THE THRESHOLD 21: NATIONAL SUSTAINABLE DEVELOPMENT MODEL

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Summary

Threshold 21 (T21) integrates economic, social, environmental, and resources sectors in a single national sustainable development model, which provides national planners with an analytical tool to understand the complex interrelationships among these sectors and to make decisions about where to invest scarce resources. T21 has three unique features which make it an exceptionally powerful and user-friendly tool for policy exploration: 1) The model has no secrets. Its assumptions, structures (relationships among sectors and between variables), equations, and data, are “transparent,” which means they are

readily available to the user for review, verification, and even modification; 2) A user-friendly interface has been developed for the model to make it easy for decisionmakers and users who have only limited experience with either computers or models to begin using the model in a matter of minutes; 3) T21 is designed in a modular way, which means that new sectors can be developed and added to the model with ease, and existing sectors can be taken out completely, or taken out, modified, and then put back into the model. In that sense T21 is a work in progress and is being improved constantly, as new requests from countries arrive, or as new data and methods become available. This paper starts with the introduction of the purposes, sectors, and functions of T21, followed by its data sources, and hardware and software requirements. After explaining the validation process of the model, an application of T21 to a sub-Saharan country for development policy analysis is presented.

The Threshold 21 model is an integrated assessment tool for application to any country— developing to developed. By this we mean that it (a) integrates many sectoral models, including economic production, finances, resources, environment, demographics, and social capital, in a transparent fashion, (b) simulates the short- and long-term consequences of alternative policies, and (c) permits easy comparison to reference scenarios and analysis of any scenario by tracing causes and consequences of change. The model provides policymakers and other users not with precise predictions but with the relative consequences of present and alternative strategies.

1. Purpose, Structure, and Function of the Model

1.2. Purpose

Threshold 21 was developed specifically for national sustainable development planning. It answers both the general question of national development strategy and specific, sectoral questions.

The general question is: How will the economic growth, social development, and environmental conditions of a country change if incentives shift the balance of investment funds among the sectors of the economy?

T21 answers many specific questions. For example:

- How should agricultural funds be divided among competing uses, such as irrigation projects and fertilizer subsidies?
- How will the total population and population pyramid change in 20 years if total fertility rate starts to change today in a certain pattern?
- How will national savings rate affect GDP growth rate?
- How will water availability influence harvested area and crop yields in the long run?
- How will greenhouse gas emission change due to deforestation and fossil fuel consumption?
- What would be the long-term consequences if girls are not encouraged to attend school?
- If more fuel-efficient stoves were available to farmers so they use less fuelwood, how would the deforestation rate change?

- If irrigated land is doubled in 5 years using groundwater, how soon will the groundwater be depleted?
- How vulnerable is a country to fluctuating (variable) world oil prices?
- If the national government continues its past trend of deficit spending, what will its debt (both domestic and foreign) be like in the future?

In addition to answering questions, Threshold 21 can help national planners make decisions. We all have to make decisions today that shape our tomorrow. Before computer models were available, we all used the alternative—our mental models. When making decisions on national or regional development, knowledge from a single person using his or her mental model is not enough. When a group of people is assembled on even one particular development issue, each will have his/her own assumptions, data, and mental models. How are they to share their data, assumptions, and mental models? How are they to communicate? How can they test their assumptions and mental models? How can they reach a consensus? It was to help people share data, assumptions, and mental models that we developed Threshold 21 for facilitating communication, testing, and consensus-building.

