity of fertilization practices.
Land	A	**Fertilization Related Practices** (Dmnl) = Effect of Input Neutral Technology Change on Agricultural Land Fertility*Effect of Management Practices on Agriculture Land Fertility **Description:** *Variable representing extent of technical advancement and management practices related to fertilization.* **Used by:** • Fertilizer Consumption - Total consumption of fertilizers. Source of historical data:

		http://faostat.fao.org
Land	A	**Fertilizer Consumption** (TonNutrient/Year) = Fertilization Intensity*Agricultural Land*Sqr m to ha*Fertilization Related Practices **Description:** *Total consumption of fertilizers. Source of historical data: http://faostat.fao.org* **Used by:** • Impact of Fertilizer Consumption on Biodiversity - Nonlinear function representing impact of fertilization practices on species carrying capacity.
Land	A	**Food Crops Land** (ha) = Crops Potential Agriculture Land-Energy Crops Land Needed **Description:** *Land area dedicated to crops production decreased by the area dedicated to energy crops production.* **Used by:** • Land for Vegetal Food - Calculated historical data and projection for land for vegetal food according to FAO. Source of historical data: http://faostat.fao.org • Vegetal Food Production - Total vegetal food production due to food crops land availability and food crops land yield. • Ratio of Crops Land Needed to Available - Ratio of food crops land needed to available.
Land	A	**Food Crops Land Needed** (ha) = Crops Production Needed/Food Crops Land Yield **Description:** *Land area required for food crops production due to food demand.* **Used by:** • Crops vs Animal Food Land Needed - Ratio of land needed for vegetal versus land needed for animal food. Used as one of drivers for land use change. • Agricultural Land Needed - Total area of required land to meed demand for food crops, energy crops and animal food. • Vegetal Food Production - Total vegetal food production due to food crops land availability and food crops land yield. • Ratio of Crops Land Needed to Available - Ratio of food crops land needed to available.
Land	A	**Food Crops Land Yield** (kcal/(ha*Year)) = Cropland Land Fertility*Nominal Food Crops Land Productivity **Description:** *Yield from a unit food crops land area.* **Used by:** • Vegetal Food Yield - Calculated historical data and projection of vegetal food land yield according to FAO. Source of historical data: http://faostat.fao.org • Food Crops Land Needed - Land area required for food crops production due to food demand. • Vegetal Food Production - Total vegetal food production due to food crops land availability and food crops land yield.
Land	F,A	**Forest Agriculture Allocation Rate** (m*m/Year) = MAX(0, Forest Agriculture Change*(Forest Land-Forest Protected Land)/(Forest to Agriculture Land Allocation Time*Deforestation Time Factor))+MIN(0,Forest Agriculture Change*(Agricultural Land-Agriculture Protected Land)/Agriculture to Forest Land Allocation Time) **Description:** *Process of transformation between Forest and Agriculture Land.* **Used by:** • Agricultural Land - Total Agriculture Land. • Forest Land - Total Forest Land.
Land	A	**Forest Agriculture Change** (Dmnl) = -Effect of Forest Land Shortage on Forest Land Expansion-Effect of Land Availability on Forest Land Expansion+Effect of Food Purpose Agriculture Land Shortage on Forest to Agriculture Land Expansion*Zero Net Deforestation and Forest Degradation Scenarios **Description:** *Parameter indicating a need for change in land use and transformation between Forest and Agriculture Land. Sign plus indicate transformation from forest to agricultural land. Sign minus indicate transformation from agricultural to forest land.* **Used by:** • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land.

Land	A	**Forest Baseline** (ha) = Forest Land ha **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Forest BioenergyPlus** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Forest Biomass Production** (Biomass ton/Year) = MIN(Total Forest Biomass Demand, Harvest Available Forest Land*Forest Land Energy Yield*(1-Biomass Production Processing Loss)) **Description:** *Total biomass production from forest.* **Used by:** • Actual Forest Land Harvested - Forest biomass production expressed in terms of forest land harvested excluding forest biomass production processing loss. • Biomass Production - Total biomass production from forest and energy crops.
Land	A	**Forest Dietshift** (ha) = Forest Land ha **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Forest GLOBIOM ha** (ha) = Forest Land ha **Description:** *Projection of forest land change according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.*
Land	S	**Forest Land** (m*m) = INIT Forest Land + ∫ (-Forest Agriculture Allocation Rate-Forest Other Land Allocation Rate-Forest Urban Industrial Land Allocation Rate) **Description:** *Total Forest Land.* **Used by:** • Impact of Forest Land Changes on Biodiversity - Nonlinear function representing impact of forest land use change on species carrying capacity. • Forest Biomass Production Land Ratio - Ratio of forest land area being used for biomass production. • Total Change in Forest Ecosystem Value - Total ecosystem value of forest. • Forest Land Change - Ratio of forest land area change compared to its initial area in year 1900. • Deforestation - Changes in forest land area from the area in year 1900. • FAO Forest area ha - Historical data and projection of total forest land change accoring to FAO. Source of historical data: http://faostat.fao.org • Forest Land ha - Total Forest Land in ha. • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land. • Forest Urban Industrial Land Allocation Rate - Transformation process of Forest into Urban and Industrial Land. • Harvest Available Forest Land - Actual area of Forest available to be harvested. • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land. • Total Land - Total considered land.
Land	A	**Forest Land Energy Yield** (Biomass ton/(Year*ha)) = Forest Land Yield*Effect of Trees Maturing on Yield*Effect of Trees Aging on Yield **Description:** *Forest Land Energy Yield accounting for reference forest biomass production and effect of trees age.* **Used by:** • Forest Biomass Production - Total biomass production from forest. • Forest Land Needed to be Harvested - Total area of Forest needed for biomass production purposes accounting for total demand for forest biomass, average forest land yield and average losses in forest biomass production process. • Actual Forest Land Harvested - Forest biomass production expressed in terms of forest land harvested excluding forest biomass production processing loss.
Land	A	**Forest Land Fertility** (Dmnl) = Normal Forest Land Fertility*Effect of Climate Change on Forest Land Fertility*Effect of

		Management Practices on Forest Land Fertility*Effect of CO2 Concentration on Forest Land Fertility *Effect of Biodiversity on Forest Land Fertility*Effect of Input Neutral Technology Change on Forest Land Fertility **Description:** *Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.* **Used by:** • Forest Land Yield - Actual annual amount of forest biomass production from unit forest land area for given Forest Land Fertility.
Land	C	**Forest Land Fraction Harvested excluding Protected Area** (Dmnl) = 0.5 **Description:** *Fraction of Forest dedicated to be harvested.* **Used by:** • Harvest Available Forest Land - Actual area of Forest available to be harvested.
Land	A	**Forest Land ha** (ha) = Forest Land*Sqr m to ha **Description:** *Total Forest Land in ha.* **Used by:** • Forest Dietshift - WWF Scenario variable. Further development required. • Forest Baseline - WWF Scenario variable. Further development required. • Forest GLOBIOM ha - Projection of forest land change according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.
Land	A	**Forest Land Needed to be Harvested** (ha) = (Total Forest Biomass Demand/(1-Biomass Production Processing Loss))/Forest Land Energy Yield **Description:** *Total area of Forest needed for biomass production purposes accounting for total demand for forest biomass, average forest land yield and average losses in forest biomass production process.* **Used by:** • Ratio of Forest Land Needed to Available - Ratio of Forest area needed for forest biomass production purposes to actual available area.
Land	A	**Forest Land Yield** (Biomass ton/(Year*ha)) = Forest Land Fertility*Nominal Energy Forest Land Productivity **Description:** *Actual annual amount of forest biomass production from unit forest land area for given Forest Land Fertility.* **Used by:** • Potential Biomass Production - Potential Biomass Production for given area to be harvested, actual yield from ha and excluding forest biomass production processing losses. • Forest Land Energy Yield - Forest Land Energy Yield accounting for reference forest biomass production and effect of trees age.
Land	A	**Forest Other Change** (Dmnl) = -Effect of Forest Land Shortage on Forest Land Expansion **Description:** *Parameter indicating a need for change in land use and transformation between Forest and Other Land. Sign plus indicate transformation from forest to other land. Sign minus indicate transformation from other to forest land.* **Used by:** • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land.
Land	F,A	**Forest Other Land Allocation Rate** (m*m/Year) = MAX(0, Forest Other Change*(Forest Land-Forest Protected Land)/Forest to Other Land Allocation Time)+MIN(0,Forest Other Change*(Other Land-Other Protected Land)/Other to Forest Land Allocation Time) **Description:** *Process of transformation between Forest and Other Land.* **Used by:** • Forest Land - Total Forest Land. • Other Land - Land not classified as Agricultural area, Forest area or Urban and Industrial Land.
Land	C	**Forest ProNature** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*

Land	C	**Forest ProNaturePlus** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	S	**Forest Protected Land** (m*m) = INIT Forest Protected Land + ∫ (Forest Protected Land Change) **Description:** *Area of forest land indicated as protected. Source of historical data: http://www.fao.org/docrep/003/x4108e/X4108E11.htm# P3941_174357* **Used by:** • Current to Max Forest Protected Land - Gap being closed between current and max forest protected land. • Forest Protected Land Change - Changes in area of forest land indicated as protected. • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land. • Forest Urban Industrial Land Allocation Rate - Transformation process of Forest into Urban and Industrial Land. • Harvest Available Forest Land - Actual area of Forest available to be harvested. • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land.
Land	A	**Forest Protected Land Change** (m*m/Year) = DELAY3(Forest Protected Land*Current to Max Forest Protected Land,Time to Adjust Forest Protected Land) **Description:** *Changes in area of forest land indicated as protected.* **Used by:** • Forest Protected Land - Area of forest land indicated as protected. Source of historical data: http://www.fao.org/docrep/003/x4108e/X4108E11.htm# P3941_174357
Land	C	**Forest Protected Land Change Ratio** (1/Year) = 0.1 **Description:** *Ratio at which the gap between current and max forest protected land is closed.* **Used by:** • Current to Max Forest Protected Land - Gap being closed between current and max forest protected land.
Land	C	**Forest Protected Land constant** (m*m) = 4.78632e+012 **Description:** *Area of Forest Land not transformable into other kind of lands.*
Land	C	**Forest to Agriculture Land Allocation Time** (Year) = 130 **Description:** *Average time which natural transformation of Forest to Agriculture Land would take.* **Used by:** • Forest Agriculture Allocation Rate - Process of transformation between Forest and Agriculture Land.
Land	C	**Forest to Other Land Allocation Time** (Year) = 50 **Description:** *Average time which natural transformation of Forest to Other Land would take.* **Used by:** • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land.
Land	C	**Forest to Urban Land Allocation Time** (Year) = 10 **Description:** *Average time which natural transformation of Forest to Urban and Industrial Land would take.* **Used by:** • Forest Urban Industrial Land Allocation Rate - Transformation process of Forest into Urban and Industrial Land.
Land	A	**Forest Urban Change** (Dmnl) = Effect of Urban and Industrial Land Shortage on the Land Expansion **Description:** *Parameter indicating a need for change in land use and transformation of Forest into Urban and Industrial Land.*

		Used by: • Forest Urban Industrial Land Allocation Rate - Transformation process of Forest into Urban and Industrial Land.
Land	A	**Forest Urban Industrial Land Allocation Rate** (m*m/Year) = MAX(0, Forest Urban Change*(Forest Land-Forest Protected Land)/Forest to Urban Land Allocation Time) **Description:** *Transformation process of Forest into Urban and Industrial Land.* **Used by:** • Forest Land - Total Forest Land. • Urban and Industrial Land m - Total Urban and Industrial Land.
Land	A	**Half Measures** (Dmnl) = (1-SCENARIO Half Measures)*1+SCENARIO Half Measures*(1+RAMP(Half Measures Scenario Ramp Change, 2010, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Zero Net Deforestation and Forest Degradation Scenarios - WWF Scenario variable. Further development required.
Land	A	**Half Measures Deforestation Time Factor** (Dmnl) = SCENARIO Half Measures*(RAMP(Half Measures Scenario Ramp Time Change, 2019, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Deforestation Time Factor - WWF Scenario variable. Further development required.
Land	C	**Half Measures Scenario Ramp Change** (1/Year) = -0.0215 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Half Measures - WWF Scenario variable. Further development required.
Land	C	**Half Measures Scenario Ramp Time Change** (1/Year) = 1 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Half Measures Deforestation Time Factor - WWF Scenario variable. Further development required.
Land	A	**Harvest Available Forest Land** (ha) = Forest Land Fraction Harvested excluding Protected Area*MAX(0, (Forest Land-Forest Protected Land))*Sqr m to ha **Description:** *Actual area of Forest available to be harvested.* **Used by:** • Ratio of Forest Land Needed to Available - Ratio of Forest area needed for forest biomass production purposes to actual available area. • Potential Biomass Production - Potential Biomass Production for given area to be harvested, actual yield from ha and excluding forest biomass production processing losses. • Forest Biomass Production - Total biomass production from forest.
Land	S	**Increase to Demand Vegetal Calories** (Dmnl) = 1 + ∫ (Change to Demand Vegetal Calories) **Description:** *Increase in daily demand of vegetal food calories.* **Used by:** • Change to Demand Vegetal Calories - Change to increase in vegetal food demand. • SCEN Demand Vegetal Calor Consum per Capita per Day - Daily demand of vegetal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.
Land	C	**INIT Agricultural Land** (m*m) = 4e+013 **Description:** *The area of agriculture land for year 1900.* **Used by:** • Impact of Agricultural Land Changes on Biodiversity - Nonlinear function representing impact of agricultural land use change on species carrying capacity.

