Modeling U.S. Energy with Threshold 21 (T21)

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The United States is about to face years of major, interrelated policy issues. Energy transition, peak oil, and the threat of global warming, together with heightened fears of terrorism, environmental and social issues are largely crowded out of public dialogue. What is needed is an analytical tool that addresses these issues in an integrated and transparent way. The Threshold 21 (T21) model customized to the USA, is such a tool. The purpose of this study is to analyze T21-USA, by highlighting its flexibility and transparency. The analysis shows that T21-USA is a good tool for understanding and analyzing validity, effectiveness and outcomes of complex energy policies, such as the Advanced Energy Initiative -follow up of the State of the Union Address. Despite its complexity, T21-USA is transparent and a user-friendly interface makes it an intuitive instrument that can be used by a broad audience, ranging from students to policy makers.

Introduction

The United States is about to face years of major, interrelated policy issues. Its national debt is rising, financed in significant part by China and its balance of payments is negative. America is increasingly dependent on foreign sources of energy, and the economy is facing increased competition for energy from China and India. Military expenditures since the beginning of the Iraq war are very high and continue beyond what was expected. There are proposals to change the Social Security system in ways that are very costly. And, the value of the dollar is declining sharply relative to other currencies. With heightened fears of terrorism, environmental, social, and sustainability issues are largely crowded out of public dialogue. Even President George W. Bush during his State of the Union address, mentioned a number of interrelated issues (e.g. war on terrorism, homeland security, dependency on foreign sources of energy, social security and Medicare sustainability, education reform, etc.) that show the complexity of policy planning and the need for a comprehensive analysis.

The public is obviously confused about these complicated issues. Politicians, economists, and commentators air conflicting opinions that leave the public with limited means to understand the big picture and resolve divergent views. Models abound, but they are either too narrowly focused or too abstract, or both. What is needed is an analytical tool that addresses the issues in an integrated and transparent way and that raises awareness about national and international issues. The T21-USA model, a country application of Threshold 21 (T21), is such a tool.

The purpose of this study is to analyze T21-USA, by highlighting its flexibility and transparency with respect to its goals and other existing models. Also, this paper is useful for understanding the potential of the T21-USA model and for evaluating its capacity to raise awareness about issues and how they can be solved.

More specifically, the focus of this analysis is mainly on energy-related issues, which recently became more relevant in the U.S. economic and political scene. Indeed, for the first time in recent years U.S. addiction to oil is identified as a serious problem, and its interactions with society, the economy and environment still need to be fully explored. In addition, the U.S. Government is recently recognizing the impact of greenhouse gas emissions on global warming, but it hasn't identified any sustainable action to cope with the Kyoto protocol requirements. With this background as a starting point, this paper will show how T21-USA is a valuable tool to decipher national problems and properly describe policies that address complex and interconnected issues.

Threshold 21 USA (T21-USA)

Purpose and Features

T21-USA is a quantitative tool for integrated, comprehensive national planning. Its purpose is to support the overall process of development planning by facilitating information collection and organization, as well as the analysis of alternative strategies. It provides insight into the potential impact of national development policies and strategies relative to targeted goals and objectives.

T21 integrates a broad range of the sectors and issues needed for comprehensive policy planning. It is also flexible enough for customization and transparent enough to facilitate informed stakeholder participation for the analysis needed to generate consensus on development strategies. T21-USA is transferable to governments, NGOs, academia and civil society, and can raise awareness of national issues and improve capacity in development analysis and planning.

The specific purpose of T21-USA is to understand energy issues and to show how those issues relate to society, the economy and the environment. Understanding the short- and long-term impact of energy issues in a far-reaching and integrated way is fundamental in testing and planning sustainable, effective and resolutive policies in our complex environment.

The Need for Comprehensive, Integrated Planning

The U.S. has a vision for its future development and that vision is comprehensive. It includes economic factors (such as economic growth, income and employment), social factors (such as health and education), and environmental factors (such as clean air and resource use). The government carefully formulates strategies for pursuing its country's vision. Since reality and a country's vision include various interrelated issues, government planning must be comprehensive and all embracing. Otherwise, development strategies will be inadequate to achieve a country's vision or to deal with inter-linkages in the real world.

Planning strategies must consider the inter-dependency, or 'integrated' nature of development factors. Economic growth, for instance, requires a healthy workforce. Likewise, a healthy workforce requires adequate national investment in social services. If government planning does not recognize the links between economy, society, and the environment, unexpected and unwanted policy consequences could result and could cause a country to move away from its vision rather than toward it.

Comprehensive, integrated planning is complex. One human mind, or 'mental model', cannot adequately compute all the elements involved and keep track of their interactions. This type of planning requires tools that can help planners consider a broad range of interconnected factors and help them share and discuss their individual understanding of a country's development situation with each other and other stakeholders.

Features of Threshold 21-USA

T21-USA is designed to support an integrated, comprehensive planning process. In many cases, this means not only including all the necessary components and links for analyzing the U.S., but also features that help users and their partners understand, adjust, and discuss the model. T21 includes features to support each of these requirements:

- Integrates economic, environmental and social elements using a systems approach;
- Accounts for a comprehensive energy sector which allows complete and detailed research analyses on national and international energy issues;
- Informs development strategies and policies by simulating possible impacts of alternative policy choices and strategic options;
- Facilitates transparency, participation and consensus building by engaging various stakeholders to test their assumptions and reach conclusions within a common framework and an easy-to-understand interface;
- Flexible and customizable to address the unique needs of the U.S. through the use of a modular design where existing sectors can be modified or removed and new sectors can be added.

Overview of the T21-USA model structure

Society, Economy and Environment

T21-USA is built around a core structure and set of sectors that broadly reflect the structure and relationships of economic development. This way, T21 is highly flexible. First, the specific structure and parameters of the core sectors are adapted to U.S.-specific data. Second, additional sectors and relationships are added and customized to address specific issues and interactions important to the country. In fact, the T21 customization to the U.S. includes a large number of energy modules needed to represent both national and global energy markets. Nonetheless, the model can be integrated by the addition of sub-sectors so as to analyze specific issues or peculiar characteristics of the U.S. energy market.

The figure below represents a conceptual overview of T21-USA, with the linkages among the economic, social, and environmental spheres. Within each major sphere are the number of sectors, modules, and structural relations that interact with each other and with factors in the other spheres. The energy sphere represented at the center of the diagram is not graphically linked to the others. As a matter of fact, energy should not be considered an independent sphere since it formally belongs to the environmental sphere. However, energy issues are so heavily interconnected with economy, society and environment that it seems appropriate to consider energy sectors as connected and even built-in the economic, social and environmental spheres.

