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IFs ENVIRONMENT MODEL DOCUMENTATION

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Note: This is a draft version.

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IFs Environment Model Documentation

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1. Introduction

1.1 Overview

Most of the environmental elements of the model are included within other modules, such as Economy and Agriculture. Please see those modules for more information, or click through the links below to learn more about how the IFs model can help environment-related analysis.

1.2 Dominant Relations

Atmospheric carbon dioxide is function of emissions from fossil fuel burning. Water use/demand is calculated two ways. In one method, water use is primarily a function of agricultural sector size (and therefore on irrigation).

In the second method, we model water demand as the sum of the water demand of three sectors—municipal, industrial, and agriculture. The data we use from Aquastat differentiates between these three sectors and many other water models use these same sectors as well. The data in Aquastat refers to these data series as "water withdrawal." For our purposes, we consider water withdrawal to be equivalent to water demand. The driving variable of the municipal water sector is the size of a country's urban population, the driving variable of industrial water demand is non-renewable electricity generation and the driving variable of agriculture water demand is irrigation.

Forest area is dependent upon the rate of conversion of forest to crop land and grazing area.

The following key dynamics are directly linked to the dominant relations:

The energy submodel determines fossil fuel use which is used to calculate carbon emissions as well as industrial water use. The agricultural submodel determines agricultural sector size and land conversion patterns. The infrastructure submodel determines land equipped for irrigation. The population submodel determines population growth and urban population growth which is used to calculate municipal water demand. See those models for discussion of dominant patterns and of control parameters.

The environmental model provides a more extended model of carbon dioxide, including oceanic absorption rates and possible impact of build-up on global temperature and agricultural patterns.

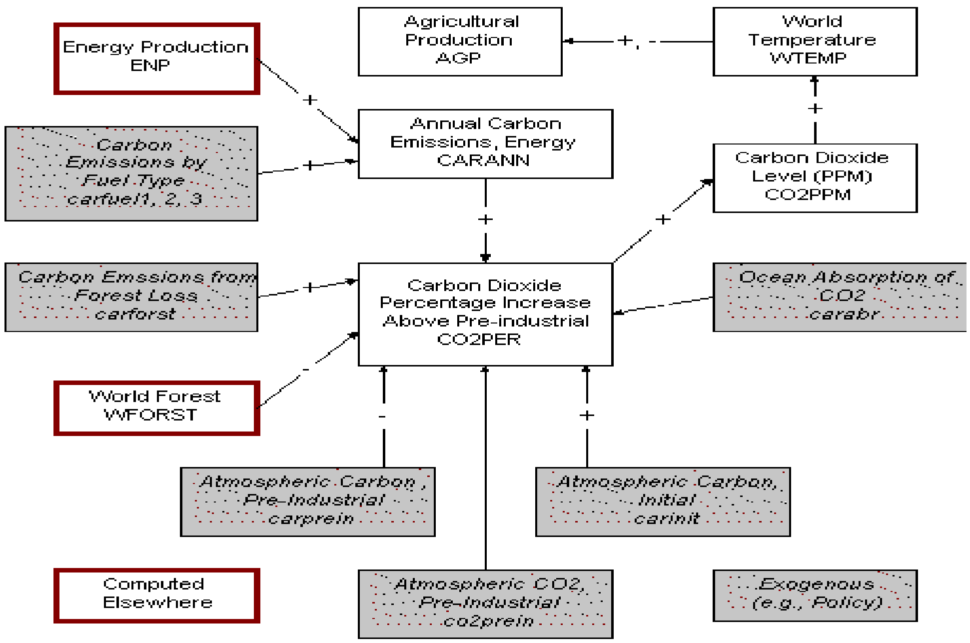
1.3 Structure and Agent System

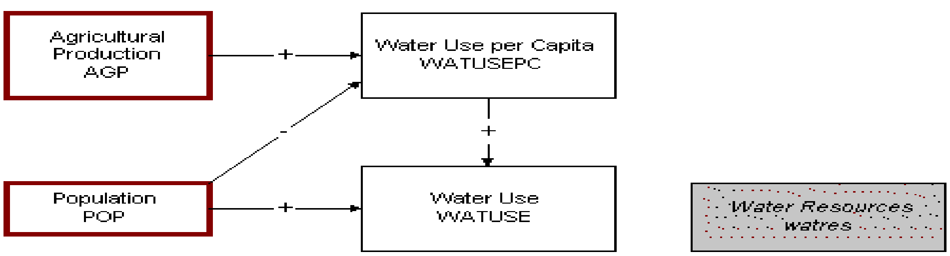
System/Subsystem	Environment (e.g. CO2, water)
Organizing Structure	Systemic Accounting
Stocks	Atmospheric carbon Oceanic carbon Forest area Fossil water
Flows	Annual Emissions Water Use Water Demand (municipal, industrial, agriculture) Renewable water resources (surface and ground) Wastewater (produced, treated, treated and reused) Desalinated water Fossil water withdrawal
Key Aggregate Relationships (illustrative, not comprehensive)	Oceanic absorption of CO2 Global temperatures with CO2
Key Agent-Class Behavior Relationships (illustrative, not comprehensive)	Governments and environmental policies regarding emissions Farmers and water use with agriculture

2. Environment Flow Charts

2.1 Environment Overview

Among the most important elements of the environmental submodel, which is imbedded in the other portions of the model, is the calculation of atmospheric carbon dioxide levels and global warming.





