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MODEL ASSESSMENT REPORT

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P.O. Box 17076
Arlington, VA 22216-7076
USA
www.OurTask.org
+1-703-525-1162
Jerry@OurTask.org

MODEL ASSESSMENT REPORT

Hazhir Rahmandad, Jonathan Moffat, Gerald O. Barney,
Lani Frerichs, Andrea M. Bassi, Angeline Cione,
Christopher Nelson and Vishwa Ramachandran

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ABSTRACT

The Youth Earth Plan uses the best current data and analytical models available to share the concerns of young generation for the future of Earth we are going to inherit. As active users of model projections we want to contribute to the improvement of current analytical tools for projecting future of the global system. We therefore conducted an assessment of current leading models that investigate the future of population, economy, energy, environment, food and

agriculture, technology, health, and education. Our analysis suggests that leading models are very detail-rich in considering one specific sector; however, few interactions with other sectors are included in these models. For example the impact of environmental change predicted in environment models is not included in economic, population, or other projections. Interactions between different sectors in global system are increasingly central to medium and long-term trends the young generation is concerned about. We therefore urge scientists and analysts to move towards capturing these interactions in their analytical frameworks.

INTRODUCTION:

The Youth Earth Plan (YEP) highlights concerns of the young generation for the future of the Earth we are going to inherit. Our view of the future is painted by the best data and analytical models that currently exist for predicting future scenarios. However, we do not wish to be passive users of these analytical tools. Our studies in preparation of the YEP have helped us see some of the strengths and weaknesses of these models. We think that improvements can and should be made to these models in order to help us see through long term global dynamics that will be part of our lives. We therefore have undertaken a review and assessment of the models we use in YEP in order to highlight the limitations of the current analytical framework used to look at the inter-generational challenges of our global system, and to suggest directions for improvement.

MODEL ASSESSMENT PROCESS

For each category of future development highlighted in YEP, i.e. Agriculture, Economy, Education, Energy, Environment and Resources, Health, Population, and Technology, the major models currently available are identified and reviewed based on available public data and reports. We focused on formal models that generate numerical projections, and therefore in some of the categories no explicit model was found that projected trends in the coming decades we are concerned about in this report. For each model we focused on four areas in our assessment:

- The cause-and-effect relationships captured by the model. Each projection is based on some assumptions about underlying variables that drive the behavior of interest; how deep do these chains of causality go and what are important missing factors?
- The assumptions underlying the model's projections in each category of interest. Of course, many assumptions need to be made to permit any projection of future trends. We have asked: What are the major assumptions underlying each model in each category?
- The comprehensiveness of the models in capturing important feedback relationships. Typically causal relationships are not one-way; rather, the dynamics are created by feedback processes: e.g. population impacts economic growth while economic well-being impacts population growth rates. Models that do not capture feedback structures tend to produce extrapolations that imply "more of the same" and may fail to inform us of major changes in future trends that can have important consequences. We therefore ask how much feedback processes crossing multiple categories (e.g. population, economy, and environment) are captured in the analyzed models.

- The consistencies and inconsistencies that exist among the projections and assumptions of different models. Each model makes assumptions about trends in other categories of interest. For example, modeling environmental impact of CO2 emissions is often based on some exogenous trajectories for population and economic development. Other models may use similar or different assumptions, and models of population and economy may estimate similar or different population and economic trajectories. We therefore ask about the consistency among models' projections and assumptions across multiple categories.

Each model is reviewed first in terms of its assumptions in different domains. Summary tables highlight the causal relationships and feedback processes resulting from these assumptions. Finally, the different assessments for each model's ability to rise to the challenges for future work are integrated by analysis of:

- Feedback processes that cut across multiple models and are not captured in the models.
- Consistencies/Inconsistencies of assumptions and results across models.

We then summarize the main observations and results of our assessment and conclude with details of different model reviews and the comparisons among them.

SUMMARY OF RESULTS AND RECOMMENDATIONS:

Our assessment of major global models observes several trends:

- The causal relationships in each model are often explained for the category of interest for that model, but for relationships not outside of that category. For example economic models have much more elaborate sets of causal relationships in looking at economic variables but fewer links are available from the impact of other categories on economic development (e.g. environment and energy categories).
- Where causal relationships exist from one category to another (e.g. from population levels to economic performance), this relationship is almost always one-directional. That is, the feedback processes that cut across multiple categories are generally missing. This is a critical point because models in each category implicitly or explicitly agree that other categories impact their projections, however, these obvious relationships are never taken into account full circle.
- In general it was hard to assess the overall consistency of different models' assumptions because many categories of interest are multidimensional (e.g. technology) and we could not determine if the trajectories assumed or derived from one model are consistent with another. Where specific variables are used by two models, typically consistent projections were drawn upon, e.g. population trajectories used in different models didn't have any major conflict. Nevertheless, the following inconsistencies were observed in our assessment:

    - Climate models project major disturbances to global economy due to rising sea levels and climate change. The magnitude of projected impact is very high and could easily reduce substantially the projected economic growth rates in other models. However, the projections of economic models or the assumptions on economic growth in other models do not include the impacts of environmental change on economy.

- The population model does not specify explicitly the specific factors that lead to changes in fertility, mortality, and migration. Other models suggest that food, bio-diversity, and climate change may breach the current trends that are embedded in the population estimation assumptions.
- Energy availability is assumed as given in economic, food production, and population projections. However, energy model raises some doubt about the robustness of this assumption.\

Given these observations, we believe major improvements in modeling global dynamics are required in order to enable us to foresee the upcoming global challenges before many options for amelioration disappear. Our major observation is that while different categories of global systems are tightly interconnected, they are typically modeled as separate entities. Feedback processes that cut across multiple categories do not show up in any of the models despite the fact that they may be the major drivers of global dynamics we should be most concerned about. As a result, important new trends may remain unobserved and unaccounted for in our global forecasting and planning efforts until it is too late to change the trend to our satisfaction.

We therefore call for the incorporation of more endogenous variables so that the models will capture feedback processes across multiple categories more completely. We highlight the importance of capturing global climate feedbacks in modeling economic and population trends, the impact of food availability and biodiversity in modeling population growth, and the impact of energy availability in modeling economic development. While we shouldn't strive to build a single model to address different questions, collaboration and communication between different global modeling communities is needed to build more feedback rich and dynamically sound models of global trends.