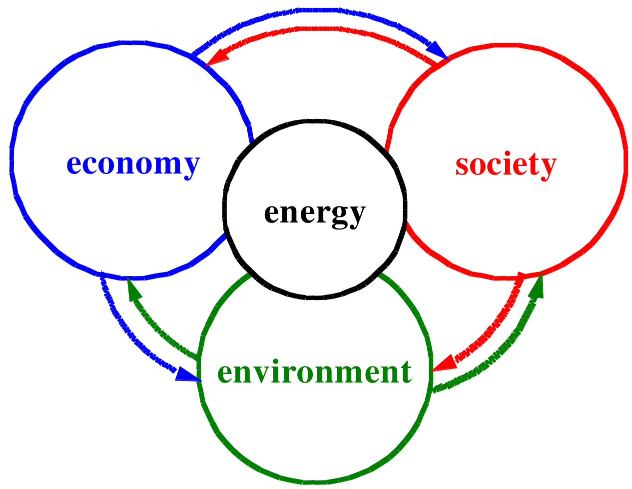


Figure 1: Conceptual overview of T21

The Economy sphere contains major production sectors (agriculture, industry and services), which are characterized by Cobb-Douglas production functions with inputs of resources, labor, capital, and technology. A Social Accounting Matrix (SAM) is used to elaborate the economic flows and balance supply and demand in each of the sectors. Demand is based on population and per capita income and distributed among sectors using Engle's Curves. This helps calculate relative prices, which are the basis for allocating investment among the sectors. The government sector generates taxes based on economic activity and allocates expenditures by major category, which then impacts the delivery of public services, subject to budget balances. Standard IMF budget categories are employed and key macro balances are incorporated into the model. The Rest of the World sector comprises trade, current account transactions, and capital flows (including debt management). Income distribution and poverty levels are calculated.

The Social sphere contains detailed population dynamics by sex and age cohort; health and education challenges and programs; and poverty levels. These sectors take into account, for example, the interactions of family planning, health care and adult literacy on fertility and life expectancy, which in turn determines population growth. Population determines the labor force, which shapes employment. Education and health levels, together with other factors, influence labor productivity. Employment and labor productivity affect the levels of production from a given capital stock.

The Environment sphere tracks pollution from production and its impact on health. It also estimates the consumption of natural resources – both renewable and non-renewable – and can estimate the impact of the depletion of these resources on production or other factors. In addition, the Environment sphere examines the effects of erosion and other forms of environmental degradation and their impact on other sectors, such as agricultural productivity or more direct health impacts. Very few models or planning processes take these factors and their feedback into account.[1]

Energy

T21-USA, a country application of the Threshold 21 model, is mainly focused on energy issues. It was built by customizing the T21 Starting Framework model to the U.S. and includes the introduction of a full set of energy modules. The T21-USA environmental sphere contains endogenously calculated energy demand, supply and trade, as well as pricing and investment. Carbon cycle and climate change are also included in the T21-USA structure in order to represent interactions between energy-environment-economy in a more comprehensive way. The energy modules are not only limited to the U.S., but the complexity of energy issues (e.g. high dependency on foreign oil, availability of resources -peak oil-, etc.) induced the introduction of global modules.

More specifically, the energy sources considered in the model are petroleum, natural gas, coal, nuclear energy, renewable resources (wind, solar, hydroelectric and alcohol fuel). Electricity is only considered as energy use.

Energy modules include:

- Energy demand: disaggregated into residential, commercial, industrial and transportation sectors;

[1] To download a demo version of T21, go to: http://www.threshold21.com/download.html.

- Demand is based on initial energy GDP intensiveness, technology, energy prices and substitution among energy sources. Demand affects, among others, energy production, trade, prices and investments.

– Energy supply: oil (the 48 states and Alaska are analyzed separately), natural gas, coal, nuclear energy, renewable, electricity (by fuel);

Energy supply is calculated based on demand, availability of resources (for fossil fuels), capital installed, profitability of the market and exogenous decisions (policies on renewable resource production). Supply impacts, among others, consumption, prices, trade and generation of pollutant emissions.

– Energy prices and costs: oil, gas, coal, nuclear, electricity;

Fossil fuels and nuclear prices are based on reserve and resource availability over the medium and long term; electricity price is calculated considering the weighted cost of the energy sources utilized to produce it. Since renewable resources production depends on exogenous decisions, their prices and costs are introduced as exogenous inputs into the model (renewable production and price will be treated as endogenously determined in the next phases of the T21-USA project, when economies of scale and decreasing profitability are introduced in the model). Energy prices and costs influence demand, investment and production in the energy sector, as well as production in the economic sectors.

– Energy investment: endogenous (oil, gas, coal), exogenous (renewable, nuclear);

Investment is based on market profitability (both per each energy source separately and the whole market), technology and production (which indirectly takes into account the effect of resources availability and demand). Investment directly impacts energy source production capacity and technology improvement.

– Energy Technology: energy consumption (for the four demand sectors), exploration, development and recovery (for fossil fuels, separately) and vehicle technology;

Energy technology is calculated based on investment and energy prices. It affects resource availability and production (in the case of fossil fuels, through exploration, development and discovery), demand, prices (indirectly) and investment (through the average energy technology available).

– Pollution: emissions (CO_2, CH_4, N_2O, SO_x, Greenhouse gasses), carbon cycle, climate change;

Pollution is based on fossil fuel consumption; it affects carbon cycle and climate change, as well as life expectancy (social sector). The emission sectors are particularly useful for defining policies aimed at reducing greenhouse gas generation and reducing air pollution.

Global energy modules, representing the Rest of the World, include energy demand (oil, gas and coal with specific modules dedicated to China and India's fossil fuel demand); energy supply (oil, gas, coal); pollution (emissions -CO_2, CH_4, N_2O, SO_x, and greenhouse gasses).

Due to its integrated nature and comprehensive structure, focused on replicating the physical characteristics of the system studied, T21-USA is a flexible and transparent tool for supporting analysis of complex issues such as:

– World oil and natural gas peaking: the World Oil production rate gives an estimate of the oil peak. The flexibility of the model allows users to test their own assumptions on the availability of oil resources and reserves, thus generating a set of scenarios based on clear and explicit assumptions. In addition, the user interface already includes a study of peak oil estimation and petroleum production projections. Customized scenarios can be directly compared with those of well know organizations such as the EIA (Energy Information Administration, Department of Energy) and AAPG (Association of American Petroleum Geologists).