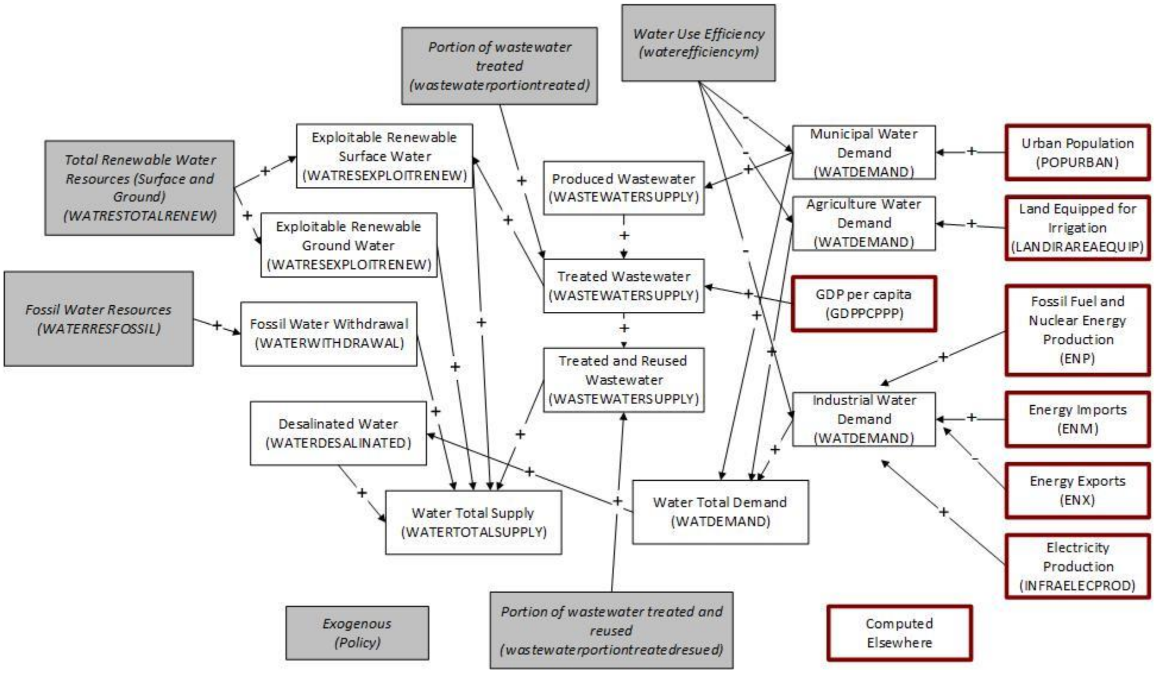


Figure 1: Water sub-module flowchart. Demand is on the right, driven by variables from other models. Supply is on the left and largely drive by data on renewable water resources. There are also parameters on all sources of supply (not pictured).

For detail, see the equations on greenhouse effect and climate change. To look at deforestation, look at the way in which agricultural production leads to changing land use.

3. Environment Equations

This section will present and discuss the equations that are central to the functioning of the environment model: the greenhouse effect, water and the Advanced Sustainability Analysis (ASA).

3.1 Greenhouse Effect

The beginning point for examining the greenhouse effect is calculation of the percentage increase in atmospheric carbon dioxide (C02PER). This figure is a percentage of the pre-industrial CO2 level, not of the total atmosphere. The model first calculates annual increase in atmospheric carbon from energy use (CARANN) and adds it to a cumulative tracking of carbon (SACARB). That increase depends on global production (WENP) in the fossil fuel categories (oil, gas and coal). The coefficients representing tons of carbon generated per barrel of oil equivalent burned (CARFUELn) multiply those fossil fuel totals (coefficients calculated from the IPCC 1995 report). The oceans and other sinks annually absorb an exogenously specified amount of atmospheric carbon (CARABR) and that retards the accumulation. Deforestation (or reforestation) has an impact via another parameter (CARFORST), the value of which was calculated using deforestation estimates from Vital Signs (Brown, Flavin, and Kane, 1996) and figures for the contribution of deforestation to CO2 emissions from the IPCC. The ultimate value was taken from Mori and Takhaashi (1997: 6). For an understanding of this process and data underlying the parameters see the report of the Intergovernmental Panel on Climate Change (IPPC) and Flavin (1996) . See also Repetto and Austin (1997) for an outstanding analysis of models used to investigate climate protection.

$$CARANN = WENP_{e=1} * \boldsymbol{carfuel1} + WENP_{e=2} * \boldsymbol{carfuel2} + WENP_{e=3} * \boldsymbol{carfuel3}$$

$$SACARB = SACARB_{t-1} + CARANN + (WFORST_{t-1} - WFORST) * \boldsymbol{carforst} - \boldsymbol{carabr}$$

where

$$SACARB_{t=1} = \boldsymbol{carinit}$$

The percentage increase in atmospheric carbon relative to pre-industrial levels (CO2PER) depends on the accumulated atmospheric level of carbon (billion tons) and the pre-industrial level of carbon in the atmosphere by weight (CARPREIN).

$$CO2PER = \frac{SACARB - carprein}{carprein} * 100$$

We can calculate the atmospheric level of carbon dioxide in parts per million (CO2PPM) from these figures, if we know the pre-industrial level of carbon dioxide in parts per million (CO2PREIN).

$$CO2PPM = co2prein + co2prein * \frac{CO2PER}{100}$$

We can use a table function to determine the average world temperature (WTEMP) in Centigrade from the atmospheric carbon dioxide level in parts per million (based on figures provided by the IPCC).