1.2. Structure

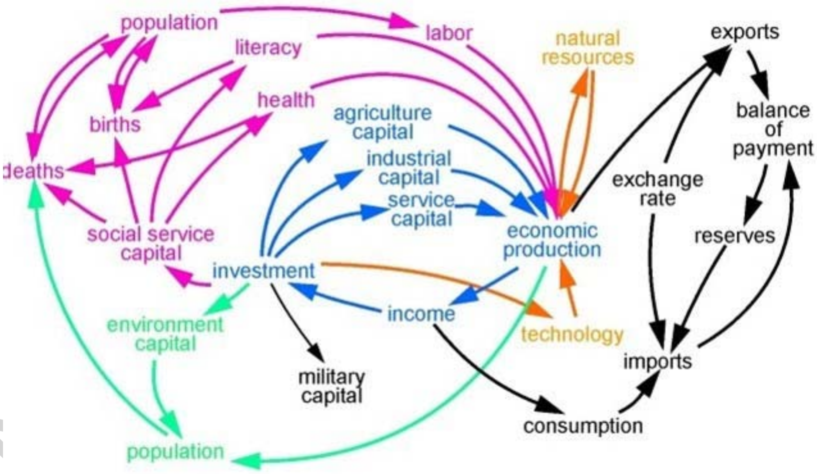

Figure 1. Overview of Threshold 21 model structure

In this diagram economic production is at the focal point, with inputs from natural resources (land and energy), labor, capital, technology, and quality of education. Out of production comes income, exports, and pollution. Income is divided between consumption and investment, and investment is further divided into different sectors much like a pie being cut into different portions. Sectors include energy, industry, agriculture, services, military, environment, and social services, which covers education, family planning, and health care. Consequences of these investments feed back to production either directly or indirectly.

On the right hand side of this diagram is the balance of payment sector that ties in imports, exports, and foreign reserves.

The actual model is much more complex than the overview diagram shows. Major sectors and the dynamics among them are introduced below.

1.2.1. Dynamics

The dynamics of the model are controlled by several thousand feedback loops among the more than 1000 variables. The major driving force of growth in the model is positive feedback. Two important positive feedback loops are (a) production provides income, some of which is invested and results in increased production; and (b) people give birth, and those births increase the population.

Many negative feedback loops related to policy, markets, resources, and environment regulate growth from the positive feedback loops. Two important negative feedback loops are (a) population naturally has deaths and deaths mean less population; (b) capital depreciates and as a result there is less capital.

1.2.2. Economy

The economic sector includes National Accounts, savings-investment balance, investment by sector, foreign debt, foreign exchange reserves, and balance of trade. Market and policy decisions combine to shift investments among the seven sectors: agriculture, industry, services, energy, environment, social services, and military.

Capital in each sector increases with investments and decreases with depreciation.

The trade sector simulates total imports and exports measured in dollar values, and imports and exports of energy (measured in heat) and food (measured in weight).

The model calculates both government debt and national debt. National debt is owed to foreign creditors. Government debt is owed to both foreign and domestic creditors.

1.2.6. Population

Population change is related to births, deaths, immigration, and emigration. Births are determined by conceptions. Deaths for each male and female age cohort are based on life tables and the analysis of the United Nation’s Population Database.

Conceptions are directly influenced by two variables: the size of the sexually active female cohorts, and their total fertility rates. Total fertility rates are influenced by many variables, including capital in social services, per capita GNP, female literacy rate, and family planning effectiveness.

1.2.7. Agriculture

Agricultural productivity is the product of agriculture land and yield.

Agricultural land increases with deforestation and conversion from fallow land, and decreases with land degradation, urban expansion, and population increase.

Land productivity is related to water availability, energy availability, soil quality, capital in agriculture (reflected in irrigation projects, machinery, and crop research funds), and agricultural technology.

1.2.8. Industry and Services

Industrial production and service production are the product of labor in these sectors and worker productivity.

Worker productivity in industry and services is influenced by: capital in the sector, capital elasticity, energy availability, adult literacy rate, and technology.

1.2.6. Energy

Energy is classified into three categories: fossil fuel, nuclear, and renewable. Fossil fuel is further classified into oil, gas, and coal.

Investment in energy is allocated to fossil fuel, nuclear, and renewable. Production of nuclear energy and renewable energy are related to capital in these two energy sub-sectors. Production of fossil fuel energy depends on both capital and proven reserves. Oil, gas, and coal are modeled individually with interactions.

Commercial energy demand depends on real GDP and energy technology. The difference between energy demand and energy production is energy exports or imports. The model assumes that needed imports of energy are partially met (depending on the country's economic ability) from the rest of the world.

1.2.8. Environment

The environment (pollution) sector simulates the generation of air pollution of CO_2, CH_4, N_2O, and SO_x from energy consumption, and nonenergy industrial, agricultural, and residential activities. With an increased investment in environmental capital, the emissions of CH_4, N_2O, and $SO_{x,}$ (but not of CO_2), decline after a delay. Carbon dioxide dissipation depends on the difference between national CO_2 pollution intensity and the global average CO_2 pollution intensity. The bigger the difference, the faster the dissipation.