– Energy transition: energy demand and supply are based on prices and resource availability. The model, in both the investment and demand sectors, is equipped with a structure that allows shifting from one energy source to cheaper and more efficient ones (when technology allows substitution, if any). The path of an energy transition beyond oil is traced by substitution and the emphasis of the analysis can shift to the development of alternative sources of energy (e.g. renewable, hydrogen, temporary utilization of tar sands, etc.) Different scenarios can be simulated: abrupt and forced transition (no technology improvement and high prices), smooth process (renewable resources become profitable thanks to investment, and capacity can shift from oil to renewables). Actions can be taken to move towards a smooth transition, and T21-USA allows users to test the outcome of some of them, such as increasing the gasoline tax.

– Renewable resources utilization and exploitation: energy production from renewable resources mainly depends on national planning. President Bush already mentioned a plan for increasing nuclear electricity production, while Europe is experimenting wind and solar energy production at a large scale. The model allows users to simulate the exploitation of renewable resources and to check its effects on society, economy and the environment.

– Kyoto protocol, emissions and Climate Change: what could we do to reach the goals set by the Kyoto protocol? What kind of action can be taken and which ones are the most effective? T21-USA allows users to test policy aimed at reducing emissions in a comprehensive manner (e.g. by modifying gasoline tax, income tax, technology improvement, nuclear and renewable resources energy production, etc.) while monitoring economy competitiveness and keeping high quality of life.

Existing models

A large number of models are available for separate analysis of energy and integrated national planning. Unfortunately only a few models account, under the same framework, for both development planning and energy resource management. Feedback from economy, society and environment (which includes energy) are difficult to identify, manage and quantify, especially in dynamic models. This is why most of the available models are detailed but "miss out on fundamental dynamics of markets and technology"[2]. Therefore

[2] John Felmy, chief economist at the American Petroleum Institute (2005).

existing models can be grouped into two main categories (energy and national planning models) and two sub categories (System Dynamics (SD) and non SD models).

In the former category, NEMS (National Energy Modeling System) proposed by the Energy Information Administration (EIA), U.S. Department of Energy - and WEM (World Energy Model) built by the International Energy Agency (IEA), seem the most complete and detailed. These models are much more detailed than T21, which focuses on macroeconomic policy planning only. However, since these models are mainly used for energy-related projections instead of policy planning, a lot of feedback from society, economy and environment are missing. In fact, crucial variables such as economic growth, population dynamics, employment, technology, and prices are treated as exogenous inputs to the models. Therefore, the projections shown in the Annual Energy Outlook (EIA projections) and in the World Energy Outlook (IAE projections) are limited to energy and are based on assumptions concerning society and economy. These models are based on econometrics and linear regression, consequently they don't capture medium and long-term trends dynamically, but projections, extended to 2030 only, are adjusted according to the latest data available. A few System Dynamics models, belonging to the energy models category, were built over the past decades to analyze energy issues in a comprehensive way. These are the IDEAS model (1979), which is an improved version of the FOSSIL models (1977) built by Roger Naill, the Energy Transition Model (1981) by John Sterman, and the Feedback-Rich Energy Economy model (1997) built by Tom Fiddaman. Unfortunately, these models do not include society, economy or environment. As a matter of fact, FOSSIL and IDEAS models consider energy in isolation, Sterman's model includes only energy-economy interactions, and Fiddaman's FREE model focuses on economy-climate interactions (oil and gas depletion are "source constraint", while climate change is a "sink constraint" on the energy-economy system). Nevertheless both FOSSIL and IDEAS models have been used by the Department of Energy for policy planning in the eighties.

Moving to the second category of models, national planning models include the World Bank's Revised Minimum Standard Model Extended (RMSM-X), Computable General Equilibrium (CGE) models, econometric models, theoretical models, and others such as the IMPA model, which is both comprehensive and complex. For the purpose of this paper, the analysis will focus only on the two most commonly used models: World Bank's RMSM-X and CGE. T21 is the leading country-level example of a new type of model that emerged over the past few decades. These models are based on the System Dynamics methodology[3].

RMSM-X, CGE and T21 can be compared according to characteristics of model formulation, methodology and comprehensiveness of the model structure. For what concerns model formulation, T21 addresses growth in production assuming that economic growth depends on inputs of labor (size of the work force and labor productivity), production capital (capital invested and its productivity), and technology. More specifically, when computing labor productivity, T21 accounts for the effect of health, education, HIV and nutrition (for some specific country applications). RMSM-X limits the formulation of growth in production to the assumption that capital is the only factor affecting economic growth. Both T21 and CGE models assume that "everything is connected to everything else", but T21, through dynamic feedback, put in practice this assumption in a more effective and comprehensive manner, by including social and environmental factors.

For what concerns the methodology used, unlike conventional CGE models, the T21 model uses dynamic equations to represent linkages. The social and environmental aspects of development (which are inherently dynamic) are

[3] The underlying mathematics of System Dynamics is calculus. Specifically, System Dynamic models are coupled sets of non-linear differential equations or their integral equivalent. The models use the concepts flow and stock (the integral of one or more flows) to make the models easy to understand and visual. Commercially available modeling languages for System Dynamics models employ the Euler or Runge-Kutta methods for numeric integration of the differential equations. The equations are independent of the solution interval, which can be as small as needed for integration accuracy. System Dynamic models include explicit statements of current theories of causation and provide time specific solutions connected to real calendar time.

fully integrated into the model, by means of appropriate cross linkages. Consequently, sudden or gradual policy changes are fully time dependent and their consequences are tracked over real, calendar-specific time.

Lastly, T21 is generally more comprehensive than RMSM-X. On the other hand, as a consequence of the fact that the level of economic, social and environmental detail exceeds that of RMSM-X, T21 requires more data to be customized. CGE models are typically characterized by detailed economic sectors (even more than T21), while social and environmental ones miss on feedbacks. As for the RMSM-X model, T21 requires more data for the social and environmental sectors, while CGE models needs a higher number of economic data series.

Issues to be analyzed

A complex and comprehensive model should always be built for a specific purpose (Sterman, 2000). With T21-USA the Millennium Institute aims at analyzing the following energy-related issues:

– Energy availability for current and future generations: fossil fuel depletion is evident. Oil peaking happened in the US in the early 70s and gas peaking followed a few years later. Since then, the production of oil and gas has decreased at a pace determined primarily by technology (through fossil fuel potential discovery and recovery improvement). Peaking is not a black box anymore. We are aware of its patterns of behavior and consequences, and we cannot deny the evidence that a world fossil fuels production peak is coming.[4] The International Energy Agency's (IEA) World Energy Outlook 2004 stated: "Fossil fuels currently supply most of the world’s energy, and are expected to continue to do so for the foreseeable future. While supplies are currently abundant, they won’t last forever. Oil production is in decline in 33 of the 48 largest oil producing countries, ...". The analysis carried out by

[4] Recent facts confirm that fossil fuels production peak is approaching in many countries: Russian Gazprom is facing major complex issues with natural gas production and its sales to Eastern European countries, leaving Western Europe with a -15% of supply; Norway oil production is rapidly decreasing, China is trying to secure future oil supply by buying Middle Eastern petroleum companies and by signing decennial contracts with the exporter countries.