$$WTEMP = \boldsymbol{A}nalFunc(CO2PPM)$$

Finally, we must compute the increase to overall energy prices (CarTaxEnPriAdd) that carbon taxes cause, because total energy demand will respond to the total price. The increase will depend on the carbon tax per fossil fuel and the production level of fossil fuels in the overall pattern of energy production.

$$CarTaxEnPriAdd_r = \frac{\sum_{e=1}^{3} ENP_{r,e} - carfuel_e * carbtax_r}{\sum_{e=1}^{3} ENP_{r,e}}$$

3.3 Water

3.3.1 Water Use

IFs calculates the water use per capita (WATUSEPC) and the total water use (WATUSE) for each model region. The biggest water use for most countries is agricultural (on a global basis 65% of freshwater use, according to Postel, 1996: 13). IFs uses a table function that relates change in per capita use to change in agricultural production per capita.

$$WATUSEPC_r = WATUSEPC_{r,t=1} * \frac{TF\left(\frac{AGP_{r,f=1}}{POP_r}\right)}{TF\left(\frac{AGP_{r,f=1,t=1}}{POP_{r,t=1}}\right)}$$

3.3.2 Water Demand

Municipal water demand

Previously, IFs used the size of a country's urban population to forecast municipal water demand. This relied on a linear regression between municipal water demand and urban population. This implicitly assumed that per capita municipal water demand remains constant. Research, however has shown that the most important factor in increasing municipal water demand is income, which drives per capita water use (Alcamo, 2007).

To forecast changes in municipal water demand per capita over time we use a new equation. The dependent variable in this equation is municipal water demand per capita (WaterWithDMunicipal / PopulationUrban). The independent variables are: GDP per capita (PPP); size of the urban population; and the percentage of the population served with piped water (WSSJMPPWaterTotal%Piped).

$$WATDEMAND_{municipal,r} = WATDEMANDPC_{Municipal,r} \times Urban\ Population$$

Where municipal water demand per capita (WATDEMANDPC) is calculated using the following equation.

$$WATDEMANDPC_{municipal,r} = x_1(\ln(GDPPC_r)) + x_2(\ln(AccessToPipedWater_r)) - x_3(\ln(PercentUrbanPopulation_r))$$

Where 'GDPPC' represents GDP per capita at purchasing power parity (PPP), 'AccessToPipedWater' represents the portion of the population with access to piped water and 'PercentUrbanPopulation' represents the portion of the population living in urban areas. The coefficients of the first two independent variables ("x_1" and "x_2") are positive—as when GDP per capita and access to piped water increase, water use per capita will also increase. The third coefficient "x_3" is negative because higher levels of urbanization are negatively correlated with water use per capita. All three of these independent variables are statistically significant at the global level.

While the portion of a country's population living in urban areas is negatively correlated with water use per capita, the rate of urbanization is not necessarily negatively correlated with water use per capita. Countries with a large portion of their population living in urban areas might have water use efficiency infrastructure and policies in place, explaining the lower water use per capita. It takes time to put these water-conservation measures in place however. For this reason, the effect of 'PercentUrbanPopulation' on water demand per capita is lagged.

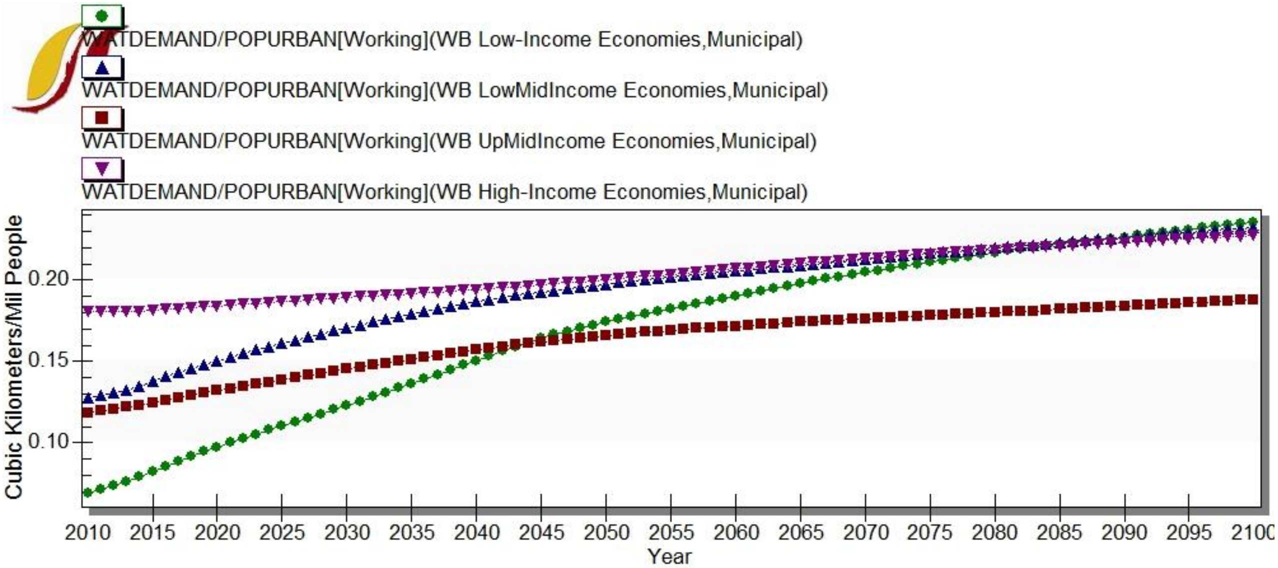
For countries where the urbanization rate is greater than 1%:

$$LaggedUrbanPercent_r = 1.01 \times \frac{(92 - UrbanPercent_r)^{.75}}{92}$$

This ensures that rapid urbanization does not lead to rapid water conservation. This is of particular concern for China, where IFs forecasts rapid urbanization over the next decades.

