Model description

This is a model description following the ODD protocol (Grimm et al. et al) of a replication of Janssen (1996) and Janssen and de Vries (1996). The original model was developed in the language M, a precursor of MyM (http://www.tizio.eu/?page=mym). The original code was not available anymore, and has been implemented in Netlogo based on the documentation available by the original programmer. One simplification is made. Instead of a genetic algorithm, a simple evolutionary process is simulated that capture the same type of adaptation process.

Overview:

Purpose: How does the world population adapt when it is confronted with a climate change? Based on the different interpretations of the information, we consider different possible models of the global system. The model simulates agents with different cultural perspectives making decisions on climate change policy. Can the world population adapt in time if it ignored initially the existence of climate change?

State variables and scales:

The model combines a system dynamics type of model of an economy-climate system and an agent-based model. The economy includes capital, economic output, CO_2 emissions, CO_2 concentration and temperature change. The agents vary in their perspectives of how the world works. Agents do not represent a particular country or individual, but the population as a whole can adapt the average perspective when new information becomes available.

Process overview and scheduling:

Each year, starting in 1995, and ending in 2100, a number of economic variables are calculated which are needed to define economic output. Those are the technological progress, the fuel composition, and the capital stock. Together with the experienced temperature change (for damage costs), we can calculate the economic output.

Economic output and fuel composition determines emissions. A simple carbon cycle is used to determine CO_2 concentration, and then the temperature change.

Once temperature change and economic development are calculated we can evaluate the fitness of the different perspectives, and define the perspectives for the next tick.

Design Concepts:

Basic principles: Cultural theory is used to define the functioning of the social-ecological system and the different management styles.

Adaptation: The average perspective of the population adapt over time towards those who are better able to explain observations.

Sensing: Agents sense economic production and temperature change.

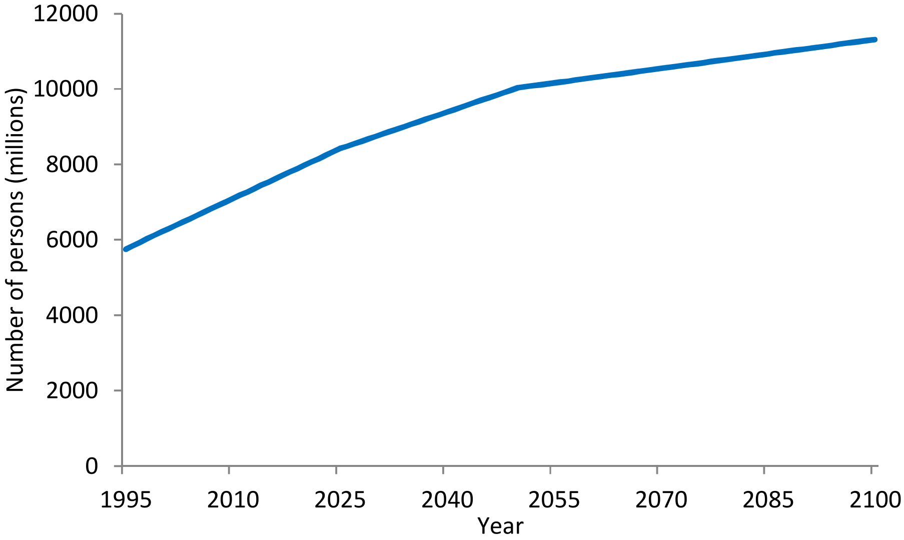
Interaction: Agents interact indirectly in a competition for better explanations of observations. In fact, agents – representing perspectives – do not represent actual physical agents.

Stochasticity: In defining new perspectives we include noise to perspective of the individual agents.

Details:
Initialization:

The initial levels of capital (K[0] = 29.476), population (P[0]=5749), and technical progress rate ($\delta_a^{rate}[0]$ = 0.011518) are defined. Furthermore, the initial perspectives of the agents are defined.

Input data:
The population scenario comes from Bulatao et al. (1990).



Submodels:

<u>Economy</u>
The economic output Y is described as

$$Y[t] = c \cdot S[t] \cdot a[t] \cdot K[t]^{\gamma} \cdot P[t]^{1-\gamma}$$

This is a standard constant-returns-to-scale, Cobb-Douglas production function with two production factors: capital K[t] and labor L[t] which is assumed to be proportional to population P[t]. Technical progress is captured by exogenous factor a[t]. To account for the economic consequences of either climate change related damage or emission reduction measures, the scale factor S[t] is introduced. Both a[t] and S[t] are normalized to be 1 in the base-year 1995.

Technological change is assumed to increase exponentially but at a declining rate (Nordhaus, 1994). This is formulated as

$$a[t] = a[t-1] + a[t-1] \cdot \delta_{ao}^{rate} \cdot e^{-\delta_a \cdot t})$$

The parameter c is estimated to be 0.0132 to derive the 1990 US$ world production numbers. The elasticity of output with respect to capital, γ, is assumed to be 0.25. The scaling factor S[t] is discussed below.