		• Total Change in Cropland Ecosystem Value - Total ecosystem value of cropland. • Agricultural Land Change - Ratio of agricultural land area change compared to its initial area in year 1900. • Agricultural Land - Total Agriculture Land.
Land	C	**INIT Fertilization Intensity** (TonNutrient/(ha*Year)) = 0.0001 **Description:** *Intencity of fertilization practices per ha per year in year 1900.* **Used by:** • Fertilization Intensity - Intencity of fertilization practices per ha per year.
Land	C	**INIT Forest Land** (m*m) = 4.41e+013 **Description:** *The area of forest land for year 1900.* **Used by:** • Impact of Forest Land Changes on Biodiversity - Nonlinear function representing impact of forest land use change on species carrying capacity. • Total Change in Forest Ecosystem Value - Total ecosystem value of forest. • Forest Land Change - Ratio of forest land area change compared to its initial area in year 1900. • Deforestation - Changes in forest land area from the area in year 1900. • Forest Land - Total Forest Land.
Land	C	**INIT Forest Protected Land** (m*m) = 2.82254e+009 **Description:** *Area of forest land indicated as protected in year 1900.* **Used by:** • Forest Protected Land - Area of forest land indicated as protected. Source of historical data: http://www.fao.org/docrep/003/x4108e/X4108E11.htm#P3941_174357
Land	C	**INIT Other Land** (m*m) = 4.1e+013 **Description:** *The area of other land for year 1900.* **Used by:** • Impact of Other Land Changes on Biodiversity - Nonlinear function representing impact of other land use change on species carrying capacity. • Total Change in Other Land Ecosystem Value - Total ecosystem value of other land. • Other Land - Land not classified as Agricultural area, Forest area or Urban and Industrial Land.
Land	C	**INIT SCENARIO Do Nothing Cropland Land Fertility** (Dmnl) = 2.839 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • SCENARIO Do Nothing Cropland Land Fertility - WWF Scenario variable. Further development required.
Land	C	**INIT Urban and Industrial Land** (m*m) = 4e+011 **Description:** *The area of urban and industrial land for year 1900.* **Used by:** • Urban and Industrial Land m - Total Urban and Industrial Land.
Land	S	**Input Neutral Agriculture Technology** (Dmnl) = Reference Input Neutral TC in Agriculture + ∫ (Input Neutral Technology Change in Agriculture) **Description:** *Exogenous variable representing technological advancement and its positive impact on agricultural land fertility.* **Used by:** • Effect of Input Neutral Technology Change on Agricultural Land Fertility - Impact of technological advancement on agricultural land fertility.
Land	S	**Input Neutral Forest Technology** (Dmnl) = Reference Input Neutral TC in Forest + ∫ (Input Neutral Technology Change in Forest) **Description:** *Exogenous variable representing technological advancement and its positive*

		impact on forest land fertility. **Used by:** • Effect of Input Neutral Technology Change on Forest Land Fertility - Impact of technological advancement on forest land fertility.
Land	A	**Input Neutral Technology Change in Agriculture** (1/Year) = Input Neutral Technology Change in Agriculture Factor **Description:** *Change in technological advancement related to agricultural land fertility.* **Used by:** • Input Neutral Agriculture Technology - Exogenous variable representing technological advancement and its positive impact on agricultural land fertility.
Land	C	**Input Neutral Technology Change in Agriculture Factor** (1/Year) = 0.01 **Description:** *Factor change of technological advancement related to agricultural land fertility.* **Used by:** • Input Neutral Technology Change in Agriculture - Change in technological advancement related to agricultural land fertility.
Land	A	**Input Neutral Technology Change in Forest** (1/Year) = Input Neutral Technology Change in Forest Factor **Description:** *Change in technological advancement related to forest land fertility.* **Used by:** • Input Neutral Forest Technology - Exogenous variable representing technological advancement and its positive impact on forest land fertility.
Land	C	**Input Neutral Technology Change in Forest Factor** (1/Year) = 0.001 **Description:** *Factor change of technological advancement related to forest land fertility.* **Used by:** • Input Neutral Technology Change in Forest - Change in technological advancement related to forest land fertility.
Land	A	**Land for Animal Food** (ha) = Animal Food Potential Agriculture Land **Description:** *Calculated historical data and projection for land for animal food according to FAO. Source of historical data: http://faostat.fao.org*
Land	A	**Land for Vegetal Food** (ha) = Food Crops Land **Description:** *Calculated historical data and projection for land for vegetal food according to FAO. Source of historical data: http://faostat.fao.org*
Land	C	**Max Animal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = 850 **Description:** *Max daily demand for animal food calories per person.* **Used by:** • Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	C	**Max Effect of CO2 Concentration on Forest Land Fertility** (Dmnl) = 1 **Description:** *Max impact of carbon concentration on forest land fertility.* **Used by:** • Effect of CO2 Concentration on Forest Land Fertility - Impact of carbon concentration on forest land fertility. Scaled between minimal and maximal impact.
Land	C	**Max Fertilization Intensity** (TonNutrient/(ha*Year)) = 0.003 **Description:** *Maximal intencity of fertilization practices per ha per year.* **Used by:** • Current to Max Fertilization Intensity - Gap between maximal and current intencity of fertilization practices.
Land	C	**Max Forest Protected Land** (m*m) = 5e+012 **Description:** *Maximum area of forest land that can become protected.* **Used by:** • Current to Max Forest Protected Land - Gap being closed between current and max

		forest protected land.
Land	C	**Max Impact of Biodiversity on Forest Land Fertility** (Dmnl) = 1 **Description:** *Max impact of mean species abundance on forest land fertility.* **Used by:** • Effect of Biodiversity on Forest Land Fertility - Impact of mean species abundance on forest land fertility. Scaled between minimal and maximal impact. Relative level is the value of mean species abundance in year 1900.
Land	C	**Max Vegetal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = 3000 **Description:** *Max daily demand for vegetal food calories per person.* **Used by:** • Demand Vegetal Calories Consumption per Capita per Day - Daily demand of vegetal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	C	**MAX Vegetal vs Animal Food Dedicated Land Ratio** (Dmnl) = 0.7 **Description:** *Scaling parameter indicating maximal percentage of vegetal versus animal food production land.* **Used by:** • Vegetal vs Animal Food Dedicated Land - Dynamic parameter responsible for allocation of land between crops and animal food production land in response to specific land demand.
Land	C	**Meadows and Pastures Percentage of Agriculture Land** (Dmnl) = 0.689 **Description:** *Percentage of agricultural land constituting the meadows and pastures land.* **Used by:** • Permanent meadows and pastures ha - Area of permanent meadows and pastures land.
Land	C	**Min Animal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = 10 **Description:** *Min daily demand for animal food calories per person.* **Used by:** • Demand Animal Calories Consumption per Capita per Day - Daily demand of animal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	C	**Min Effect of CO2 Concentration on Forest Land Fertility** (Dmnl) = 2 **Description:** *Min impact of carbon concentration on forest land fertility.* **Used by:** • Effect of CO2 Concentration on Forest Land Fertility - Impact of carbon concentration on forest land fertility. Scaled between minimal and maximal impact.
Land	C	**Min Impact of Biodiversity on Forest Land Fertility** (Dmnl) = 0.1 **Description:** *Min impact of mean species abundance on forest land fertility.* **Used by:** • Effect of Biodiversity on Forest Land Fertility - Impact of mean species abundance on forest land fertility. Scaled between minimal and maximal impact. Relative level is the value of mean species abundance in year 1900.
Land	C	**Min Urban and Industrial Land per Capita** (m*m/Person) = 10 **Description:** *Minimal average land area of Urban and Industrial Land required per Capita.* **Used by:** • Ratio of Min Urban and Industrial Land Needed to Available - Ratio comparing minimal required Urban and Industrial Land per Capita to actual available area.
Land	C	**Min Vegetal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = 750 **Description:** *Min daily demand for vegetal food calories per person.* **Used by:** • Demand Vegetal Calories Consumption per Capita per Day - Daily demand of

		vegetal food calories per person. Related to wealth of the population as a driver for food demand increase. Scaled between max and min demand level.
Land	C	**MIN Vegetal vs Animal Food Dedicated Land Ratio** (Dmnl) = 0.21 **Description:** *Scaling parameter indicating minimal percentage of vegetal versus animal food production land.* **Used by:** • Vegetal vs Animal Food Dedicated Land - Dynamic parameter responsible for allocation of land between crops and animal food production land in response to specific land demand.
Land	C	**Nominal Animal Food Land Yield** (kcal/(ha*Year)) = 10000 **Description:** *Reference annual amount of food yield from unit animal food land area for year 1900.* **Used by:** • Animal Food Land Yield - Yield from a unit animal food land area.
Land	C	**Nominal Energy Agriculture Land Productivity** (Biomass ton/(ha*Year)) = 12.5 **Description:** *Reference annual amount of energy crops biomass yield from unit energy crops land area.* **Used by:** • Agriculture Land Energy Yield - Yield from a unit energy crops land area.
Land	C	**Nominal Energy Forest Land Productivity** (Biomass ton/(Year*ha)) = 50 **Description:** *Reference annual amount of forest biomass production from unit forest land area.* **Used by:** • Forest Land Yield - Actual annual amount of forest biomass production from unit forest land area for given Forest Land Fertility.
Land	C	**Nominal Food Crops Land Productivity** (kcal/(ha*Year)) = 1.8e+006 **Description:** *Reference annual amount of food yield from unit food crops land area for year 1900.* **Used by:** • Food Crops Land Yield - Yield from a unit food crops land area.
Land	C	**Normal Animal Food Land Fertility** (Dmnl) = 1 **Description:** *Reference value of animal food land fertility in year 1900.* **Used by:** • Animal Food Land Fertility - Multiplier inidcating animal food land fertility i.e. how many times the nominal animal food land yield has changed since the reference value in year 1900.
Land	C	**Normal Cropland Fertility** (Dmnl) = 1 **Description:** *Reference value of cropland fertility in year 1900.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900.
Land	C	**Normal Forest Land Fertility** (Dmnl) = 1 **Description:** *Reference value of forest land fertility in year 1900.* **Used by:** • Forest Land Fertility - Multiplier inidcating forest land fertility i.e. how many times the nominal forest land yield has changed since the reference value in year 1900.
Land	S	**Other Land** (m*m) = INIT Other Land + ∫ (Agriculture Other Land Allocation Rate+Forest Other Land Allocation Rate) **Description:** *Land not classified as Agricultural area, Forest area or Urban and Industrial Land.*

		Used by: • Impact of Other Land Changes on Biodiversity - Nonlinear function representing impact of other land use change on species carrying capacity. • Total Change in Other Land Ecosystem Value - Total ecosystem value of other land. • FAO Other land ha - Historical data and projection of other land change accoring to FAO. Source of historical data: http://faostat.fao.org • Other Land ha - Land not classified as Agricultural area, Forest area or Urban and Industrial Land in ha. • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land. • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land. • Total Land - Total considered land.
Land	A	**Other Land Baseline** (ha) = Other Land ha **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Other Land BioenergyPlus** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Other Land Dietshift** (ha) = Other Land ha **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Other Land GLOBIOM ha** (ha) = Other Land ha **Description:** *Projection of other land change according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.*
Land	A	**Other Land ha** (ha) = Other Land*Sqr m to ha **Description:** *Land not classified as Agricultural area, Forest area or Urban and Industrial Land in ha.* **Used by:** • Other Land Dietshift - WWF Scenario variable. Further development required. • Other Land Baseline - WWF Scenario variable. Further development required. • Other Land GLOBIOM ha - Projection of other land change according to GLOBIOM model. Source of projection data: GLOBIOM model, IIASA.
Land	C	**Other Land ProNature** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Other Land ProNaturePlus** (ha) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Other Protected Land** (m*m) = 5e+012 **Description:** *Area of Other Land not transformable into other kind of lands.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land. • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land.
Land	A	**Other to Agriculture Land Allocation Time** (Year) = 60+ProNature Time Factor **Description:** *Average time which natural transformation of Other to Agriculture Land would take.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land.
Land	C	**Other to Forest Land Allocation Time** (Year) = 40