T21-USA, with respect to this issue, focuses on domestic fossil fuel depletion, and on the development of alternative sources of energy.

– Fossil Fuels price future development: fossil fuel prices, to a certain extent, are driving energy demand, consumption and production, and even national economies (both at national and global level). The recent appreciation of oil and gas has not produced considerable negative effects on energy demand and on the national economy, but a prolonged high price period will.

– High dependence on foreign sources of energy: the US is a net energy import country, with all the disadvantages that come with it. How could high dependency be reduced?

– National and Global oil demand growth: given fossil fuel depletion and high prices, how will national and global oil demand behave in the years to come?

– China and India's need for energy impact on the US: what is the impact of fast growing countries, such as China and India, on fossil fuels availability for the US?

– Pollution: how to reduce emissions to respect the Kyoto protocol and assure a cleaner air for US citizens? Also, how to help reduce the greenhouse gas emissions, major cause of the earth-heating trend?

T21-USA Model analysis

Behavior

The behavior analysis of T21-USA concentrates on energy and its interconnections with the three spheres. Graphics are used to show the links between economy, society and environment and to assess the validity of the model.

Society

Total population and population pyramid projections are shown in the following graphs (historical data are taken from United Nations, Population Division database). Total population is projected to grow by 38% in the period 2005 – 2050, reaching 414 million people. Population growth per se is not considered an issue if the economy and environment guarantee the improvement of the overall quality of life. In the US, a population-related problem is represented by the sustainability of social security and Medicare. The population pyramid, reported below, shows that the number of people aged 65 and older will increase in the years to come more than proportionally with respect to the total population (especially if compared to those younger). A solution to the problem of social security and Medicare sustainability is still debated. T21-USA is a good tool to analyze this issue and test appropriate policies.

Furthermore, population - energy linkages include the effect of air concentration of fossil fuels-related emissions on life expectancy.

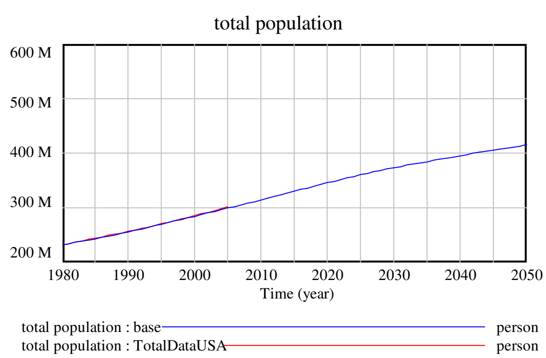


Figure 2: Comparing total population in T21-USA to historical data

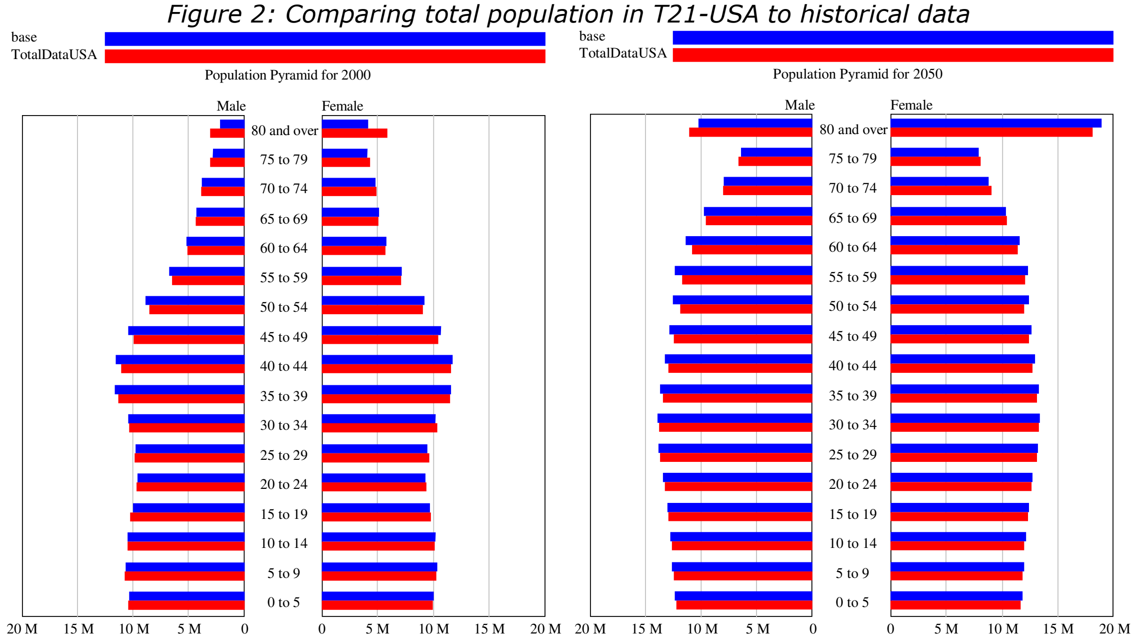


Figure 3 and 4: Comparing population pyramid in T21-USA to historical data (2000 – 2050)

Economy

Issues related to the economy sphere, GDP and value added produced by each sector (agriculture, industry and services) are shown below. Real GDP is projected three times as much as it is now, reaching 4.18 trillion USD by 2050 (using 2000 as base year). More interesting are the projections about each sector contributing to GDP: agriculture is projected to grow by 80%, agriculture by 135%, and services by 315%, quadrupling their present value. In the economic sectors historical comparison is made with International Monetary Fund (IMF) and Bureau of Economic Analysis (BEA) data.

Economic and energy sectors are linked by the following factors: energy prices, resources availability (energy outputs – economy inputs); taxes on gasoline, investments in technology, GDP and consequently energy demand (economy outputs – energy inputs).