1.2.8. Social Sector

The social service sector has its own capital and investment rate. Capital in Social Services influences education, health care, and family planning.

The education sector simulates the primary school system, including students, teachers, and classrooms. Low ratios of students per teacher and students per classroom encourage enrollment and discourage dropouts. Graduates from primary schools are assumed to be literate who grow to be adults and change adult literacy rate.

The health care sector simulates the numbers of doctors, nurses, hospital beds, and immunizations, and from them the quality of health care indicator is derived.

The food and nutrition sector computes the per capita intake of calories and protein. It computes the quality of nutrition against international standards. This sector includes separately both crop food and animal food. Animal food includes beef, mutton, pork, poultry, eggs, milk, and fish.

1.2.9. Technology

The technology sector simulates the technological advances in agriculture, industry, services, energy, and environment. The rate of technological advance is related to the characteristics of the sector and the investment rate for the sector.

1.2.10. Rest of World

The Rest of World sector simulates the world oil resource and global carbon in the atmosphere. When oil resource is further depleted, the real price of world oil will increase, affecting the ability of the country to meet its energy import demand. The global carbon concentration will affect the air pollution dissipation of the country.

1.2.12. Other Sectors in Threshold 21

Other sectors in Threshold 21 are water, forest, land use, greenhouse gas emission, government, and HIV/AIDS.

1.2.12.Indicators in Threshold 21

National Accounts as calculated in the World Bank's Revised Minimum Standard Model-Extended

UN Human Development Index (HDI) and Gender-related Development Index (GDI) as computed in UNDP's Human Development Report

World Bank's Monitoring Environmental Progress (MEP) indicators

EU Sustainable Development Indicators of Economy (per capita GDP, investment percentage in GDP, industrial value added, per capita energy consumption, and percentage of renewable in energy production)

EU Social Indicators of Development (population growth rate, net immigration rate, total fertility rate, infant mortality rate, unemployment rate, women per 100 men in labor force, population density, and percentage of urban population)

EU Indicators of the Environment (emissions of CO_2, N_2O, SO_x, and CH_4, per capita domestic water consumption, per capita arable land, agriculture land, and forest land)

Selected indicators from UNICEF, UNCSD, UNFPA, and UN Common Country Assessment (CCA)

1.2.13. Functions

Threshold 21 can be used by individuals as a learning tool, or by a group of people as a communication and consensus building tool. It is also a powerful tool for policy analysis, for contrasting long-term consequences of different policies.

With the structure of relationships among variables clearly diagrammed and the equations visible to the users, Threshold 21 allows an individual researcher or a decisionmaker to see how other people (in this case, the model) think. For instance, CO_2 emission in the model comes from three sources: forest land change, cement production, and fossil fuel consumption. It further defines how much CO_2 is released with each unit change in each of these sources. The equations and parameters for calculating CO_2 emission are based on reliable sources which are referenced in the Threshold 21 documentation. But if you disagree with the CO_2 emission sources, or if you want to use different equations to calculate it, you can quickly change Threshold 21 according to your mental model and test it, which will help you learn more about not only the Threshold 21 model, but also your own mental model, and the conditions of the country. You can also implement different policies, such as in investment allocation, or forest protection, or family planning, then run the model to generate different scenarios. By comparing results from these scenarios for the short-term and long-term, you will find out which policies are better than others.

When a group of people is assembled to make decisions related to sustainability at the national level, Threshold 21 can serve as a communication tool as each participant's mental model can now be viewed by the whole group. During the group discussion, it is much easier to understand each other with the help of Threshold 21. Different hypotheses can be tested with Threshold 21, and finally, differences can be more clearly identified or resolved, resulting in either improved understanding of each other or larger consensus on the directions or decisions to take.

Once consensus is reached and the model is satisfactorily developed, it can be used for policy analysis, to test different what-if assumptions (see *section 6* for more details).