MODEL ANALYSES:

In the following section we review and summarize the assumptions and causal relationships captured in each of the major models in different domains.

A. Population Models

Reviewer: *Jerry Barney*

1. Model Name and Reference

- No name is given in the reports. There are several models used, and collectively they might be referred to as the UN Population Division Model.
- The organization is Population Division, United Nations Department of Economic and Social Affairs.
- "Methodology for United Nations population estimates and projections," in World Population Prospects: The 2004 Revision, vol. III, Analytical Report (UN publication, Sales No. E.05.XIII.7), Chapter VI, New York: United Nations.

- United Nations Department of Economic and Social Affairs/Population Division, World Population Prospects: The 2006 Revision, Highlights, (UN publication, Sales No. E.05.XIII.7), New York: United Nations, pages 27-33.

2. Modeling Methodology

- The Population Division employed the cohort-component projection method for individual country projections.
- The decline of fertility is modeled using logistic functions. Model age patterns of fertility are presented as proportionate age-specific mortality, indexed by the mean age at childbirth.
- Trends of mortality improvement are modeled as gains in life expectancy over a five-year period for a given range of life expectancy at the previous five-year period.
- The Epidemiological model used to derive annual estimates of HIV/AIDS incidence from observed prevalence levels is based on three differential equations used by UNAIDS representing the dynamics of the epidemic over time. The age-specific HIV infection pattern for the adult population has been parameterized as a Weibull probability distribution function. Survival of children infected at birth with HIV is modeled with a double Weibull probability distribution function.

3. Model Purpose

The purposes of this model are:

- To estimate the future population of each country.
- To provide comprehensive tables presenting the major demographic indicators (population, fertility, mortality, and migration) for each country of the world for 1950-2050
- To provide distributions by age and sex of the population for each country for the period 1950-2050
- To analyze the results obtained.

4. Model Assumptions

- **Population:** An output, not an assumption
- **Energy:** No explicit assumptions reported.
- **Environment:** No explicit assumptions reported.
- **Technology:** One scenario assumes a completely effective vaccine against HIV that is universally and instantaneously available as of 2010.
- **Food and Natural Resources:** No explicit assumptions reported.
- **Economy:** No explicit assumptions reported.
- **Other:** See Table 1.

Table 1: Projection Variants or Scenarios in Terms of Assumptions for Fertility, Mortality, and International Migration

Projection variant or scenario	Assumptions: Fertility	Assumptions: Mortality	Assumptions: International Migration
Low fertility	Low	Normal*	Normal
Medium fertility	Medium	Normal*	Normal
High fertility	High	Normal*	Normal
Constant-fertility	Constant as of 2000-2005	Normal*	Normal
Instant-replacement-fertility	Instant-replacement	Normal*	Normal
Constant-mortality	Medium	Constant as of 2000-2005	Normal
No Change	Constant as of 2000-2005	Constant as of 2000-2005	Normal
Zero-migration	Medium	Normal*	Zero
No-AIDS	Medium	No-AIDS since 1980	Normal
High-AIDS	Medium	High-AIDS as of 2005	Normal
AIDS-vaccine	Medium	AIDS-vaccine as of 2005-2010	Normal

* Including the impact of HIV/AIDS in 62 countries, as depicted within the AIDS scenario (medium/default).
Source: United Nations Department of Economic and Social Affairs/Population Division, World Population Prospects: The 2006 Revision, Highlights, (UN publication, Sales No. E.05.XIII.7), New York: United Nations, p. 33.

- In the medium-fertility assumption, total fertility rate in all countries is assumed to converge eventually toward a level of 1.85 children per woman; this is below replacement level of 2.1 children per woman.

- Under the high variant, fertility is projected to remain 0.5 children above the fertility in the medium variant over most of the projection period.

- Under the low variant, fertility is projected to remain 0.5 children below the fertility rate in the medium variant over most of the projection period.

- Under the constant-fertility assumption, fertility rate remains constant for each country at the level estimated for 2000-2005.

- Under the instant-replacement-fertility assumption, the fertility rate is set for each country to the level necessary to ensure a net reproduction rate of 1 starting in 2005-2010.

- Under the normal-mortality assumption, small gains in life expectancy are projected in countries that have already reached a relatively high life expectancy. The choice of mortality model is determined by recent trends. The pace of mortality decline is reduced in countries highly affected by the HIV/AIDS epidemic.

- All normal mortality scenarios including the impact of HIV/AIDS in 62 countries, as depicted within the AIDS scenario (medium/default). For all 62 countries seriously affected by HIV/AIDS, mortality and the yearly incidence of HIV infection are projected using the HIV/AIDS model developed by UNAIDS.

- Under the No-AIDS assumption, mortality is estimated and projected by applying the mortality levels likely to be exhibited by the non-infected population to the whole population, thus excluding the direct impacts of the epidemic.

- Under the High-AIDS scenario, mortality is projected by assuming the epidemic remains untreated at its 2005 level.

- Under the AIDS-vaccine scenario, mortality is projected by assuming that there are no new HIV infections starting in 2006 because of completely effective vaccine against HIV that is universally and instantaneously available as of 2010.

- Under the constant-mortality scenario, mortality is maintained constant in each country at the level estimated for 2000-2005.

- Under the no-mortality-and-fertility-change assumption, mortality and fertility rates remain constant at the levels estimated for 2000-2005 for all countries.

- Under the normal migration scenario, the future path of international migration is set (and kept constant) on the basis of past international migration estimates and consideration of the policy stance of each country with regard to future international migration flows.

- Under zero-migration scenario international migration is set to zero for each country.

5. Inter-Model Interactions for Population

Table 2 is an example of a table we will use to display the inter-model interactions. The top row of the table lists six models as follows: population, energy, environment and resources, technology, food, and economy. In the left column is one model, population, in the case of Table 2. The meaning of the entries in the table are as follows: if there is information from energy model, for example, that is used in the population model, the cell at the intersection of energy (top row) and population (left column) is blackened, if not, the cell is left white. In the case of the population model, all of the cells are white because no explicit information flows from the energy, environment and resources, technology, food, and economy models to the population projections. For other models, there are some explicit information flows, and as a result, some of the cells are black (e.g., see Table 3 for the economy model below).