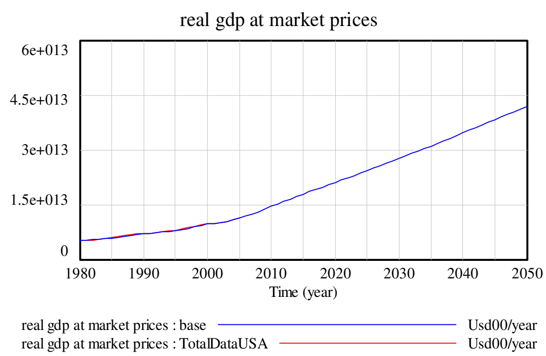


Figure 5: Comparing nominal GDP at market prices in T21-USA to historical data

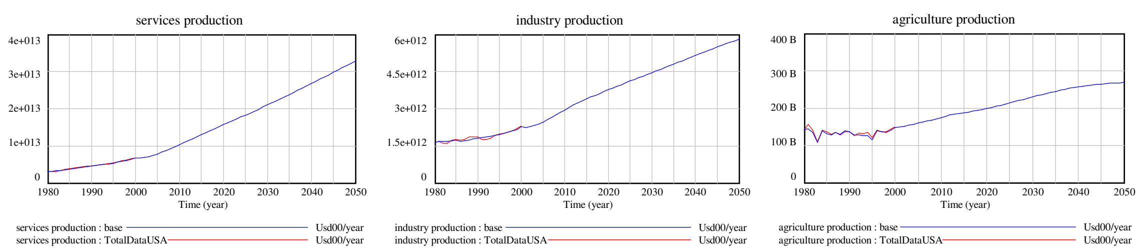


Figure 6, 7 and 8: Comparing services, industry, and agriculture production in T21-USA to historical data

Energy and Environment

Energy sectors in T21 were built taking into account the physical structure of the energy market. As a consequence, the utilization of exogenous inputs is limited and the full process of production is endogenously represented in the model. Energy demand is generated by GDP and technology; supply is determined by availability of resources, technology, capital and demand; investments are determined by the availability of reserve and by the profitability of the market; prices are defined by the availability of reserve and resources (please note that T21 is focused on medium-long term integrated planning). Emissions are generated from fossil fuel consumption, they affect population and are subject to various policies (Kyoto protocol, development of clean and more effective technology, etc.)

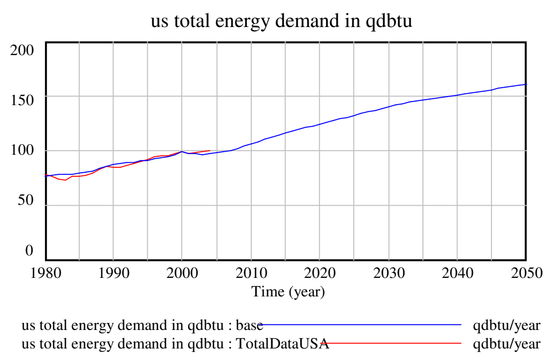
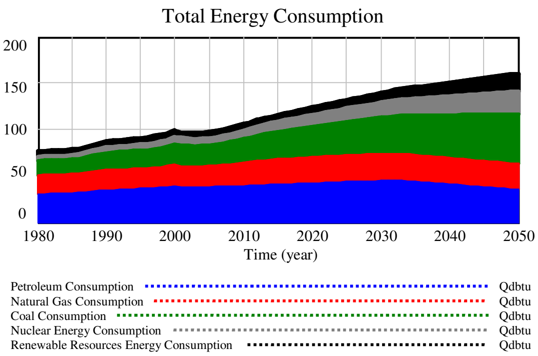


Figure 9: Comparing U.S. total energy demand in T21-USA to historical data

Total energy demand projections indicate a growing trend over the next 50 years. Technology will reduce the intensity of energy on GDP, but energy demand will still increase. In fact, energy demand is projected to increase by 60% by 2050, reaching 160 QDBTU (Quadrillion British Thermal Units), while simulated GDP will increase by 373%, which shows that the energy intensiveness of the GDP is decreasing. A more interesting analysis regards consumption by energy source, which is going to shift from oil and gas, to coal, nuclear and renewables. In fact, the projected rise of oil prices will stimulate substitution from oil towards nuclear and renewable energy sources. Energy sources that are not profitable now may become profitable in the future (e.g. tar sands, solar cell, wind energy, hydrogen, alcohol fuels, etc.) due to a general increase in energy prices. Despite an increase in total energy demand, the projected share of consumption of oil and natural gas will decrease by 2050 from 40 to 22% and from 23 to 17% respectively. The coal share of total consumption is projected to increase from 23 to 34%, while renewable energy doubles (6 to 12%) and nuclear reaches 15% (starting from 8% in 2005).



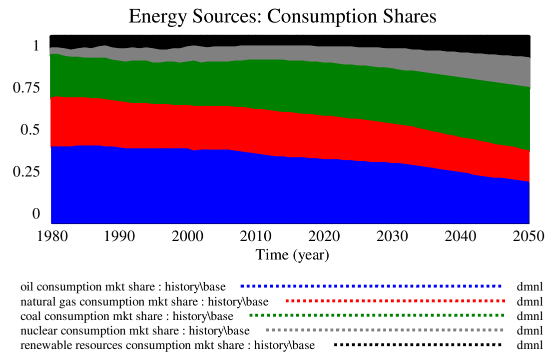
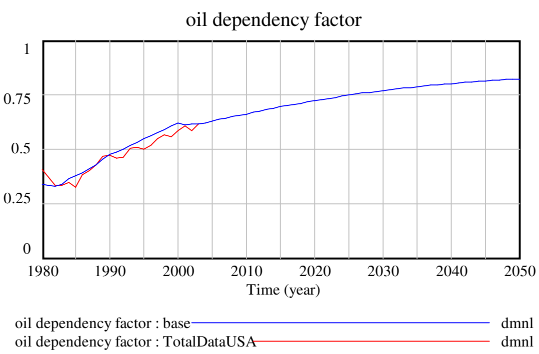


Figure 10 and 11: Total energy consumption and consumption shares in T21-USA

Looking at oil more in detail, the dependency from foreign crude is projected to increase (from 62 to 82% by 2050), mainly due to the incapacity of maintaining domestic production at constant rate (US production has decreased since 1970, even after the exploitation of the Prudhoe Bay fields). On the other hand both US and world demand are still increasing, and world oil production is projected to peak in 2020 (base case). Specifically, simulated world oil demand doubles by 2050, reaching 44,600 MB/year (Million Barrels per year), while production decreases by 15% after having reached its peak of 33700 Mb/year in 2020).