Economic output is produced by capital stock K[t]. The average lifetime of stock is 10 years, and the fraction of the economic output that is re-invested is I. This leads to the following balance equation

$$K[t] = K[t-1] \cdot (1 - \delta_K) + I[t] \cdot Y[t-1]$$

Where δ_K is the rate of depreciation of the capital stock. Consumption C is equal to economic output minus gross investments, thus

$$C[t] = (1 - I[t]) \cdot Y[t-1]$$

Energy System

The economy has an energy intensity e defined as the amount of fuel required per unit of economic output. This energy-intensity is assumed to decline logistically to a lower bound e_{min}. The rate at which this happens is dependent by L_e which is the number of years it takes to halve the initial (1995) value of e.

The energy supply to the economy is a mix of fuel of which a fraction F[t] consists of fossil fuels, which leads to CO_2 emissions. Also here we assume a transition away from fossil fuels using L_f which defined the number of years it takes to reduce the initial (1995) value of F[t] with 50%.

The CO_2 emissions is defined as

$$E[t] = \alpha \cdot F[t] \cdot e[t] \cdot Y[t]$$

Where α is the unit parameter equal to 0.32 GtC/bil$.

The share of fossil fuels is defined as a logistic function, where L_f is the number of years which are required to reduce the share of fossil fuels within the energy mix by 50%, and ε is the autonomous decarbonization rate equal to 0.01 (Lempert et al., 1996).

$$F[t] = \frac{1}{1-\varepsilon} \cdot \frac{1}{1 + \exp(\rho_m[t] \cdot (\frac{L_f[t] \cdot (t - L_f[t]}{L_f[t-1]}))}$$

Where

$$\rho_m[t] = \frac{-1}{L_f[t]} \cdot \ln(\frac{\varepsilon}{1-\varepsilon})$$

The decline of energy intensity is described by a logistical function where δ is the contribution of available low-cost conservation measures and where the number of years required to energy efficiency is assumed to be 50 years:

$$e[t] = (1 - \delta) + \frac{1}{1 - \varepsilon} \cdot \frac{\delta}{1 + \exp(-0.02 \cdot \ln(\frac{\varepsilon}{1 - \varepsilon}) \cdot (t - 50)}$$

Climate system

A simple climate system model translates the CO_2 emissions into temperature change. We use a reduced-form carbon cycle model by Maier-Raimer and Hasselmann (1987) to capture the carbon cycle. Carbon emissions contributes to 5 carbon stocks, which have different atmospheric lifetimes. The initial carbon stock C_1 is 365 ppmv, and the rest is initially 0. Each year the carbon stocks increase in size as defined by

$$C_1[t] = C_1[t - 1] + 0.131 \cdot 0.471 \cdot E[t]$$
$$C_2[t] = C_2[t - 1] + 0.471 \cdot E[t] \cdot (0.201 \cdot e^{\frac{t}{362.9}})$$
$$C_3[t] = C_3[t - 1] + 0.471 \cdot E[t] \cdot (0.321 \cdot e^{\frac{t}{73.6}})$$
$$C_4[t] = C_4[t - 1] + 0.471 \cdot E[t] \cdot (0.249 \cdot e^{\frac{t}{17.3}})$$
$$C_5[t] = C_5[t - 1] + 0.471 \cdot E[t] \cdot (0.098 \cdot e^{\frac{t}{1.9}})$$

Leading to a concentration of CO_2 in the atmosphere equal to

$$pCO_2[t] = C_1[t] + C_2[t] \cdot e^{-t/362.9} + C_3[t] \cdot e^{-t/73.6} + C_4[t] \cdot e^{-\frac{t}{17.3}} + C_5 \cdot e^{-t/1.9}$$

The radiative forcing of CO_2 is defined as

$$\Delta Q_{CO2}[t] = \frac{\Delta Q_{2XCO2}}{\ln(2)} \cdot \ln(\frac{pCO_2[t]}{296})$$

Where ΔQ_{2XCO2} is the radiative forcing associated with a doubled CO_2 concentration (4.3 W/m^2) and 296 is the pre-industrial CO_2 concentration.

This aggregated radiative forcing has the following impact on the change in the global mean surface temperature

$$\Delta T^p[t] = \frac{\Delta T_{2XCO2}}{\Delta Q_{2XCO2}} \cdot \Delta Q_{CO2}[t]$$

Where $\Delta T_{2CO2}$is the global mean surface temperature change in the event of a CO_2 concentration (best estimate is $2.5^{O}C$). Since oceans take a long time to warm up, the actual temperature increase (ΔT) will lag behind the potential increase:

$$\Delta T[t] = \Delta T[t - 1] + \beta \cdot (\Delta T^p[t] - \Delta T[t - 1])$$

Where β is assumed to be 0.05.