Table 2: Inter-Model Interactions for the Population Model

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Population	N/A					

6. Caveats

While mortality, fertility, and migration obviously depend on energy, environment, resources, food, and the economy, the population projections provide no information on assumptions in these areas. Only assumptions concerning mortality, fertility, and migration are reported.

B. Economics Models

Reviewer: *Lani Frerichs*

1. Model Name and Reference

- Global Economic Scenario-based Model, World Bank 2007. *Global Economic Prospects 2007: Managing the Next Wave of Globalization*

2. Modeling Methodology

- Projections are based on existing statistics and World Bank projections; there is some relation to the linkage model.

3. Model Purpose

- The model was created, based on existing 'facts and figures,' to analyze the current threat to factors such as; continued global growth, social unrest, poverty reduction from environmental damage, new increases in protectionist sentiments, etc. (GEP 2007, p. vii).
- The scenario-based model approach is designed, not to predict the future, but to "analyze the opportunities and stresses of integration." (GEP 2007, p. viii, xi)
- The purpose is ultimately to think about and simulate the dynamics in the global economy (the model creates this in a coherent analytical framework in order to be able to posit solutions to the aforementioned issues. (GEP 2007, p. viii)

4. Model Assumptions (combined with some potential outcomes):

- **Years**: 2006-2030 (GEP 2007, p. xi)
- **Population**: The population will grow from its current 6.5 billion to roughly 8.0 billion by the year 2030 and more than 97% of this growth will take place in developing

countries. The EU and Japan will experience a decrease in population, and in the other developed countries, much of the growth will be due to migration. (GEP 2007, p. xii)

- **Energy**: Little to no mention made.
- **Environment**: In reference to the importance of international cooperation, the environment belongs to all countries and thus, integration of developing countries into discussions concerning the environment is essential. (GEP 2007, p. xxii) Current trends are used to predict the increase in annual emissions of green-house gasses by roughly 50% by 2030 and twofold by 2050 (GEP 2007, p. xxii, Figure 14); this is coupled with a sharp increase in the concentrations of GHGs in the atmosphere with strong negative effects. Curbing environmental damage is seen as essential to the continued growth of the global economy, as is containing contagious diseases and reducing the unrestrained pillage of the environment's resources. (GEP 2007, p. xxiii)
- **Technology**: Technological improvements are assumed in the model formulations. (GEP 2007, p. xiv) They are assumed to contribute positively to the possibility for more growth. However, it is noted that technological progress, "by generating demand for greater skills, tends to widen the gap between the wages of skilled and unskilled workers." (GEP 2007, p. xvi) Thus, technology can both contribute to increased incomes, and increase general inequalities.
- **Food**: Mention is made of the disastrous effect of unrestrained marine fishing upon the degradation of a critical global food source. The answer to this problem is effective multilateral cooperation so that future generations continue to have access to the possibility of food. (GEP 2007, p.xxiii) While the legal framework to deal with this particular problem is in place, the problem persists due to a lack of effective regulation and enforcement of those rules. (GEP 2007, p. xxiv) For further information about food, see natural resources
- **Natural Resources**: By 2030, the assumption is that a few countries and regions that are rich in resources (including Latin America and Australia) will "be the source of 90% of the world's sugar, 50% of its grain, and 40% of its dairy products." Major divergences from these numbers can be attributed to the policies that those countries adopt between now and 2030. (GEP 2007, p. xiv) The biodiversity that is currently enjoyed will decrease unless measures are taken, such as restraining marine fishing, to curb destructive and non-sustainable activities. (GEP 2007, p. xxiii)
- **Economy:** If the model-based scenario that this report promotes is true, economic growth in its studied period will likely occur at a faster rate than global economic growth from 1980-2005. (GEP 2007, p. xiii) That growth will be increasingly driven by, and provide benefit to, developing countries. There is an assumption, for the purpose of an accurate comparison, that they are at current market exchange rates and prices. Despite continued population growth, poverty will decline to the order of 550 million people living in dire poverty (less than $1 per day; down from 1.1 billion today). (GEP 2007, p. xiii) Developing countries will become the main driver of economic growth, thus increasing their share of the global economy from 1/5 to 1/3 by 2030. (GEP 2007, p. xiii-xiv)
- **Threats to Growth:** Very important to this model are the cautionary threats to growth. They include the following stresses to the global economy: "widening inequality, growing tensions in labor markets, and new environmental pressures." (GEP 2007, p. xv)

- **Other:** The income gap between low and middle income countries is likely to decrease based on the World Bank linkage model. (GEP 2007, p. xiii, figure 2) This is due to the increase in the global labor force from 3.0 billion to 4.1 billion by the year 2030. (GEP 2007 p. xiii) Labor force growth rate is larger than the expected population growth, thus the difference is expected to create a decreased dependency ratio and a slight convergence of incomes. (GEP 2007, p. xiii) In addition, political policies that countries adopt are considered to have a very important impact upon these projections. (GEP 2007, p. xv, xx).

5. Inter-Model Interactions for the Economic Model

Table 3 summarizes the inter-model interactions for the economic model. While there in no explicit linkage to any model, the economic model does make explicit assumptions about energy, environment, and technology, namely that technological dev elopements prevent energy and climate change from slowing economic growth. Note that no explicit interactions reported.

Table 3: Inter-Model Interactions for the Economic Model
(white cell means no interaction; black cell means interaction).

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Economy						N/A

6. Model Caveats:

This model, while it has some problems, is very comprehensive and takes those potential problems into account early on. As it is not designed to be an accurate predictor of the future, but merely to provide a picture of a possible and sanguine 2030, and then to assess arenas that might prevent that picture from becoming a reality. Even so, there are few areas in which it falls short. The main issues are mentioned throughout, and neatly dealt with in the final sentence: “The way the international community, acting together, manages the process of integration will determine whether the world of 2030 will realize its potential.” (GEP 2007, p. xxiv) Thus, as a view of the potential of 2030, this report uses a relevant model. The reality, however, as acknowledged throughout the report, could present itself so differently as to render this model and its conclusions insignificant.