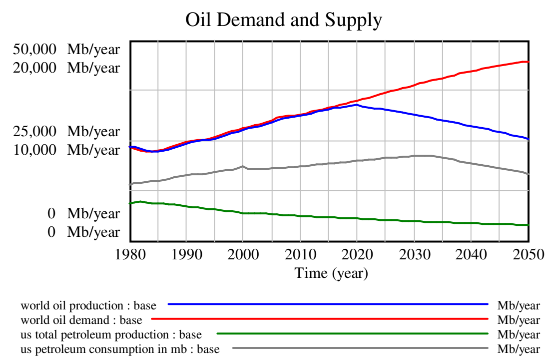


Figure 12: Comparing oil dependency factor in T21-USA to historical data
Figure 13: Comparing U.S. and world oil production and demand in T21-USA

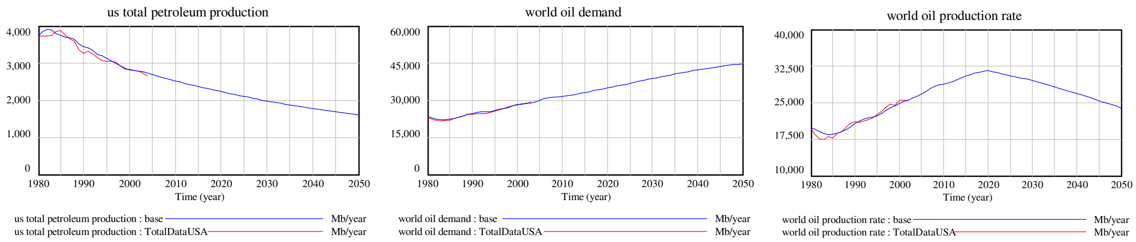


Figure 14, 15 and 16: Comparing U.S. total petroleum production, world oil demand, and world oil production rate in T21-USA to historical data

Fossil fuel demand from the rest of the world is going to increase at a higher rate than in the US, mainly due to demand from fast growing countries such as China and India. Specifically, simulated petroleum demand will increase by 312% in China and by 245% in India, by 2050. The impact of the growing demand from large countries on the availability of resources for the US is visible. China and India's consumption will reduce the availability of fossil fuels (especially oil and gas) for the US for two main reasons: first, China is taking care of future petroleum needs by buying oil companies and securing availability for the future; lastly, the geographical location of China and India is an important asset: these countries are closer to net exporter countries (e.g. Russia and the Middle East) than America.

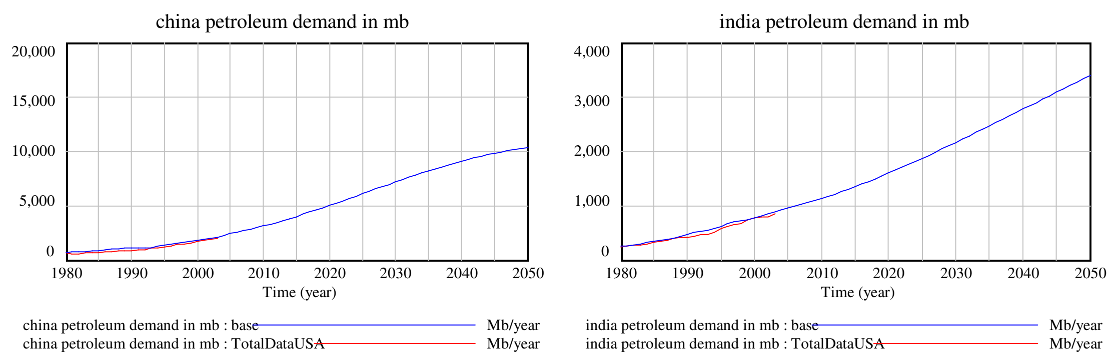


Figure 17 and 18: Comparing China and India petroleum demand in T21-USA to historical data

As well as energy demand, U.S. fossil fuels emissions are projected to increase by 2050. The simulated growing consumption of oil, gas and coal generates 9.6 Million Tons of greenhouse gas by 2050 (scoring a +50% with respect to the 2005 level). CO_2 emissions are projected to follow the same path, showing that effective and timely actions must be taken in order to reach the goals set by the Kyoto Protocol. On the other hand simulated greenhouse gas emissions intensiveness of GDP decreases by 60% over the next 45 years, nonetheless this is not enough to reduce the growth of emissions due to fossil fuel consumption (which is projected to increase by 28%). Similarly, at the World level GHG emissions are projected to increase by 70% by 2050.

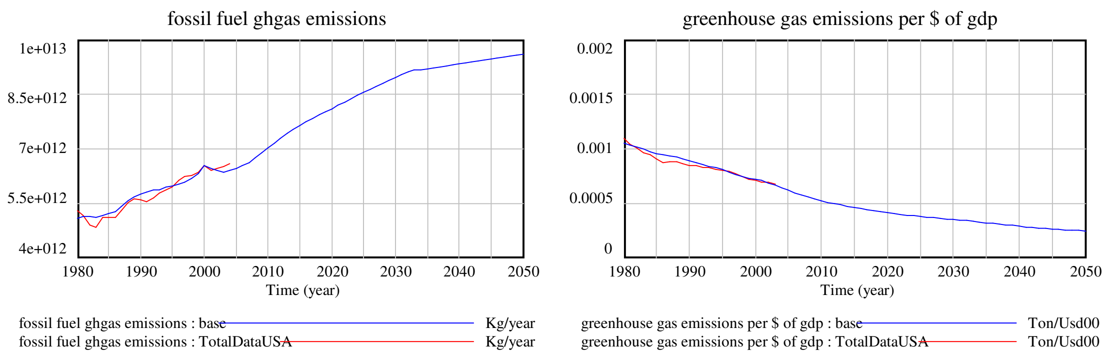


Figure 19 and 20: Comparing fossil fuel GHG emissions and GHG emissions per dollar of GDP in T21-USA to historical data

Since T21 is intended to be a tool for integrated policy planning accessible to anyone, one of its most important characteristics is flexibility in testing assumptions and policies. The following two sensitivity analyses, on world oil production and oil price, are an example of the behavior of the model under extreme assumption testing. For instance, if Matthew Simmons is right when stating that Saudi Arabia is overproducing its biggest fields, the total amount of recoverable oil would have to be decreased. If recoverable oil decreases, peak oil happens earlier than expected. This is the worst-case scenario shown by the sensitivity analyses below: peak oil will happen in the next few years (by 2010) and oil prices rise faster than expected. On the other hand, if the EIA projections are correct, peak oil won't happen before 2030 (best-case scenario shown below) and oil prices remain at a lower level for a few years before rising due to oil depletion. To be noted that in the latter case, oil price will not reach the level of the former case because technology and availability of alternative sources will ease the transition beyond oil.