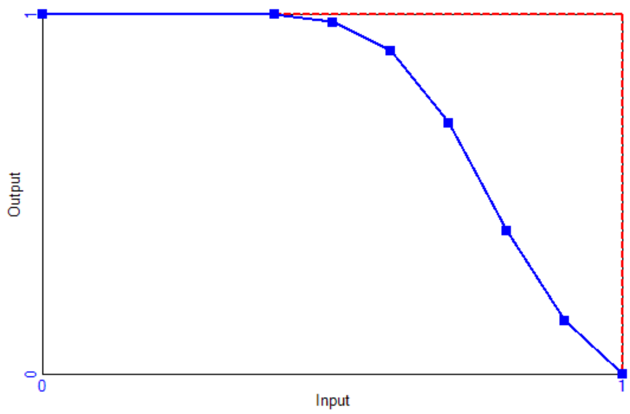
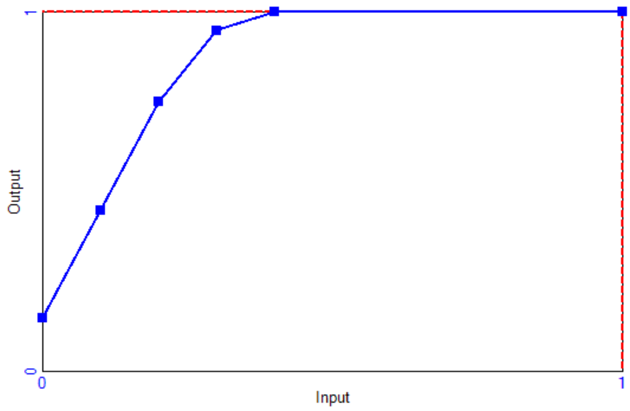
		Description: *Average time which natural transformation of Other to Forest Land would take.* **Used by:** • Forest Other Land Allocation Rate - Process of transformation between Forest and Other Land.
Land	A	**Permanent crops ha** (ha) = Agricultural Land*Sqr m to ha*Permanent Crops Percentage of Agriculture Land **Description:** *Area of permanent crops land.* **Used by:** • Animal Food Potential Agriculture Land - Land area dedicated to animal and food for animal production. • FAO Permanent crops ha - Historical data and projection of permanent crops land change accoring to FAO. Source of historical data: http://faostat.fao.org • Crops Potential Agriculture Land - Land area dedicated to crops production.
Land	C	**Permanent Crops Percentage of Agriculture Land** (Dmnl) = 0.024 **Description:** *Percentage of agricultural land constituting the permanent crops land.* **Used by:** • Permanent crops ha - Area of permanent crops land.
Land	A	**Permanent meadows and pastures ha** (ha) = Agricultural Land*Sqr m to ha*Meadows and Pastures Percentage of Agriculture Land **Description:** *Area of permanent meadows and pastures land.* **Used by:** • Animal Food Potential Agriculture Land - Land area dedicated to animal and food for animal production. • FAO Permanent meadows and pastures ha - Historical data and projection of permanent meadows and pastures land change accoring to FAO. Source of historical data: http://faostat.fao.org
Land	A	**Potential Biomass Production** (Biomass ton/Year) = Forest Land Yield*Harvest Available Forest Land*(1-Biomass Production Processing Loss) **Description:** *Potential Biomass Production for given area to be harvested, actual yield from ha and excluding forest biomass production processing losses.* **Used by:** • Desired Production Fraction - Ratio of demand for forest biomass to potential production.
Land	A	**ProNature** (Dmnl) = (1-SCENARIO ProNature)*1+SCENARIO ProNature*(1+RAMP(-0.002, 2010, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land.
Land	A	**ProNature Time Factor** (Year) = SCENARIO ProNature*(RAMP(ProNatureSlope, 2010, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Other to Agriculture Land Allocation Time - Average time which natural transformation of Other to Agriculture Land would take.
Land	A	**ProNaturePlus** (Dmnl) = (1-SCENARIO ProNaturePlus)*1+SCENARIO ProNaturePlus*(1+RAMP(-0.1, 2010, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Agriculture Other Land Allocation Rate - Process of transformation between Agriculture and Other Land.
Land	C	**ProNatureSlope** (Dmnl) = 1 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • ProNature Time Factor - WWF Scenario variable. Further development required.
Land	A	**Ratio of Agricultural Land Available to Needed** (Dmnl) = Agricultural Land Available/Agricultural Land Needed

		Description: *Ratio of agricultural land available to needed indicating shortage of land available for agricultural production.* **Used by:** • Effect of Land Availability on Forest Land Expansion - Impact of agricultural land shortage on land use and transformation from forest to agricultural land.
Land	A	**Ratio of Animal Food Land Needed to Available** (Dmnl) = Animal Food Land Needed/Animal Food Land **Description:** *Ratio of animal food land needed to available.* **Used by:** • Effect of Food Purpose Agriculture Land Shortage on Forest to Agriculture Land Expansion - Impact of food production purpose land shortage on land use and transformation from forest to agricultural land.
Land	A	**Ratio of Crops Land Needed to Available** (Dmnl) = Food Crops Land Needed/Food Crops Land **Description:** *Ratio of food crops land needed to available.* **Used by:** • Effect of Food Purpose Agriculture Land Shortage on Other to Agriculture Land Expansion - Impact of food production purpose land shortage on land use and transformation from agricultural to other land. • Effect of Food Purpose Agriculture Land Shortage on Forest to Agriculture Land Expansion - Impact of food production purpose land shortage on land use and transformation from forest to agricultural land.
Land	A	**Ratio of Forest Land Needed to Available** (Dmnl) = Forest Land Needed to be Harvested/Harvest Available Forest Land **Description:** *Ratio of Forest area needed for forest biomass production purposes to actual available area.* **Used by:** • Effect of Forest Land Shortage on Forest Land Expansion - Impact of forest land shortage on land use and transformation from other to forest.
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 **Description:** *Ratio comparing minimal required Urban and Industrial Land per Capita to actual available area.* **Used by:** • Effect of Urban and Industrial Land Shortage on the Land Expansion - Parameter indicating a need for change in land use and transformation of Agriculture and Forest Land into Urban and Industrial Land due to land shortage for living and industrial purposes.
Land	C	**Reference Input Neutral TC in Agriculture** (Dmnl) = 1 **Description:** *Reference variable representing technological advancement and its positive impact on agricultural land fertility in year 1900.* **Used by:** • Effect of Input Neutral Technology Change on Agricultural Land Fertility - Impact of technological advancement on agricultural land fertility. • Input Neutral Agriculture Technology - Exogenous variable representing technological advancement and its positive impact on agricultural land fertility.
Land	C	**Reference Input Neutral TC in Forest** (Dmnl) = 1 **Description:** *Reference variable representing technological advancement and its positive impact on forest land fertility in year 1900.* **Used by:** • Effect of Input Neutral Technology Change on Forest Land Fertility - Impact of technological advancement on forest land fertility. • Input Neutral Forest Technology - Exogenous variable representing technological advancement and its positive impact on forest land fertility.
Land	A	**SCEN Demand Animal Calor Consum per Capita per Day** (kcal/(Person*Day)) = (1- SCENARIO Diet Shift) *(Demand Animal Calories Consumption per Capita per Day) + SCENARIO Diet Shift * (IF THEN ELSE (Time<2011,Demand Animal Calories Consumption per Capita per Day,Starting in 2010 Demand Animal Calories Consumption per Capita per Day))

		Description: *Daily demand of animal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.* **Used by:** • Animal Food Production Needed - Total demand for animal food accounting for total population and annual food requirements per capita.
Land	A	**SCEN Demand Vegetal Calor Consum per Capita per Day** (kcal/(Person*Day)) = (1- SCENARIO Diet Shift) *(Demand Vegetal Calories Consumption per Capita per Day) +SCENARIO Diet Shift * (IF THEN ELSE (Time<2011,Demand Vegetal Calories Consumption per Capita per Day,Demand Vegetal Calories Consumption per Capita per Day*Increase to Demand Vegetal Calories)) **Description:** *Daily demand of vegetal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.* **Used by:** • Crops Production Needed - Total demand for vegetal food accounting for total population and annual food requirements per capita.
Land	C	**SCENARIO Diet Shift** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Diet shift scenario assumes future animal calories consumption constant at 2010 level. An increase in vegetal calories consumption is to follow in order to make up for constant amount of animal calories consumption.* **Used by:** • Vegetal Calories Baseline - WWF Scenario variable. Further development required. • Vegetal Calories Dietshift - WWF Scenario variable. Further development required. • SCEN Demand Vegetal Calor Consum per Capita per Day - Daily demand of vegetal food calories per person. Variable enable testing business as usual scenario and diet shift scenario. • SCEN Demand Animal Calor Consum per Capita per Day - Daily demand of animal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.
Land	C	**SCENARIO Do Nothing** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900.
Land	A	**SCENARIO Do Nothing Change in Cropland Land Fertility** (1/Year) = SCENARIO Do Nothing Cropland Land Fertility*SCENARIO Do Nothing Cropland Land Fertility Change Factor **Description:** *WWF Scenario variable. Further development required.* **Used by:** • SCENARIO Do Nothing Cropland Land Fertility - WWF Scenario variable. Further development required.
Land	S	**SCENARIO Do Nothing Cropland Land Fertility** (Dmnl) = INIT SCENARIO Do Nothing Cropland Land Fertility + ∫ (SCENARIO Do Nothing Change in Cropland Land Fertility) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Cropland Land Fertility - Multiplier inidcating food crops land fertility i.e. how many times the nominal food crops land yield has changed since the reference value in year 1900. • SCENARIO Do Nothing Change in Cropland Land Fertility - WWF Scenario variable. Further development required.
Land	C	**SCENARIO Do Nothing Cropland Land Fertility Change Factor** (1/Year) = 0.0103 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • SCENARIO Do Nothing Change in Cropland Land Fertility - WWF Scenario variable. Further development required.
Land	C	**SCENARIO Half Measures** (Dmnl [0,1,1]) = 0

		Description: *WWF Scenario variable. Further development required.* **Used by:** • Half Measures - WWF Scenario variable. Further development required. • Half Measures Deforestation Time Factor - WWF Scenario variable. Further development required.
Land	C	**SCENARIO ProNature** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • ProNature - WWF Scenario variable. Further development required. • ProNature Time Factor - WWF Scenario variable. Further development required.
Land	C	**SCENARIO ProNaturePlus** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • ProNaturePlus - WWF Scenario variable. Further development required.
Land	C	**SCENARIO Target** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Target Deforestation Time Factor - WWF Scenario variable. Further development required. • Target - WWF Scenario variable. Further development required.
Land	C	**SCENARIO Target Delayed** (Dmnl [0,1,1]) = 0 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Target Delayed - WWF Scenario variable. Further development required. • Target Delayed Deforestation Time Factor - WWF Scenario variable. Further development required.
Land	C	**Sqr m to ha** (ha/(m*m)) = 0.0001 **Description:** *Coefficient to convert sqr meters into ha.* **Used by:** • Forest Biomass Production Land Ratio - Ratio of forest land area being used for biomass production. • Total Change in Forest Ecosystem Value - Total ecosystem value of forest. • Total Change in Cropland Ecosystem Value - Total ecosystem value of cropland. • Total Change in Other Land Ecosystem Value - Total ecosystem value of other land. • Agricultural Water Demand - Total water demand for agricultural purposes. Source of Historical Data: International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/ • Irrigated Agriculture Land - Area of agricultural land on which the supply of water is only due to irrigation. Source of Historical Data: Gleick,P.H., et al. The World's Water Volume 7: The Biennial Report on Freshwater Resources. Washington: Island Press, 2012. • Rainfed Agriculture Land - Area of agricultural land on which the supply of water is only due to rain. • Deforestation - Changes in forest land area from the area in year 1900. • Fertilizer Consumption - Total consumption of fertilizers. Source of historical data: http://faostat.fao.org • Urban and Industrial Land ha - Total Urban and Industrial Land in ha. • Permanent meadows and pastures ha - Area of permanent meadows and pastures land. • FAO Agricultural area ha - Historical data and projection of total agriculture land change accoring to FAO. Source of historical data: http://faostat.fao.org

		• FAO Forest area ha - Historical data and projection of total forest land change accoring to FAO. Source of historical data: http://faostat.fao.org • Permanent crops ha - Area of permanent crops land. • FAO Other land ha - Historical data and projection of other land change accoring to FAO. Source of historical data: http://faostat.fao.org • Other Land ha - Land not classified as Agricultural area, Forest area or Urban and Industrial Land in ha. • Forest Land ha - Total Forest Land in ha. • Agriculture Land ha - Total Agriculture Land in ha. • Arable Land ha - Area of arable land. • Harvest Available Forest Land - Actual area of Forest available to be harvested.
Land	S	**Starting in 2010 Demand Animal Calories Consumption per Capita per Day** (kcal/(Person*Day)) = 0 + ∫ (Change to 2010 Demand Animal Calories-Decrease to Change to 2010 Demand Animal Calories) **Description:** *Daily demand of animal food calories per person as of year 2010.* **Used by:** • Decrease to Change to 2010 Demand Animal Calories - Change in animal food calories demand due to diet shift. • SCEN Demand Animal Calor Consum per Capita per Day - Daily demand of animal food calories per person. Variable enable testing business as usual scenario and diet shift scenario.
Land	C	**Strength of Food Purpose Agriculture Land Expansion Effect** (Dmnl) = 2 **Description:** *Strength of the effect of land shortage for food purposes on transformation of Forest and Other Land into Agriculture Land.* **Used by:** • Effect of Food Purpose Agriculture Land Shortage on Other to Agriculture Land Expansion - Impact of food production purpose land shortage on land use and transformation from agricultural to other land. • Effect of Food Purpose Agriculture Land Shortage on Forest to Agriculture Land Expansion - Impact of food production purpose land shortage on land use and transformation from forest to agricultural land.
Land	C	**Strength of Forest Land Expansion Effect** (Dmnl) = 0.5 **Description:** *Strength of the effect of land shortage for energy purposes forest biomass on transformation of Agriculture and Other Land into Forest.* **Used by:** • Effect of Forest Land Shortage on Forest Land Expansion - Impact of forest land shortage on land use and transformation from other to forest.
Land	C	**Strength of Land Availability on Forest Land Expansion Effect** (Dmnl) = 0.5 **Description:** *Strenght of impact of agricultural land shortage on land transformation from forest to agricultural land.* **Used by:** • Effect of Land Availability on Forest Land Expansion - Impact of agricultural land shortage on land use and transformation from forest to agricultural land.
Land	C	**Strength of Urban and Industrial Land Expansion Effect** (Dmnl) = 0.5 **Description:** *Strength of the effect of land shortage for living and industrial purposes on transformation of Agriculture and Forest Land into Urban and Industrial Land.* **Used by:** • Effect of Urban and Industrial Land Shortage on the Land Expansion - Parameter indicating a need for change in land use and transformation of Agriculture and Forest Land into Urban and Industrial Land due to land shortage for living and industrial purposes.
Land	L	**Table for ETAY** (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) **Description:** *Table for Effect of Trees Aging on Yield.*