C. Energy Models

Reviewer: *Andrea M. Bassi*

1. Model Name and Reference

- World Energy Model (WEM), International Energy Agency (IEA) – 10^{th} version.
- World Energy Outlook (WEO) 2006 (1993 through 2007), Annex C: World Energy Model: Methodology and Assumptions.

2. **Modeling Methodology**
   - The World Energy Model is partial equilibrium model. It is made up of six main modules: final energy demand, power generation, refinery and other transformation, fossil-fuel supply, CO2 emissions and investment.
   - While the production-side modules are optimized, in accordance to physical constraints, to minimize production cost among the various energy sources considered, econometrics is used to estimate the parameters of the demand-side modules, normally using data for the period 1971-2002. When data are unavailable or significant structural changes take place, a shorter time period is analyzed. Econometrics and other modeling techniques are used to simulate various scenarios based on alternative policies and assumptions concerning technology development. In regions such as the transition economies, where most data are available only from 1992 and where econometrics lacks in accuracy, assumptions are made based on the basis of cross-country analyses or expert judgment.

3. **Model Purpose**
   The tenth version of the WEM used to produce the World Energy Outlook 2006 is designed to analyze:
   - Global energy prospects: such as trends in demand, supply availability and constraints, international trade and energy balances by sector and by fuel to 2030.

   - Environmental impact of energy use: CO2 emissions from fuel combustion are derived from the detailed projections of energy consumption.

   - Effects of policy actions and technological changes: Alternative policy scenarios analyze the impact of policy actions and technological developments on energy demand, supply, trade, investments, and emissions.

   - Investment in the energy sector: The model evaluates investment requirements in the fuel supply chain needed to satisfy projected energy demand to 2030. It also evaluates demand-side investment requirements in the Alternative Policy Scenario.

4. **Model Assumptions**
   - **Population:** Exogenous. Global population grows by 1% per year on average, from 6.4 billion in 2004 to 8.1 billion in 2030. Population growth slows progressively over the projected period, as it did in the last three decades. Population expanded by 1.5% per year from 1980 to 2004. The population of the developing regions continues to grow most rapidly, boosting their share of the world's population. Projections are taken form World Population Prospects: The 2004 Revision, UNDP, 2005).
   - **Energy:** Energy demand, supply, and investment are calculated endogenously. Energy demand is generally based on GDP, population, technology, and international energy prices (all of which are exogenous inputs to the model). Crude oil import price is assumed to average slightly over $60 per barrel (in real year-2005 dollars) through 2007, up from $51 in 2005, and then to decline to about $47 by 2012 only to rise again slowly thereafter, reaching $55 in 2030. Natural gas prices follow the trend of oil prices. Steam-coal imports stabilize at about $55 per tonne in the next few years and then rise to $60 in 2030.

- **Environment:** Energy related Co2 emissions are calculated endogenously, based on fossil fuels consumption.
- **Technology:** Energy efficiency is exogenous. Technology is assumed to increase steadily (both energy efficiency and production technology). Different technology improvements are associated with different energy sources and end-use sectors. A recently published IEA report, Energy Technology Perspectives, contains an exhaustive study of energy-related technology developments used in the WEO 2006.
- **Food:** Not considered. It is mentioned that biofuels and biodiesel are in competition with food. The availability of arable land will most probably become a constraint for biofuels production.
- **Natural Resources:** Fossil fuel consumption is endogenously calculated and depletion increases with production.
  - Total proven oil reserves are equal to 1,293 billion barrels in 2005 (oil and Gas Journal, 19 December 2005). Undiscovered conventional resources that are expected to be economically recoverable could amount to 800 billion barrels in its mean case (USGS, 2000). Total on-conventional resources, including oil sands, extra heavy oil, and oil shale are thought to amount to at least 1 trillion barrels (WEC, 2004).
  - Gas proven reserves amounted to 180 trillion cubic meters at the end of 2005. Ultimately recoverable remaining resources could total 314 trillion cubic meters in a mean probability case (USGS, 2000).
  - Coal proven reserves at the end of 2005 amounted to around 909 billion tones.
- **Economy:** Exogenous: the rate of growth of world GDP is assumed to average 3.4% per year over the period 2004/2030, compared with 3.2% from 1980 to 2004. It falls progressively over the projection period, from 4% in 2004-2015 to 2.9% in 2015-2030.

5. Inter-Model Interactions for the Energy Model

Table 4 describes the inter-model interactions for the energy model. Note that in addition to making use of population, environment and resources, technology, and economy models, the energy model makes projections of carbon dioxide emissions.

Table 4: Inter-Model Interactions for the Energy Model
(white cell means no interaction; black cell means interaction).

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Energy		N/A				

6. Caveats

The WEM heavily relies on data availability. While the IEA has over the years assembled a very comprehensive database, one might still wonder if econometric is the most appropriate modeling technique to capture the main characteristics of an energy sector constantly in transition and subject to major changes in the years to come.

D. Environmental Models

Reviewer: *Angeline Cione*

1. Model Name and Reference

There are many resource and environmental models, more than can be reviewed here. To keep our task within limits, we are focusing only on the models used by Intergovernmental Panel on Climate Change for its fourth assessment report. The IPCC Fourth Assessment Report (FAR) is based on projections from multiple computer models.

2. Modeling Methodology

Multiple models are used. Information on each model is not provided in the report.

3. Model Purpose

These models are used to project greenhouse gas emissions and global temperature changes over the course of the next century.

4. Model Assumptions

- **Variables Included in Assumptions**
  - Population Trends (steady increase or peak mid-century)
  - Technological Growth (towards efficiency)
  - Energy Sources (Fossil or non-fossil-based)
  - Economic Growth (rapid and global or fragmented and local)
  - Focus on Global vs. Local Sustainability

Table 5 describes the inter-model interactions for the climate models.

Table 5: Inter-Model Interactions for the Climate Model
(white cell means no interaction; black cell means interaction).

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Environment and Resources			N/A			

Within the climate models, inputs about globalization also impact the outcomes of economy, population, and technology.

Fossil-based energy is strongly linked with temperature increase.