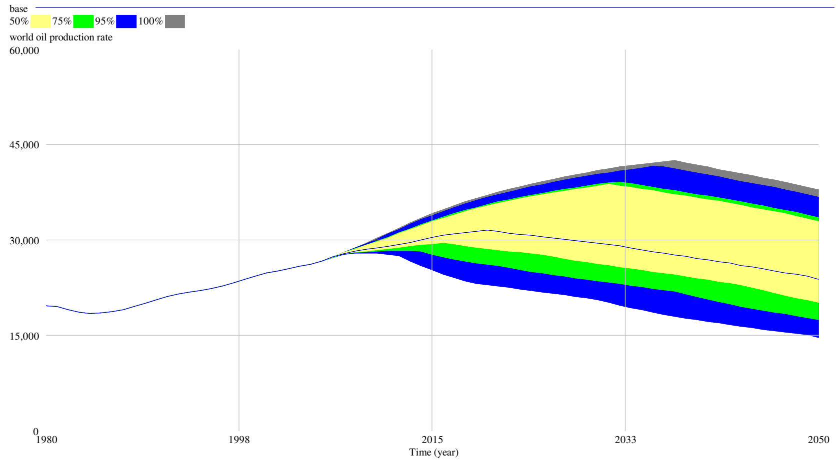


Figure 21: Sensitivity analysis on the world oil production rate;
obtained by varying the amount of undiscovered resource and discovered reserve

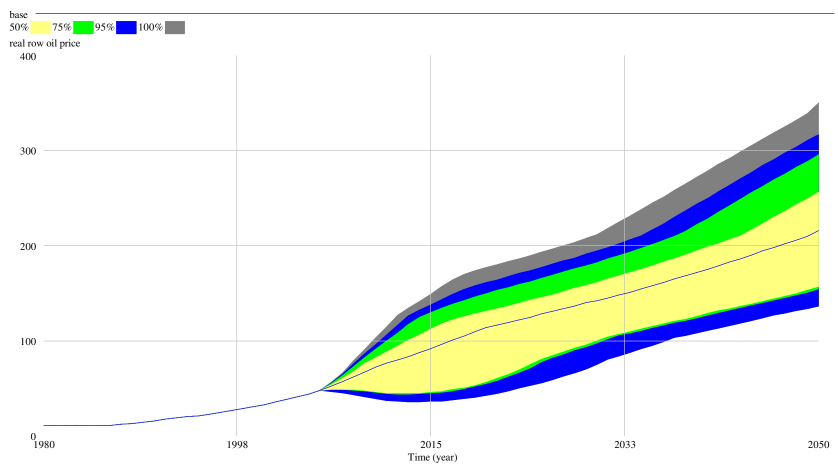


Figure 22: Sensitivity analysis on the real oil price;
obtained by varying the amount of undiscovered resource and discovered reserve

One of the goals of T21-USA is to bring people, experts, politicians and students together to let them communicate and reach a general consensus about both the validity of the model and actions to be taken to solve issues. This would be a first step toward an objective analysis of issues, a rational research for a solution, and a shared effort to achieve tangible results. This means that T21-USA can also be a tool for research, in fact it can be useful to organize data and carry out detailed and comprehensive energy-related analyses. An oil peak analysis is hereby proposed, based on comparisons of EIA, AAPG (American Association of Petroleum Geologists) and T21 projections. Furthermore, the research version of T21-USA can be used to do analyses about society, economy and environment especially on topics involving all of those sectors simultaneously.

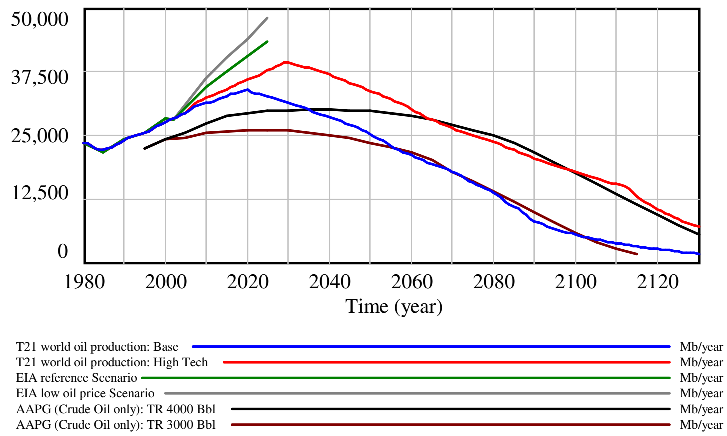


Figure 21: Comparing T21-USA, EIA and AAPG world petroleum production scenarios (AAPG only considers crude oil)

Policies

T21-USA is intended to be a tool for integrated policy planning. A set of policies is built in the model structure and additional ones can easily be added thanks to the flexibility of the methodology utilized. A list of the policies included in the T21-USA v3.3 Beta follows:

– Gasoline Tax: it affects government revenues (1 and 2), gasoline price (1) and as a consequence gasoline (transportation) demand (1, 3 and 4), and technological improvement of vehicle technology (1 and 3). This set of policies also include the possibility to test the effect of cultural local habits on gasoline consumption, by changing the desired mileage per year (which is affected by the proximity to the cities, the level of congestion, the efficiency of public transportation, etc.)

1. Gasoline Tax (Dollars per Gallon)
2. Income tax (as a fraction of Nominal GDP at factor cost)
3. Miles per gallon per vehicle
4. Desired mileage per vehicle per year

– Energy Technology: this set of policies mainly impacts oil price (1, 2) by varying the availability of recoverable resources, and on oil demand (1, 2 and

3) by increasing the efficiency of technology in the residential, commercial and industrial sectors.

1. Oil Recovery technology enhancement
2. Overproduction effect on oil fraction recoverable
3. Energy consumption technology enhancement

– Oil Reserve and resource: a variation in oil reserve and resource affects oil price and demand of fossil fuels (1 and 2). The world oil production rate also changes, but it is strongly dependent on the year when changes are happening.

1. Discovered reserve addition (year)
2. Undiscovered resource addition (year)

– Nuclear, Wind and Solar energy production: since nuclear and renewable resources production is heavily dependent on investment decisions, in the model those variables are treated as exogenous parameters, as pure policy variables. Nuclear and renewable energy production affect total demand of fossil fuels, especially for electricity production (1, 2 and 3).

1. Nuclear energy production
2. Wind energy production
3. Solar energy production

As previously mentioned a wide range of energy policies, in combination with (or separated from) various economic and social policies, can be added to the model. T21-USA can then become an integrated tool for policy planning that considers interactions among the three main spheres governing a country: economy, society and environment.

Conclusions

T21 is a quantitative tool for integrated, comprehensive development analysis. Its purpose is to support the larger process of development planning by facilitating information collection, deepening understanding of the key structural relations, and enhancing the analysis of development strategies. It can provide insights into the potential impact of development policies across a wide range of sectors and show how different strategic alternatives achieve desired goals and objectives.