		Used by: • Effect of Trees Aging on Yield - Parameter accounting for decreased forest biomass production from aging tress. 
Land	L	**Table for ETMY** (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) **Description:** *Table for Effect of Trees Maturing on Yield.* **Used by:** • Effect of Trees Maturing on Yield - Parameter accounting for increased forest biomass production from mature trees. 
Land	A	**Target** (Dmnl) = (1-SCENARIO Target)*1+SCENARIO Target*(1+RAMP(Target Scenario Ramp Change, 2010, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Zero Net Deforestation and Forest Degradation Scenarios - WWF Scenario variable. Further development required.
Land	A	**Target Deforestation Time Factor** (Dmnl) = SCENARIO Target*(RAMP(100, 2019, 2020)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Deforestation Time Factor - WWF Scenario variable. Further development required.
Land	A	**Target Delayed** (Dmnl) = (1-SCENARIO Target Delayed)*1+SCENARIO Target Delayed*(1+RAMP(Target Delayed Scenario Ramp Change, 2020, 2030)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Zero Net Deforestation and Forest Degradation Scenarios - WWF Scenario variable. Further development required.
Land	A	**Target Delayed Deforestation Time Factor** (Dmnl)

		= SCENARIO Target Delayed*(RAMP(100, 2025, 2030)) **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Deforestation Time Factor - WWF Scenario variable. Further development required.
Land	C	**Target Delayed Scenario Ramp Change** (1/Year) = -0.09 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Target Delayed - WWF Scenario variable. Further development required.
Land	C	**Target Scenario Ramp Change** (1/Year) = -0.0673 **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Target - WWF Scenario variable. Further development required.
Land	C	**Time to Adjust Fertilization Intensity** (Year) = 1 **Description:** *Time to enable change in intencity of fertilization practices per ha per year.* **Used by:** • Fertilization Intensity Change - Change in intencity of fertilization practices per ha per year.
Land	C	**Time to Adjust Forest Protected Land** (Year) = 2 **Description:** *Average time required to establish land protection.* **Used by:** • Forest Protected Land Change - Changes in area of forest land indicated as protected.
Land	A	**Total Calories Baseline** (kcal/(Person*Day)) = Calories Consumption GLOBIOM kcal cap day **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Total Calories BioenergyPlus** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Total Calories Dietshift** (kcal/(Person*Day)) = Calories Consumption GLOBIOM kcal cap day **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Total Calories ProNature** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Total Calories ProNaturePlus** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Total Crops Biomass Demand** (Biomass ton/Year) = Energy Demand*Market Share Biomass Crops/Biomass Conversion Efficiency **Description:** *Total demand for energy crops accounting for biomass energy market share and reference technology development.* **Used by:** • Energy Crops Land Needed - Land area dedicated to energy crops production.
Land	A	**Total Forest Biomass Demand** (Biomass ton/Year) = Energy Demand*Market Share Biomass Forest/Biomass Conversion Efficiency **Description:** *Total demand for forest biomass accounting for forest biomass energy market share and reference technology development.* **Used by:** • Forest Biomass Production - Total biomass production from forest. • Forest Land Needed to be Harvested - Total area of Forest needed for biomass production purposes accounting for total demand for forest biomass, average forest land yield and average losses in forest biomass production process. • Desired Production Fraction - Ratio of demand for forest biomass to potential production.

Land	A	**Total Land** (m*m) = Agricultural Land+Forest Land+Other Land+Urban and Industrial Land m **Description:** *Total considered land.*
Land	A	**Urban and Industrial Land ha** (ha) = Urban and Industrial Land m*Sqr m to ha **Description:** *Total Urban and Industrial Land in ha.* **Used by:** • FAO Land area ha - Total land accoring to FAO. Source of historical data: http://faostat.fao.org
Land	S	**Urban and Industrial Land m** (m*m) = INIT Urban and Industrial Land + ∫ (Agriculture Urban Industrial Land Allocation Rate+Forest Urban Industrial Land Allocation Rate) **Description:** *Total Urban and Industrial Land.* **Used by:** • Urban and Industrial Land ha - Total Urban and Industrial Land in ha. • Urban and Industrial Land per Capita - Actual available area of Urban and Industrial Land per capita assuming equal land distribution between the total population. • Total Land - Total considered land.
Land	A	**Urban and Industrial Land per Capita** (m*m/Person) = Urban and Industrial Land m/Population **Description:** *Actual available area of Urban and Industrial Land per capita assuming equal land distribution between the total population.* **Used by:** • Ratio of Min Urban and Industrial Land Needed to Available - Ratio comparing minimal required Urban and Industrial Land per Capita to actual available area.
Land	A	**Vegetal Calories Baseline** (kcal/(Person*Day)) = (1-SCENARIO Diet Shift)*Vegetal Food supply kcal capita day **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Vegetal Calories BioenergyPlus** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Vegetal Calories Consumption Increase Factor** (1/Year) = 0.0003 **Description:** *Factor change to increase in vegetal food demand.* **Used by:** • Change to Demand Vegetal Calories - Change to increase in vegetal food demand.
Land	A	**Vegetal Calories Dietshift** (kcal/(Person*Day)) = SCENARIO Diet Shift*Vegetal Food supply kcal capita day **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Vegetal Calories ProNature** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	C	**Vegetal Calories ProNaturePlus** (kcal/(Person*Day)) = 0 **Description:** *WWF Scenario variable. Further development required.*
Land	A	**Vegetal Food Production** (kcal/Year) = MIN(Food Crops Land,Food Crops Land Needed)*Food Crops Land Yield **Description:** *Total vegetal food production due to food crops land availability and food crops land yield.* **Used by:** • Vegetal Food supply kcal capita day - Average amount of vegetal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org • Calories Consumption per Capita per Day - The average amount of food calories each person consumes per day.
Land	A	**Vegetal Food supply kcal capita day** (kcal/(Person*Day)) = Vegetal Food Production/Population/Days in Year **Description:** *Average amount of vegetal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org*

		Used by: • Calories Consumption GLOBIOM kcal cap day - Total average amount of food measured in calories available for each person per day. Source of projection data: GLOBIOM model, IIASA. • Vegetal Calories Baseline - WWF Scenario variable. Further development required. • Vegetal Calories Dietshift - WWF Scenario variable. Further development required.
Land	A	**Vegetal Food Yield** (kcal/(ha*Year)) = Food Crops Land Yield **Description:** *Calculated historical data and projection of vegetal food land yield according to FAO. Source of historical data: http://faostat.fao.org*
Land	SM	**Vegetal vs Animal Food Dedicated Land** (Dmnl) = SMOOTH(MIN Vegetal vs Animal Food Dedicated Land Ratio+(MAX Vegetal vs Animal Food Dedicated Land Ratio-MIN Vegetal vs Animal Food Dedicated Land Ratio)*(Crops vs Animal Food Land Needed/(Crops vs Animal Food Land Needed+1)), Vegetal vs Animal Food Dedicated Land Change Time) **Description:** *Dynamic parameter responsible for allocation of land between crops and animal food production land in response to specific land demand.* **Used by:** • Animal Food Potential Agriculture Land - Land area dedicated to animal and food for animal production. • Crops Potential Agriculture Land - Land area dedicated to crops production.
Land	C	**Vegetal vs Animal Food Dedicated Land Change Time** (Year) = 5 **Description:** *Parameter indicating time delay required to change land from vegetal to animal food production land.* **Used by:** • Vegetal vs Animal Food Dedicated Land - Dynamic parameter responsible for allocation of land between crops and animal food production land in response to specific land demand.
Land	A	**Zero Net Deforestation and Forest Degradation Scenarios** (Dmnl) = Target*Target Delayed*Half Measures **Description:** *WWF Scenario variable. Further development required.* **Used by:** • Forest Agriculture Change - Parameter indicating a need for change in land use and transformation between Forest and Agriculture Land. Sign plus indicate transformation from forest to agricultural land. Sign minus indicate transformation from agricultural to forest land.
Population	F,A	**Births Rate** (Person/Year) = Total Fertility*Population 15 to 64*Reproductive Ratio*0.5/Reproductive Lifetime **Description:** *The total number of births per year in the world. Source of historical data: http://esa.un.org/unpp* **Used by:** • Population 0 to 14 - World population of 0 to 14 years old. Source of historical data: http://esa.un.org/unpp
Population	A	**Calories Consumption per Capita per Day** (kcal/(Person*Day)) = (Animal Food Production+Vegetal Food Production)/Population/Days in Year **Description:** *The average amount of food calories each person consumes per day.* **Used by:** • Food Ratio - Available food to subsistence food per capita ratio.
Population	A	**Change in Impact of Climate Risk on Life Expectancy** (1/Year) = ((C Concentration Ratio*Impact of Carbon Concentration on Life Expectancy Strength)-Impact of Climate Risk on Life Expectancy)/Impact of Carbon Concentration on Life Expectancy Delay **Description:** *Change in Impact of Climate Risk on Life Expectancy.* **Used by:** • Impact of Climate Risk on Life Expectancy - Impact of climate risk related to carbon concentration on Life Expectancy.
Population	A	**Change in Wealth Impact on Health** (1/Year) = (Impact of GWP on Health-Impact of Wealth on Health)/Health Impact Delay **Description:** *Change in Health Impact.*

		Used by: • Impact of Wealth on Health - Impact of health services availability on health taking into account delay.
Population	A	**Death Rate** (Person/Year) = Deaths Rate 0 to 14+Deaths Rate 15 to 64+Deaths Rate 65 plus **Description:** *The number of deaths per year among the whole population.*
Population	F,A	**Deaths Rate 0 to 14** (People/Year) = Population 0 to 14*Mortality 0 to 14/Year Period **Description:** *The number of deaths per year among 0 to 14 population cohort.* **Used by:** • Death Rate - The number of deaths per year among the whole population. • Population 0 to 14 - World population of 0 to 14 years old. Source of historical data: http://esa.un.org/unpp
Population	F,A	**Deaths Rate 15 to 64** (People/Year) = Population 15 to 64*Mortality 15 to 64/Year Period **Description:** *The number of deaths per year among 15 to 64 population cohort.* **Used by:** • Death Rate - The number of deaths per year among the whole population. • Population 15 to 64 - World population of 15 to 64 years old. Source of historical data: http://esa.un.org/unpp
Population	A	**Deaths Rate 65 plus** (People/Year) = Population 65 Plus*Mortality 65 plus/Year Period **Description:** *The number of deaths per year among 65Plus population cohort.* **Used by:** • Death Rate - The number of deaths per year among the whole population. • Population 65 Plus - World population of 65Plus years old. Source of historical data: http://esa.un.org/unpp
Population	A	**FAO Population** (Person) = Population **Description:** *Historical data and projection of population volume according to FAO. Source of historical data and projections: http://faostat.fao.org*
Population	A	**Food Ratio** (Dmnl) = Calories Consumption per Capita per Day/Subsistence Food per Capita **Description:** *Available food to subsistence food per capita ratio.* **Used by:** • Impact of Food on Life Expectancy - Impact of food availability on life expectancy.
Population	C	**Health Impact Delay** (Year) = 20 **Description:** *Time delay to account for impact of health services on life expectancy.* **Used by:** • Change in Wealth Impact on Health - Change in Health Impact.
Population	A	**Impact of Biodiversity on Health** (Dmnl) = Min Impact of Biodiversity on Health+(Max Impact of Biodiversity on Health-Min Impact of Biodiversity on Health)*(Mean Species Abundance/Initial Species Abundance) **Description:** *Impact of changes in biodiversity on health. Scaled between minimum and maximum impact.* **Used by:** • Lifetime Multiplier from Health Services - Multiplier to account for changes in life expectancy due to health factors related to biodiversity, health services and water quality.
Population	C	**Impact of Carbon Concentration on Life Expectancy Delay** (Year) = 50 **Description:** *Delay with which the carbon concentration ratio impacts Life Expectancy.* **Used by:** • Change in Impact of Climate Risk on Life Expectancy - Change in Impact of Climate Risk on Life Expectancy.
Population	C	**Impact of Carbon Concentration on Life Expectancy Strength** (Dmnl) = 0.01 **Description:** *Strength of carbon concentration impact of Life Expectancy.*