This new formulation means that municipal water use per capita (urban) increases in all income groups (see Figure 1).

Figure 2: *Municipal water demand per capita for urban populations.*



Agricultural water demand

We use the area of land under irrigation to drive agricultural water demand.

$$WATDEMAND_{agriculture,r} = TF(LandIrAreaEquip_r)$$

Industrial water demand

Industrial water demand is calculated as the sum of water demand for thermo-electric power generation (cooling) and water demand for the manufacturing sector.

Thermo-electric power generation

To forecast water consumption for thermo-electric power generation, we multiply total non-renewable electricity generation (in kWh) by a calculated value of water consumption per kWh. Water use per kWh is calculated as a function of both water scarcity within a country and the GDP per capita of the country. The more water-scarce a country is, the lower the desired water use per kWh. The actual water use per kWh is determined by this desired value together with the GDP per capita (PPP) of the country.

Water scarcity is calculated as the total water supply divided by the country's population. This water-scarcity figure is then linearly mapped onto the range of [0.4 – 2.0]. This is a reasonable range for water use per kWh in a country (in terms of liters per kWh).[1]

GDP per capita (PPP) for each country is linearly mapped onto the range [0-1] to calculate an 'AbilityToAffordEfficiency' variable.

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[1] National Renewable Energy Laboratory, NREL, Consumptive water use for U.S. power production, NREL/TP-550-33905. <http://www.nrel.gov/docs/fy04osti/33905.pdf>

Actual water use per unit of power generation (liters/kWh) is then calculated as:

$ActualWaterUsePerkWh_r = 2 - (AbilityToAffordEfficiency_r \times (2 - DesiredWaterUsePerkWh_r))$

This water use per kWh variable is then multiplied by non-renewable electricity generation to calculate total water consumption for electricity generation.

$$IndustrialWaterDemandforElectricity_r = ActualWaterUsePerkWh_r \times NonRenewablePowerGeneration_r$$

Where NonRenewablePowerGeneration is calculated as:

$$INFRAELECPROD_r - elecrenew_r$$

Where 'elecrenew' is calculated as:

$$\left(ENP_{renew,r} + ENP_{hydro,r}\right) \times 1699.41 \times 1000$$

Renewable energy production is forecast in terms of billion barrels oil equivalent so the model must convert to gigawatt hours and then to kWh before it is subtracted from INFRAELECPROD.

Industrial water demand for electricity is thus a function of non-renewable electricity generation, water scarcity, and GDP per capita (PPP).

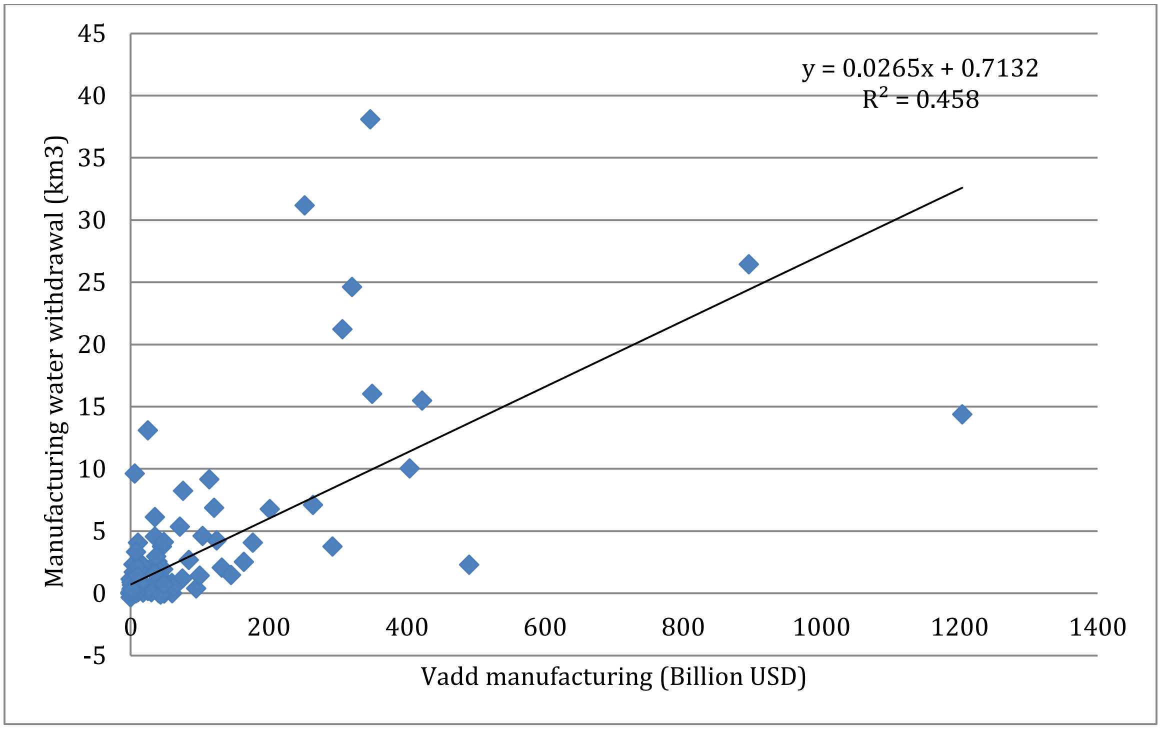
Manufacturing

Although we do not have data on water demand for the manufacturing sector, using the calculations above for industrial water demand for electricity generation, we can estimate the portion of industrial water demand that is required for the manufacturing sector:

$$IndustrialWaterDemand_{manufacturing,r} = IndustrialWaterDemand_r - IndustrialWaterDemand_{electricity,r}$$