The strengths of T21 rely on its features that complement the national development planning process. These features include the integration of a broad range of sectors and issues, flexibility for customization, support in development analysis and planning, improved transparency and participation, informed analysis for policy documents.

T21-USA is the first model for integrated planning aimed at analyzing energy issues in a comprehensive way, while simultaneously considering society, economy and environment. The model represents all the issues required and integrates previous T21 models with an endogenously generated set of energy sectors. The flexibility of the methodology used and the comprehensiveness of the structure make T21-USA a good tool for understanding and analyzing validity, effectiveness and outcomes of complex policies, such as the Advanced Energy Initiative -follow up of the State of the Union Address by U.S. President George W. Bush. Despite its complexity, T21-USA is a tool for anyone, in fact its transparency and user-friendly interface makes it an intuitive instrument that can be used by a broad audience, ranging from students to policy makers.

In addition, the T21-USA model can be customized to any country -industrialized or developing- especially those with critical needs for national energy planning. T21-USA can also be used to carry out research on such energy issues as peak oil and quantification of the effect of pollution on life expectancy.

The model is flexible, the tool is accessible and the audience is broad: T21-USA is a valid comprehensive tool for understanding energy issues and learning how to deal with interrelated topics.

References

- AES Corporation, *An Overview Of The IDEAS MODEL: A Dynamic Long-Term Policy Simulation Model Of U.S. Energy Supply And Demand*, Prepared For The U.S. Department Of Energy Office Of Policy, Planning, And Evaluation, Arlington, VA, October 1993;
- Backus, G., et al. FOSSIL 79: *Documentation*, Resource Policy Center, Dartmouth College, Hanover NH, 1979;
- Barlas, Y., *Formal aspects of model validity and validation in system dynamics*, System Dynamics Review Vol. 12, 1996;
- Barney, G. O., *Managing a Nation: the Microcomputer Software Catalog*, Institute for 21st Century Studies and Westview Press, 1991;
- Bunn, D. W., E. R. Larsen, eds., *Systems Modelling for Energy Policy*, Wiley, Chichester, 1997;
- Davidsen, P. I., J. D. Sterman, G. P. Richardson, *A Petroleum Life Cycle Model for the United States with Endogenous Technology, Exploration, Recovery, and Demand*, System Dynamics Review 6(1), 1990;
- Deffeyes, K. S., *Beyond Oil- The View from Hubbert's Peak*, Hill and Wang, New York, 2005;
- Economides, M., R. Oligney, *The Color of Oil- The History, the Money and the Politics of the World's Biggest Business*, Round Oak Publishing Company, Texas, 2000;
- Edmonds, J., J. M. Reilly, *Global Energy- Assessing the Future*, Oxford University Press, Oxford, 1985;
- Energy Information Administration (EIA), *Annual Energy Review 2005*, 2005;
- Energy Information Administration (EIA), Department of Energy, *Annual Energy Outlook 2006*, 2006.
- Energy Information Administration (EIA), Department of Energy, *Assumptions to the Annual Energy Outlook 2005*, 2005;

- Energy Information Administration (EIA), Department of Energy, Integrating Module of the National Energy Modeling System: Model Documentation 2004, 2004;
- Fiddaman, T. S., *Feedback Complexity in Integrated Climate-Economy Models*, Doctoral Thesis, Massachusetts Institute of Technology, Cambridge, MA, 1997;
- Hirsch, R. L., *Six Major Factors in Energy Planning,* Report for SAIC, National Energy Technology Laboratory, 2005;
- Hubbert, M. K., *Exponential Growth as a Transient Phenomenon in Human History*, In Daly, H. E., K. N. Townsend, eds., Valuing the Earth: Economics, Ecology Ethics. MIT Press, Cambridge, MA, 113-126, 1993;
- Hubbert, M. K., *Nuclear Energy and the Fossil Fuels. Drilling and Production Practice,* Washington: American Petroleum Institute, 1956;
- Intergovernmental Panel on Climate Change (IPCC), *IPCC Third Assessment Report: Climate Change 2001*, 2001;
- International Energy Agency (IEA), *World Energy Outlook 2004, Annex C*, WEM (World Energy Model), 2004;
- International Energy Agency (IEA), *World Energy Outlook 2005,*2005;
- International Monetary Fund, *International Finance Statistics, Government Finance Statistics, Balance of Payments Statistics*, 1980 – 2005;
- Laherrère, J., *Modelling Future Oil Production, Population and the Economy*, Aspo Second International Workshop on Oil&Gas, Paris, 2003;
- Lovins, A. B., et al., *Winning the Oil Endgame- Innovation for Profits, Jobs, and Security*, Rocky Mountain Institute, Colorado, 2005;
- Millennium Institute, Threshold 21 (T21) Overview, Internal report, 2005;
- Naill, R. F., A., *System Dynamics Model for National Energy Policy Planning*, System Dynamics Review 8(1), 1992;
- Naill, R. F., *Managing the Energy Transition*, Ballinger, Cambridge, MA, 1977;

- OPEC, World Energy Model (OWEM), *Oil Outlook to 2025*, OPEC Review, September 2004;
- Pedercini, M., *An Assessment of Existing Computer-based Models' Potential Contributions to the Development of a Methodology for Comparing the Development Effectiveness of Large-scale Public Investment Programs in Different Locations or Socio-economic Sectors*, Working paper in System Dynamics, University of Bergen, and Conservation International, 2003;
- Salvador, A., *Energy: A Historical Perspective and 21st Century Forecast*, AAPG Studies in Geology #54, The American Association of Petroleum Geologists, Oklahoma, 2005;
- Simmons, M. R., *Twilight in the Desert -The Coming Saudi Oil Shock and the World Economy*, Wiley & Sons, New Jersey, 2005;
- Sterman, J. D., G. P. Richardson, P. I. Davidsen, *Modeling the Estimation of Petroleum Resources in the United States*, Technological Forecasting and Social Change 33, 1988;
- Sterman, John D., *Business Dynamics*, Mc Graw-Hill, 2000;
- Sterman, John D., *The energy transition and the economy: A system dynamics approach*, Ph.D. Thesis, MIT, 1981;
- Stobaugh, R., D. Yergin, eds., *Energy Future- Report of the Energy Project at the Harvard Business School*, Vintage Books Edition, New York, 1983;
- United Nations, *UN World Population Prospects, The 2004 Revision, Population Database*, 2004;
- Yergin, D., *The Prize- The Epic Quest for Oil, Money & Powe*r, Free Press, New York, 1991.