2. Data-Supporting System of the Model

The following is a list of major data sources to support Threshold 21:

- Data published by national statistics agencies
- World Bank, *World Development Indicators 1998*, on CD-ROM
- Food and Agriculture Organization, *FAOSTAT 1997*, on CD-ROM
- US Department of Agriculture, *World Agriculture, Trends and Indicators, 1970–91*, USDA, 1993
- Immigration and Naturalization Service, US, *1993 Statistical Yearbook*
- UN Population Division, *Sex and Age Annual, 1950–2050* (The 1994 revision) (on disks)
- United Nations Statistics Division, *The United Nations Energy Statistics Database (1995)*, New York, June 1997 (on disks)
- US Department of Energy, *Annual Energy Review 1993*, Energy Information

Administration, July 1994

- UNDP, *Human Development Report 1997*, Oxford, 1997
- World Resources Institute, *World Resources 1994–95*, New York: Oxford University Press, 1994.
- United States Department of the Interior, Mineral Facts and Problems, *Bureau of Mines Bulletin 667*
- Central Intelligence Agency, US, *The World Factbook 1997*
- The World Bank, *Purchasing Power of Currencies, Comparing National Incomes Using ICP Data*, The World Bank, 1993

Even with access to all the above data sources and many more, it is impossible to find all the data items required by Threshold 21. For instance, Threshold 21 uses the Cobb-Douglas (CD) Production Function for industry and services, and the CD Production Function requires the capital elasticity of production for a specific country as input data. So far we have not been able to find this data, so we have developed an algorithm to estimate it. Another example is fertility distribution, which is the probability distribution of women giving births at different ages. Again we have not found that data for every country, so we have to use a general format and modify it for a specific country based on historical fit.

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Bibliography

Barney G.O. et al. (1991). *Managing a Nation: the Microcomputer Software Catalog*. Institute for 21st Century Studies and Westview Press. [This includes major computer simulation models for national planning.]

Chin James (1995). *A Guide for Using EPIMODEL, a Computer Program for Use in the Estimation and Projection of AIDS*..

Fiddaman T. (1997). *Feedback complexity in integrated climate-economy models*. Doctoral Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, US.

Hoekstra A. (1995). AQUA, a Framework for Integrated Water Policy Analysis. The Netherlands' National Institute of Public Health and Environment (RIVM), July 1995. The Netherlands. [This introduces a water sector model.]

Intergovernmental Panel on Climate Change (1994). *IPCC Guidelines for National Greenhouse Gas Inventories: Greenhouse Gas Inventory Workbook*. [This presents algorithms for calculating greenhouse gas emissions.]

Colby Hunter, Giordano Mark and Hjort Kim (1997). *The ERS China CPPA Model: Documentation*..

Miller G.T. (1992). *Living in the Environment*, Seventh Edition. Wadsworth. [This covers a wide range of environment-related topics.]

Mitchell Donald O. and Ingco Merlinda D. (1993). *The World Food Outlook*. The World Bank, November 1993.

Nordhaus W.D. (1992). The DICE Model: Background and structure of a dynamic integrated climate-economy model of the economics of global warming. *Discussion Paper No.1009*. Yale University, Cowles Foundation for Research in Economics.

Rosegrant Mark W., Agcaoili-Sombilla Mercidita and Perez Nicostrato D. (1995). Global Food Projections to 2020: Implications for Investment. *2020 Vision Discussion Paper No. 5*. International Food Policy Research Institute.

Sehgal J. (1989). *An introduction to techniques of population and labor force projections*. Geneva: International Labor Office.

Shorter F.C. et al. (1995). Computational Methods for Population Projections. New York: The Population Council. [This is about a population projection model, the FIV-FIV Model.

US Department of Energy and AES Corporation (1993). An Overview of the IDEAS Model (updated and extended FOSSIL2 Model). [This is about an energy sector model.]

World Bank (1997). *Expanding the measure of wealth: indicators of environmentally sustainable development*. The World Bank. [This is about indicators to measure sustainable development using the Monitoring Environmental Progress (MEP) Model.]

World Resources Institute (1994). *World Resources 1994–95*. New York: Oxford University Press. [This is about resource and environment indicators.]