Materials-based economy (thus materials production and transport) is linked with temperature increase. This may be due to deforestation and/or the need of fossil fuels to supplement the energy needs of material production and transport.

Globalization is strongly linked with rapid economic and technological growth and population decline.

Model Assumptions for Each of the Six Scenarios (in order, from the lowest global temperature increase to the greatest)

Six scenarios, A1FI, A1B, A1T, A2, B1, and B2, are referenced from the IPCC Special Report on Emissions Scenarios (SRES).

Scenario B1 - 1.8° increase (best scenario)

- Population – peaks in mid-century and declines thereafter
- Energy – clean energy technology
- Environment – emphasis on global solutions to environmental sustainability
- Technology – introduction of clean and resource efficient technologies
- Economy –
    - Rapid change toward a service and information economy, reductions in material intensity
    - Emphasis on global solutions to economic sustainability
- Other:
    - Emphasis on global solutions to social, (as well as economic and environmental) sustainability including improved equity
    - No climate initiatives

Scenarios A1T, B2 – (2.4° increase). The assumptions for these two scenarios are provided in Table 6.

Table 6: List of Assumptions for Scenarios A1T and B2

	A1T	B2
Population	Peaks mid-century and declines afterwards	Continuously increasing slowly
Energy	Non-fossil energy sources	diverse
Technology	Rapid introduction of new, more efficient technologies	Less rapid, more diverse
Economy	Very rapid growth Reduction in regional differences in per capita income	Intermediate growth with local economic sustainability
Globalization/ Localization	**Globalization**: convergence among regions, capacity building, increased cultural and social interactions	**Local**: Emphasis on local solutions to sustainability, environmental protection, and social equity

Scenario: A1B – (2.8° increase)

- Population: peaks in mid-century and declines thereafter
- Energy: balance in use and improvement/advancement across all sources
- Technology: rapid introduction of new, efficient technologies

- Economy:
  - Very rapid growth
  - Reduction in regional differences in per capita income
- Other: Globalization
  - Convergence among regions
  - Capacity building
  - Increased cultural and social interactions

Scenario: A2 – (3.5° increase)

- Population: fertility patterns across regions converge very slowly, resulting in continuously increasing population
- Energy: None specifically stated.
- Technology: change fragmented, regionally oriented, and slower
- Economy: regionally oriented growth, slower than other scenarios
- Other: Localization
  - Heterogeneous world
  - Themes of regional/local self-reliance
  - Preservation of local identities

Scenario: A1FI – (4° increase)

- Population: peaks in mid-century and declines thereafter
- Energy: fossil intensive
- Technology: rapid introduction of new, efficient technologies
- Economy:
  - Very rapid growth
  - Reduction in regional differences in per capita income
- Other: Globalization
  - Convergence among regions
  - Capacity building
  - Increased cultural and social interactions

7. Inter-Model Interactions for the Environmental Models

Table 7 summarizes the inter-model interactions for the environmental models. Note that no explicit interactions reported.

Table 7: Inter-Model Interactions for the Environmental Model
(white cell means no interaction; black cell means interaction).

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Environment and Resources			N/A			

5. Caveats

The IPCC report is a comprehensive report that draws on decades of scientific research by researchers across the world, and thus, the report is based on many different simulation models. Because the report is a consensus report with contribution from politicians and non-scientists, many people believe it is slightly conservative in its projections. Most outcomes described in our summaries are "very likely", meaning they have greater than 90% chance of occurring, and the rest are "likely", meaning they have greater than a 66% chance of occurring.

E. Agricultural and Food Models

Reviewer: *Chris Nelson*

1. Model Name and Reference

World Agriculture towards 2015/2030 – An FAO Perspective (2003)

2. Model Methodology

The model is a partial equilibrium model, composed of single commodity modules and world market feedbacks leading to national and world market clearing through price adjustments. The results of the model were subjected to many rounds of iterative adjustment by various specialists, particularly during the phase of analyzing the scope of production growth and trade (p. 380).

3. Model Purpose

The purpose of this model is to project possible future developments in global food, nutrition, and agriculture. The model was not designed to solve a specific problem, but to highlight the potential for global food demand and supply based upon various projections. The projections reflect the most likely future, but not necessarily the most desirable one. The main focus of the report is on how the world will feed itself in the future and what the need to produce more food means for the natural resource base. The model provides projections of global food supply and demand based upon anticipated population, economic growth and trends for country food production.

4. Model Assumptions

- **Population:** Demographic projections were adopted from the United Nations Medium Variant model from 2000. This model assumes a global population range of 7.0-7.4 billion by 2015 and 7.7-8.9 billion by 2030. These assumptions indicate a gradual slowing of the population growth rate resulting in a slower increase in food demand. The U.N. also has high and low variants, which are not considered. Significant revisions to model projections would need to be made if a different population assumption were assumed as there is no easy way provided to scale production and need.

- **Energy:** The report does not provide projections for energy usage in agriculture and forestry, but did make a few assumptions. As discussed above, the report highlights the fact that wood is a significant source of energy production in developing countries, especially in rural areas. This relationship is assumed to continue through 2030 as the rural poor have readily easy access to forests and other wood products. Further considerations on wood availability are discussed in below in “Environment and Resources”. Energy also significantly factors in to agricultural production and the projections given throughout the report. Energy through petroleum consumption is needed to maintain and operate many of the mechanical tools (tractors, etc.) in agricultural production. As GDPs expand and people are able to afford to mechanize their food production, energy will factor increasingly into production assumptions. Countries that continue to rely upon people and animal power for harvesting and tillage will not be as dramatically affected by fluctuations in commercial energy costs. In addition, significant amounts of energy are needed to produce the inputs (e.g., fertilizers and irrigation water) that are applied to agricultural lands. Technological innovations are assumed to reduce energy consumption through inputs and to lead to new energy-saving techniques such as no-till or conservation tillage.