We use the size of a country's manufacturing sector to drive industrial water demand for manufacturing. There is a correlation between this calculated industrial water demand for manufacturing and the size of the country's manufacturing sector.

Figure 2: *Manufacturing water withdrawal (km^3) versus value added from the manufacturing sector (US$ billions).*



Industrial water demand for manufacturing is calculated by using the annual growth rate in the size of the manufacturing sector, adjusted by an elasticity of 0.45.

$$IndustrialWaterDemand_{manufacturing,r,t} = IndustrialWaterDemand_{manufacturing,r,t-1} \times \left[\frac{VADD_{manufacturing,r,t}}{VADD_{manufacturing,r,t-1}}\right]^{0.45}$$

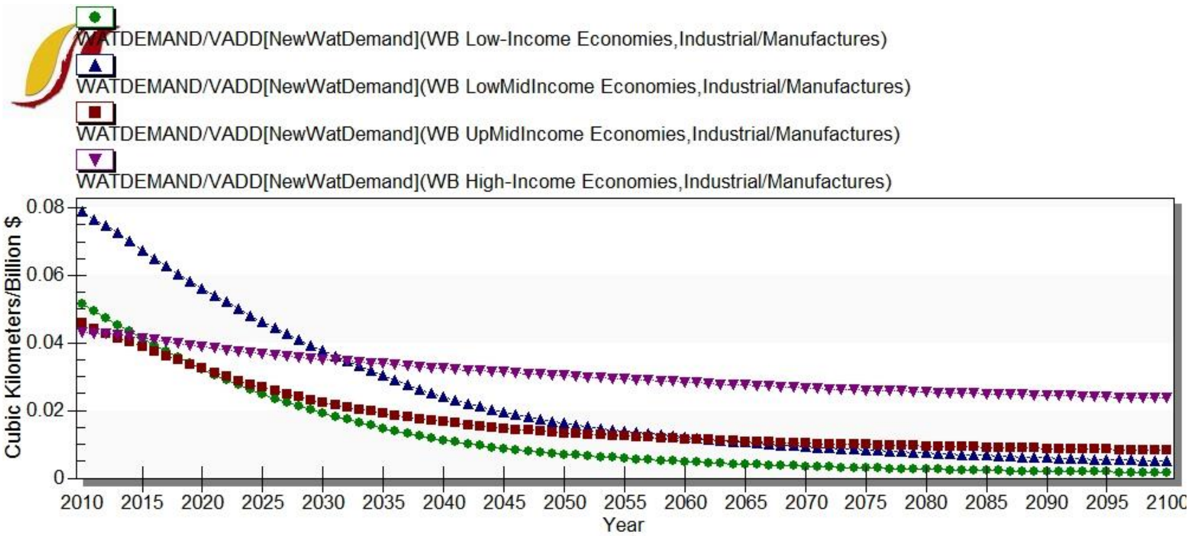
This elasticity figure (0.45) was calculated using country-specific elasticities between manufacturing value added growth rates and manufacturing water demand growth rates weighted by GDP:

$$\frac{\sum_{r}^{All\ Countries}\left[\frac{\log(ManufacturingWaterWithdrawalGR_r)}{\log(ManufacturingValueAddedGR_r)} \times GDP_r\right]}{Global\ GDP}$$

Where ManufacturingWaterWithdrawalGR is the compound annual growth rate for industrial water demand for the manufacturing sector and ManufacturingValueAddedGR is the compound annual growth rate for value added from the manufacturing sector. We log both growth rates because the elasticity is calculated as an exponent rather than a multiplicative factor.

This new formulation means that industrial water use per unit of value added from the manufacturing sector decreases for all income groups (see Figure 3).

Figure 3: *Industrial water demand per unit (US$ billions) of value added from the manufacturing sector.*



Using the equations described above, we calculate an "expected" water demand for each sector for each country. Using data from the pre-processor we are able to calculate residuals—the difference between the expected water demand and the actual water demand.

$$Residual_{r,s} = ExpectedWaterDemand_{r,s} - WATDEMAND_{r,s}$$

These residuals do not change over time. We do, however, include efficiency parameters (waterefficiencym) on each of the water demand variables so that the user may decrease water demand in any sector.

Water demand is calculated the same way in all other years. We recalculate the expected level of water demand for each sector for each country using the driving variable, and then apply the residual. We also include the efficiency parameter multipliers in these calculations.

$$WATDEMAND_{r,w} = (ExpectedWatDemand_{r,w} - Residual_{r,w}) * waterefficiencym_{r,s}$$

3.3.3 Water Supply

To model water supply in IFs we use the sum of surface water yield, renewable groundwater yield, non-renewable (fossil) groundwater withdrawal, treated and reused wastewater, and desalinated water.[2] Treated wastewater that is not directly reused is added to surface water yield. This constitutes secondary water.