Biographical Sketches

Weishuang Qu, Ph.D., is interested in applying quantitative methods to practical problem-solving. His interdisciplinary skills of research, engineering, and teaching include systems engineering, operations research, system dynamics modeling, econometric modeling, applied statistics, computer programming, and Monte Carlo simulation modeling. Dr. Qu obtained his Ph.D. and M.S. degrees from the University of Wisconsin-Madison in Systems Engineering, another M.S. degree from the Graduate School of the University of Science and Technology of China, and a B.S. degree from Shanghai Jiaotong University. Since July 1994 he has been the Director of Analysis and Information Systems at the Millennium Institute in Arlington, Virginia, US, where he helped develop the Threshold 21 National Sustainable Development Model. Before joining the Millennium Institute, he had worked as a diplomat, a technical administrator, a researcher, and a professor. Dr. Qu has published more than ten papers in international journals.

Gerald O. Barney, Ph.D., founder and executive director, Millennium Institute, has worked for more than twenty years to promote long-term integrated global thinking in national governments, universities, foundations, and the faith traditions of the world. He founded the Millennium Institute in 1983. He and his colleagues have assisted research teams in more than 40 developing and industrialized countries in preparing strategic studies of their countries' sustainable development possibilities. In 1993 Dr. Barney and his colleagues prepared *Global 2000 Revisited: What Shall We Do?* as a report to the Parliament of the World's Religions. This report outlines the critical issues of the 21st century and presents them in a framework that is relevant to the spiritual leaders of the world. Previously Dr. Barney directed and edited the classic *Global 2000 Report to The President* for Jimmy Carter, led the national program of the Rockefeller Brothers Fund, worked with former Governors Nelson Rockefeller and Russell Peterson on The Commission for Critical Choices for Americans, was responsible for the long-range forecasting and technology assessment work of the Council on Environmental Quality during the Nixon Administration, and worked for the Center for Naval Analysis. He earned his Ph.D. at the University of Wisconsin in fusion energy physics and conducted postdoctoral research in environmental, demographic, and energy policy issues at Harvard University and MIT. He has authored and co-authored several other books, including *Studies for the 21st Century* (1991), *Managing a Nation: The Microcomputer Software Catalog* (1990), *Global 2000: Implications for Canada* (1981), and *The Unfinished Agenda: The Citizens Policy Guide to Environmental Issues* (1971). Dr. Barney and his wife, Carol, live in a stone house in Arlington, Virginia, and have three children, William, Kristen, and Stephen.

Mr. Douglas Jon Symalla, Development Modeler, is responsible for modifying, updating, and applying parts of the Millenium Institute's models, including the RMSM Quick (the Institute's improved version of the World Bank's principal model), THRESHOLD 21 (the Institute's national sustainable development model), and CPPA Quick (agricultural models developed for the US Department of Agriculture). He has performed research on economic, environmental social issues, and other issues related to sustainable development for clients including the World Bank and the US Department of Agriculture. He has worked in Guinea and Haiti, and is fluent in French and has a working knowledge of Haitian Creole. He has a Master of Science in Development Management from American University, Washington, DC, (1997), and a Bachelor of Arts in Mathematics and Economics from St. John's University, Collegeville, Minnesota (1991), where he graduated summa cum laude.

Leslie A. Martin, Development Systems Modeler, Millennium Institute, is personally devoted to the use of computer simulation tools for studying the complex dynamic systems associated with poverty alleviation and sustainable development. At the Millennium Institute, she incorporates poverty alleviation features and environmental feedback into the Institute's Threshold 21 national sustainable development model. Before joining the Institute, Ms. Martin led a team at the Massachusetts Institute of Technology, Cambridge, Massachusetts, US, developing an Internet correspondence course in system dynamics modeling. She also worked for three years on the MIT System Dynamics in Education Project (SDEP) where she contributed to a series of self-study guides. Previously, Ms. Martin was a consultant to the U.S. West telephone company where she developed policy recommendations based on her model of deregulation of the telecommunications industry. She has written several technical papers on simulation software, generic model structures, model behavior, and sensitivity analyses. Ms. Martin holds a bachelor's degree from MIT in applied mathematics and economics. She grew up in both the United States and in France and is fluent in both French and English. Her interests include sailing, backpacking, reading, and languages.