		Used by: • Change in Impact of Climate Risk on Life Expectancy - Change in Impact of Climate Risk on Life Expectancy.
Population	S	**Impact of Climate Risk on Life Expectancy** (Dmnl) = 0.000556194 + ∫ (Change in Impact of Climate Risk on Life Expectancy) **Description:** *Impact of climate risk related to carbon concentration on Life Expectancy.* **Used by:** • Change in Impact of Climate Risk on Life Expectancy - Change in Impact of Climate Risk on Life Expectancy. • Lifetime Multiplier from Climate Risk - Multiplier to account for changes in life expectancy due to industralization represented here by risk factors related to climate change.
Population	A	**Impact of Educational on Fertility** (Dmnl) = (Impact of Educational on Fertility Inflection^Impact of Educational on Fertility Steepness/(Impact of Educational on Fertility Inflection^Impact of Educational on Fertility Steepness+Education index^Impact of Educational on Fertility Steepness)) **Description:** *A nonlinear function representing the impact of population educational on fertility. With increasing education the fertility decreases.* **Used by:** • Total Fertility - Total fertility of mature reproductive population. Source of historical data: http://esa.un.org/unpp
Population	C	**Impact of Educational on Fertility Inflection** (Dmnl) = 0.565 **Description:** *A parameter determining the inflection point of the nonlinear function representing the impact of population educational on fertility.* **Used by:** • Impact of Educational on Fertility - A nonlinear function representing the impact of population educational on fertility. With increasing education the fertility decreases.
Population	C	**Impact of Educational on Fertility Steepness** (Dmnl) = 2 **Description:** *A parameter determining the steepness of the nonlinear function representing the impact of population educational on fertility.* **Used by:** • Impact of Educational on Fertility - A nonlinear function representing the impact of population educational on fertility. With increasing education the fertility decreases.
Population	A	**Impact of Food on Life Expectancy** (Dmnl) = (2/(1+EXP(-Impact of Food on Life Expectancy Strength*Food Ratio))) **Description:** *Impact of food availability on life expectancy.* **Used by:** • Lifetime Multiplier from Food - Multiplier to account for changes in life expectancy due to food availability.
Population	C	**Impact of Food on Life Expectancy Strength** (Dmnl) = 0.6 **Description:** *Parameter determining a strength of food availability on life expectancy.* **Used by:** • Impact of Food on Life Expectancy - Impact of food availability on life expectancy.
Population	A	**Impact of GDP on Fertility** (Dmnl) = (Impact of GDP on Fertility Inflection^Impact of GDP on Fertility Steepness/(Impact of GDP on Fertility Inflection^Impact of GDP on Fertility Steepness+(GWP per Capita/Reference World GDP per Capita for Fertility)^Impact of GDP on Fertility Steepness)) **Description:** *A nonlinear function representing the impact of population wealth, represented by GDP compared to reference GDP, on fertility. With increasing wealth the fertility decreases.* **Used by:** • Total Fertility - Total fertility of mature reproductive population. Source of historical data: http://esa.un.org/unpp
Population	C	**Impact of GDP on Fertility Inflection** (Dmnl) = 6.4 **Description:** *A parameter determining the inflection point of the nonlinear function representing the impact of population wealth on fertility.* **Used by:**

		• Impact of GDP on Fertility - A nonlinear function representing the impact of population wealth, represented by GDP compared to reference GDP, on fertility. With increasing wealth the fertility decreases.
Population	C	**Impact of GDP on Fertility Steepness** (Dmnl) = 0.3 **Description:** *A parameter determining the isteepness of the nonlinear function representing the impact of population wealth on fertility.* **Used by:** • Impact of GDP on Fertility - A nonlinear function representing the impact of population wealth, represented by GDP compared to reference GDP, on fertility. With increasing wealth the fertility decreases.
Population	A	**Impact of GWP on Health** (Dmnl) = (1+(1-Impact of GWP on Health Inflection Point^Impact of GWP on Health Steepness/(Impact of GWP on Health Inflection Point^Impact of GWP on Health Steepness+(GWP per Capita/Reference World GDP per Capita for Health)^Impact of GWP on Health Steepness))) **Description:** *Impact of wealth on health services availability.* **Used by:** • Change in Wealth Impact on Health - Change in Health Impact.
Population	C	**Impact of GWP on Health Inflection Point** (Dmnl) = 2.1 **Description:** *Parameter determining inflection point of impact of wealth on health services availability.* **Used by:** • Impact of GWP on Health - Impact of wealth on health services availability.
Population	C	**Impact of GWP on Health Steepness** (Dmnl) = 3 **Description:** *Parameter determining intensity of impact of wealth on health services availability.* **Used by:** • Impact of GWP on Health - Impact of wealth on health services availability.
Population	A	**Impact of Water Quality on Health** (Dmnl) = Quality of Domestic Water **Description:** *Impact of changes in water quality on health.* **Used by:** • Lifetime Multiplier from Health Services - Multiplier to account for changes in life expectancy due to health factors related to biodiversity, health services and water quality.
Population	S	**Impact of Wealth on Health** (Dmnl) = 1.00466 + ∫ (Change in Wealth Impact on Health) **Description:** *Impact of health services availability on health taking into account delay.* **Used by:** • Lifetime Multiplier from Health Services - Multiplier to account for changes in life expectancy due to health factors related to biodiversity, health services and water quality. • Change in Wealth Impact on Health - Change in Health Impact.
Population	C	**INIT Population 0 to 14** (People) = 6.5e+008 **Description:** *Volume of 0 to 14 year old population cohort as estimated for year 1900.* **Used by:** • Population 0 to 14 - World population of 0 to 14 years old. Source of historical data: http://esa.un.org/unpp
Population	C	**INIT Population 15 to 64** (People) = 8.9e+008 **Description:** *Volume of 15 to 64 year old population cohort as estimated for year 1900.* **Used by:** • Population 15 to 64 - World population of 15 to 64 years old. Source of historical data: http://esa.un.org/unpp • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional

		form of production functions.
Population	C	**INIT Population 65 Plus** (People) = 6e+007 **Description:** *Volume of 65Plus year old population cohort as estimated for year 1900.* **Used by:** • Population 65 Plus - World population of 65Plus years old. Source of historical data: http://esa.un.org/unpp
Population	A	**Labor Force** (People) = Population 15 to 64*Labor Force Participation Fraction **Description:** *Labor force as a percentage of 15 to 64 population cohort.* **Used by:** • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions.
Population	C	**Labor Force Participation Fraction** (Dmnl) = 0.75 **Description:** *Fraction of 15 to 64 population able to work.* **Used by:** • Labor Force - Labor force as a percentage of 15 to 64 population cohort. • Reference Economy Output - Reference Output before effects of climate damage and emissions abatement are considered. Calculated as Cobb-Douglas functional form of production functions.
Population	A	**Life Expectancy** (Year) = Life Expectancy Normal*Lifetime Multiplier from Food*Lifetime Multiplier from Health Services*Lifetime Multiplier from Climate Risk **Description:** *The average life expectancy. Source of historical data: http://esa.un.org/unpp* **Used by:** • Health index - Index of achievement in Life Expectancy. Source of historical data: http://hdr.undp.org/en/reports/global/hdr2011/ • Mortality 65 plus - A nonlinear function representing mortality among 65Plus population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases. • Mortality 15 to 64 - A nonlinear function representing mortality among 15 to 64 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases. • Mortality 0 to 14 - A nonlinear function representing mortality among 0 to 14 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.
Population	C	**Life Expectancy Normal** (Year) = 28 **Description:** *The normal life expectancy with subsistence food, no medical care and no industrialization.* **Used by:** • Life Expectancy - The average life expectancy. Source of historical data: http://esa.un.org/unpp
Population	A	**Lifetime Multiplier from Climate Risk** (Dmnl) = MAX(0,1-Impact of Climate Risk on Life Expectancy) **Description:** *Multiplier to account for changes in life expectancy due to industralization represented here by risk factors related to climate change.* **Used by:** • Life Expectancy - The average life expectancy. Source of historical data: http://esa.un.org/unpp
Population	A	**Lifetime Multiplier from Food** (Dmnl) = Impact of Food on Life Expectancy **Description:** *Multiplier to account for changes in life expectancy due to food availability.* **Used by:** • Life Expectancy - The average life expectancy. Source of historical data: http://esa.un.org/unpp
Population	A	**Lifetime Multiplier from Health Services** (Dmnl) = Impact of Wealth on Health*Impact of Biodiversity on Health*Impact of Water Quality on

		Health **Description:** *Multiplier to account for changes in life expectancy due to health factors related to biodiversity, health services and water quality.* **Used by:** • Life Expectancy - The average life expectancy. Source of historical data: http://esa.un.org/unpp
Population	F,A	**Maturation 14 to 15** (Person/Year) = Population 0 to 14*(1-Mortality 0 to 14)/Time in 0 to 14 Cohort **Description:** *The fractional rate at which people aged 0 to 14 mature per year into the next age cohort.* **Used by:** • Population 0 to 14 - World population of 0 to 14 years old. Source of historical data: http://esa.un.org/unpp • Population 15 to 64 - World population of 15 to 64 years old. Source of historical data: http://esa.un.org/unpp
Population	F,A	**Maturation 64 to 65** (Person/Year) = Population 15 to 64*(1-Mortality 15 to 64)/Time in 15 to 44 Cohort **Description:** *The fractional rate at which people aged 15 to 64 mature per year into the next age cohort.* **Used by:** • Population 15 to 64 - World population of 15 to 64 years old. Source of historical data: http://esa.un.org/unpp • Population 65 Plus - World population of 65Plus years old. Source of historical data: http://esa.un.org/unpp
Population	C	**Max Impact of Biodiversity on Health** (Dmnl) = 1 **Description:** *Max impact of biodiversity on health and thus life expectancy.* **Used by:** • Impact of Biodiversity on Health - Impact of changes in biodiversity on health. Scaled between minimum and maximum impact.
Population	C	**MIN Fertility** (Dmnl) = 1 **Description:** *The minimal level of the fertility. Logically set to 1 child.* **Used by:** • Total Fertility - Total fertility of mature reproductive population. Source of historical data: http://esa.un.org/unpp
Population	C	**Min Impact of Biodiversity on Health** (Dmnl) = 0.95 **Description:** *Minimal impact of biodiversity on health and thus life expectancy.* **Used by:** • Impact of Biodiversity on Health - Impact of changes in biodiversity on health. Scaled between minimum and maximum impact.
Population	A	**Mortality 0 to 14** (Dmnl) = 2/(1+EXP(Mortality 0 to 14 Strength*Life Expectancy/Ref Life Expectancy)) **Description:** *A nonlinear function representing mortality among 0 to 14 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.* **Used by:** • Deaths Rate 0 to 14 - The number of deaths per year among 0 to 14 population cohort. • Maturation 14 to 15 - The fractional rate at which people aged 0 to 14 mature per year into the next age cohort.
Population	C	**Mortality 0 to 14 Strength** (Dmnl) = 11 **Description:** *A parameter determining the strength of impact of life expectancy on mortality among 0 to 14 population cohort.* **Used by:** • Mortality 0 to 14 - A nonlinear function representing mortality among 0 to 14 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.
Population	A	**Mortality 15 to 64** (Dmnl)

		= 2/(1+EXP(Mortality 15 to 64 Strength*Life Expectancy/Ref Life Expectancy)) **Description:** *A nonlinear function representing mortality among 15 to 64 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.* **Used by:** • Maturation 64 to 65 - The fractional rate at which people aged 15 to 64 mature per year into the next age cohort. • Deaths Rate 15 to 64 - The number of deaths per year among 15 to 64 population cohort.
Population	C	**Mortality 15 to 64 Strength** (Dmnl) = 14 **Description:** *A parameter determining the strength of impact of life expectancy on mortality among 15 to 64 population cohort.* **Used by:** • Mortality 15 to 64 - A nonlinear function representing mortality among 15 to 64 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.
Population	A	**Mortality 65 plus** (Dmnl) = 2/(1+EXP(Mortality 65 Strength*Life Expectancy/Ref Life Expectancy)) **Description:** *A nonlinear function representing mortality among 65Plus population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.* **Used by:** • Deaths Rate 65 plus - The number of deaths per year among 65Plus population cohort.
Population	C	**Mortality 65 Strength** (Dmnl) = 3.55 **Description:** *A parameter determining the strength of impact of life expectancy on mortality among 65Plus population cohort.* **Used by:** • Mortality 65 plus - A nonlinear function representing mortality among 65Plus population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.
Population	C	**Normal Fertility** (Dmnl) = 9 **Description:** *Reference fertility of reproductive fraction of population as estimated for year 1900.* **Used by:** • Total Fertility - Total fertility of mature reproductive population. Source of historical data: http://esa.un.org/unpp
Population	A	**Population** (People) = Population 0 to 14+Population 15 to 64+Population 65 Plus **Description:** *Total world population. Source of historical data: http://esa.un.org/unpp* **Used by:** • Domestic Water Demand - Total water demand for domestic purposes. Source of Historical Data:International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activitieshttp://webworld.unesco.org/water/ihp/db/shiklomanov/ • Emission per Capita - Emissions of carbon from energy use and other sources per capita. • Emission from Fossil Fuels per Capita - Carbon emission from energy production and it use per capita. • Animal Food Production Needed - Total demand for animal food accounting for total population and annual food requirements per capita. • Vegetal Food supply kcal capita day - Average amount of vegetal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org • Animal Food supply kcal capita day - Average amount of animal food measured in calories available for each person per day. Source of historical data: http://faostat.fao.org • Crops Production Needed - Total demand for vegetal food accounting for total population and annual food requirements per capita.