While the data for exploitable renewable water resources is more important for our model than total renewable water resources, there are more data for total renewable water resources. Thus, we fill in holes for total renewable water resources first. Since total renewable freshwater resources is the sum of total renewable surface water and total renewable groundwater, we can estimate data if we have 2 of these 3 series.

$$WATRESTOTALRENEW = WATRESTOTALRENEW(Surface) + WATRESTOTALRENEW(Groundwater)$$

There are data for total renewable water resources for most countries—for the 12 countries without data we use land area to estimate the volume of total renewable freshwater resources.

Since total renewable water resources does not account for the overlap between surface water and groundwater, we must recalculate total renewable water resources by subtracting this overlap. We then recalculate total renewable surface water and total renewable groundwater using this adjusted total.

$$WATRESTOTALRENEW_{r,w} = \left(\frac{WATRESTOTALRENEW_{r,w}}{WATRESTOTALRENEW(Overlap)}\right) * WATRESTOTALRENEW(No\ Overlap)$$

Now that we have data for total renewable water resources for every country we estimate total renewable surface water and groundwater for those countries without data. To do this, we use global averages to determine the portion of a country's total renewable water resources that are surface water, and the portion that are groundwater. We assume that 71% of total renewable resources are surface water resources and 29% are groundwater resources.

Now that we have data for total renewable water resources for both surface and groundwater for every country, we estimate the portion of these resources that are exploitable (for countries without data) using global averages. We assume that 89% of total renewable groundwater resources are exploitable and 36% of total renewable surface water resources are exploitable.

We use WATRESTOTALRENEW as a limit on the increase in WATRESEXPLOITRENEW. Exploitable water resources are usually a portion of total resources. This is because exploitable resources consider several restrictions on the use of water resources. The Aquastat data handbook defines these restrictions in terms of

[2] Must include non-treated and reused wastewater.

technical-economic criteria, environmental criteria, and geopolitical criteria.[3] Exploitable water resources do however include secondary water so it can sometimes exceed total renewable water resources. This is rare but an important factor to keep in mind when forecasting. Thus, when we use total renewable resources as a limit on exploitable resources, we must remember to subtract secondary water from exploitable water resources first.

It is not possible, however, for exploitable water resources (excluding secondary water) to reach the TRWR limit. While exploitable water resources can increase, we assume that it cannot grow by more than 20%. We also assume that exploitable water resources cannot grow by more than .5% per year and that only one fortieth of remaining resources can be extracted in any year. Thus, the equation for exploitable water resources is:

$$WATRESEXPLOITRENEW_{t,w} = Min(WATRESEXPLOITRENEW_{t-1,w} * 1.005, \left(\left(\frac{(MaxExploitRenew_w - WATRESEXPLOITRENEW_{t-1,w})}{40}\right) + WATRESEXPLOITRENEW_{t-1,w} \right))$$

Where

$$MaxExploitRenew_{w,r} = iwatresexploitrenew_{w,r} * 1.2$$

iwatresexploitrenew is the exploitable renewable water resources in the first year. The subscript "w" represents that the variable is dimensioned in terms of surface and ground water. We also include a parameter, watresexploitrenewm on the total volume of exploitable water resources so that the user may increase or decrease this supply over time. After this growth rate is applied to exploitable surface water resources the secondary component is added to WATRESEXPLOITRENEW (surface). Secondary water is the total volume of treated wastewater that is not directly reused.

WASTEWATERSUPPLY is a multidimensional variable in the IFs model. The three dimensions are Produced, Treated, and TreatedAndReused. Most of our data on wastewater comes from the Aquastat database so we use their conceptual framework to model and forecast wastewater.[4] Total produced wastewater is forecast in IFs as a portion of total municipal water demand. This relies on the assumption that wastewater that is reused *among* sectors comes primarily from collected municipal wastewater. Wastewater that is reused within a sector (for example, reuse of industrial wastewater within the same industrial factory) does not increase the water supply but, rather, decreases water demand in that particular sector.

Since we take the most recent data for each of these series they often do not reconcile. For example, treated wastewater may exceed produced wastewater, which is impossible.

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[3] Margat, Jean. Et al. Key water resources statistics in Aquastat, 2005. <http://doc.abhatoo.net.ma/doc/IMG/pdf/key_water_resources_statistics_in_aquastat.pdf> pg. 11

[4] Aquastat Wastewater Conceptual Framework <http://www.fao.org/nr/water/aquastat/catalogues/Wastewater_Methodology_paper_20121130.pdf>

If a country's volume of treated wastewater exceeds their supply of produced wastewater we assume that they treat 95% of their produced wastewater.

If we do not have data for a country's volume of produced wastewater, we estimate this value using their municipal water demand. If we do not have data on the volume of treated wastewater, we estimate this value using a portion of their produced wastewater. The portion of a country's produced wastewater that is treated is driven by GDP per capita. If we do not have data on the portion of treated wastewater that is directly reused, we estimate this value using a global average of 66%. Parameters are in IFs on both the portion of wastewater that is treated and the portion of treated wastewater that is directly reused: wastewaterportiontreated and wastewaterportiontreatedreused.

A portion of treated wastewater is directly reused and a portion of treated wastewater is discharged directly back into the water system. This discharge is considered "secondary water" and is added to exploitable surface water resources. Likewise, a portion of non-treated wastewater is directly re-used, usually by the agricultural sector, and a portion is discharged. The portion of non-treated wastewater that is not directly re-used is not added to exploitable surface water resources however. We do not yet have forecasts in IFs for the amount of non-treated wastewater that is directly reused. This is something that needs to be added to the model as some countries, like Mexico, use a large volume of non-treated municipal wastewater to irrigate crops.

