IFs ENVIRONMENT MODEL DOCUMENTATION

Author: Barry B. Hughes
September 2013

Note: This is a draft version.
IFs Environment Model Documentation

Table of Contents

1. Introduction .............................................................................................................................................. 2
   1.1 Overview ........................................................................................................................................... 2
   1.2 Dominant Relations ....................................................................................................................... 2
   1.3 Structure and Agent System ............................................................................................................. 3
2. Environment Flow Charts ....................................................................................................................... 4
   2.1 Environment Overview ..................................................................................................................... 4
3. Environment Equations .......................................................................................................................... 5
   3.1 Greenhouse Effect ............................................................................................................................. 5
   3.3 Water ................................................................................................................................................. 6
     3.3.1 Water Use .................................................................................................................................. 6
   3.4 Advanced Sustainability Analysis (ASA) ......................................................................................... 6
4. References .............................................................................................................................................. 9
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 is primarily a function of agricultural sector size (and therefore on 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, and the agricultural model determines agricultural sector size and land conversion patterns. 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

<table>
<thead>
<tr>
<th>System/Subsystem</th>
<th>Environment (e.g. CO2, water)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organizing Structure</strong></td>
<td>Systemic Accounting</td>
</tr>
<tr>
<td>Stocks</td>
<td>Atmospheric carbon Oceanic carbon Forest area Renewable water resources</td>
</tr>
<tr>
<td>Flows</td>
<td>Annual Emissions Water Use</td>
</tr>
<tr>
<td><strong>Key Aggregate Relationships</strong> <em>(illustrative, not comprehensive)</em></td>
<td>Oceanic absorption of CO2 Global temperatures with CO2</td>
</tr>
<tr>
<td><strong>Key Agent-Class Behavior Relationships</strong> <em>(illustrative, not comprehensive)</em></td>
<td>Governments and environmental policies regarding emissions Farmers and water use with agriculture</td>
</tr>
</tbody>
</table>
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.

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 (CO2PER). 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 (IPCC) and Flavin (1996). See also Repetto and Austin (1997) for an outstanding analysis of models used to investigate climate protection.

\[
\begin{align*}
\text{CARANN} &= WENP_{e=1} \times \text{carfuel1} + WENP_{e=2} \times \text{carfuel2} + WENP_{e=3} \times \text{carfuel3} \\
\text{SACARB} &= \text{SACARB}_{t-1} + \text{CARANN} + (WFORST_{t-1} - WFORST) \times \text{carforst} - \text{carabr} \\
\text{where} \\
\text{SACARB}_{t=1} &= \text{carinit} \\
\end{align*}
\]

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).

\[
\text{CO2PER} = \frac{\text{SACARB} - \text{carprein}}{\text{carprein}} \times 100
\]

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).

\[
\text{CO2PPM} = \text{co2prein} + \text{co2prein} \times \frac{\text{CO2PER}}{100}
\]
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).

\[ \text{WTEMP} = \text{AnalFunc(CO2PPM)} \]

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.

\[
\text{CarTaxEnPriAdd}_r = \frac{\sum_{e=1}^{3} ENP_{r,e} - carfuel_e \cdot carbtax_r}{\sum_{e=1}^{3} ENP_{r,e}}
\]

### 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.

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

### 3.4 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.

\[
\text{ASARAW}_{r,1} = \text{ENP}_{r,e=oil} + \text{ENP}_{r,e=gas} + \text{ENP}_{r,e=coal}
\]

\[
\text{ASARAW}_{r,2} = \text{CARANN}_r
\]

\[
\text{ASARAW}_{r,3} = \text{Forest}_{t-1} - \text{LD}_{t=\text{forest},t}
\]

\[
\text{ASARAW}_{r,4} = \text{WATUSE}_r
\]

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.

\[
\text{ASARAW}_{r,2} = \text{CARANN}_r
\]

\[
\text{ASAGDP}_{r,2} = \frac{\text{CARANN}_r \times 1000}{\text{GDP}_r}
\]

\[
\text{ASAPOP}_{r,2} = \frac{\text{CARANN}_r \times 1000}{\text{POP}_r}
\]

\[
\text{ASALAB}_{r,2} = \frac{\text{CARANN}_r \times 1000}{\text{LAB}_r}
\]

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 (ASAGDPPDPOP), and to labor (ASAGDPDMAT)
\[
\text{ASARAWDMAT}_{r,a} = \frac{\text{ASARAW}_{r,a,t} - \text{ASARAW}_{r,a,t=1}}{\text{ASARAW}_{r,a,t=1}}
\]
\[
\text{ASAGDPDMAT}_{r,a} = \frac{\text{ASAGDP}_{r,a,t} - \text{ASAGDP}_{r,a,t=1}}{\text{ASAGDP}_{r,a,t=1}}
\]
\[
\text{ASAPOPDMAT}_{r,a} = \frac{\text{ASAPOP}_{r,a,t} - \text{ASAPOP}_{r,a,t=1}}{\text{ASAPOP}_{r,a,t=1}}
\]
\[
\text{ASALABDMAT}_{r,a} = \frac{\text{ASALAB}_{r,a,t} - \text{ASALAB}_{r,a,t=1}}{\text{ASALAB}_{r,a,t=1}}
\]

Gross rebounds are also calculated for the ASA system. They are basically the raw impact times the growth in either GDP, population, or labor.
\[
\text{ASAGDPRBB}_{r,1} = \text{ASAGDP}_{r,a} \times \frac{(\text{GDP}_{r,t} - \text{GDP}_{r,t=1})/1000}{1}
\]
\[
\text{ASAPOPRBB}_{r,1} = \text{ASAPOP}_{r,a} \times \frac{(\text{POP}_{r,t} - \text{POP}_{r,t=1})/1000}{1}
\]
\[
\text{ASALABRBB}_{r,1} = \text{ASALAB}_{r,a} \times \frac{(\text{LAB}_{r,t} - \text{LAB}_{r,t=1})/1000}{1}
\]

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.
\[
\text{ASAGDCUMCHG}_{r} = \frac{\text{GDP}_{r,t} - \text{GDP}_{r,t-1}}{\text{GDP}_{r,t-1}} \times 100
\]
\[
\text{ASAPOPCUMCHG}_{r} = \frac{\text{POP}_{r,t} - \text{POP}_{r,t-1}}{\text{POP}_{r,t-1}} \times 100
\]
\[
\text{ASALABCUMCHG}_{r} = \frac{\text{LAB}_{r,t} - \text{LAB}_{r,t-1}}{\text{LAB}_{r,t-1}} \times 100
\]
4. References


Intergovernmental Panel on Climate Change (IPCC). 1995. Several volumes by various working groups. Published by Cambridge University Press. See the IPCC web page at http://www.unep.ch/ipcc/ipcc-0.html