- **Environment and Resources:** The report identifies several environmental challenges resulting from agricultural production, but does not give many projections as to how these challenges will change in the future. These challenges include: increased air pollution and climate change from burning biomass to clear land; greenhouse gas emissions from crop and livestock production; land degradation through changes in land cover, cultivation of marginal land, reclamation of wetlands, and competition for arable land; water pollution through salinization, pollution, over extraction; and loss of biological diversity through monoculture agriculture and the reduction of wild species. The report indicates that many of these environmental challenges may increase with more intensive agricultural practices to meet the needs of a growing population, but policies may be developed to limit some of the environmental damages.

  There is limited discussion in the report of non-fuel minerals in this report. Some discussion is given regarding soil fertilities and the use of mineral fertilizers. Projections indicate that fertilizer consumption will increase by 1.0 percent per year from 138 million tones in 1999 to 188 million tones in 2030.

  While the report does not go into detail on water for agriculture, it does discuss some of the constraints on using irrigation in agricultural production. Agriculture already accounts for about 70 percent of freshwater withdrawals in the world. The projections for land under irrigation indicate that a 20 percent growth is likely to occur by 2030. The majority of irrigated land is presently found in developed countries. As developing countries’ economies mature and GDPs increase, further use of irrigation will be common in developing countries. As a result, some countries may be faced with severe water shortages by 2030, particularly in the Near East/North Africa region. The report highlights several contributions to this issue including; salinization of groundwater and pollution by fertilizers, pesticides, and livestock waste.

  Forest projections indicate an increase in demand for wood products due to the increase in population. The projections, however, identify that an increasing percentage of this demand will be met through technological innovations and expansion of forest plantations. The ever-increasing recognition of the environmental benefits of forest resources is predicted to affect future forest product supply and demand. Deforestation has been halted in most developed countries and it is expected to slow greatly in developing countries by 2030. Wood, however, is expected to continue to be an important fuel source in developing countries and little change in fuel-wood consumption is anticipated before 2015. Current estimates show that 55 percent of wood production is used as fuel-wood with the majority (80%) coming from tropical countries.

- **Technology:** Technology assumptions are discussed in some detail, especially regarding increases in agricultural productivity and sustainable agriculture. Though limited specifics are given as to how much technology will contribute to increased food production in the future, technology is assumed to be relied upon heavily to meet future demand. Increased land intensification through technological improvements such as irrigation, improved varieties, and modern inputs is expected to outpace the expansion of production area for increased yields. Potential growth through technology will depend upon each countries capacity to develop and accept new technological advancements. The study assumes that 80 percent of projected growth in crop production in developing countries will result from yield increases and crop intensification, both of which could depend heavily on new technology. High technology production could more than triple wheat production, as an example, over low technology or subsistence production techniques. Technology such as genetic modification also holds potential for environmental and trade issues. It is also projected that more technology developments will be focused on sustainable agriculture practices.

- **Food:** Food projections for the report are based on several factors including, among other things, estimates for consumption and production of 32 crop and livestock commodities for 140 individual countries. These calculations were adjusted based upon input from FAO country and program experts to refine the final product. Once these criteria were finalized for each country, they were combined for the overview report. The consumption and production projections are based upon input assumptions such as land availability, labor, nutrition levels, irrigation, technology developments, etc. Projections for food demand suggest that per capita food consumption will grow significantly, and certain countries will continue to experience high levels of food insecurity.

  Fishery projections suggest that the demand for fish products as food will grow over time. The calculations have annual fish consumption increasing from 16.3 kg per capita in 1999 to nearly 20 kg per capita in 2030. Due to past and potential future exploitation of fish stocks, the composition of fish for food will depend greatly upon policies to regulate over-fishing, along with increased reliance on aquaculture. Fish consumption, like meat consumption, will depend largely on access to the product along with a growth in GDP and a person's ability to buy the product. Consumption is expected to increase rapidly until 2015 and increase at a slower rate after that time due to supply constraints.

- **Economy:** Income projections are based largely upon the latest GDP data from the World Bank. The growth in a country's projected GDP is assumed to affect its level of development and nutritional attainment in future years. The World Bank projections indicate a relatively high growth in GDP in most regions that could have a dramatic effect on poverty alleviation. Such poverty alleviation (down from 32% in 1990 to 13.3% in 2015) could dramatically effect levels of undernourishment, leading to additional food demand.

5. Inter-Model Interactions for the Food, Forestry, and Fisheries Models

Table 8 describes the Inter-Model Interactions for the Food, Forestry, and Fisheries Models.

Table 8: Inter-Model Interactions for the Food, Forestry, and Fisheries Models (white cell means no interaction; black cell means interaction).

Info from: / **Is used in:**	Population	Energy	Environment and Resources	Technology	Food	Economy
Food		■	■		N/A	■

6. Caveats

Several issues are identified in the report and suggest some potential shortcomings of the model. First, FAO deals with a large quantity of data from many different sources. Some parts of the data are more reliable than other parts due to its source and method of acquisition. Errors will exist in some of the data leading to issues in the projections. Second, the report acknowledges that world trade balances could not always be verified with data. For example, there are situations where the global export of a specific commodity did not match global import of that same commodity. Third, assumptions were made that will most likely not be the case in 2030. For example, each country is projected to have a higher food consumption per capita and higher income growth than at present. Since assumptions were needed to make the projections, unpredictable circumstances such as economic collapse or food reductions could not be factored into the calculations.

F. Technology Models

Reviewer: *Vishwa Ramachandran*

1. Model Name and Reference

There is no well recognized analytical model in general use for making technological forecasts.

2. Modeling Methodology

There is no modeling methodology involved since a model doesn't exist.

3. Model Purpose

The purpose of technological forecasting is to anticipate future changes in production, resource consumption, and waste generation as a result of technological changes. However, there is no model purpose because there is no generally accepted model.

4. Model Assumptions

Since a model doesn't exist, no comments can be made on its assumptions.

5. Inter-Model Interactions for the Technology Models

Table 9 describes the Inter-Model Interactions for the Technology Model.

Table 9: Inter-Model Interactions for the Technology Model
(white cell means no interaction; black cell means interaction).