		• Urban and Industrial Land per Capita - Actual available area of Urban and Industrial Land per capita assuming equal land distribution between the total population. • Calories Consumption per Capita per Day - The average amount of food calories each person consumes per day. • Population GLOBIOM - Projection of population volume according to GLOBIOM model. • FAO Population - Historical data and projection of population volume according to FAO. Source of historical data and projections: http://faostat.fao.org • Energy Demand - Total world demand for energy determined by population and energy demand per capita. Source of historical data: International Energy Agency Key World Energy Statistics 2007 • GWP per Capita - Gross World Product per Capita. Source of historical data: http://www.ggdc.net/MADDISON/oriindex.htm
Population	S	**Population 0 to 14** (People) = INIT Population 0 to 14 + ∫ (Births Rate-Deaths Rate 0 to 14-Maturation 14 to 15) **Description:** *World population of 0 to 14 years old. Source of historical data: http://esa.un.org/unpp* **Used by:** • Deaths Rate 0 to 14 - The number of deaths per year among 0 to 14 population cohort. • Maturation 14 to 15 - The fractional rate at which people aged 0 to 14 mature per year into the next age cohort. • Population - Total world population. Source of historical data: http://esa.un.org/unpp
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) **Description:** *World population of 15 to 64 years old. Source of historical data: http://esa.un.org/unpp* **Used by:** • Births Rate - The total number of births per year in the world. Source of historical data: http://esa.un.org/unpp • Maturation 64 to 65 - The fractional rate at which people aged 15 to 64 mature per year into the next age cohort. • Deaths Rate 15 to 64 - The number of deaths per year among 15 to 64 population cohort. • Population - Total world population. Source of historical data: http://esa.un.org/unpp • Labor Force - Labor force as a percentage of 15 to 64 population cohort.
Population	S	**Population 65 Plus** (People) = INIT Population 65 Plus + ∫ (Maturation 64 to 65-Deaths Rate 65 plus) **Description:** *World population of 65Plus years old. Source of historical data: http://esa.un.org/unpp* **Used by:** • Deaths Rate 65 plus - The number of deaths per year among 65Plus population cohort. • Population - Total world population. Source of historical data: http://esa.un.org/unpp
Population	A	**Population GLOBIOM** (Person) = Population **Description:** *Projection of population volume according to GLOBIOM model.*
Population	C	**Ref Life Expectancy** (Year) = 100 **Description:** *A reference value against which the life expectancy is compared to calculate the impact of the life expectancy on mortality.* **Used by:** • Mortality 65 plus - A nonlinear function representing mortality among 65Plus population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases. • Mortality 15 to 64 - A nonlinear function representing mortality among 15 to 64 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.

		• Mortality 0 to 14 - A nonlinear function representing mortality among 0 to 14 population cohort as dependent on life expectancy. With growing life expectancy the death rate decreases.
Population	C	**Reference World GDP per Capita for Fertility** ($/(Year*Person)) = 1500 **Description:** *A reference value against which the GDP per Capita is compared to calculate the impact of population wealth on fertility.* **Used by:** • Impact of GDP on Fertility - A nonlinear function representing the impact of population wealth, represented by GDP compared to reference GDP, on fertility. With increasing wealth the fertility decreases.
Population	C	**Reference World GDP per Capita for Health** ($/(Year*Person)) = 1500 **Description:** *Reference average world gross domestic product per capita.A reference value against which the GDP per Capita is compared to calculate the impact of wealth on health.* **Used by:** • Impact of GWP on Health - Impact of wealth on health services availability.
Population	C	**Reproductive Lifetime** (Year) = 30 **Description:** *Number of years the women can reproduce.* **Used by:** • Births Rate - The total number of births per year in the world. Source of historical data: http://esa.un.org/unpp
Population	C	**Reproductive Ratio** (Dmnl) = 0.76 **Description:** *Average reproductive percentage of mature population.* **Used by:** • Births Rate - The total number of births per year in the world. Source of historical data: http://esa.un.org/unpp
Population	C	**Subsistence Food per Capita** (kcal/(Person*Day)) = 2000 **Description:** *Subsistence amount of food per person required to survive.* **Used by:** • Food Ratio - Available food to subsistence food per capita ratio.
Population	C	**Time in 0 to 14 Cohort** (Year) = 14 **Description:** *Years range to stay in 0 to 14 cohort.* **Used by:** • Maturation 14 to 15 - The fractional rate at which people aged 0 to 14 mature per year into the next age cohort.
Population	C	**Time in 15 to 44 Cohort** (Year) = 49 **Description:** *Years range to stay in 15 to 64 cohort.* **Used by:** • Maturation 64 to 65 - The fractional rate at which people aged 15 to 64 mature per year into the next age cohort.
Population	A	**Total Fertility** (Dmnl) = MIN Fertility+(Normal Fertility-MIN Fertility)*(Impact of Educational on Fertility*Impact of GDP on Fertility) **Description:** *Total fertility of mature reproductive population. Source of historical data: http://esa.un.org/unpp* **Used by:** • Births Rate - The total number of births per year in the world. Source of historical data: http://esa.un.org/unpp
Water	C	**Additional Change in Reliable Water Supply** (Dmnl) = 1 **Description:** *A parameter that enables testing additional changes in reliable water supply independently from changes due to climate risk.* **Used by:** • Net Change in Reliable Water Supply - Change in reliable water supply due to

		changes in water resources or infrastructure availability.
Water	A	**Agricultural Water Demand** (m*m*m/Year) = (Average Agricultural Water Use per m2 Irrigated*Irrigated Agriculture Land/Sqr m to ha)+(Average Agricultural Water Use per m2 Rainfed*Rainfed Agriculture Land/Sqr m to ha) **Description:** *Total water demand for agricultural purposes. Source of Historical Data: International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/* **Used by:** • Agricultural Water Withdrawal Fulfillment Rate - Nonlinear relation that describes agricultural water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing agricultural water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits. • Agricultural Water Withdrawal Rate no Drought - Drought scenario variable. Accounts for Agricultural Water Withdrawal Rate in no drought case. • Agricultural Water Withdrawal Rate - Water withdrawal rate for agricultural purposes. • Total Water Demand - Total world water demand related to various purposes.http://webworld.unesco.org/water/ihp/db/shiklomanov/index.shtml
Water	C	**Agricultural Water Withdrawal Fulfillment Factor** (Dmnl) = 3.5 **Description:** *A factor determining the strength of infrastructure operating limits on agricultural water withdrawal fulfillment.* **Used by:** • Agricultural Water Withdrawal Fulfillment Rate - Nonlinear relation that describes agricultural water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing agricultural water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	A	**Agricultural Water Withdrawal Fulfillment Rate** (Dmnl) = (2/(1+EXP(-Agricultural Water Withdrawal Fulfillment Factor*(Max Water Withdrawal Rate/Agricultural Water Demand)))-1) **Description:** *Nonlinear relation that describes agricultural water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing agricultural water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.* **Used by:** • Agricultural Water Withdrawal Rate no Drought - Drought scenario variable. Accounts for Agricultural Water Withdrawal Rate in no drought case. • Agricultural Water Withdrawal Rate - Water withdrawal rate for agricultural purposes. • Effect of Water Withdrawal on Animal Food Land Fertility - Impact of water availability on land fertility related to animal food. • Effect of Water Withdrawal on Agriculture Land Fertility - Impact of water availability on cropland fertility.
Water	F,A	**Agricultural Water Withdrawal Rate** (m*m*m/Year) = Agricultural Water Demand*Agricultural Water Withdrawal Fulfillment Rate * (1-Extreme Drought) **Description:** *Water withdrawal rate for agricultural purposes.* **Used by:** • Drought Out - Water resources decrease rate due to drought. • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use. • Used Water Resources - Water resources that have been used for industrial, agricultural and domestic purposes. • Water Consumption Adjustment - The sum of consumption of water in industrial, agricultural and domestic sectors corected by used water recovery rate.
Water	A	**Agricultural Water Withdrawal Rate no Drought** (m*m*m/Year) = Agricultural Water Demand*Agricultural Water Withdrawal Fulfillment Rate **Description:** *Drought scenario variable. Accounts for Agricultural Water Withdrawal Rate in no drought case.* **Used by:** • Drought Out - Water resources decrease rate due to drought.

Water	S	**Available Water Resources** (m*m*m) = Desired Available Water Resources + ∫ (Recovery of Used Water Resources Rate+Water Supply Rate-Agricultural Water Withdrawal Rate-Domestic Water Withdrawal Rate-Industrial Water Withdrawal Rate-Drought Out) **Description:** *Available water resources to be used for domestic, agricultural and industrial use.* **Used by:** • Max Water Withdrawal Rate - Max possible water withdrawal rate due to available water resources. • Used Water Resources - Water resources that have been used for industrial, agricultural and domestic purposes. • Available Water Resources Adjustment - Adjustment of available water resources to desired available water resources.
Water	A	**Available Water Resources Adjustment** (m*m*m/Year) = (Desired Available Water Resources-Available Water Resources)/Available Water Resources Adjustment Time **Description:** *Adjustment of available water resources to desired available water resources.* **Used by:** • Desired Water Supply Rate - Desired water supply including constant water consumption and available water resources adjustment.
Water	C	**Available Water Resources Adjustment Time** (Year) = 1 **Description:** *Time required to adjust available water resources to desired water resources.* **Used by:** • Available Water Resources Adjustment - Adjustment of available water resources to desired available water resources.
Water	A	**Average Agricultural Water Use per m2 Irrigated** (m*m*m/(Year*m*m)) = MIN Agricultural Water Use Irrigated+(MAX Agricultural Water Use Irrigated-MIN Agricultural Water Use Irrigated)*(GWP per Capita/(GWP per Capita+Reference GWP per Capita for Agricultural Water Use Irrigated)) **Description:** *Nonlinear relation that describes average agricultural water use on irrigated part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.* **Used by:** • Agricultural Water Demand - Total water demand for agricultural purposes. Source of Historical Data: International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/
Water	A	**Average Agricultural Water Use per m2 Rainfed** (m*m*m/(Year*m*m)) = MIN Agricultural Water Use Rainfed+(MAX Agricultural Water Use Rainfed-MIN Agricultural Water Use Rainfed)*(GWP per Capita/(GWP per Capita+Reference GWP per Capita for Agricultural Water Use Rainfed)) **Description:** *Nonlinear relation that describes average agricultural water use on rainfed part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.* **Used by:** • Agricultural Water Demand - Total water demand for agricultural purposes. Source of Historical Data: International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/
Water	A	**Average Domestic Water Use per Capita** (m*m*m/(Year*People)) = MIN Domestic Water Use per Capita+(MAX Domestic Water Use per Capita-MIN Domestic Water Use per Capita)*(GWP per Capita/(GWP per Capita+Reference GWP per Capita for Domestic Water Use)) **Description:** *Nonlinear relation that describes average domestic water use per capita as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.* **Used by:** • Domestic Water Demand - Total water demand for domestic purposes. Source of Historical Data:International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activitieshttp://webworld.unesco.org/water/ihp/db/shiklomanov/