Costs and Benefits

The scaling factor S[t] takes into account the damage costs due to global temperature change, and the cost of reducing emissions (Nordhaus, 1994).

$$S[t] = \frac{1 - b_1 \cdot (1 - F[t])^{b_2}}{1 + \theta_1 \cdot \Delta T[t]^{\theta_2}}$$

With θ_1 representing the scale of damage and/or adaptation, θ_2 the non-linearity in the damage function, and b_1 and b_2 the scale and non-linearity of the emission reduction cost function.

Worldviews

A number of parameters of the model differ in their values based on the world view we may use. Individualists assume a rapid technological development, low climate sensitivity, low damage costs and high mitigation costs. The egalitarian world view is the opposite, and the hierarchist world view is in between. The parameter values are listed below

	Individualist	Hierarchist	Egalitarian
Technology			
δ	0.4	0.5	0.6
δ_a	0.004	0.012	0.024
Climate sensitivity			
ΔT_{2xCO2}	0.5	2.5	5.5
Damage costs			
θ_1	0	0.0014	0.004
θ_2	0	2	
Mitigation costs			
b_1	0.25	0.11	0.05
b_2	3.5	2.9	2.3

Management styles

The management style is assumed to be based on an average response of the different perspective weighted for the different shares of worldviews in the population. The population makes decisions on investments in economic development and alternative energy.

Hierarchists are assumed to favor a smooth expansion of the economy and strive for a growth rate of 1.5% (dY_D), leading to an investment strategy defined as:

$$I^H[t] = 0.9 \cdot I[t-1] + 0.1 \cdot \frac{dY_D}{dY[t-1]} \cdot I[t-1]$$

Which leads the investment adjusting to get the derived growth rate, if no surprises (such as severe climate change) are happening.
The investment in alternative fuel is based on observed temperature increase. The higher the observed temperature increase, the more drastic – and costly – the policy:

IF $\Delta T_{obs} < 0.5$ THEN $L_f^H[t] = 100$
IF $0.5 \leq \Delta T_{obs} < 1$ THEN $L_f^H[t] = 20 + (L_f[t-1] - 20) \cdot 0.995$
IF $1 \leq \Delta T_{obs} < 1.5$ THEN $L_f^H[t] = 20 + (L_f[t-1] - 20) \cdot 0.99$
IF $\Delta T_{obs} \geq 1.5$ THEN $L_f^H[t] = 20 + (L_f[t-1] - 20) \cdot 0.98$

Egalitarians desire a steady economic system and therefore their desired investment level is a equal to the depreciation rate of existing capital goods:

$$I^E[t] = \frac{\delta_K \cdot K[t-1]}{Y[t-1]}$$

The egalitarians aim to rapidly make a transition to a low carbon society and thus $L_f^E = 20$ years.

Individualists aim to have at least a minimum economic growth of 2%, min[dY], and the resulting investment decision is therefore

$$IF\ dY[t] < \min[dY]\ THEN\ I^I[t] = \min\left(1, \min[dY] \cdot \frac{I[t-1]}{dY[t-1]}\right) ELSE\ I^I[t] = I[t-1].$$

As long as the damage costs are lower than 1% of the economic output, no acceleration of fuel transition towards a low carbon fuel economy is implemented.

$$IF\ \theta_1 \cdot \Delta T[t]^{\theta_2} < 0.01\ THEN\ L_f^I = 1000\ ELSE\ L_f^I[t] = 20 + (L_f[t-1] - 20) \cdot 0.99$$

<u>Fitness of perspectives</u>
The fitness of a perspective relates to how well it is able to predict relevant indicators. Individualists focus on economic growth, egalitarians on temperature change, and hierarchists look at both indicators.

$$IF\ Eindicator - \tau \leq Oindicator \leq Eindicator + \tau$$

$$THEN\ Fitness = 1$$

$$ELSE\ Fitness = \frac{abs(Eindicator - Oindicator - \tau)}{\omega + abs(Eindicator - Oindicator - \tau)}$$

Where ω is a scaling factor and τ is a tolerance level.

Change of perspectives

Each agent has a perspective which is build up by x_h hierarchist, x_i individualist and x_e egalitarian, where the sum $x_h + x_i + x_h = 1$. Each year perspectives are evaluated and the new perspectives are drawn for the next generation based on the relative fitness of the perspectives of the agents. Hence perspectives with better explanations of observations do get more offspring. Once new perspectives are generated, we add some noise to them from a normal distribution n(0,0.02), to allow mutations and for new perspectives to emergence

Model implementation

The model is implemented in Netlogo 5.0.3

References

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