Wastewater that is treated but not directly reused is then added to exploitable surface water resources.

$$WATRESEXPLOITRENEW(Surface) = WATRESEXPLOITRENEW(Surface) + WASTEWATERSUPPLY(Treated) - WASTEWATERSUPPLY(TreatedAndReused)$$

Wastewater supply is calculated for all years using the same regressions described above for all years. The residuals for each of the equations do not change. The only way to increase supply of wastewater is to adjust municipal demand (which will affect total wastewater produced) or to adjust the wastewaterportiontreated parameter. This parameter is initialized as 1 but can be adjusted by the user. If the user does not change this parameter, the portion of produced wastewater that is treated will be driven by GDP per capita. If the user changes this to a value between 0 and 1 then that is the portion of produced wastewater that is treated.

If wastewaterportiontreated != 1 Then

$$WASTEWATERSUPPLY_{treated,r} = WASTEWATERSUPPLY_{produced,r} * wastewaterportiontreated_r$$

Else

$$WASTEWATERSUPPLY_{treated,r} = WASTEWATERSUPPLY_{produced,r} * TF(GDP\ per\ capita\ PPP_r)$$

We use a log function of GDP per capita to forecast the portion of wastewater that is treated.

We take fossil water resources data from 3 sources: FAO, UNESCO, and a peer-reviewed journal article from IOPScience[5]. The IOP article however, does not differentiate between renewable groundwater resources and fossil groundwater resources so we subtract renewable groundwater resources from total fossil water resources.
For some countries, we have data on fossil water withdrawals but not fossil water resources. This creates problems in the forecast since future water withdrawals are based on remaining fossil water resources. For these countries, we estimate that their total fossil water resources are 10 times their current fossil water withdrawals.

$$WATERRESFOSSIL = 10 * WATERWITHDRAWAL(Fossil)$$

We model fossil water in IFs using a stock and flow dynamic. Total fossil water resources are used as a stock and fossil water withdrawal is the flow. Fossil water withdrawals increase at a one percent growth rate. This increase is bounded by the total supply of fossil water remaining. A country cannot extract more than one seventh of their remaining fossil water resources in any year. This number is taken from current fossil water extraction rates. The highest rate of extraction globally, occurring in the Nubian Sandstone Aquifer, is about one seventh of remaining resources.[6]

$$WATERWITHDRAWAL_{t+1,f} = Min(WATERWITHDRAWAL_{t,f} * 1.01, \frac{WATERRESFOSSIL}{7})$$

The subscript f represents fossil water.

Our data for desalinated water also comes from the Aquastat database. For countries where total water supply exceeds demand, desalination potential is set at 20% higher than the initial value of desalinated water. For countries where demand exceeds supply, remaining potential is equivalent to the gap between total demand and total supply (excluding desalinated water). Desalinated water grows at an 8% growth rate, but this growth rate diminished over time. Desalinated water cannot decrease faster than 2% per year.

For countries where total demand exceeds supply,

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[5] MacDonald, A. M. Quantitative maps of groundwater resources in Africa. *Environmental Research Letters.*

[6] UNESCO Non-Renewable Groundwater Resources. 2006. < http://portalsostenibilidad.upc.edu/archivos/fichas/informes/aguassubterraneasnorenovables.guiagestion..pdf>

$$RemainingDesalPotential_r = WaterTotalDemand_r - WaterTotalSupply_r$$

Then,

$$WaterDesalinated_{r,t} = Min\left(WaterDesalinated_{r,t-1} * WaterDesalGR_r * \left(\frac{ShareDemandDesal_{r,i}}{ShareDemandDesal_{r,t}}\right)^{\frac{1}{20}}\right), \left(\frac{RemainingDesalPotential_r}{20} + WaterDesalinated_{r,t-1}\right)$$

We do not let desalinated water grow to the point where total water supply exceeds demand. For countries where total water demand exceeds total water supply (excluding desalinated water), desalinated water grows to fill this demand.

Total water supply (WATERTOTALSUPPLY) is then calculated as the sum of these 5 water sources i.e. reused water, desalinated water, surface water, ground water, and fossil water.

$$WATERTOTALSUPPLY = WASTEWATER(TreatedAndResued) + DESALINATEDWATER + WATERRESEXPLOITRENEW(Surface) + WATERRESEXPLOITRENEW(Ground) + WATERWITHDRAWAL(FossilGround)$$

Because of the way we define water supply, demand can exceed supply of water resources. This usually means that the country is over exploiting their resources. This means that the country is using more surface water then their available yield, or withdrawing groundwater faster than the recharge rate. There are currently 23 countries that are over exploiting their water resources on a national level. It should be noted however, that since we are only looking at the national scale, local over-exploitation is not captured. This is particularly relevant to China and India—countries where over-exploitation is known to occur but not captured in our analysis. The top 5 countries in terms of national water exploitation are: Turkmenistan, Singapore, Egypt, Uzbekistan, and Syria, respectively.[7]

While we do not forecast water withdrawal by source (surface, ground, and fossil ground), we have the data in IFs. This will be useful to forecast in the future so that we can determine the type over-exploitation that is occurring in water scarce countries. We pull in data on surface water withdrawal, groundwater withdrawal, and total water withdrawal from Aquastat. Since total water withdrawal is the sum of surface water