Water	A	**Average Industrial Water Use** (m*m*m/Year) = MIN Industrial Water Use+(MAX Industrial Water Use-MIN Industrial Water Use)*(GWP per Capita/(GWP per Capita+Reference GWP per Capita for Industrial Water Use)) **Description:** *Nonlinear relation that describes average industrial water use as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.* **Used by:** • Industrial Water Demand - Total water demand for industrial purposes. Source of Historical Data:International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activitieshttp://webworld.unesco.org/water/ihp/db/shiklomanov/
Water	C	**Average Used Water Recovery Fraction** (1/Year) = 0.1 **Description:** *Factor determining the percentage of consumed water resources that can be recovered.* **Used by:** • Recovery of Used Water Resources Rate - Rate of water consumption possible to be recovered and thus return to available water resources stock. • Non Recoverable Water Consumption Rate - Rate of water consumption not possible to be recovered.
Water	A	**Desired Available Water Resources** (m*m*m) = Total Water Demand*(Min Water Withdrawal Time+Water Safety Stock Coverage) **Description:** *Total desired available water resources including demand from industrial, agricultural and domestic sectors as well as safety coverage.* **Used by:** • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use. • Available Water Resources Adjustment - Adjustment of available water resources to desired available water resources.
Water	A	**Desired Water Supply Rate** (m*m*m/Year) = MAX(0,Water Consumption Adjustment+Available Water Resources Adjustment) **Description:** *Desired water supply including constant water consumption and available water resources adjustment.* **Used by:** • Water Supply Rate - Water supply taking into account the desired water supply and the supply fulfillment rate. The water supply includes withdrawals from surface water, groundwater or nonconventional sources for example desalination. • Water Supply Fulfillment Rate - Nonlinear relation that describes water supply fulfillment as a relation of water supply and demand. With growing water demand the supply fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	A	**Domestic Water Demand** (m*m*m/Year) = Population*Average Domestic Water Use per Capita **Description:** *Total water demand for domestic purposes. Source of Historical Data:International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activitieshttp://webworld.unesco.org/water/ihp/db/shiklomanov/* **Used by:** • Domestic Water Withdrawal Fulfillment Rate - Nonlinear relation that describes domestic water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing domestic water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits. • Domestic Water Withdrawal Rate - Water withdrawal rate for domestic purposes. • Total Water Demand - Total world water demand related to various purposes.http://webworld.unesco.org/water/ihp/db/shiklomanov/index.shtml
Water	C	**Domestic Water Withdrawal Fulfillment Factor** (Dmnl) = 0.8 **Description:** *A factor determining the strength of infrastructure operating limits on domestic water withdrawal fulfillment.* **Used by:** • Domestic Water Withdrawal Fulfillment Rate - Nonlinear relation that describes

		domestic water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing domestic water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	A	**Domestic Water Withdrawal Fulfillment Rate** (Dmnl) = (2/(1+EXP(-Domestic Water Withdrawal Fulfillment Factor*(Max Water Withdrawal Rate/Domestic Water Demand)))-1) **Description:** *Nonlinear relation that describes domestic water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing domestic water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.* **Used by:** • Quality of Domestic Water - Nonlinear relation describing the quality of domestic as dependent on withdrawal fulfillment rate. • Domestic Water Withdrawal Rate - Water withdrawal rate for domestic purposes.
Water	F,A	**Domestic Water Withdrawal Rate** (m*m*m/Year) = Domestic Water Demand*Domestic Water Withdrawal Fulfillment Rate **Description:** *Water withdrawal rate for domestic purposes.* **Used by:** • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use. • Used Water Resources - Water resources that have been used for industrial, agricultural and domestic purposes. • Water Consumption Adjustment - The sum of consumption of water in industrial, agricultural and domestic sectors corected by used water recovery rate.
Water	A	**Drought Out** (m*m*m/Year) = Agricultural Water Withdrawal Rate no Drought-Agricultural Water Withdrawal Rate **Description:** *Water resources decrease rate due to drought.* **Used by:** • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use.
Water	C	**Extreme Drought** (Dmnl) = 0 **Description:** *Drought scenario trigger.* **Used by:** • Agricultural Water Withdrawal Rate - Water withdrawal rate for agricultural purposes.
Water	A	**Impact of Climate Damage on Reliable Water Supply** (Dmnl) = Climate Damage Fraction **Description:** *A parameter that determines the impact of climate risk on water resources or infrastructure availability to provide reliable water supply.* **Used by:** • Net Change in Reliable Water Supply - Change in reliable water supply due to changes in water resources or infrastructure availability.
Water	A	**Industrial Water Demand** (m*m*m/Year) = Average Industrial Water Use **Description:** *Total water demand for industrial purposes. Source of Historical Data:International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activitieshttp://webworld.unesco.org/water/ihp/db/shiklomanov/* **Used by:** • Industrial Water Withdrawal Fulfillment Rate - Nonlinear relation that describes industrial water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing industrial water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits. • Industrial Water Withdrawal Rate - Water withdrawal rate for industrial purposes. • Total Water Demand - Total world water demand related to various purposes.http://webworld.unesco.org/water/ihp/db/shiklomanov/index.shtml
Water	C	**Industrial Water Withdrawal Fulfillment Factor** (Dmnl) = 2 **Description:** *A factor determining the strength of infrastructure operating limits on industrial water withdrawal fulfillment.*

		Used by: • Industrial Water Withdrawal Fulfillment Rate - Nonlinear relation that describes industrial water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing industrial water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	A	**Industrial Water Withdrawal Fulfillment Rate** (Dmnl) = (2/(1+EXP(-Industrial Water Withdrawal Fulfillment Factor*(Max Water Withdrawal Rate/Industrial Water Demand)))-1) **Description:** *Nonlinear relation that describes industrial water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing industrial water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.* **Used by:** • Industrial Water Withdrawal Rate - Water withdrawal rate for industrial purposes.
Water	F,A	**Industrial Water Withdrawal Rate** (m*m*m/Year) = Industrial Water Demand*Industrial Water Withdrawal Fulfillment Rate **Description:** *Water withdrawal rate for industrial purposes.* **Used by:** • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use. • Used Water Resources - Water resources that have been used for industrial, agricultural and domestic purposes. • Water Consumption Adjustment - The sum of consumption of water in industrial, agricultural and domestic sectors corected by used water recovery rate.
Water	C	**INIT Reliable Water Supply** (m*m*m/Year) = 4.2e+012 **Description:** *Amount of water that can be reliably provided on annual basis for domestic, agricultural and industrial use due to resources and infrastructure availability for year 1900.* **Used by:** • Net Change in Reliable Water Supply - Change in reliable water supply due to changes in water resources or infrastructure availability. • Reliable Water Supply - Amount of water that can be reliably provided on annual basis for domestic, agricultural and industrial use due to resources and infrastructure availability. Source of historical data: 2030 Water Resources Group, 2009. Charting Our Water Future - Economic frameworks to inform decision-making. http://www.mckinsey.com/App_Media/Reports/Water/Charting_Our_Water_Future_Full_Report_001.pdf
Water	A	**Irrigated Agriculture Land** (ha) = Agricultural Land*Sqr m to ha*Percent of Irrigated Land/100 **Description:** *Area of agricultural land on which the supply of water is only due to irrigation. Source of Historical Data: Gleick,P.H., et al. The World's Water Volume 7: The Biennial Report on Freshwater Resources. Washington: Island Press, 2012.* **Used by:** • Agricultural Water Demand - Total water demand for agricultural purposes. Source of Historical Data: International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/
Water	C	**MAX Agricultural Water Use Irrigated** (m*m*m/(Year*m*m)) = 0.05 **Description:** *Max level of average agricultural water use on part of agricultural land that is irrigated.* **Used by:** • Average Agricultural Water Use per m2 Irrigated - Nonlinear relation that describes average agricultural water use on irrigated part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MAX Agricultural Water Use Rainfed** (m*m*m/(Year*m*m)) = 0.1 **Description:** *Max level of average agricultural water use on part of agricultural land that is rainfed.* **Used by:** • Average Agricultural Water Use per m2 Rainfed - Nonlinear relation that describes

		average agricultural water use on rainfed part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MAX Domestic Water Use per Capita** (m*m*m/(Year*People)) = 140 **Description:** *Max level of average domestic water use per capita.* **Used by:** • Average Domestic Water Use per Capita - Nonlinear relation that describes average domestic water use per capita as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MAX Industrial Water Use** (m*m*m/Year) = 2.8e+012 **Description:** *Max level of average industrial water use.* **Used by:** • Average Industrial Water Use - Nonlinear relation that describes average industrial water use as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MAX Percent of Irrigated Land** (Dmnl) = 100 **Description:** *Max percentage of total agricultural land that can be eventually irrigated.* **Used by:** • Percent of Irrigated Land - Nonlinear relation that determines the area of irrigated land as percentage of total agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal percentage.
Water	A	**Max Water Withdrawal Rate** (m*m*m/Year) = Available Water Resources/Min Water Withdrawal Time **Description:** *Max possible water withdrawal rate due to available water resources.* **Used by:** • Agricultural Water Withdrawal Fulfillment Rate - Nonlinear relation that describes agricultural water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing agricultural water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits. • Industrial Water Withdrawal Fulfillment Rate - Nonlinear relation that describes industrial water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing industrial water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits. • Domestic Water Withdrawal Fulfillment Rate - Nonlinear relation that describes domestic water withdrawal fulfillment as a relation of max water withdrawal and demand. With growing domestic water demand the withdrawal fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	C	**MIN Agricultural Water Use Irrigated** (m*m*m/(Year*m*m)) = 0.005 **Description:** *Min level of average agricultural water use on part of agricultural land that is irrigated.* **Used by:** • Average Agricultural Water Use per m2 Irrigated - Nonlinear relation that describes average agricultural water use on irrigated part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MIN Agricultural Water Use Rainfed** (m*m*m/(Year*m*m)) = 0.005 **Description:** *Min level of average agricultural water use on part of agricultural land that is rainfed.* **Used by:** • Average Agricultural Water Use per m2 Rainfed - Nonlinear relation that describes average agricultural water use on rainfed part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MIN Domestic Water Use per Capita** (m*m*m/(Year*People)) = 5 **Description:** *Min level of average domestic water use per capita.* **Used by:**

		• Average Domestic Water Use per Capita - Nonlinear relation that describes average domestic water use per capita as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MIN Industrial Water Use** (m*m*m/Year) = 2000 **Description:** *Min level of average industrial water use.* **Used by:** • Average Industrial Water Use - Nonlinear relation that describes average industrial water use as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**MIN Percent of Irrigated Land** (Dmnl) = 0 **Description:** *Min percentage of total agricultural land that can be irrigated.* **Used by:** • Percent of Irrigated Land - Nonlinear relation that determines the area of irrigated land as percentage of total agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal percentage.
Water	C	**Min Reliable Water Supply Decrease Time** (Year) = 1 **Description:** *Minimal period of time used to consider changes in water resources or infrastructure availability.* **Used by:** • Net Change in Reliable Water Supply - Change in reliable water supply due to changes in water resources or infrastructure availability.
Water	C	**Min Water Withdrawal Time** (Year) = 1 **Description:** *Minimal time unit constraining water withdrawal.* **Used by:** • Max Water Withdrawal Rate - Max possible water withdrawal rate due to available water resources. • Desired Available Water Resources - Total desired available water resources including demand from industrial, agricultural and domestic sectors as well as safety coverage.
Water	A	**Net Change in Reliable Water Supply** (m*m*m/(Year*Year)) = ((INIT Reliable Water Supply*Impact of Climate Damage on Reliable Water Supply*Additional Change in Reliable Water Supply)-Reliable Water Supply)/Min Reliable Water Supply Decrease Time **Description:** *Change in reliable water supply due to changes in water resources or infrastructure availability.* **Used by:** • Reliable Water Supply - Amount of water that can be reliably provided on annual basis for domestic, agricultural and industrial use due to resources and infrastructure availability. Source of historical data: 2030 Water Resources Group, 2009. Charting Our Water Future - Economic frameworks to inform decision-making. http://www.mckinsey.com/App_Media/Reports/Water/Charting_Our_Water_Future_Full_Report_001.pdf
Water	F,A	**Non Recoverable Water Consumption Rate** (m*m*m/Year) = Used Water Resources*(1-Average Used Water Recovery Fraction) **Description:** *Rate of water consumption not possible to be recovered.* **Used by:** • Used Water Resources - Water resources that have been used for industrial, agricultural and domestic purposes.
Water	A	**Percent of Irrigated Land** (Dmnl) = MIN Percent of Irrigated Land+(MAX Percent of Irrigated Land-MIN Percent of Irrigated Land)*(GWP per Capita/(GWP per Capita+Reference GWP per Capita for Land Irrigation)) **Description:** *Nonlinear relation that determines the area of irrigated land as percentage of total agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal percentage.* **Used by:** • Irrigated Agriculture Land - Area of agricultural land on which the supply of water is only due to irrigation. Source of Historical Data: Gleick,P.H., et al. The World's Water Volume 7: The Biennial Report on Freshwater Resources. Washington: Island Press,