Info from: / Is used in:	Population	Energy	Environment and Resources	Technology	Food	Economy
Technology				N/A		

6. Caveats

- There are many methods used commonly for technology forecasting. These methods include the popular Delphi method[i], consensus method, analogy method, causal method, interpolation method etc.[ii]

- When attempting to assess the impacts of future technologies on future developments generally, it is important that the methods used have an in-built assessment of the reliability and accuracy of the forecasting methodology chosen so that (a) the forecasts can be fine-tuned for better accuracy and (b) actions can be taken in the present with confidence that they will improve conditions in the future. In this regard, though the methods mentioned above can in a general sense be considered to be "models", they lack the disciplined spelling out of the assumptions that determine the results of the forecast. We therefore do not consider them to be a "model' in this review.

- The utility of the methods mentioned above should however, not be discounted. The Delphi method, for example, is an excellent example of how knowledgeable experts in even the most abstract and esoteric topics can actually arrive at a consensus through successive refinements. The Bass technology diffusion model[iii] is another example; it is very useful for forecasting consumer technology, and might be usefully applied in other areas of technology. If practical knowledge of the current state of art is combined with a clear idea of a technology's future ramifications (for example, on the environment), the Bass model could be used as a model for forecasting the impact of the particular consumer technology on the environment. In this sense, the Bass model could be "a" model, but not "the" model because there is more than one way to achieve the same or better forecast result.

- The use of "mental models" must also be considered. A mental model is mental concept of how things would work in a real world if a particular change is made. The key difference between mental and formal models is that with mental models there is no explicit statement of assumptions and no formal mathematics or science involved in tracing out the consequences of the assumptions. So as with intuition, one is free to interpret one's mental models as one chooses, without explaining or justifying the assumptions or their implications to others. The result may be a great insight (e.g., discovery of new nuclear particle) as well as an absurdity (e.g., a perpetual motion machine).

- All technological forecasts should make clear their assumption concerning investments in research and development. Many forecasts suggest continued technological advances with no investment, which is quite unlikely.

G. Health Models

Reviewer: *Jerry Barney*

1. Model Name and Reference

There is no model for health.

The organizations that one might expect to have a health model are United Nations Development Programme (UNDP), World Health Organization (WHO), and United Nations Children's Fund (UNICEF).

Human Development Report Office, United Nations Development Programme, Human Development Report 2006, New York: United Nations.

United Nations Children's Fund, State of the World's Children 2007, New York: United Nations.

World Health Organization, Working Together for Health: The World Health Report 2006, New York: United Nations.

2. Modeling Methodology

A health model would produce projection of health for the future under alternative sets of policy assumptions. The major health reports listed above provide no projections of health for the future. All time series presentations stop with the date of the report or earlier and are merely databases of past statistics. Some would argue that the Human Development Index (HDI) and the Gender-related Development Index (GDI) are "models" related to health, but neither the HDI nor the GDI make projections into the future for alternative scenarios. The HDI and GDI are merely weighted combinations of historic data. They tell us nothing about the future health conditions to be expected form alternative policy choices.

3. Model Purpose

There is no model.

4. Model Assumptions

There is no model.

5. **Inter-Model Interactions for the Health Models**
Table 10 describes the Inter-Model Interactions for the Health Model.

Table 10: Inter-Model Interactions for the Health Model
(white cell means no interaction; black cell means interaction).

Info from: / **Is used in:**	Population	Energy	Environment and Resources	Technology	Food	Economy
Health				N/A		

6. **Caveats**
There are many "mental models" of health in the minds of many individuals. Each of these mental models is a theory of how various factors combine to shape the future of health. No one, however, has put these theories into a formal quantitative mathematical model explicitly representing the various causal factors assumed to determine the future of health. Until such a model is developed and tested against historic data and experience, health policy will continue to be a verbal battle among competing, shifting, and limited mental models. Currently, the closest approximation to a health model is probably the health sector of the Threshold 21 model by the Millennium Institute (see www.Millennium-Institute.org).

H. Education Models

Reviewer: *Jerry Barney*

1. **Model Name and Reference**
There is no model for education.

The organizations that one might expect to have an education model are United Nations Development Programme (UNDP) and United Nations Children's Fund (UNICEF).

Human Development Report Office, United Nations Development Programme, Human Development Report 2006, New York: United Nations.

United Nations Children's Fund, State of the World's Children 2007, New York: United Nations.

2. **Modeling Methodology**
An education model would produce projection of education for the future under alternative sets of policy assumptions. The major education reports listed above provide no projections of education for the future. All of their time based presentations stop with the date of the report or earlier and are merely databases of past statistics. Some would argue that the Human Development Index (HDI) and the Gender-related Development Index (GDI) are "models" dealing with education, but neither the HDI nor the GDI make projections into the future for alternative scenarios. The HDI and GDI are merely weighted combinations of historic data. They tell us nothing about the future education conditions to be expected form alternative policy choices.

3. **Model Purpose**
   There is no model.

4. **Model Assumptions**
   There is no model.

5. **Inter-Model Interactions for the Education Models**
   Table 11 describes the Inter-Model Interactions for the Education Model.

Table 11: Inter-Model Interactions for the Education Model
(white cell means no interaction; black cell means interaction).

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Education				N/A		

6. **Caveats**
   There are many "mental models" of education in the minds of many individuals. Each of these mental models is a theory of how various factors combine to shape the future of education. No one, however, has put these theories into a formal quantitative mathematical model explicitly representing the various causal factors assumed to determine the future of education. Until such a model is developed and tested against historic data and experience, education policy will continue to be a verbal battle among competing, shifting, and limited mental models. The closest approximation to an education model is probably the education sector of the Threshold 21 model by the Millennium Institute (see www.Millennium-Institute.org).

OVERVIEW OF MISSING FEEDBACK PROCESSES

Table 12 collects and summarized the inter-model interactions from summary Tables 2 to Table 11. The black areas represent the existence of important interactions among the models; the white areas represent areas of potentially important feedback linkages where no interaction is taking place among the models.

What emerges from the black areas of Table 12 is a clear indication that the energy, food, and economics models are taking in important inputs information from other models. The energy model, for example, is receiving input information from the population, environment and resources, technology, and economic models.

Table 12 also indicates areas where important feedbacks are missing (the white areas). For example, the population model provides no means for explicit input of energy, environment, resources, technology, food, and economy inputs into the population projections.