[7] Singapore imports water from Malaysia. Water imports are not yet captured in the model.

withdrawal and groundwater withdrawal, we can estimate surface water withdrawal if we have total water withdrawal and groundwater withdrawal. Likewise, if we have total water withdrawal and groundwater withdrawal we can estimate surface water withdrawal. Since, however, Aquastat does not differentiate between renewable groundwater withdrawal and fossil groundwater withdrawal we must first subtract fossil water withdrawal from groundwater withdrawal using other data.

$$WATERWITHDRAWAL(Ground) = WATERWITHDRAWAL(Ground) - WATERWITHDRAWAL(FossilGround)$$

If we have data on total water withdrawals but not surface water withdrawals and groundwater withdrawals then we estimate using global averages. We assume that 67% of a country's water withdrawals come from surface water and 33% come from groundwater. If we do not have data on total water withdrawals we assume that a country's total water withdrawals are equivalent to their total water demand. We then use the same global averages to determine which portion of this demand is met by surface water and which portion is met by groundwater. We do not yet reconcile total water demand with total water withdrawals, though, theoretically, they should be equivalent.

3.4 Advanced Sustainability Analysis (ASA)

The Advanced Sustainability Analysis (ASA) is a framework developed by the Finland Futures Research Centre (FFRC), and the partial implementation in IFs was in cooperation with the FFRC within the TERRA project. For further information on ASA see: Kaivo-oja, Jari, Jyrki Luukhanen, and Pentti Malaski (2002). "'Methodology for the Analysis of Critical Industrial Ecology Trends: an Advanced Sustainability Analysis of the Finnish Economy' " Turku, Finland: Finland Futures Research Centre.

The ASA builds on resource use or emissions calculations such as those for annual carbon emissions. The implementation in IFs represents four different environmental impact areas:

1. Fossil fuel use
2. Carbon emissions
3. Deforestation
4. Water use

The raw values for each environmental impact are put into the ASA raw value matrix (ASARAW), drawing upon variables from elsewhere in IFs.

$$ASARAW_{r,1} = ENP_{r,e=oil} + ENP_{r,e=gas} + ENP_{r,e=coal}$$

$$ASARAW_{r,2} = CARANN_r$$
$$ASARAW_{r,3} = Forest_{r,t-1} - LD_{r,l=forest,t}$$
$$ASARAW_{r,4} = WATUSE_r$$

Within each area there are four environmental impact views, including the raw impact view shown above. The views are:

1. Raw values of impact (e.g. ASARAW, 2 for raw carbon emissions)
2. Impact per unit of GDP (e.g. ASAGDP, 2 for carbon emissions per unit of GDP)
3. Impact per unit of population (e.g. ASAPOP, 2 for carbon emissions per unit of POP)
4. Impact per member of the labor force (e.g. ASALAB, 2 for carbon emissions per unit of LAB)

The equations below illustrate those for views, using carbon emissions. The other three sets for the other three impact areas would be completely parallel.

$$ASARAW_{r,2} = CARANN_r$$
$$ASAGDP_{r,2} = \frac{CARANN_r * 1000}{GDP_r}$$
$$ASAPOP_{r,2} = \frac{CARANN_r * 1000}{POP_r}$$
$$ASALAB_{r,2} = \frac{CARANN_r * 1000}{LAB_r}$$

In addition, there are calculations within each view of dematerialization over time. Dematerializations are calculated within each impact area (a) relative to raw impact (ASARAWDMAT), to GDP (ASAGDPDMAT), to population (ASAGDPDPOP), and to labor (ASAGDPDMAT)

$$ASARAWDMAT_{r,a} = \frac{ASARAW_{r,a,t} - ASARAW_{r,a,t=1}}{ASARAW_{r,a,t=1}}$$
$$ASAGDPDMAT_{r,a} = \frac{ASAGDP_{r,a,t} - ASAGDP_{r,a,t=1}}{ASAGDP_{r,a,t=1}}$$
$$ASAPOPDMAT_{r,a} = \frac{ASAPOP_{r,a,t} - ASAPOP_{r,a,t=1}}{ASAPOP_{r,a,t=1}}$$
$$ASALABDMAT_{r,a} = \frac{ASALAB_{r,a,t} - ASALAB_{r,a,t=1}}{ASALAB_{r,a,t=1}}$$

Gross rebounds are also calculated for the ASA system. They are basically the raw impact times the growth in either GDP, population, or labor.

$$ASAGDPGRRB_{r,1} = ASAGDP_{r,a} * (GDP_{r,t} - GDP_{r,t=1})/1000$$

$$ASAPOPGRRB_{r,1} = ASAPOP_{r,a} * (POP_{r,t} - POP_{r,t=1})/1000$$
$$ASALABGRRB_{r,1} = ASALABP_{r,a} * (LAB_{r,t} - LAB_{r,t=1})/1000$$

Finally, there are three measures of cumulative change created for the display system, once for each of the GDP, population, and labor bases of the system.

$$ASAGDPCUMCHG_r = \frac{GDP_{r,t} - GDP_{r,t-1}}{GDP_{r,t-1}} * 100$$
$$ASAPOPCUMCHG_r = \frac{POP_{r,t} - POP_{r,t-1}}{POP_{r,t-1}} * 100$$
$$ASALABCUMCHG_r = \frac{LAB_{r,t} - LAB_{r,t-1}}{LAB_{r,t-1}} * 100$$

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