		2012. • Rainfed Agriculture Land - Area of agricultural land on which the supply of water is only due to rain.
Water	A	**Quality of Domestic Water** (Dmnl) = Domestic Water Withdrawal Fulfillment Rate^Water Quality Steepness*(Water Quality Inflection^Water Quality Steepness+1)/(Water Quality Inflection^Water Quality Steepness+Domestic Water Withdrawal Fulfillment Rate^Water Quality Steepness) **Description:** *Nonlinear relation describing the quality of domestic as dependent on withdrawal fulfillment rate.* **Used by:** • Impact of Water Quality on Health - Impact of changes in water quality on health.
Water	A	**Rainfed Agriculture Land** (ha) = Agricultural Land*Sqr m to ha*(1-Percent of Irrigated Land/100) **Description:** *Area of agricultural land on which the supply of water is only due to rain.* **Used by:** • Agricultural Water Demand - Total water demand for agricultural purposes. Source of Historical Data: International Hydrological Programme (IHP) of UNESCO, data by Shiklomanov, I.A Dynamics of water use in the world (total) over the kinds of economic activities http://webworld.unesco.org/water/ihp/db/shiklomanov/
Water	F,A	**Recovery of Used Water Resources Rate** (m*m*m/Year) = Used Water Resources*Average Used Water Recovery Fraction **Description:** *Rate of water consumption possible to be recovered and thus return to available water resources stock.* **Used by:** • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use. • Used Water Resources - Water resources that have been used for industrial, agricultural and domestic purposes. • Water Consumption Adjustment - The sum of consumption of water in industrial, agricultural and domestic sectors corected by used water recovery rate.
Water	C	**Reference GWP per Capita for Agricultural Water Use Irrigated** ($/(Year*Person)) = 4000 **Description:** *A reference value against which the GDP per Capita is compared to calculate the impact of population wealth on average agricultural water use on the land where the supply of water is due to irrigation.* **Used by:** • Average Agricultural Water Use per m2 Irrigated - Nonlinear relation that describes average agricultural water use on irrigated part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**Reference GWP per Capita for Agricultural Water Use Rainfed** ($/(Year*Person)) = 8000 **Description:** *A reference value against which the GDP per Capita is compared to calculate the impact of population wealth on average agricultural water use on the land where the supply of water is only due to rainfall.* **Used by:** • Average Agricultural Water Use per m2 Rainfed - Nonlinear relation that describes average agricultural water use on rainfed part of agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**Reference GWP per Capita for Domestic Water Use** ($/(Year*Person)) = 10000 **Description:** *A reference value against which the GDP per Capita is compared to calculate the impact of population wealth on domestic water use.* **Used by:** • Average Domestic Water Use per Capita - Nonlinear relation that describes average domestic water use per capita as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**Reference GWP per Capita for Industrial Water Use** ($/(Year*Person)) = 17000 **Description:** *A reference value against which the GDP per Capita is compared to calculate*

		the impact of population wealth on average inductrial water use. **Used by:** • Average Industrial Water Use - Nonlinear relation that describes average industrial water use as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal level.
Water	C	**Reference GWP per Capita for Land Irrigation** ($/(Year*Person)) = 120000 **Description:** *A reference value against which the GDP per Capita is compared to calculate the impact of population wealth on percentage of agricultural land irrigation.* **Used by:** • Percent of Irrigated Land - Nonlinear relation that determines the area of irrigated land as percentage of total agricultural land as dependent on the population wealth represented by GWP per capita. Scaled between minimal and maximal percentage.
Water	S	**Reliable Water Supply** (m*m*m/Year) = INIT Reliable Water Supply + ∫ (Net Change in Reliable Water Supply) **Description:** *Amount of water that can be reliably provided on annual basis for domestic, agricultural and industrial use due to resources and infrastructure availability. Source of historical data: 2030 Water Resources Group, 2009. Charting Our Water Future - Economic frameworks to inform decision-making. http://www.mckinsey.com/App_Media/Reports/Water/Charting_Our_Water_Future_Full_Report_001.pdf* **Used by:** • Net Change in Reliable Water Supply - Change in reliable water supply due to changes in water resources or infrastructure availability. • Water Supply Fulfillment Rate - Nonlinear relation that describes water supply fulfillment as a relation of water supply and demand. With growing water demand the supply fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	A	**Total Water Demand** (m*m*m/Year) = Agricultural Water Demand+Domestic Water Demand+Industrial Water Demand **Description:** *Total world water demand related to various purposes.http://webworld.unesco.org/water/ihp/db/shiklomanov/index.shtml* **Used by:** • Desired Available Water Resources - Total desired available water resources including demand from industrial, agricultural and domestic sectors as well as safety coverage.
Water	S	**Used Water Resources** (m*m*m) = Available Water Resources + ∫ (Agricultural Water Withdrawal Rate+Domestic Water Withdrawal Rate+Industrial Water Withdrawal Rate-Non Recoverable Water Consumption Rate-Recovery of Used Water Resources Rate) **Description:** *Water resources that have been used for industrial, agricultural and domestic purposes.* **Used by:** • Recovery of Used Water Resources Rate - Rate of water consumption possible to be recovered and thus return to available water resources stock. • Non Recoverable Water Consumption Rate - Rate of water consumption not possible to be recovered.
Water	A	**Water Consumption Adjustment** (m*m*m/Year) = Agricultural Water Withdrawal Rate+Domestic Water Withdrawal Rate+Industrial Water Withdrawal Rate-Recovery of Used Water Resources Rate **Description:** *The sum of consumption of water in industrial, agricultural and domestic sectors corected by used water recovery rate.* **Used by:** • Desired Water Supply Rate - Desired water supply including constant water consumption and available water resources adjustment.
Water	C	**Water Quality Inflection** (Dmnl) = 0.5 **Description:** *Inflection point of nonlinear relation describing domestic water quality.* **Used by:** • Quality of Domestic Water - Nonlinear relation describing the quality of domestic as dependent on withdrawal fulfillment rate.

Water	C	**Water Quality Steepness** (Dmnl) = 5 **Description:** *Steepness of nonlinear relation describing domestic water quality.* **Used by:** • Quality of Domestic Water - Nonlinear relation describing the quality of domestic as dependent on withdrawal fulfillment rate.
Water	C	**Water Safety Stock Coverage** (Year) = 0.1 **Description:** *Water resources safety stock expressed in terms of time duration. Additional time period during which the water resources need to be available at the total water demand level.* **Used by:** • Desired Available Water Resources - Total desired available water resources including demand from industrial, agricultural and domestic sectors as well as safety coverage.
Water	C	**Water Supply Fulfillment Factor** (Dmnl) = 3 **Description:** *A factor determining the strength of infrastructure operating limits on water supply fulfillment.* **Used by:** • Water Supply Fulfillment Rate - Nonlinear relation that describes water supply fulfillment as a relation of water supply and demand. With growing water demand the supply fulfillment might be impaired which relates to infrastructure design and its operating limits.
Water	A	**Water Supply Fulfillment Rate** (Dmnl) = 2/(1+EXP(-Water Supply Fulfillment Factor*(Reliable Water Supply/Desired Water Supply Rate)))-1 **Description:** *Nonlinear relation that describes water supply fulfillment as a relation of water supply and demand. With growing water demand the supply fulfillment might be impaired which relates to infrastructure design and its operating limits.* **Used by:** • Water Supply Rate - Water supply taking into account the desired water supply and the supply fulfillment rate. The water supply includes withdrawals from surface water, groundwater or nonconventional sources for example desalination.
Water	F,A	**Water Supply Rate** (m*m*m/Year) = Desired Water Supply Rate*Water Supply Fulfillment Rate **Description:** *Water supply taking into account the desired water supply and the supply fulfillment rate. The water supply includes withdrawals from surface water, groundwater or nonconventional sources for example desalination.* **Used by:** • Available Water Resources - Available water resources to be used for domestic, agricultural and industrial use.

The model documentation produced using:
SDM – System Dynamics Model Documentation Tool Beta Version 3.3.2
by Decision and Information Sciences Division, Argonne National Laboratory

Literature

Adams, R.M, Bryant, K.J., McCarl, B.A., Legler, D.M., OBrien, J., Solow, A., and Weiher, R. (1995). Value of improved long-range weather information. *Contemporary Economic Policy*, 13 (3): 10-19.

Andersen, D. F., Richardson, G. P., and Vennix, J. A. M. (1997). Group model building: adding more science to the craft. System Dynamics Review, 13(2): 187-201.

Bolin, B. (1986). Requirements for a Satisfactory Model of the Global Carbon Cycle and Current Status of Modeling Efforts. In *The Changing Carbon Cycle: A Global Analysis*, ed. J. R. Trabalka and D. E. Reichle. New York: Springer-Verlag.

Bouma, J.A., van der Woerd, H.J., and Kuik, O.J. (2009). Assessing the value of information for water quality management in the North Sea. *Journal of Environmental Management*, 90(2): 1280-1288.

Considine, T.J., Jablonowski, C., Posner, B., and Bishop, C.H. (2004). The Value of Hurricane Forecasts to Oil and Gas Producers in the Gulf of Mexico. *Journal of Applied Meteorology*, 43(9): 1270–1281.

Craglia, M., Goodchild, M. ; Annoni, A., Camara G., Gould, M.; Kuhn W., Mark D., Masser I., Maguire D., Liang, St., and Parsons, E. (2008). Next-Generation Digital Earth. A position paper from the Vespucci Initiative for the Advancement of Geographic Information Science, *International Journal of Spatial Data Infrastructures Research*, 2008(3): 146-167.

Crutzen, P.J., and Stoermer, E.F. (2000). "The 'Anthropocene'." *Global Change Newsletter* 41: 17-18.

Davidsen, P. I., Sterman, J. D., Richardson, G. P., (1990) A petroleum life cycle model for the United States with endogenous technology, exploration, recovery and demand. *System Dynamics Review* 6 (no. 1, Winter 1990): 66-93.

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy and X. Zhang, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

European Commission (2008). Research for Europe. A selection of EU success stories. Edited by Julia Acevedo Bueno, at http://bookshop.europa.eu/eubookshop/bookmarks.action?target=EUB:NOTICE:KINA22984:EN:HTML&request_locale=EN, [accessed 22 October 2009].

Fiddaman, T. (1997). *Feedback Complexity in Integrated Climate-Economy Models*, PhD Thesis: MIT Sloan School of Management.

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

Forrester, J.W. (1958). Industrial Dynamics: A Major Breakthrough for Decision Makers. *Harvard Business Review* 26 (4):37-66.

Forrester, J.W. (1961). *Industrial Dynamics*. Cambridge MA: Productivity Press.

GEA, 2012: *Global Energy Assessment – Toward a Sustainable Future*, Cambridge University Press, Cambridge UK andNew York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria.

Goudriaan, J. and P. Ketner. (1984). A Simulation Study for the Global Carbon Cycle, including Man's Impact on the Biosphere. *Climatic Change* 6: 167-192.

Katz, R.W, and Murphy, A.H. (1997). *Economic Value of Weather and Climate Forecasts*. Cambridge, U.K.: Cambridge Univ. Press.

Leyequien, E., Verrelst, J., Slot, M., Schaepman-Strub, G., Heitkönig, I.M.A., and Skidmore, A. (2007). Capturing the fugitive: Applying remote sensing to terrestrial animal distribution and diversity. *International Journal of Applied Earth Observation and Geoinformation*, 9(1):1-20.

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

Muchoney, D.M. (2008). Earth observations for terrestrial biodiversity and ecosystems, *Remote Sensing of Environment*, 112(5): 1909-1911.

Nordhaus, W. 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.

Nordhaus, W. D. (1994). *Managing the Global Commons*. Cambridge, MA: MIT Press.

Obersteiner, M., Rydzak, F., McCallum, I., Fritz, S., Valuing the potential impacts of GEOSS: A Systems Dynamics Approach. In: *The Value of Information. Methodological Frontiers and New Application in Environment and Health*, R. Laxminarayan and M.K. Macauley (eds). Springer, Dordrecht, The Netherlands pp.67-90, 2012.

Oeschger, H., Siegenthaler,U., Schotterer, U., and Guglemann, A. (1975). A Box Diffusion Model to Study the Carbon Dioxide Exchange in Nature. *Tellus* XXVII(2): 167-192.

Richardson, G. P., Andersen, D. F. (1995) Teamwork in group model building. *System Dynamics Review*, 11(2): 113-137.

Richardson, G. P., and Pugh, III A. L. (1981). *Introduction to System Dynamics Modeling with DYNAMO*. Cambridge MA: Productivity Press.

Rotmans, J. (1990). *IMAGE: An Integrated Model to Assess the Greenhouse Effect*. Boston: Kluwer Academic Publishers.

Rydzak, F., Obersteiner, M., Kraxner, F. (2009). GEO-BENE Global Earth Observation—Benefit Estimation: Now, Next and Emerging. Synthesis Report. International Institute for Applied Systems Analysis (IIASA), Laxenburg.

Rydzak, F., Obersteiner, M., Kraxner, F. (2010). Impact of Global Earth Observation – Systemic view across GEOSS Societal Benefit Areas. *International Journal of Spatial Data Infrastructures Research*¸ 2010 (5), 216-243.

Schellnhuber*, H.J.* (2009) From the Cover: Tipping Elements in Earth Systems Special Feature: Tipping elements in the Earth System. *PNAS* 106: 20561-20563.

Sterman, J.D. (1984). Appropriate Summary Statistics for Evaluating the Historical Fit of System Dynamics Models. *Dynamica*, 10 (Winter): 51-66.

Sterman, J. D., Richardson, G. P. (1985) An Experiment to Evaluate Methods for Estimating Fossil Fuel Resources. *Journal of Forecasting*, Vol. 4, 197-226.

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

Sterman, J., T. Fiddaman, T. Franck, A. Jones, S. McCauley, P. Rice, E. Sawin, L. Siegel (2012). Climate Interactive: The C-ROADS Climate Policy Model. *System Dynamics Review* 28(3): 295-305.

Stern, N. (2007). *The Economics of Climate Change. The Stern Review*. Cambridge, UK: Cambridge University Press.

Vennix, J. A. M. (1997). *Group Model Building: Facilitating Team Learning Using System Dynamics*. Chichester: Wiley & Sons Ltd.

Wieand, K. (2008). A Bayesian Methodology for Estimating the Impacts of Improved Coastal Ocean Information on the Marine Recreational Fishing Industry. *Coastal Management*, 36(2): 208-223.

Wullschleger, S.D., Post, W.M., King, A.W. (1995) On the Potential for a CO2 Fertilization Effect in Forests: Estimates of the Biotic Growth Factor Based on 58 Controlled-Exposure Studies. In Woodwell, G. & Mackenzie, F. (eds), *Biotic Feedbacks in the Global Climatic System*, New York: Oxford Univ. Press, 85-107.