It is also important to note that where interactions are noted (black areas), are uni-directional, not bi-directional feedback loops. For example, the food model receives exogenous inputs of population projections (half of a feedback loop), but the population model is not influenced by the food projections. Such feedbacks are very important in understanding the behavior of the overall global system, so these missing (open) feedbacks (the white areas) deserve special attention.

Table 12: Summary of Inter-Model Interactions from Tables 2 to Table 11.

Info from:	Population	Energy	Environment and Resources	Technology	Food	Economy
Is used in:						
Population	N/A					
Health						
Education						
Energy		N/A				
Environment and Resources			N/A			
Technology				N/A		
Food					N/A	
Economy						N/A

Even a glace at Table 12 shows that while there interactions among several of the models, none of the models reviewed comes close to capturing all the important feedback relationships. Moreover, even Table 12 does not reflect all the feedback processes that *should be* included. For example lack of any comprehensive model on technology, health, and education has left the rows for these models empty, where as all these domains are strongly impacted by other sectors. The importance of these relationships are all acknowledged by the authors of the current reports and models, it is not easy to justify the exclusion of many feedback processes in the models. Admittedly, the impact of some of these categories on others has been negligible in the past. For example, the availability of environmental resources has not been a constraint on food and energy production and climate has been relatively stable, so excluding the resources and environment from the analysis would have provided a reasonable approximation in the past. Today, however, this assumption is no longer justified. The changed situation in each category is significant, depends on developments in other categories, and is happening at speeds that make its dynamics relevant to the lives of young people.

MODEL ASSUMPTIONS' COMPARISON

In this overview provided in Table 13, we go through each category, highlight the different assumptions made about that category in different models, and discuss major points of consistency and inconsistency across models. The first column assesses the internal consistency of the assumptions: are the assumptions in one model consistent with those on other models? The second column discusses the consistency of results: do the results of one model agree with the results or assumptions of other models?

In several categories the assumption of interest is not a one-dimensional number or a single variable, and different models may be looking at different variables. In such cases, it is not easy to define a single consistency metric, and we do our best to summarize the assumptions made and allow the reader to draw his or her own conclusions based on this data.

Table 13: Model Consistency Summary

Category	Internal Consistency of Assumptions	Consistency with the Results of Models	The Model Focusing on This Category
Population (fertility, mortality, migration)	FAO assumptions are taken from UN Medium variant, so they are identical; IPPC: half of scenarios peak at 2050 (A1s); other half are continuously increasing with no specific number given; 2030: 8B (about the UN low) POP: No explicit assumption elaborated.	POP: UN Population Division: 2025: 8.5, 2100: 12 Since specific causality factors are not discussed, it is not possible to assess connectors.	UN Population Division Model
Energy	IPPC: Whether coming from fossil fuel or none fossil. The first is very problematic in terms of climate change. FAO: It is not a bottleneck. ECON: Nothing mentioned.	WEM: Availability may be a problem. Price is projected remain high (current price) until 2012 and then to decline.	World Energy Model
Environment and Resources	ECON: 50% and 100% increase of CO2 emission by 2050 and 2100; no further discussion. Fishing and decreased biodiversity are mentioned as potential problems. Other challenges are raised as well. IPPC: No climate change initiatives. No assumptions on availability of other resources mentioned. FAO: Problems with achieving the production. Mostly assumes that resources will be available as needed, but highlights challenges that may arise. WEM: Energy prices are assumed to go down after 2012. They calculate CO2 emissions exogenously, with no impact back. Biofuel energy will be in competition for land and energy with food production.	IPPC: 3% GDP reduction if we stabilize emissions. STERN: 5% of GDP if we don't fix the problem and 1-3% if we stabilize emissions.	IPPC Report

Category	Internal Consistency of Assumptions	Consistency with the Results of Models	The Model Focusing on This Category
Technology	IPPC: Technology is becoming more efficient. No numbers specified for what they mean by fast or slow. FAO: Technology will be growing fast. Different rates for different outputs and crops, e.g. 3 times more wheat. ECON: Technological advance will tend to enable growth. No numbers associated. WEM: Energy efficiency and production technology are both impacted. Steady increase is assumed.		
Food	IPPC: No mention of food. WEM: The competition with biofuel for land can be important ECON: Increased concentration of food production from different countries. Reduced biodiversity in fishing.	FAO: Consumption per capital will be growing. Fishery usage as well, though it can be a bottleneck. Growth increases to 2015 and then slows down.	FAO model
Economy	IPPC: Less global economies grow slower than global. Shifting from material to service based economy helps with emissions. No numbers. FAO: Assumes sustained economic growth. WEM: 3.4% average growth to 2030; overall falling to 2.9% in 3030.	ECON: The result suggests fast economic growth (fasters than 1980-2005)	WB Global Economic Model

Even given the extensive information presented by these models, it is difficult to discuss consistencies and inconsistencies between them due to the presence of multidimensional constructs like food and economy. In particular, globalization (i.e. whether large-scale development is focused locally or globally) is predicted or assumed to make a large difference. For instance, more global development means more rapid economic growth and lower population growth. In spite of the difficulties, a few observations can be safely made regarding the models' assumptions and their consistencies:

With respect to the environment, global climate change is predicted in general to lead to significant economic problems, according to climate models. However, this trajectory is not taken into account in any other model. Taking the climate impact into account would make a big difference for the economic forecasts and economic assumptions carried over exogenously to other models.

The loss of fisheries and bio-diversity, as well as competition for energy use between food production and economic sectors create some challenges and uncertainties for meeting the projected food demand. The impact of these issues on population growth could be important.

There are no explicit models for health, education, water, and technology. Qualitative changes in these domains can significantly impact other categories; however, the current modeling frameworks do not allow us to include those factors.

In addition to these caveats, it should be noted that the models collectively present such a wide range of assumptions and projections that making an analysis of consistency among them is difficult. Perhaps the best that can be said is that in general they do not strongly contradict each another.

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[i] See RAND publications on Delphi method (http://www.rand.org/nsrd/pardee/pubs/methodologies.html#delphi).
[ii] Check articles on individual methods in, for example, Wikipedia (http://www.wikipedia.org/).
[iii] See website on Bass Model: http://en.wikipedia.org/wiki/Bass_diffusion_model.